Automated Harvesting of Burley Tobacco I. System Development

Larry G. Wells  
*University of Kentucky, larry.wells@uky.edu*

George B. Day V  
*University of Kentucky, george.day@uky.edu*

Timothy D. Smith  
*University of Kentucky, tim.smith@uky.edu*

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AUTOMATED HARVESTING OF BURLEY TOBACCO

I. SYSTEM DEVELOPMENT

L. G. Wells, G. B. Day, V. Research
MEMBER ASSOC. MEMBER MEMBER
ASAE ASAE ASAE

ABSTRACT

A fully automated system for harvesting and handling mature burley tobacco has been developed. This article identifies the operations essential to this harvesting concept and describes the development of the mechanisms by which they were accomplished. The system detaches, inverts and places mature plants into portable holders for air curing under waterproof covering without requiring any manual handling of the crop. Manual labor currently required to harvest burley tobacco would be reduced by 80-85% and the system would eliminate the drudgery associated with manual handling. The harvesting system has an approximate capacity of 1.4 to 2.0 ha/day (3.5 to 5.0 ac/day) and is operated by two workers.

INTRODUCTION

Burley tobacco is presently harvested by means of cutting (cutting) mature plants near the ground and placing them in curing facilities for on-the-plant curing of leaves via natural ventilation. The present cultural practice by which burley tobacco is prepared for the curing process involves impaling (spearing) 5 to 6 plants upon a wooden member (stick) which has nominal dimensions of 2.5 cm x 2.5 cm x 135 cm. Filled sticks are placed upon parallel rails in curing barns, allowing adequate spacing for ventilation and curing.

For the most part, both cutting/spearing and the placement of filled sticks in curing barns remain manual operations. There are at least two primary reasons for this. First, burley plants are highly susceptible to leaf breakage and loss owing to leaf turgidity, plant size and orientation of leaves on the plant. These factors severely limit the extent to which any mechanism can engage a buried plant because aggressive mechanical contact with a turgid leaf will generally result in breakage and detachment (loss). Secondly, burley tobacco has traditionally been a relatively high value crop grown on limited land area. Thus, typical crop sizes are generally too small to justify the purchase of a relatively complicated and expensive harvesting machine.

In spite of such obstacles, innovators and researchers have continued to pursue development of a mechanical burley harvester. Yoder (1978) states that during the past 50 years the U.S. Patent Office has granted over 30 patents for stalk-cut tobacco harvesters or components thereof. Smith et al. (1967) described a mechanism for restraining a steel spear by the intermittent action of oscillating lateral pawls while a plant is impaled and pushed onto a stick. This "floating" spear was successfully tested but was characterized by limited capacity. This concept was also employed by an experimental stalk harvester tested in Maryland.

Several years of research on mechanical cutting and spearing plants onto sticks resulted in the construction of an automatic spearing machine for burley tobacco (Casada et al., 1972). This machine operated with a very high percentage of plants being speared, however, projected harvest capacity was not sufficient to justify anticipated cost.

Despite some limitations, these machines clearly established the reliability and utility of certain mechanical components. Both machines successfully used a circular saw to detach plants near the ground. Furthermore, the latter machine demonstrated that plants can be held securely when engaged near the base of the stalk between opposed roller chains with specially constructed links having barbs or teeth to partially penetrate the stalk. This allowed for minimal area of mechanical contact with the stalk and, thus, limited corresponding leaf damage or loss.

The next phase of harvester development bypassed automatic spearing and concentrated on automation of other harvesting activities. Yoder (1978) developed a burley harvesting aid which cut plants and delivered them to an operator standing on the machine for manual spearing via an inclined opposed roller chain conveyor. Swetnam et al. (1981) developed a machine which allowed an operator to spear plants while seated. Both of these machines successfully eliminated much of the strenuous physical activity associated with manual cutting and spearing. Furthermore, both utilized an important advancement in harvester development, i.e., automatic guidance via mechanical guides which maintain contact with standing plants in the row ahead. Elimination of manual steering was an essential development in increasing the labor productivity of these harvesting aids.

