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Development of a Willow Biomass Crop Harvester Based on a New Holland Forage Harvester and Specially Designed Willow Cutting Head

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Willow shrubs have several characteristics that make them an ideal feedstock for biofuels, bioproducts and bioenergy. They provide high yields that can be obtained in three to four years, are easily propagated from dormant hardwood cuttings, have a broad genetic base, have potential for significant improvements from traditional breeding, can be planted once and harvested multiple times, will provide a uniform feedstock, and have limited pest and diseases problems. Despite the numerous environmental and rural development benefits associated with willow biomass crops, they have not yet been widely adopted, primarily due to the current cost of production and delivery, which is $47 to $57 per OTD[1] The main economic factors are crop yield, and the cost of harvesting and transportation. Harvesting and transportation can account for 39 to 60% of the delivered cost of willow biomass[1]. SUNY-ESF has been working with Case New Holland and Cornell University to design a more efficient and effective harvester for willow biomass crops to lower harvesting costs and improve chip quality.

Willow is planted using 8 to 10 inch long dormant cuttings at a density of about 6,000 plants/acre. Site preparation uses a combination of chemical and mechanical weed control. The crop is coppiced after the first year during the dormant season to promote the production of multiple stems. The first harvest typically occurs three to four years after coppicing. The willow crop resprouts the following spring and is harvested again three to four years later. Seven or more harvests are anticipated from a single planting. Yields have ranged from 3 to 5 oven-dry tons/acre-year or about 18 to 30 green tons/acre at harvest with a three-year rotation (Figure 1). Increases in yield of 20 to 40% are anticipated from planting new willow varieties developed from our breeding and selection efforts[2]. The average number of stems per plant ranges from 4 to 13 among varieties, resulting in 25,000 to75,000 stems/acre depending on variety. Variability in number of stems per plant and corresponding variation in stem size

[1] Tharakan, P.J., T.A. Volk, C.A. Lindsey, L.P. Abrahamson, and E.H. White. 2005. Evaluating the impact of three incentive programs on cofiring willow biomass with coal in New York State. Energy Policy 33(3): 337-347.

[2] Smart, L.B., T.A. Volk, J. Lin, R.F. Kopp, I.S. Phillips, K.D. Cameron, E.H. White and L.P. Abrahamson. 2005. Genetic improvement of shrub willow (*Salix* spp.) crops for bioenergy, bioproducts, and environmental applications. Unasylva. 56:51-55

means that the harvesting equipment being developed needs to be able to manage a range of stem numbers, sizes and heights.

Figure 1: Three-year-old willow biomass crops grown in central NY.

A 140 HP tractor and harvester (a new model of the Bender willow harvester developed in Sweden) that cut and chipped willow biomass crops in one pass was tested over two growing seasons (2002 – 2003). It had several advantages for the willow crop system being developed in the U.S. However, the new model Bender produced chips of inconsistent size and quality, some of which were long and stringy. These pieces formed "bird nests" that jammed the chip handling systems in the field and at some of the bioenergy facilities where the willow chips were tested. Further, the machine was not mechanically robust and failed numerous times, especially in willow crops with yields >25 green tons/acre. Despite implementing a number of design modifications, the new model Bender was not suitable for willow crop harvesting in the U.S. and was discontinued from further testing in 2004.

During the summer of 2004 Case New Holland (CNH) expressed interest in developing a harvesting system for willow biomass crops based on their New Holland FX forage harvesters. During the fall of 2004, CNH purchased and modified a row independent (Kemper) corn head to determine if this type of cutting head could effectively harvest willow crops with smaller stem diameters (<1.5 inches) and to assess the capability and efficiency of the FX45 forage harvester (450 HP engine) to chip willow stems and produce high quality willow chips. Field trials in December 2004 and January 2005 (Figure 2) showed that the FX45 forage harvester could effectively and efficiently chip willow biomass crops and produce a consistent size, high quality product with >95% of the chips being less than one inch in size. Adjustments to feed roller speeds and the number of cutting knives provide options for changing the size distribution of the chips that are produced by the New Holland forage harvester. The modified corn head was able to harvest willow crops up to 1.5 inches in diameter, but was not robust enough to harvest more than about 0.5 acre at a time without stoppages for repairs or adjustments.

