THE DESIGN PARAMETERS OF A POWERED GRASS-DIVIDER

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Gary W. Ash

1962

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THE DESIGN PARAMETERS OF A

POWERED GRASS-DIVIDER

by

Gary W. Ash

AN ABSTRACT

Submitted to the Colleges of Agriculture and Engineering, of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURAL ENGINEERING

Department of Agricultural Engineering

1962

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ABSTRACT GARY W. ASH

A mechanism for reducing the stoppages encountered at the inner and outer shoe of a mower bar was studied. The construction and testing of a powered grass divider are described. The divider was a high speed pick up reel 15 in. long with fingers that oscillated in and out of a drum surface as the drum revolved. The divider was mounted above the outer shoe of the mower cutter bar and was driven by a hydraulic motor.

Tests were run at three different rotational speeds and four different reel settings of angularity with line of travel and tilt from the horizontal.

Alfalfa stalks were tagged and their displacement measured after the divider operation. Corresponding stalk displacements were averaged and plotted to show the distribution pattern. The plotted data show that the forage experiences a separation effect. The inner end of the reel throws forage farther forward than does the outer end. The amount of separation is not significantly affected by changes in reel speed. The mean of the distribution pattern shifts from a forward to a rearward position in relation to the initial stalk position with an increase of reel speed. The distribution was not affected significantly by changes in reel positions in the forage used for qualitative tests.

The width of the distribution pattern was approximately 2½ ft. and the width of path cleared by the reel was from 11 to 15 in.

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INTRODUCTION

Forage and cereal crops are removed by cutting from approximately 70% of the 360 million acres of crop land each year in the United States. Hay is cut from two to six times per season and accounts for about 72 million acres each year in the United States. The mowing machine is primarly used to cut the hay crop.

The mower is also used to control weeds in pastures, fence lines, and road right-aways.

Because of its extensive and repeated use, the mower covers more acres each year than any other farm machine.

Mower development was closely associated with that of the reaper; the first machines were used to cut both grain and grass crops. Ketchum, in the 1840's, marketed the first mowers that were distinct from reapers.

Except for the use of a power-take-off shaft to deliver the tractor power to operate the mowing machine, few significant improvements were designed into the mower until the late 1940's. The production of a double knife mower was followed by the dynamically-balanced mower.

Recent mower research has been primarily concerned on drive mechanisms, cutting energies, and cutting action.

The purpose of this research was to increase the usefulness and reduce stoppages of the mower by the design and development of a mechanism to replace the swath board and grass stick presently employed at the outer shoe of the cutter bar.

The information, so gained, can be used in the improvement of mower design, thereby increasing their utilization by reducing stoppages under a wider range of conditions.

LITERATURE REVIEW

In 1833 the principle of the reciprocating sickle knife and slotted guards was patented by Hussey.(1) Blaauw states that this is still the major mechanism for mowing forage crops.

Smith (2) reported a 1856 patent granted to Cornelius Aultman contained the basic principles of mowers (the rachet-pawl drive).

In the early 1900's the horse-drawn mower tongue was cut off and the mower was pulled by a tractor. The manufacturing of tractor mounted mowers began about 1920.

Mowers underwent few changes as to increased effectiveness until in the late 1940's and early 1950's the double-knife mower was produced. According to Blaauw (1), this idea was not new; it was patented in 1833. This was even before an efficient machine had been produced; they experienced difficulties with clogging and drive mechanism balancing.

The double-knife mower has no guards; consequently, the knives dull rapidly in gravelly soils and a poor job results. In addition, this mower tends to ride up on thick or matted crops, as there are no guards to give suction.

Elfes (3) discussed the design of a dynamically balanced, pitmanless, minimum vibration mower capable of many more cutting-strokes per minute.

Both of the above mowers were capable of operating with the cutter bar in any position from the vertical to 45° degrees below the horizontal.

Scarnato (4) reported on the counter balancing of a mower drive to facilitate smoothness of operation, absorb the change of balance encountered with optional length knives, and be capable of enduring a continuous crank speed of 1000 R.P.M.

Feller (5) studied the effect of knife angle on cutting energy. Prince and Wheeler (6) investigated energies and velocities required to cut forage crops.

Personal field experiences and observations, as well as farmer comments, indicated that one of the major deficiencies of the modern mower was the swath board and grass stick.

The operation of the swath board limits the overall effectiveness of the mower in many applications.

The present swath board, consisting of a divider board and/or grass stick, has undergone little change from the earliest mowers. This lack of improvement can be, in part, attributed to the cheapness of the present board.

The present-day functional requirements of the swath board are two-fold. First, it must effectively clear a path for the inner shoe to travel in the next cut around. Failure to clear the strip of swath next to the uncut crop causes stoppages at the inner shoe on the next round. In many cases of long, viney forage, the stems drape over the board and are dragged along by the grass stick. This causes a stoppage of the mower, and requires the operator to dismount to remove the hay from the grass board and stick.