Yoder and Smith (1965) described a system for handling manually speared tobacco on free-standing portable frames or holders. The holders were handled by a tractor equipped with a front-end loader and were placed in a curing barn. Casada et al. (1986) described a harvesting system whereby notched plants were placed in wire-strung...
portable curing frames, thereby eliminating the necessity of spearing plants onto wooden sticks. A tractor-mounted harvesting mechanism was tested which cut, notched and conveyed plants to workers who placed them into portable curing frames. This system greatly reduced the drudgery associated with manual handling of burley tobacco during harvesting and significantly increased the productivity of a 4-5 worker crew.

The objective of the work reported herein was to develop a high-capacity, fully mechanized system for harvesting burley tobacco. The system should facilitate air curing of whole plants so as to maintain or exceed the quality of tobacco harvested by conventional means. This paper describes the conceptualization and development of the system, whose central feature is a self-propelled harvester prototype shown in figure 1.

**DESIGN OF COMPONENT MECHANISMS**

Ross and Yoder (1983) described a method of notching tobacco plants and placing them into a continuous-slot receiver. They placed opposed notches near the base of plants and used sections of overhead door track as the receiver. We judged this concept to offer the greatest potential for adaptation to total mechanical handling during harvesting. Thus, our effort was directed toward development of mechanical components necessary for its implementation. A description of the various components follows.

**AUTOMATIC GUIDANCE**

The harvester prototype was equipped with a mechanism to provide automatic “on row” guidance. A pair of parallel tines were utilized which extended forward of the detachment point and on each side of the row of plants being harvested. Mechanisms of this type were described by Yoder (1978) and Swetnam et al. (1981). However, the steering forces required for this harvester required the design of an electro-hydraulic steering assist mechanism (Day and Smith, 1988). The system utilized microswitches placed on each steering tine which, in turn, operated solenoid hydraulic directional control valves directing flow to each end of a bi-directional steering cylinder. The system was designed to permit the operator to override the automatic guidance system via operation of a rotary directional control valve activated by a steering wheel.

**DETACHMENT AND CONVEYANCE**

Circular saw blades (30 to 40 cm dia) have been effectively used to detach burley plants on several harvester prototypes (Smith et al., 1967; Yoder, 1978; and Swetnam et al., 1981). We used a circular saw blade in this system because of its proven reliability and because it permits detachment of plants at near ground level.

Smith et al. (1967) first described the use of opposed gripper chains to aggressively convey tobacco plants over a spearing device. Roller chain links with protruding tines or “teeth” were specially fabricated for this application. Yoder (1978) used such opposed gripper chains to grasp plants at the base after detachment and convey them up an incline.

We adopted this concept of conveyance because it offered the potential of manipulating plants while limiting mechanical contact to a small area near the base. Figure 2 shows the resulting configuration used in this system. No. 60 roller link chain with special links grasp the plants as shown. This conveyance method is essential in controlling mechanical contact with plants and the leaf damage and/or loss which results.

**INVERSION OF PLANTS**

Tobacco plants growing in the field occupy approximately 0.488 m², whereas, when placed in conventional curing facilities, the area per plant is 0.046 m² or less. This is accomplished by inverting plants so that leaves align with the stalk via gravity without breaking. Thus, it is essential that plants be inverted prior to reducing their spacing.

A mechanism was conceived to invert plants while maintaining field spacing. Figure 3 illustrates the mechanism and its operational characteristics. The mechanism consists of three component parts: 1) an inclined conveyor
with two 90° changes-of-direction, 2) two opposed inversion disks, and 3) a horizontal conveyor. A description of each component follows.

Plants are grasped immediately after detachment near the base by the inclined conveyor. This conveyor consists of four segments of gripper chain. A continuous inner segment is opposed by three outer segments in a configuration which results in three perpendicular sections. All chain segments had the same linear velocity so that all three sections operate at the same speed.

Section 1 is inclined 45° relative to horizontal and conveys plants upward and rearward from the detachment or entry point (front). Plants remain vertical as detached within this section and at approximate field spacing, provided the horizontal component of conveyor velocity is equivalent to ground speed.

