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

M. J. Bader
University of Kentucky

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AUTOMATED SORTING OF ORIENTED TOBACCO LEAVES

L. G. Wells, M. J. Bader
MEMBER ASAE, STUDENT MEMBER ASAE

ABSTRACT

A mechanism has been developed which removes cured burley tobacco leaves from plants so that midribs are oriented parallel. A photosensor was utilized to count leaves as they were removed and a microprocessor determined the number of leaves allocated to each of three grades. Experiments indicated that 84% of leaves removed could be correctly sorted with a 2.4% material loss at an effective rate of approximately 2.4 times that of conventional methods.

BACKGROUND

Traditional manual methods used to prepare burley tobacco for market remained essentially unchanged from colonial days until recent times. Generally, these methods entailed removing and sorting oriented leaves by hand and then tying leaves together in hand-size units. Approximately 340-420 worker hours/hectare (150-170/acre) were required, which accounted for 40% of the labor required for conventional production methods (Duncan et al., 1980).

In the 1970s, an alternative method of packaging Canadian tobacco, which used compressed rectangular bales of oriented leaves, was experimentally evaluated for U.S. burley (Morrison and Yoder, 1972a). Subsequently, this method was introduced to producers and shown to be capable of reducing burley market preparation labor requirement by up to 50% (Duncan et al., 1978).

Morrison and Yoder (1972b) designed and tested a mechanical device to remove intact cured leaves from burley plants. This device made no provision for sorting or orienting leaves upon removal. Several other simple mechanical devices for burley leaf removal have been commercially manufactured during the last decade. These devices provide only marginal reduction in labor requirement and do not facilitate effective grading or sorting of leaves into grades (Duncan and Tapp, 1984).

Segmenting or slicing cured burley plants was proposed by Morrison and Yoder (1978). Pneumatic separation of stalk and leaf fragments was shown to be feasible (Morrison and Yoder, 1977), as was the separation of leaf grades by stalk position (Morrison and Yoder, 1972c). Whole-plant slicing offers the potential of high capacity market preparation, however, it requires market acceptance of non-traditional leaf segments and necessitates a degree of leaf type mixing. Such mixing occurs because of overlapping of leaves along the stalk, which results from plants hanging inverted during the curing process (Morrison and Yoder, 1978).

Miyake and Manzawa (1988) have described the successful development of a mechanism which removes intact leaves and facilitates their separation into multiple grades based upon stalk position. Plants are held horizontally with leaves hanging downward. Opposed rollers, positioned parallel to the stalk axis (as held), grasp leaves and pull them from the stalk which is held above by metal retainers. Movable partitions are arranged below the rollers to separate the leaves into grades. A decrease in labor requirement of 50% was reported; however, this device does not orient leaves for baling as is currently required for marketing of U.S. burley.

MECHANISM DESCRIPTION

An experimental mechanism was designed and fabricated to accomplish the following: (a) remove intact cured leaves from plants, (b) sort or separate leaves into three (3) grades based upon stalk position, and (c) orient leaves horizontally such that midribs were parallel and leaf nodes were in approximate longitudinal alignment. The mechanism employed a horizontal section of opposing undulated flexible belts attached to special roller chain links. The opposing roller chains were positioned so that the undulated flexible belts engaged or meshed between the sprockets on one end and disengaged as the belts moved around the sprockets on the other end (see Fig. 1). This type of conveyor was