The second requirement of the swath board and stick is that the divider arrangement should distribute the transferred forage over the swath rather than windrow it on top of the outer edge. There are two reasons for this requirement.

First, when the forage is deposited in a narrow strip on top of the swath, that portion dries slowly because of the double layer. Secondly, the double layer tends to plug hay conditioners. To minimize plugging the conditioner, the rolls are often adjusted with a non-uniform tension in springs or spacing between rollers. This permits greater clearance at the end where the double layer of forage is conditioned. Not only does poor conditioning result to the double thickness of material, but also, because of the tapered roll spacing, the forage passing between the rolls adjacent to the two-layer area is not adequately conditioned. This is shown schematically in Figure 1.

The present swath board aggravates the situation by accumulating under certain conditions small bunches of hay and dropping them onto the swath. This increases swath thickness and non-uniform drying.

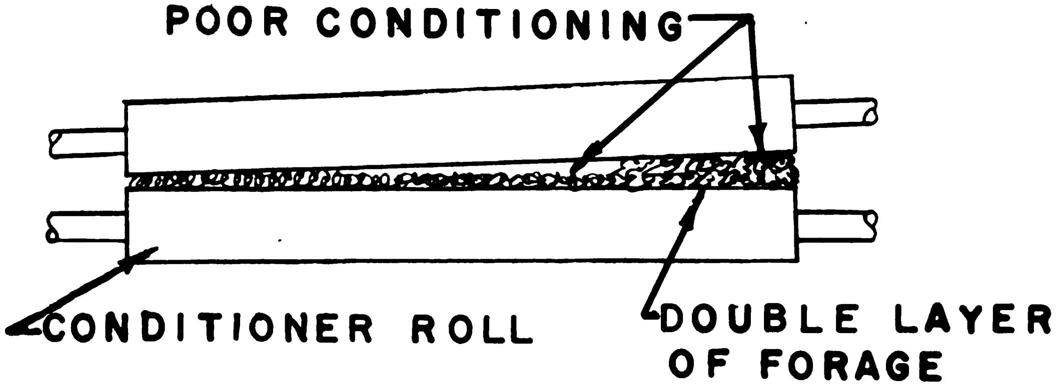

Fig. 1. Schematic of non-uniform spacing of conditioner rolls.

Secondary requirements of the grass divider were that it be light in weight and positive in action.

APPARATUS

A powered grass divider was designed, constructed, and mounted above the outer end of the cutterbar as shown in Figure 2. Basically, this device was a high speed pickup reel.

Sixteen pickup-fingers were free to rotate about their mounting shaft, which was mounted eccentrically in a 6 in. diameter drum. The drum rotated about its concentric axis. The fingers were spaced 13/16 in. apart laterally, but so arranged that they protruded through the drum surface at 90^{o} intervals. The drum rotation forced the fingers to rotate and move in and out, relative to the drum surface. The maximum extension of the fingers beyond the drum was 3 in.

Fingers were held by holders made from tubing. The tubing wall was drilled perpendicularly to its concentric axis, and the finger pressed into the hole. The fingers were then brazed to the tubing. An oilite bronze bearing was pressed into the tubing to complete the holder. See Figure 3.

The eccentric mounting shaft was made by offsetting the finger shaft from the bearing support shafts with two pieces of ½ in x 1 in. flat steel. This is shown in Figure 3. The offset is 1½ in. The support shafts were held in two upright mounting brackets. The inner bracket was "L" shaped and extended behind the reel before dropping

Fig. 2. Tractor and mower with powered grass divider.

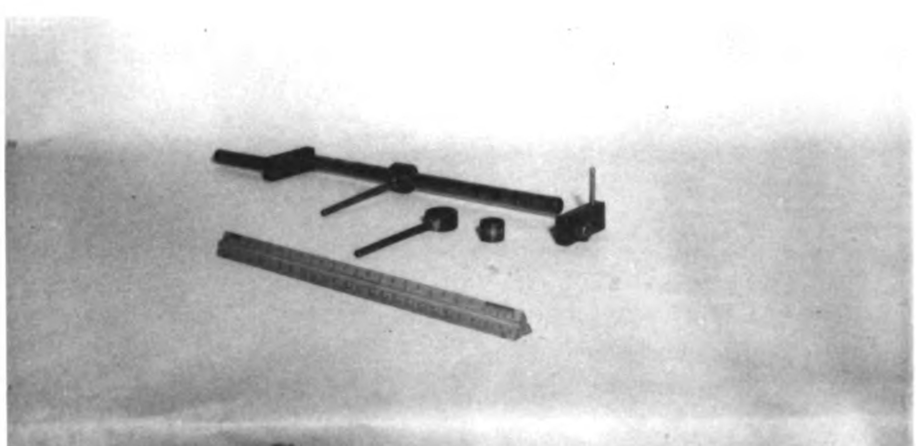

Fig. 3. Finger assembly and eccentric mounting shaft.

down to fasten to the mower bar. This was done to avoid forage catching on the inner bracket. The outer bracket was fastened to the outer shoe. The reel could be adjusted in the vertical and horizontal planes as well as be operated at various angles to the direction of travel.

