

A PROTOTYPE HARVESTER FOR SHORT-ROTATION PLANTATIONS

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Abstract.--A promising approach to increasing the supply of wood fiber for pulp and energy is short-rotation intensively cultured (SRIC) forestry. To apply the principles of agriculture to the growing of wood fiber, designers of harvesting equipment must consider a unique set of operating criteria. This paper summarizes the design criteria relevant to the SRIC concept and describes the results of initial trials with a prototype short-rotation harvester.

INTRODUCTION

Short-rotation intensively cultured (SRIC) plantations are a promising way to increase the supply of wood for fiber and energy in the future (U.S. Department of Agriculture, Forest Service 1980). To be applied commercially, SRIC systems must have technically and economically feasible equipment and systems to carry out the required silvicultural treatments and perform the necessary harvesting and processing operations.

The harvesting of wood fiber grown on SRIC plantations has received little attention. One advantage of SRIC systems is a completely mechanized harvesting operation to reduce labor costs and make a year-round operation more practical, but the mechanics of implementing the harvesting have not been extensively studied.

The forest engineering project at the Forestry Sciences Laboratory, Houghton, Michigan, has designed and fabricated a prototype harvester for SRIC plantations. This prototype is basically a test rig to evaluate the feasibility of several equipment concepts included in its design and also to develop a base of design criteria for an eventual commercial harvester.

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CHARACTERISTICS OF SRIC PLANTATIONS RELEVANT TO HARVESTER DESIGN

Short-rotation intensively cultured forests are expected to consist of selected, rapidly growing, hardwood tree species. The crop would be harvested at appropriate rotations, and the succeeding crops would arise by coppicing (sprouting from stumps), precluding the need to replant after each harvest.

Suggested plantation scenarios have row spacings ranging from 1.2 to 2.4 m with spacings between trees within the rows ranging from 1.2 to 1.8 m. Anticipated rotation age ranges from 8 to 15 years depending upon the spacing option chosen. These combinations will produce trees ranging from 10 to 25 cm in diameter at groundline and from 10 to 20 m tall. Most of the trees will be in the 10- to 20-cm diameter range, but some along the edges of the plantation may reach 30 cm in diameter. These stands are expected to produce from 10 to 15 dry tonne equivalents of biomass per hectare per year from trees ranging from less than 50 kg to more than 200 kg in the first harvest. Tree size will decrease with successful coppicing of the stands, and number of trees per hectare will increase.

Most envisioned SRIC systems use coppicing to regenerate the stand after harvesting. To ensure a suitable level of regeneration, the harvester will be required to maintain a preset stump height, up to 25 cm. The stump must have a clean-cut surface (such as would be produced with a saw). Lateral pressure against the stump will have to be minimized to avoid disturbing roots below ground. The harvester will have to stay within the rows of the plantation to avoid damaging the stump system.

Because the coppicing of the original stumps to produce new sprouts may produce a wider plant structure in subsequent harvests, the harvester will have to be able to handle a sprout cluster up to about 65 cm wide.

The need to obtain an adequate level of coppicing may limit the harvest season to the dormant season when ground conditions may be adverse. To aid mobility of the harvest equipment and avoid excessive damage to the site and root system, vehicle ground pressure will have to be minimized, possibly to as low as 15 to 20 kPa in extremely low bearing sites. The number of vehicle passes over the stand during harvest should also be minimized to avoid rutting, soil compaction, and other site damage.

Most sites envisioned for energy farms contain terrain suitable for vehicle travel. The harvester will probably only have to be capable of operating on side slopes up to 10 percent and direct slopes up to 20 percent. The plantations will also probably be free of rocks in the operating zone of the harvester felling device.

APPLICATIONS OF CONVENTIONAL EQUIPMENT

The biomass produced in SRIC forests may be handled and transported as whole-tree chips. The chips are suitable for most subsequent conversion and processing operations.

Whole tree chipping is a highly mechanized system capable of producing large quantities of wood per man-day. Besides the advantages of high productivity and reduced labor requirements, the yield per hectare of usable wood is greatly increased due to the additional amounts of fiber recovered from the tops, limbs, and other residue materials normally left in the woods after a conventional roundwood operation. Additionally, the site is left in a clean, esthetically more acceptable condition that facilitates subsequent silvicultural operations.