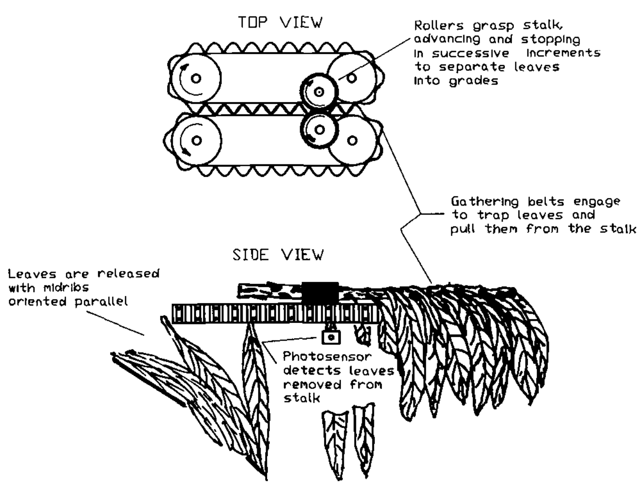

Figure 1-Diagram illustrating the basic components of the leaf removing and sorting mechanism.

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The authors are **L. G. Wells**, Professor, and **M. J. Bader**, Research Specialist, Agricultural Engineering Dept., University of Kentucky, Lexington.

developed to grasp and convey plants into a combine or forage harvester. They are commonly known as gathering belts and will be so designated throughout the remainder of this article.

An opposing pair of steel rollers with grousers was positioned immediately above the gathering belts at the entry point. The base end of the stalk was inserted between the opposing steel rollers and held independent of the gathering belts (see Fig. 1). Leaves hanging downwards from a plant held horizontally were trapped between the opposing belts as they engaged (meshed) between the sprockets. As the rollers moved the stalk into the machine, additional leaves were grasped between the gathering belts. Because the linear speed of the gathering belts was greater than the tangential speed of the rollers, leaves were pulled from the stalk and conveyed to the rear sprockets where they were released.

Separation of leaves into grades was achieved as follows. A photosensor was mounted 20 mm below the bottom edge of the gathering belts such that leaves trapped within the belts would be detected as they passed (see Fig. 1). A microprocessor circuit was devised to count pulses and compare to a preset number for each leaf grade. Thus, when a plant stalk was initially inserted between the rollers it would continue to advance until the preset number of leaves for the first grade was detected. At that point the controller circuit would stop the rollers by closing a solenoid-operated hydraulic, directional control valve. After sufficient time delay for leaves trapped within the belts to be conveyed to the end and released, the solenoid valve was reopened, advancing the stalk, and leaves from the second grade would be removed from the stalk. After detecting the preset number of pulses for the second grade, the rollers again would be stopped and the process repeated. The rollers would then advance until the final grade was removed and the bare stalk was ejected.

The experimental prototype did not include a means for automatically collecting leaves from the respective grades as they were delivered to the conveyor exit. However, leaves were reliably deposited with midribs parallel and their ends in approximate alignment as they were released from the gathering belts. (see Fig. 1). An automatic collection device will be added to the mechanism at a later time.

The specific objectives of the experiment were:

1. To determine the preferred linear speed of the gathering belts.
2. To determine the preferred speed ratio between the steel rollers engaging the stalk and the gathering belts engaging the leaves.
3. To estimate the potential capacity of the system in comparison to manual leaf removal and sorting.

Experimental Procedure

The experimental prototype stripping mechanism was subjected to a series of tests to evaluate its performance. A factorial experimental design was used to determine potential effects of linear belt speed, belt-to-roller speed ratio and stalk position upon sorting accuracy and effectiveness of leaf detachment.

Conventionally cured specimens of KY 14 burley tobacco were removed from the curing facility at a nominal wet basis moisture content of 24% and covered with plastic. At this moisture content both the leaf lamina and midribs were sufficiently pliable to hang vertically downward when the stalk was held horizontally. Four (4) replications of six (6) plants each were manually graded by experienced workers in order to determine the desired number of leaves to comprise each of three (3) grades; flyings (bottom of stalk), lugs (middle of stalk), and leaf (top of stalk). The average number of leaves assigned to the grades were, respectively, 4.67, 5.36, and 6.58.