The arc positioner was a part of the outer mounting bracket. The positioner was composed of a hub welded to a semi-circle of flat steel. Adjusting holes were drilled on an arc close to the perimeter. The positioner was pinned to the support shaft with a split key and a bolt through an adjusting hole secured the positioner to the support bracket. See Figure 4. Rotating the positioner moves the mounting shaft inside of the drum, which changes the maximum reach position as well as the "flipping" position.

The drum consisted of a 15 in. length of a 6 in. outside diameter aluminum tubing (wall thickness 1/16 in.). Sixteen 5/16 in. by 1½ in. slots were cut into the drum wall to provide clearance for the fingers to arc as they rotate. Each slot was 90° apart on the drum periphery at a lateral distance of 13/16 in. apart.

Stabilizing bushings for the fingers to slide in were constructed from ½ in. diameter wood-doweling. These bushings were rocked in their retainers as the fingers oscillated.

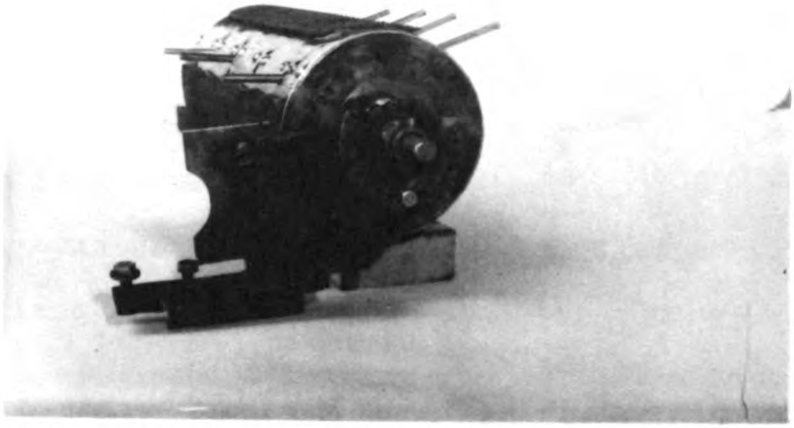

Fig. 4. "Arc positioner" mounted on the end of the reel.

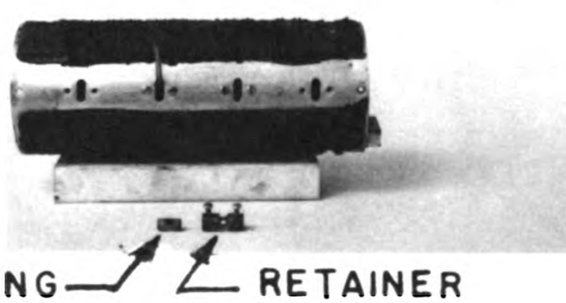

Fig. 5. View of drum, drum slots, retainer and stabilizing bushing.

Retainers were built from 3/8 in. standard pipe. Each retainer was 1½ in. long, reamed to ½ in. inside diameter. An end-mill was then used to slot them laterally, the length of slot equal to the ½ in. inside diameter. The slot width was 5/16 in. See Figure 5.

Two self-tapping metal screws position each retainer on the inside of the drum directly under each drum slot, as shown in Figure 5.

Reel ends were built from 1/8 in. flat steel with a ½ in. long piece of 1 in. outside diameter tubing, welded to the center for increased bearing support. The tubing was then chucked in a lathe, ends turned to 5 7/8 in. diameter, and tubing and plate drilled and reamed for oilite bronze bearings. Clips were welded even with the outside diameter to provide mounting tabs to join drum and ends. The ends fit flush into the drum. The power sprocket was pressed over the bronze bushing and fastened to the outer reel end. Figure 6 shows the completed reel.

The pickup finger tips travel in a true arc, but tip velicity is not constant, as the mounting shaft is eccentric in the drum. At the "in" position, tip velocity is identical with drum velocity. At the extended position, tip velocity is equal to 3 1/8 times drum velocity. As the fingers approach the fully extended position, the tips are accelerated rapidly, and have a flipping effect.

To insure positive action, independent of forward travel, the divider was chain-driven from a hydraulic

Fig. 6. Powered grass divider assembly.