Upon reaching the end of section 1, plants are transferred into section 2 via a spring-loaded device which holds plants against the inner segment until engagement with the second outer segment of gripper chain is achieved. A 90° change-of-direction results with plants being conveyed horizontally, perpendicular to the plant row or direction of travel. Because the angle of the plant axes and the inner segment of chain remains unchanged (45°), plants are tilted relative to their original orientation by the amount of this angle.

Plants are similarly transferred from section 2 to section 3 where they are tilted an additional 45° and are conveyed downward toward the front of the harvester. Thus, plants within section 3 are tilted approximately 90° relative to vertical and are elevated to a sufficient height to be placed into portable curing frames. Section 3 terminates at sufficient elevation to maintain adequate ground clearance for plants after inversion.

At the exit of section 3, two (2) flexible steel disks (50 cm in dia) are positioned immediately below the inclined conveyor (see fig. 3). The centers of these disks are separated by approximately 15 cm in a horizontal plane and the axes are misaligned such that the peripheries of the disks are in contact through an arc of approximately 90°. A portion of each plant extending beneath the inclined conveyor is captured between the opposed disks. Thus, a plant in section 3 of the inclined conveyor is engaged by the inversion disks prior to release and rotated to a fully inverted (180°) orientation (see fig. 3).

The horizontal grasping conveyor is positioned immediately below the inversion disks (see fig. 3). This conveyor consists of two opposed sections of gripper chain and conveys plants horizontally rearward. The speed of this conveyor is independent of the inclined conveyor so plants spacing can be changed if desired. The segment of a plant stalk engaged by the inclined conveyor is also engaged by this conveyor in order to minimize leaf damage due to the aggressive action of the gripper chains.

**PLANT NOTCHING**

Plants are engaged by the horizontal gripper conveyor, after being inverted, such that a portion of stalk extends above the gripper chains. Opposed stacks of circular saw blades positioned above the horizontal conveyor cut notches near the base of each stalk.

**PLACEMENT OF NOTCHED PLANTS INTO RECEIVERS**

Figure 4 illustrates the placement of notched plants into a continuous-slot receiver similar to the original door track described previously. Casada et al. (1986) suggested a placement of plants within a 15.2 cm x 15.2 cm grid for curing. They suggested that this reduced spacing (0.023 m² versus 0.046 m² for conventional curing) could be offset by a 7-10 day period of field curing within a free standing portable curing frame before placement under shelter.

A slotted receiver is positioned above the centerline and rearward of the horizontal gripper conveyor such that the notched portion of the plant enters the receiver slot (see fig. 4). Figure 5 shows the placement of a tined conveyor parallel to the receiver. The tines were equally spaced along the roller chain and extended below and perpendicular to the receiver slot.

Plants reaching the exit of the notching conveyor engage a switch which activates the tined stepping conveyor. A switch closure causes a wrap-spring clutch to engage and advance the conveyor a distance equivalent to one tine spacing (7.6 cm). The stepping operation occurs rapidly (up to 3 times/second) assuring the singulation of plants within the tined conveyor and a uniform spacing of 7.6 cm within the receivers.
the tracks a distance equivalent to the spacing between hydraulic cylinder which rapidly pushes the frame along frame indexing sequence.

Rear end, where it activates a switch which initiates the receiver via the stepping conveyor until a plant reaches the 1036

Fig. 5). Notched plants are conveyed rearward into this receiver aligned with the horizontal notching conveyor (see lowermost frame is in the initial position with its outside members or legs which fold parallel to the receivers for storage. Each portable curing frame holds approximately 450 plants at the spacing of 7.6 cm x 30.5 cm (0.023 m²).

A mechanism was designed and fabricated for automatic dispensing and filling of the portable curing frames. A stack of six frames with a capacity of 0.13 ha (0.33 acre) is stored in a magazine on the harvester prototype. The dispensing mechanism lowers the magazine stack onto front and rear horizontal tracks which are perpendicular to previously described conveyors. The mechanism then lifts the stack of frames from atop the bottom frame, which is engaged by a carrier mechanism via control pin extending from each end.

Resting on the track beneath the magazine stack, the lowermost frame is in the initial position with its outside receiver aligned with the horizontal notching conveyor (see fig. 5). Notched plants are conveyed rearward into this receiver via the stepping conveyor until a plant reaches the rear end, where it activates a switch which initiates the frame indexing sequence.