Preliminary tests revealed that the photosensor failed to detect all of the leaves which were trapped within the belts. Possible causes of such failure were that (a) leaves were not always sufficiently singulated within the belts, or (b) leaves would sometimes be too thin or narrow to interrupt the light beam long enough to be detected. Thus, the number of pulses was set at less than the number of leaves desired from the lower and midstalk positions, 3 pulses vs. 4.67 leaves and 4 pulses vs. 5.36 leaves, respectively, in an attempt to compensate for the observed sensor error. Thus, the average compensation was 1.67 for flyings and 1.36 for lugs. These integer pulse settings were selected to minimize sorting error in preliminary tests of the apparatus.

Tobacco plant specimens were separated into lots of seven (7) plants each for processing by the prototype in a series of treatment configurations, i.e., combinations of belt speed and belt-to-roller speed ratio. The number of leaves segregated into each of three grades was recorded for each plant. The following additional data were recorded concurrently for each composite lot of seven plants: (a) total weight of leaves in each grade, (b) gravimetric moisture content of leaves in each grade (by random sampling), and (c) total weight of leaf material not removed from stalks. Such lots were replicated four times for each prototype configuration. Three belt speeds: 1.12, 1.24, and 1.36 m/s (220, 244, and 268 ft/min) and three belt-to-roller speed ratios: 2, 4, and 6 were examined.

The consistent failure of the photosensor to detect the correct number of leaves removed from the stalk led to a separate experiment to determine any potential effect of sensor position upon its performance. Cured KY 14 burley plants were exposed to steam to raise leaf moisture content such that they became sufficiently pliable to hang from the stalk and be grasped by the gathering belts. Triplicate lots of ten plants were processed at each of two sensor positions: 20 mm (0.8 in.) and 60 mm (2.4 in.) below the bottom edge of the gathering belt. These experiments were conducted at a gathering belt speed of 1.24 m/s (244 ft/min) and a belt-to-roller speed ratio of 4. As before, the electronic counters were set at 3 and 4 pulses for lower and mid stalk positions, respectively.

The number of leaves removed from each position of each plant was recorded. Leaves from each lot of ten plants were sorted by stalk position and samplers were collected for the determination of moisture content.

Results and Discussion

Table 1 presents the results of experiments conducted

TABLE 1. Sorting accuracy, leaf loss and moisture content corresponding to stalk position, belt speed and belt-to-roller speed ratio

Belt Speed, m/s (ft/min)	Belt-to Roller Speed Ratio	Stalk* Position	Avg. No. of Leaves Collected	Sensor† Error	Sorting‡ Error	Leaf Loss Percent	Moisture Content % w.b.
1.12	2	Cum.	15.36	8.36	5.07	5.29	–
(220)		Lower	7.68	4.68	3.01	–	24.92
		Mid	7.68	3.68	2.06	–	24.95
		Upper	3 79	–	-2.79	–	26.45
	4	Cum.	11.83	4.83	1.78	3.78	–
		Lower	6.33	3.33	1.66	–	27.88
		Mid	5.50	1.50	-0.12	–	23.41
		Upper	5.04	–	-1.54	–	24.52
	6	Cum.	12.68	5.68	2.49	6.06	–
		Lower	7.11	4.11	2.44	–	23.76
		Mid	5.57	1.57	-0.55	–	24.52
		Upper	4.29	–	-2.29	–	25.88
1.24	2	Cum.	15.07	8.07	4.78	4.29	–
(244)		Lower	7.93	4.93	3.26	–	26.12
		Mid	7.14	3.14	1.52	–	25.55
		Upper	1.96	–	-4.62	–	27.07
	4	Cum.	13.15	6.15	2.86	2.41	–
		Lower	6.47	3.47	1.80	–	26.73
		Mid	6.68	2.68	1.06	–	25.93
		Upper	5.07	–	-2.44	–	26.28
	6	Cum.	13.35	8.07	4.60	4.40	–
		Lower	7.75	4.93	3.08	–	24.57
		Mid	5.68	3.14	1.52	–	25.61
		Upper	4.14	–	-4.62	–	28.01
1.36	2	Cum.	16.57	9.57	6.28	3.92	–
(268)		Lower	9.82	6.82	5.15	–	23.90
		Mid	6.75	2.75	1.13	–	25.77
		Upper	1.07	–	-5.51	–	26.27
	4	Cum.	13.65	6.65	3.36	2.26	–
		Lower	7.86	4.86	3.19	–	23.94
		Mid	5.79	1.79	0.17	–	25.37
		Upper	3.50	–	-3.08	–	26.68
	6	Cum.	12.85	6.85	2.58	5.25	–
		Lower	6.71	4.71	2.04	–	23.01
		Mid	6.14	2.14	0.52	–	25.35
		Upper	4.68	–	-1.90	–	25.44