Fig. 7. Mounting position of the hydraulic motor and enclosure of hydraulic lines.

motor, Char-Lynn, Model A-10. The motor was positioned directly behind the drum, as shown in Figure 7.

The hydraulic motor was driven by the tractor's hydraulic system, using the tractor's control valve. The hydraulic lines to the motor were enclosed in a sheet metal case, and positioned right behind the cutterbar. Drum speed was controlled by tractor engine speed, and by changing sprocket sizes.

Drum speed ranged from 260 R.P.M. to 600 R.P.M., giving a peripheral drum velocity of 408 F.P.M. and 942 F.P.M., respectively. The ratio of peripheral velocity to ground speed was between 2 and 3 to 1.

PROCEDURE

Initial field tests revealed that forage caught on the left mounting bracket of the reel, and caused stoppages. The inner mounting bracket was removed, and the support shaft machined flush with the end plate. The outer mounting bracket was rebuilt to support the entire divider. No further plugging occurred at the inner end of the reel.

The mounting was built from 3/4 in. diameter shafting and setscrew collars. The reel was adjustable in the vertical and horizontal planes, and could also be positioned at various angles to the line of travel and tilted from the horizontal position.

The chain and sprockets were tightly shielded to prevent grass entanglement.

The divider scattered a narrow strip of cut material, adjacent to the uncut forage. Lateral adjustment of the divider, to permit the outer end of the reel to skim the uncut grass, eliminated this loss.

During high speed operation, the fingers broke loose from the holders. Fingers were replaced and arc-welded in the holders.

The path width and the distribution pattern were unsatisfactory below reel speeds of 400 R.P.M. Consequently, a speed range of 400 to 600 R.P.M. was selected for qualitative testing. The operation of the divider was satisfactory in upright forage up to 2 ft. in height. General operation

Fig. 8. General field operation of the divider.

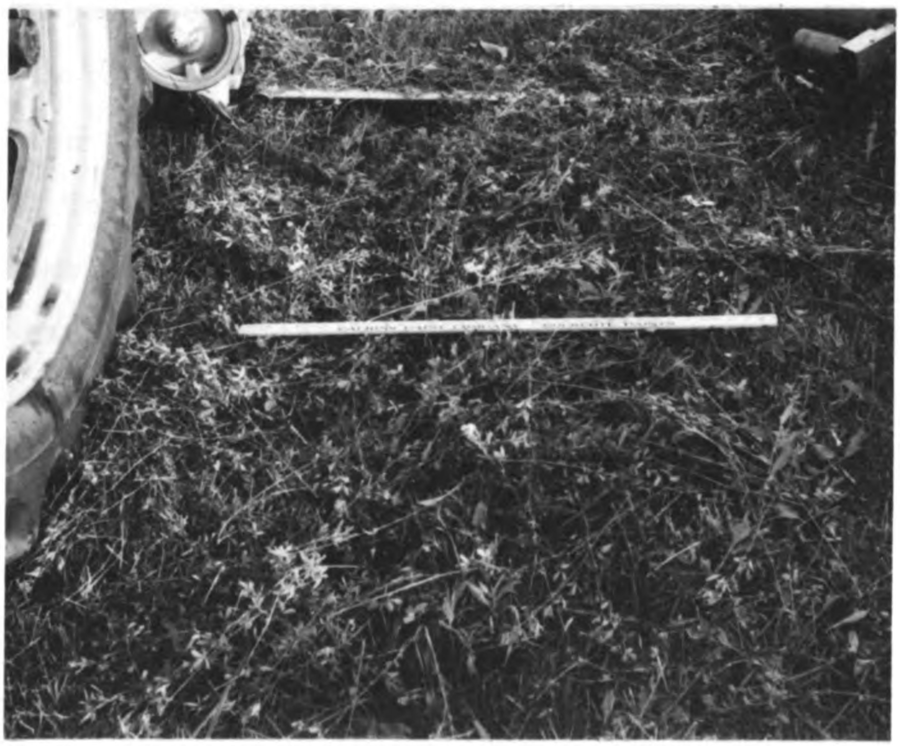

Fig. 9. Distribution width after divider operation.

is shown in Figure 8. The forage underwent a rapid acceleration, and experienced a trajectory sufficient to clear a path of 11 to 15 in., and be distributed over the swath in a width up to 40 in. See Figure 9.

Although the bar would go through longer, slightly tangled forage without clogging, the forage did not receive a great enough acceleration to distribute it. The drum was roughened to increase the acceleration. Four 2½ in. by 14 in. rough rubber strips were cemented longitudinally onto the drum. This is shown in Figure 10. Little improvement in the acceleration was noticed.