The basic whole-tree chipping system consists of feller/bunchers that sever the trees and accumulate them into bunches, grapple skidders that move the bunches from the forest to the chipper, portable chippers that operate at a woods landing to reduce the whole trees to chips, and chip vans that transport the chips to the mill (fig. 1).

An earlier study by Mattson (in preparation) used simulation methods to study the potential for utilizing whole-tree chipping to harvest SRIC plantations. The results of the simulator trials showed that tree size is the major factor affecting productivity and cost.

Current harvesting equipment requires large trees to operate economically.

The felling/bunching phase of the harvesting operation is the area where current technology is the most deficient with respect to harvesting small trees. Current skidding/forwarding and chipping equipment is designed for multiple-tree operation, so it can be adjusted to the design parameters presented by the small trees of an intensively cultured stand. However, the basic design of conventional shears is based on handling one tree at a time. For stands of small trees, this restriction limits the potential productivity of the equipment.

The development of felling/bunching equipment that operates on a continuous or multitree basis is the most significant research need in the area of harvesting SRIC fiber.

HARVESTER CONCEPT CONSIDERATIONS

The requirement of coppicing to produce subsequent crops from the original stumps in SRIC plantations may preclude the use of a conventional whole-tree harvesting system as discussed previously. Preliminary studies have shown that the small stumps found in SRIC plantations are susceptible to mechanical damage by equipment working in the stand (Crist *et al.* in this proceedings). Skidding in particular, as it is typically done, would be unacceptable in an SRIC stand because the machine's maneuvering and turning would certainly cause excessive damage. Skidding the loads of trees across the plantation would also be likely to cause excessive damage. Because of the possibilities of damage, harvesting operations would probably have to be laid out so that whatever machinery is involved can stay tracked between rows of the plantation and carry out its required function while making a pass through the plantation.

The number of passes through the stand should also be minimized to minimize soil compaction---so a machine needing only one pass would be desirable. Such a machine would be capable of severing the stems and simultaneously collecting the severed stems and forwarding them to the plantation edge.

A machine that could simultaneously fell and chip the trees and transport the chips to the plantation edge would be much heavier than a machine that only fells and collects the severed trees and forwards them to the plantation edge. The lighter machine could be expected to cause less soil compaction and cost less. Considering that the harvester will probably be used only for a portion of the year,

a smaller, less costly machine would be preferable. If the harvester could be built to utilize a standard prime mover as its motive and functional power source, it could cost even less.

The possibility of the harvest being limited to the dormant season has some definite implications for the design of the harvesting equipment because the fiber must be stored for year-round use. Storing the material on the edge of the plantation would eliminate any initial transport because the harvester could offload right at the storage site, also eliminating the need for extensive storage at the use point. The harvesting would also be more efficient because any delays caused by interaction with the transportation system would be eliminated.

From the utilization standpoint, collecting the whole trees at the plantation edge for storage appears to have some advantages over chipping the material in the stand and then storing the chips. Also, chips are not a preferred form for long-term storage because problems with heating of the chip piles and deterioration of the material can occur. Dirt and grit can get into the material when chips are recovered from the ground for loading and subsequent transport to a use point. If the trees are stored in whole-tree form at the plantation edge, conventional chipping equipment can efficiently convert them into chips and load the chips onto trucks for transport. Also, the whole trees could be converted into an alternate product form such as chunks or blocks, which may be preferred for a particular application such as burning (Arola *et al.* in this proceedings).

A PROTOTYPE SRIC HARVESTER

The prototype harvester is composed of three major parts: a felling head, a directional felling device, and an accumulating section (fig. 2). The felling head on this prototype is constructed around an elongated two-flute milling cutter with spiral cutting edges, or auger cutter (fig. 3). It severs the stems by milling out a section of the trunks equal to the cutter diameter, 5 cm in the case of this prototype. The advantages of this device include the ability to cut anywhere along its 0.6 m length, no need for an anvil, and a fairly clean cut on the residual stump. The cutter is relatively heavy and compared to a circular saw, shouldn't be as vulnerable to damage from occasional contact with foreign objects or require sharpening as often.