*Cumulative (Cum.) = Lower plus Mid stalk positions.
†Average number of leaves removed minus preset number of photosensor pulses.
‡Average number of leaves removed minus the prescribed number of leaves in each grade.

to determine the effects of gathering belt speed and belt-to-roller speed ratio upon prototype performance. Sensor error is the difference between the number of leaves removed and the respective pulse setting for the lower and mid-stalk positions (3 and 4 pulses, respectively). Cumulative sensor error is the sum of errors for both positions. The average sensor error for the lower and mid-stalk positions were 4.65 and 2.49 leaves, respectively. Clearly, the attempt to compensate for sensor error was not adequate as indicated by consistently positive sorting error for the lower and middle stalk positions. These errors dictated the consistently negative sorting error for the upper stalk position by default.

Sorting Error

Analysis of variance revealed a significant effect ($\alpha < 0.01$) of belt-to-roller speed ratio upon sorting error, whereas an effect of belt speed was indicated but not significant ($\alpha > 0.01$). Sorting error was significantly greater for the lower (versus middle) stalk position ($\alpha < 0.01$). This suggests that the prototype could be operated at any belt speed within the range tested so long as the optimum belt-to-roller speed ratio was maintained. Also, the results clearly indicate that photosensor error compensation must be greater for the lower (vs. middle) stalk position.

A highly significant ($\alpha < 0.01$) interaction between belt speed, speed ratio and stalk position was indicated, whereas the interaction between belt speed and speed ratio was not significant. Although a separate combination of belt speed and speed ratio may perform better for each stalk position, the practical difficulties of achieving such an adjustment would be prohibitive.

There was no significant correlation between sorting error and moisture content for these tests. However, because of the relatively narrow range of moisture content ($\overline{mc}$ = 25.37% w.b., S_{mc} = 1.37% w.b.) encountered, such an effect cannot be discounted.

Duncan's multiple range test (see Table 2) indicated that mean sorting error corresponding to the lowest belt speed is significantly lower than that of the highest speed. Also, sorting error associated with the lowest speed ratio was significantly higher than that of the other

TABLE 2. Duncan's multiple range test for mean sorting error as influenced by belt speed and belt-to-roller speed ratio

Belt Speed m/s (ft/min)	1.12 (220)	1.24 (244)	1.36 (268)
Mean Sorting Error	1.49ab	1.80ab	2.03b
Belt-to-Roller Speed Ratio	2	4	6
Mean Sorting Error	2.68a	1.28b	1.36b

Note: Means with different letters under each category are different at the 5% level of significance.

ratios. Table 1 indicates that the minimum cumulative sorting error for the lower and mid-stalk grades was 1.78 for belt speed = 1.12 m/s (220 ft/min) and speed ratio = 4. However, leaf loss at this setting was over 50% greater than for 1.24 m/s (244 ft/min) and 4, where cumulative sorting error was 2.86. The preferred setting chosen to minimize both leaf loss and sorting error was therefore: belt speed = 1.24 m/s (244 ft/min) and belt-to-roller speed ratio = 4.