Another interesting result was noticed. When cutting the last swath, or at any time the outershoe must pass through previously cut swaths, the outershoe and grassboard usually plug. The powered divider pulls the forage in an unbroken flow of material up and over the reel. (Figure 11) This occurred in both new and old cuttings.

Some wrapping occurred in long, viney, mature alfalfa. Wrapping started from forage being deposited on the hydraulic motor, and then being dragged between motor and reel. To eliminate this, the motor was remounted at a 45^0 angle below the horizontal from the reel.

A sheet metal shield was also made to extend from the rear side of the drum, out over the motor. See Figure 12. This lessened wrapping, but did not completely eliminate it.

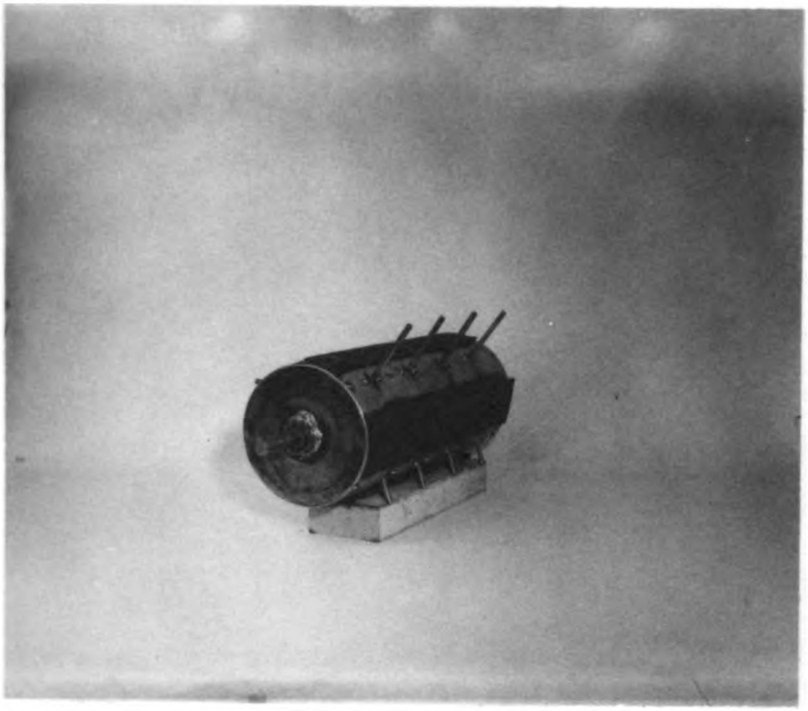

Fig. 10. Rubber strips mounted on the drum.

Fig. 11. Operation of the divider in previously cut material.

Fig. 12. Shielding the hydraulic motor to prevent wrapping.

Fig. 13. Method of tagging alfalfa stalks (arrows indicate tags).

The motor was then mounted 20^0 from being directly under the reel. The shield was also utilized, but wrapping still occurred. The reel speed appeared to be adequate at 500 to 600 R.P.M; however, because of the length and tangled condition of the forage (first cutting, mid-July), insufficient velocity was imparted to throw it clear of the reel. Reel and finger action were positive in that material was always carried over the reel, but not positive enough to impart to the forage a velocity approaching drum peripherial speed.

When forage did wrap around the drum, a careful operator could quickly clear the reel by alternately changing the rotational direction, by operating the control valve.

The relief valve, in the hydraulic circuit of the control valve, served as a safety clutch. When the divider became severely wrapped, the torque requirement increased rapidly, producing a high pressure surge, which caused the valve to return to neutral.

Once wrapping started, the divider's rapid rotation would usually cause it to plug before the operator could stop its rotation.

QUALITATIVE TESTING

Second cutting alfalfa of approximately 16 in. high was used for the following tests. To conserve forage and ease of measurements, 14 in. wide strips were cut rather than full cutter bar width.

Three 4 in. strips 10 ft. apart at right angles to the line of travel were marked with paint from an instant spray can. This facilitated the location of the hay after it was distributed.

After the 14 in. strips were measured, the alfalfa stalks were tagged at 2 in. intervals beginning at the outside edge. This is shown by Figure 13. The tagged stalks were used to establish the distribution pattern after cutting and to analyze the trajectory. Each test consisted of three tagged strips.

Tests were run at reel speeds of 400, 500, and 600 R.P.M. The reel was set at angles of 45° and 60° with the line of travel. The reel was operated level and at a tilt of 30° below the horizontal for each of the angled settings. All four conditions were repeated for the three reel speeds.

The width of path cleared was measured for each test. The lateral and forward or backward position of each tagged stalk was measured with respect to the edge of the standing marked strip as shown in Figure 14. From this, the movement of the tagged stalks from their initial positions could readily be determined. Figure 15 shows divider operation in tagged stalks.

Fig. 14. Measurement of displacement of alfalfa stalks.