The auger cutter is mounted in a movable subframe assembly that also contains the auger

drive motor and a cutting height adjustment feature. The movable subframe assembly is mounted to the harvester in such a way as to allow relative motion in the direction of harvester travel between the harvester and the auger cutter. This is accomplished by the use of two guided shafts that form part of the forward section of the movable subframe. Each shaft is supported by two linear motion bearings contained on the rear section of the assembly. The rear section is pinned to the harvester to allow for different auger cutter height settings and to permit the subframe to float over irregular ground contours. The interface between the forward and rear sections of the auger cutter subframe assembly, in addition to the linear motion bearing and shafts, is two air cylinders. These cylinders keep the forward section extended to its outmost position and provide three functions: First, they allow for the setting of the maximum lateral load applied to the tree during the cutting process; this factor controls the chip thickness and horsepower requirements of the auger cutter. A large air reservoir incorporated in the harvester frame maintains an almost constant air pressure in the cylinders regardless of their relative position. Second, the cylinders allow for the forward section to return to the extended position once severing is completed. Their third and probably most important function is to allow for relative motion between the harvester main frame and the auger cutter. This is of utmost importance in obtaining good production rates. An ideal harvesting machine should be severing trees 100 percent of the time without any travel time between cuts. A rigidly fixed cutting device can require the harvester to slow during each cut and then speed up between cuts. The auger cutter retraction feature allows the cutter to sever the tree at its own rate while the main harvester frame travels at a steady rate along the row of trees. Production rates depend on tree spacing and size. The size or diameter of the tree determines the required cutting time which in turn will dictate the maximum harvester ground speed. By proper adjustment of the variables, cutter speed, feed pressure, and ground speed, the harvester would conceivably approach the 100-percent efficiency rate.

The cutting height adjustment feature consists of a pneumatic tire mounted on either side of the forward moving frame section adjacent to the end supports of the auger cutter. The wheels can be positioned so that stump heights will vary between 5 and 22 cm.

The cutter rotates upward so that stump damage is minimal during severing. The upward rotation also tends to move the butt of the tree rearward onto a shelf mounted behind the cutter. This shelf is an integral portion of

the forward-moving subframe. Once the tree is cut and placed in a vertical position on the support shelf, the directional felling device pushes and tips the tree towards the rear of the harvester. Guides direct the tree so that it falls to rest on the harvester bunks (wide U-shaped forms located at the front and rear of the harvester).

The directional felling device consists of two shafts mounted vertically on each side of the auger cutter. Each shaft has several spring steel blades mounted in a horizontal plane about the axis of the shaft. The shafts and blades rotate in opposite directions so that the cut portion of the tree is directed between the felling guides.

Once the tree has been felled onto the harvester bunks, slow-moving drag chains with tall fingers on each bunk move the tree towards the left side of the machine. When a small collection of trees has accumulated at the end of the drag chains, a packing arm on each bunk picks up the load and places it at the extreme left of the bunk and packs it, along with other small loads, into a bundle. Once a full load has been established in the packing area or at the end of a row of trees, the load is offloaded onto a pile for storage and subsequent processing and/or transportation to the use point.

The harvester was constructed so that several processing concepts could be tested; therefore, a drive and power system was not included as part of the main machine. Because most woods-working equipment is hydraulically operated, we decided that the harvester should also function hydraulically. To field test the harvester, all we needed to do was obtain the use of a prime mover with adequate hydraulic power and capacity to operate each of the harvester functions. Another advantage of a hydraulic system is the versatility of most hydraulic components. Motor and cylinder speeds can be controlled simply by monitoring and adjusting the oil flow to them. Motor torques and cylinder forces can be controlled by simply regulating the oil pressure. Because these controlling and regulating devices are commonly installed as part of a standard system, additional components are not necessary. If an entirely mechanical system were incorporated, then additional belts, pulleys, and other components would be necessary to vary the system functions.

Briefly, the harvester's functions are controlled by the following devices; the auger cutter is driven by a Abex-Dennison spring vane motor, Model M4C. The motor is capable of 2500 psi at 2500 rpm continuous operation and 2500 psi at 4000 rpm intermittent. Because the

motor is of a cartridge construction, various torque and speed combinations can be obtained. The "egg beaters" or directional felling devices are driven by Char-Lynn hydraulic motors, Model "H" of the gerotor design. The drag chains are operated by the same type of motor. The pack arms are controlled by hydraulic cylinders.