Leaf Removal

Analysis of variance indicated a significant ($\alpha < 0\ 01$) effect of belt speed upon leaf loss, i.e., failure to remove all leaf material from the plant. A slightly less significant effect of belt-to-roller speed ratio was also indicated ($\alpha < 0.02$). Table 1 shows that minimum leaf loss (percent of material left on stalk) occurred at both the mid-speed [1.24 m/s (244 ft/min)] and mid-ratio (4) settings.

Sensor Position

Table 3 presents the results of experiments to determine the potential effect of sensor position (20 mm vs 60 mm below gathering belt) upon sorting error. Analysis of variance did not indicate significant effect. The variation of moisture contents in these data ($\overline{mc}$ = 33.9% w.b., S_{mc} = 12.5% w.b.) was much greater than in the data of Table 1.

Overall sorting error was much smaller for these limited tests than was indicated in Table 1. These results indicate that low sorting error can be achieved with the prototype, however, this was possibly only after compensating for the sizable sensor error (1.67 and 1.36 leaves in the flyings and lugs, respectively). Although these results indicate superior performance of the prototype at the higher mean moisture content, it should be noted that the mean moisture content of the former speciments (25.4% w.b.) is approaching the upper limit for safe storage and that the latter moisture content is almost certainly too high for storage.

TABLE 3. Sorting accuracy and moisture content corresponding to stalk position and sensor position (belt speed = 1.24 m/s, belt-to-roller speed ratio = 4)

Sensor Position*	Stalk Position 2	Sorting Error†	Moisture Content (% w.b.)
Low	Lower	0.36	33.72
	Mid	0.30	33.10
	Cum.	0.66	33.41
High	Lower	-0.14	31.28
	Mid	0.04	35.86
	Cum.	0.28	33.57

*Sensor Positions: Low = 60 mm (2.4 in) below gathering belts, High = 20 mm (0.8 in.) below gathering belts.
†Sorting error = no. of leaves captured minus target no. of leaves for that stalk position.

Projected Capacity

The projected capacity of the prototype was calculated for the preferred belt speed of 1.24 m/s and belt-to-roller speed ratio of 4. We assumed a leaf mass of 0.1 kg per m of plant length. Thus, by assuming a plant feeding rate of 1.24 m/s ÷ 4 = 0.31 m/s and an operating efficiency of 70%, the projected capacity is 78 kg/h. When two workers operate the mechanism (one feeding plants, one removing sorted leaves) the production is 39 kg/worker hour, which is 2.4 times the conventional manual rate of 16.3 kg/worker hour. However, if two workers feed two such mechanisms and one worker removes the sorted leaves of both, then the potential production per worker would be 52 kg/h which is 3.2 times the conventional manual rate. The determination of actual capacity must await the design and testing of a mechanism to receive sorted leaves from the gathering belts.

Summary and Conclusions

The primary mechanical components of the mechanism, i.e., the opposing steel rollers and the opposing grasping belts, performed reliably with respect to the removal and sorting of cured burely tobacco leaves. In the optimum configuration, 97.6% of usable leaf material was removed from the plants tested. The estimated processing rate at this configuration (belt speed = 1.24 m/s (244 ft/min), belt-to-roller speed ratio = 4) is approximately 39 kg of tobacco per worker hour, which is 2.4 times the current manual rate.

Experiments revealed that the photosensor, regardless of how it was positioned, did not reliably indicate the removal of leaves from plants by the gathering belt mechanism. This was especially true for the lower stalk position where only half of leaves removed were detected. Substantial compensation for sensor error was required by stalk position. Thus, it seems apparent that sorting on the basis of stalk length would result in better performance of the mechanism. In this configuration, the rollers would simply advance in specified increments to expose each plant segment to the gathering belts below, as opposed to attempting to specify and count a prescribed number of leaves for each grade. The prototype will be so modified for further evaluation.

Further, these experiments indicate the need to closely examine the effect of moisture content upon mechanism performance. Although inconclusive, the results indicated potentially important effects of moisture content upon sorting accuracy and leaf loss. Thus, and acceptable range of moisture content for use of the prototype must be determined.

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