The indexing sequence begins with the extension of a hydraulic cylinder which rapidly pushes the frame along the tracks a distance equivalent to the spacing between parallel receiver slots (30.5 cm). Frame indexing occurs in less than the elapsed time between engagement of two successive plants by the stepping conveyor so that harvesting is not interrupted. After indexing, the carrier mechanism disengages from the frame control pins and the cylinder is retracted. The carrier re-engages the pins in a ratcheting fashion. Thus, as each successive receiver is filled, the frame is indexed from left to right until the eighth (last) receiver is filled.

A programmable controller executes the indexing sequence via the operation of solenoid directional control valves. Sequential extension and retraction of both the frame indexing cylinder and the carrier control cylinder is required. The controller also determines when a frame is full and stops all harvesting functions for unloading. When placed in the final indexed position, the curing frame engages a device which unlatches the support legs and allows them to rotate into the support position via gravity.

Unloading is accomplished via a linkage which is operated by hydraulic cylinders. By using manually operated directional control valves, an operator raises the lift arms to engage the control pins located at each end of the curing frames. Outside sections of the frame support tracks are lowered by retraction of hydraulic cylinders. The unloading arms are then extended to place the filled frame on the ground beside the harvester. The operator then lowers a frame onto the tracks from the magazine, resets the programmable controller, and continues harvesting. As soon as the harvester clears the unloaded frame, the support tracks are raised to their normal position.

Frame Handling Operations

We developed the system as a two-worker operation. One worker operates the harvester while the second worker executes the required frame handling operations. The first priority of these operations is to deliver stacks of empty frames to the harvester as needed and to load them into the frame magazine. Stacks of frames are handled using a specially constructed boom attached to a front-end tractor loader.

When the last empty frame on the harvester is filled, the harvester moves to the end of the field or elsewhere to ensure convenient access to the loader/tractor. The outside frame magazine supports are folded back and a stack of empty frames is loaded into the magazine via the loader/tractor. A special yoke is utilized on each end of the boom to engage the frame control pins. When the stack is maneuvered into position, a pin is removed from the bottom of each yoke (below the control pins of the bottom frame of the stack), disengaging the yoke from the stack, and the magazine supports are locked back into position.

During the time required for the harvester to fill the stack of six (6) portable curing frames, the loader operator is free to execute the second priority operation, i.e., moving filled frames from the field to a location for curing. Generally, frames are moved to intermittent untilled strips parallel to the rows or, to a convenient location near the field boundary. Frames are positioned side-to-side to facilitate placing waterproof coverings on the frames following a period of field curing (7-10 days). The loader operator would be sure to avoid causing a harvesting delay...

Figure 5–Stepping conveyor for placement of notched plants into portable curing frame receivers.

Figure 6–Portable curing frame with support legs down.
by not having a stack of empty frames ready to load when
needed.

Clearly, both the unloading of filled frames and the
reloading of empty frame stacks contributes to lower field
efficiency. These operations, along with turning at the end
of each row, are primary factors in establishing potential
harvesting rate. Unfortunately, on-the-go loading or
unloading, such as is employed with the operation of grain
combines, is not readily achievable with this system. Thus,
every effort was directed toward devising the most efficient
operational scheme possible.

Additional details concerning the design and function of
the automatic guidance system, the dispensing and filling
of portable curing frames, and the novel features of the
frames are given in Day and Smith (1988), Day et al.
(1989), and Day et al. (1988), respectively. A companion
paper (Wells et al., 1990) presents the results of extensive
laboratory and field experiments wherein operational
parameters were determined and field performance was
evaluated.

SUMMARY

The conceptualization, design, and development of a
prototype system for automated harvesting of burley
tobacco has been described. Unique mechanisms for the
specific functions of conveying and inverting mature plants
were successfully developed. Also, an original concept of
notching plants and hanging them in continuous-slot
receivers was developed, as were the mechanical systems
to dispense and handle portable curing frames in which the
receivers were incorporated. The resulting system has an
estimated harvesting capacity of up to 2 ha/day (5
acre/day), requiring only two workers to operate the
harvester and a front-loader equipped tractor.

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