RESULTS OF INITIAL TESTS

Once the "bugs" were worked out of the auger cutting system, it performed remarkably well. The original auger cutter did not have enough chip space causing it to plug with chips and not feed properly. The cutter was reworked to deepen the gullet and enlarge the chip space. We also encountered problems with the first version of the auto retracting system and completely redesigned the sliding guides. With the auger running at 2000 rpm, the pressure relief set at 2500 psi, and with 60 psi in the air cylinders, the cutter cleanly severs a tree, leaving a relatively smooth stump surface. The forward moving frame section retracts effortlessly when vehicle speeds exceed the cutting speed.

The directional felling device was less successful; every so often a tree would not drop directly on the bunk. Usually the top of the tree would miss the rear bunk. Although this was not a serious problem, it could lead to delays and jams with a production-style machine. The bunk collection system (drag chain and packing device) worked as it was intended.

RECOMMENDATIONS FOR FURTHER RESEARCH

The harvester worked well for a first prototype, although several problems still exist in the directional felling phase. For this reason we are continuing with research into additional concepts for short-rotation harvesters. Presently, we are considering two concepts to combine the directional felling and collection phases into a single operation using an accumulator for collecting the trees in a vertical position behind the cutter. This approach could possibly increase the harvester's load carrying capacity while decreasing its physical size. Other concepts utilizing multirow harvesting will also be considered.

³The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture to the exclusion of others which may be suitable.

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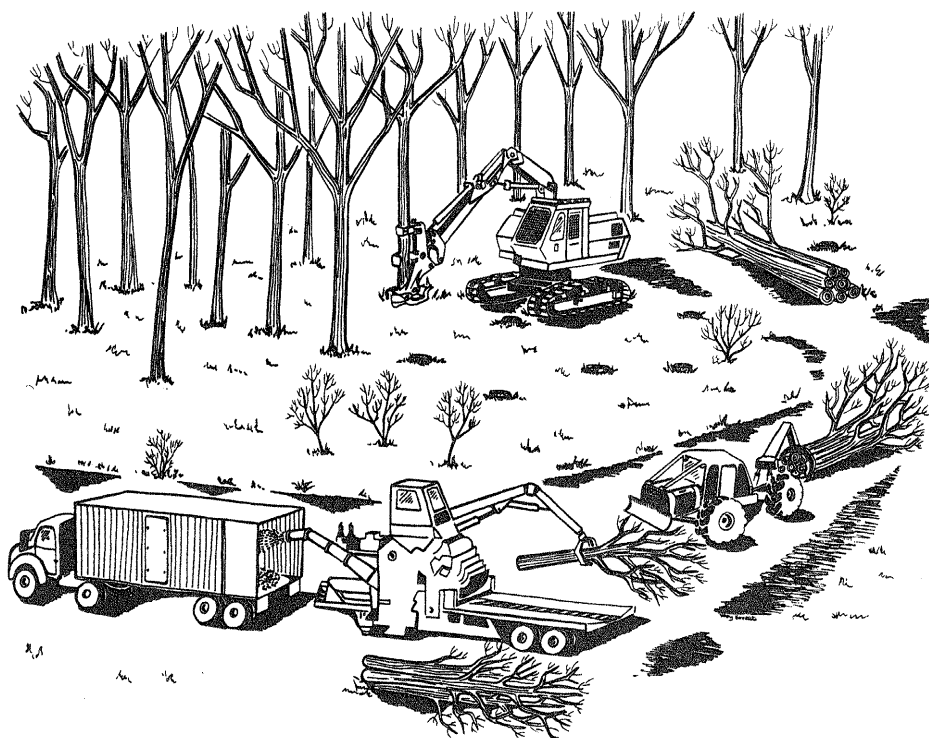


Figure 1.--Schematic of a typical whole-tree chipping operation.