Fig. 15. Reel operation in tagged stalks.

RESULTS AND DISCUSSION

The data discussed in this thesis were obtained by measuring the lateral and forward or rearward displacements of tagged alfalfa stalks. The displacements for all of the grass divider settings are recorded in Tables V thru XV. The settings were at 45° angle-0° tilt, 45° angle-30° tilt, 30° angle-0° tilt, and 30° angle-30° tilt with reel speeds of 400, 500, and 600 R.P.M.

The 3 displacements for each replicated stalk position in each test were averaged and tabulated in Tables I to IV. Data that did not appear consistent was not included in the averages. The original positions of the stalk and the data from Tables I and IV, representing the averaged displacements for reel settings of 45° angle-0° tilt and 30° angles-30° tilt for the 400, 500, and 600 R.P.M. reel speeds, have been plotted to show the distribution pattern in Figures 16 and 17.

Analysis of the graphs indicate the following:

1. The forage does not undergo uniform acceleration but suffers a severe separation. In relation to each other, the inner group of stalks is accelerated forward, but the outer portion is accelerated rearward.
2. In general, the overall displacement changes from a forward to rearward direction with an increase of reel speed.

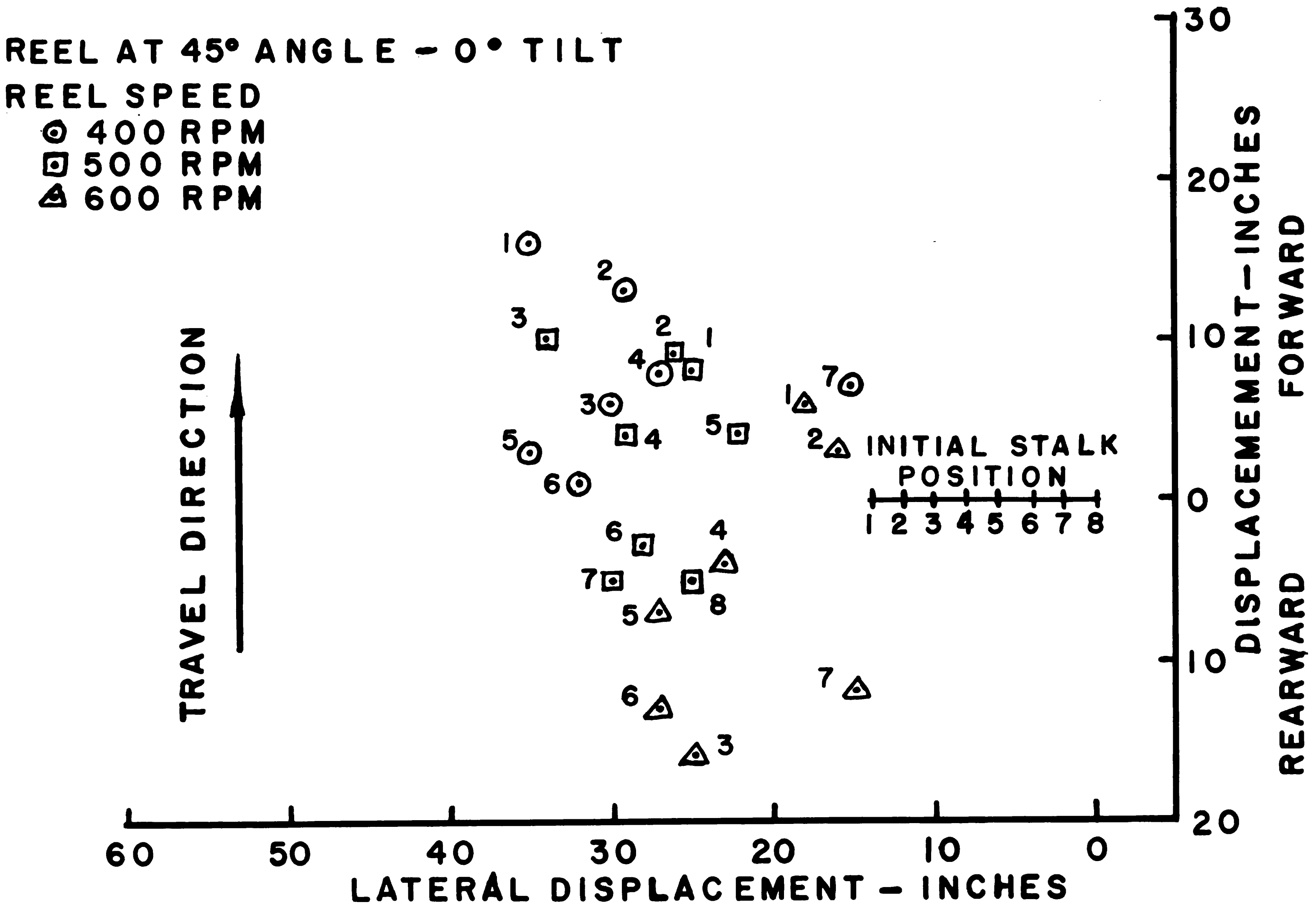

Fig. 16 Average Alfalfa Stalk Displacement; Reel At 45° Angle-0° Tilt; Reel Speed of 400,500, and 600 R.P.M.