These initial field trials provided valuable information on the flow and chipping of willow stems. It was clear that a different cutting head would be required. A review of willow cuttings heads that have been designed and tested indicated that a head made by Coppice Resources Ltd. (CRL) in Doncaster, U.K. was probably the most robust for the size of willow produced in the U.S. Several versions of this cutting head have been built and operated by CRL. Modifications were made to the latest design including changing the drive mechanism for the cutting blades from mechanical to hydraulic. Two large diameter saw blades run at about 1200 rpm to cut the willow stems and feed them into the forage harvester to be chipped. Support from Congressman James T. Walsh (NY-25th) was vital in moving this project forward and in acquiring a new cutting head. Congressman Walsh has been a short-rotation woody crops advocate since the mid-1990s, securing vital and repeated federal project funding in the Agriculture, Interior, and Energy and Water Development appropriations bills.

Figure 2: New Holland FX45 forage harvester with a modified row independent (Kemper) corn head harvesting 3-year-old willow biomass crops during field trials in December 2004 and January 2005 at the SUNY-ESF Genetic Research Field Station in Tully, NY.

Initial field trials with the new head mounted on the FX45 forage harvester were run in willow crops during summer of 2006 with support from the New York State Energy Research and Development Authority (NYSERDA). NYSERDA has been a long-term supporter of various aspects of willow biomass crop research, development and deployment. The chipped material produced continued to be consistent and high quality, but there were problems in the flow of material into the harvester. This problem was complicated by the foliage, which caused the cut willow stems to hang up rather than fall down and feed into the harvester. Field trials during the dormant season in the late fall of 2006 (Figure 3) indicated that material flow was improved, but was still not optimal. The harvester was able to operate at ground speeds of 3-4 miles/hour (1.9-2.5 acres/hour with 70% field efficiency) if stem diameters were less than 3 inches and the crop was fairly uniform. During the fall of 2006 we also developed a new willow harvesting system with the help Glenn Zimmerman who is owner of Mar-Allen Farms out of Waterloo, NY (who does custom baling and chopping) who very successfully uses a system for custom harvesting of forage corn with a forage harvester similar to our FX45. Glenn convinced us that we should be using large forage wagons that are capable of self unloading a full wagon of chips in approximately 5 minutes. They would unload the chips into a forage blower which in turn blows the willow chips into a trailer for hauling over the road. The custom applicator would run the forage harvester which cuts and chips the willow into two or three forage wagons pulled by tractors running along side the harvester and transporting the chips to the road edge and unload their chips into a silage/forage blower which would blow the chips into a trailer for hauling over the road. This would keep the harvester operating at peek efficiency. During the fall of 2006 we tried this method of moving the harvested chips from the harvester to the end user with great success (Figure 3-4).

Because of problems related to the harvester and cutting head we were not able to run the system to maximum efficiency. We only used one forage

Figure 3: Harvesting willow biomass crops with a New Holland FX45 forage harvester and a specially designed Coppice Resources Ltd. (CRL) willow cutting head in NY during fall 2006. The chips are being blown into a large tandem forage wagon and tractor which will haul the chips to the field edge to be loaded into a chip trailer.

wagon during most of the operation and one tractor trailer. However, we were very pleased how the system worked and we were able to haul 100 tons of willow chips to an end user.

Figure 4: The large tandem forage wagon in position to unload harvested willow chips into a forage blower which in turn will blow the chips into the chip trailer for hauling over the road to the end user.

The development of this harvesting system is helping to overcome barriers to the commercialization of willow biomass crops by producing a consistent, uniform size chip and increasing the efficiency of harvesting operations. Over the next year the system will be modified and tested to further increase its performance and reduce costs associated with harvesting willow biomass crops.