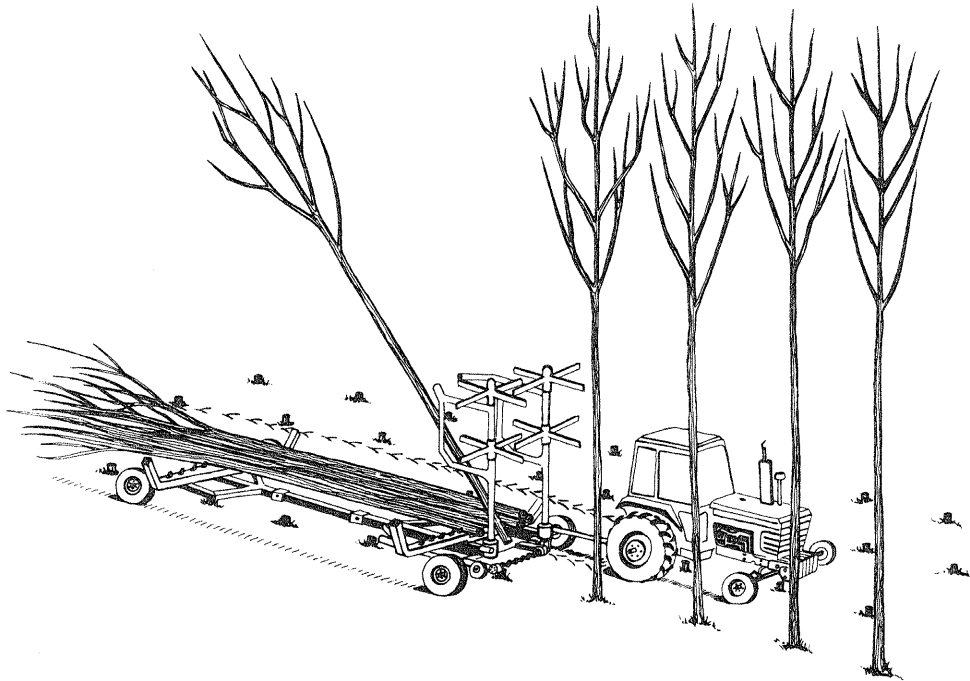


Figure 2.--A prototype SRIC harvester.

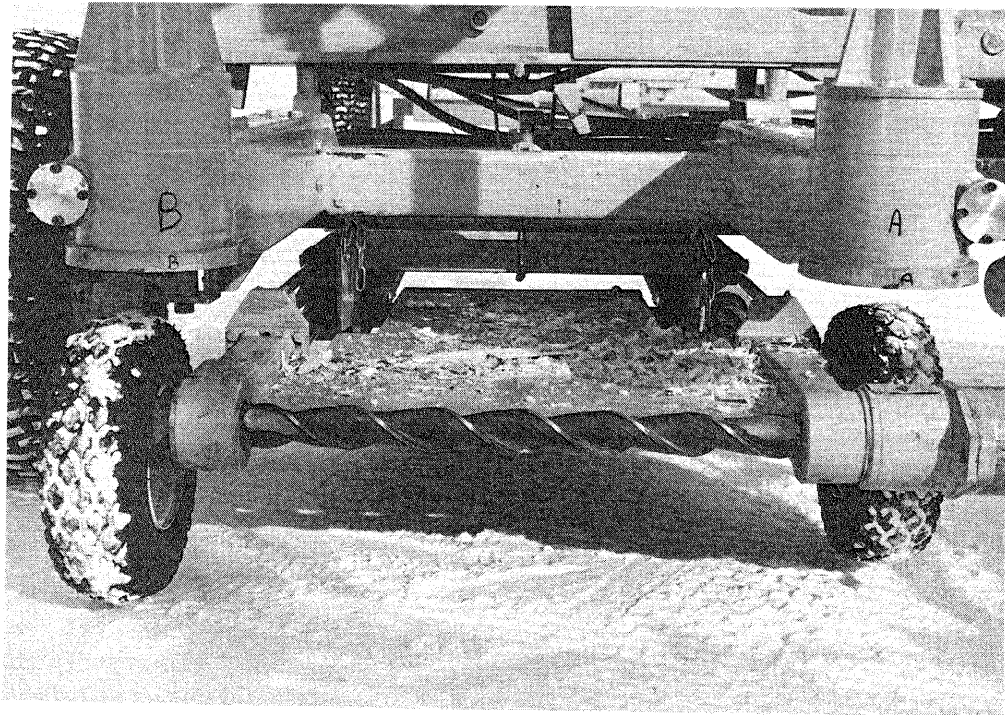


Figure 3.--Felling head of prototype SRIC harvester.