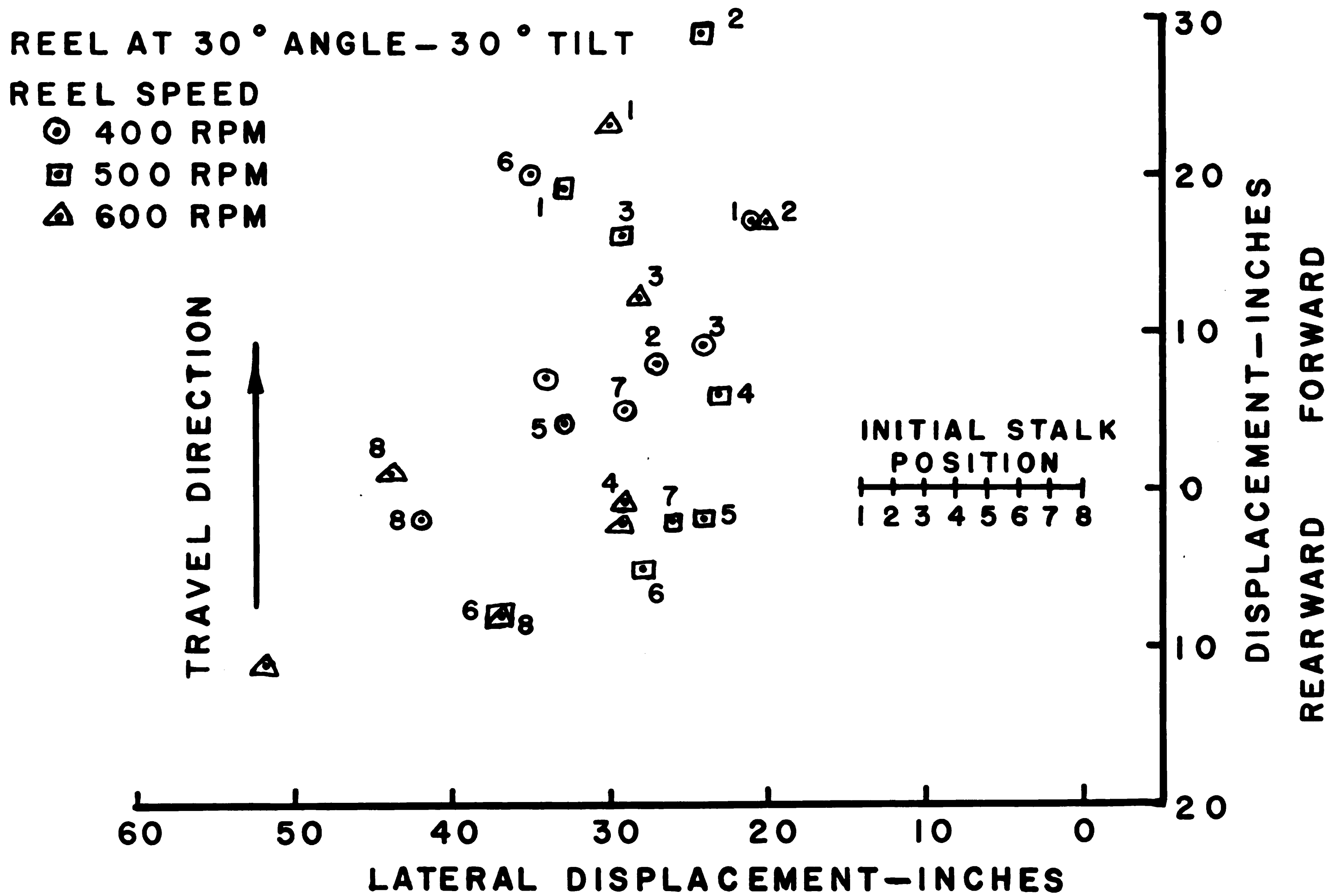

Fig. 17 Average Alfalfa Stalk Displacement; Reel At 30° Angle-30° Tilt; Reel Speed of 400, 500, and 600 R.P.M.

The separation effect occurs as follows. The inner front reel edge was positioned directly above the point where cutting occurs. The outer front reel edge was positioned approximately 6 in. behind the point of cutting. The stalks at the inner end meet the drum in a vertical position. Consequently they are propelled forward by the forward motion before being accelerated by the drum and fingers. In addition, because they do meet the drum in a vertical position, the largest component of their initial acceleration is vertical.

The forage at the outer end fell on to the reel after being cut. It receives a "toppling effect" from the cutter bar hitting the lower end of the stalks. The outer stalks, therefore, fall in a direction in which they will ultimately be accelerated. Hence, they achieved a greater trajectory.

For example, Table II (45° angle-30° tilt) shows that the average separation in the direction parallel to the line of travel was approximately 20-24 inches. Separation in the parallel direction was not significantly affected by reel speed.

The shift of the general location of the distributed forage with a change of reel speed can be seen in Table I. The mean displacement for the reel setting of 45° angle-0° tilt was 8 in. forward, 3 in. forward, and 8 in.

rearward for reel speeds of 400, 500, and 600 R.P.M., respectively. For the 30° angle, 30° tilt from Table I, the mean displacement of 9 in. forward, 7 in. forward and 4 in. forward for 400, 500, and 600 R.P.M., respectively. Visual observation of Figures 16 and 17 also reveal this trend.

Qualitative testing showed the amount of distribution was not significantly affected by the angular position of the reel with the direction of travel or by the tilt of the reel from the horizontal plane. By visual observation the operation of the divider in alfalfa from 20 to 30 in. high appeared to be improved by a tilted position of 30° from the horizontal. At this tilted position, the forage was accelerated more smoothly onto the swath.

The tests for the reel setting of 30° angle-0° tilt were conducted on a windy day. The wind blew in the direction of travel. Consequently, the forage, upon being tossed into the air, drifted with the wind. Little forward-rearward separation occurred as is shown in Table III.

Crosswinds in the direction from inner shoe to outer shoe restricted the dividers efficiency. Some of the tossed forage were carried over into the uncut material. This accumulation of cut and uncut forage was well scattered, but this requires the material to be rehandled. The arc-positioner was rotated rearward until the material was pulled over the reel without becoming airborne. The path was cleared but little distribution occurred.

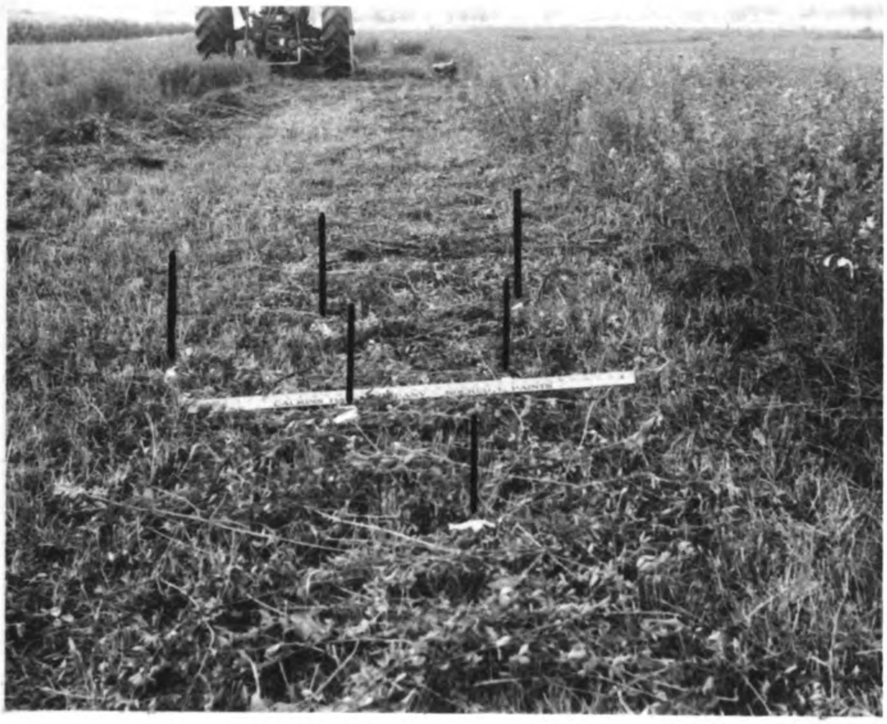

Fig. 18. Distribution pattern of tagged alfalfa stalk after divider operation (see pointer).

Overall distribution was good. Material was thrown by the divider on top of the swath in a width of 2½ feet; this width generally extended from a point 1½ feet to a point 4 feet from standing forage. Figure 18 shows a distribution pattern.

The initial area of tagged stalks was 28 square inches (14 in long by 2 in. wide; tagging was done on row of stalks within a 2 in width.) The triangle in Figure 19 (Table IX, 500 R.P.M., 45° angle-30° tilt) shows that the stalks were scattered over an area approximately thirteen times as large as the initial area.

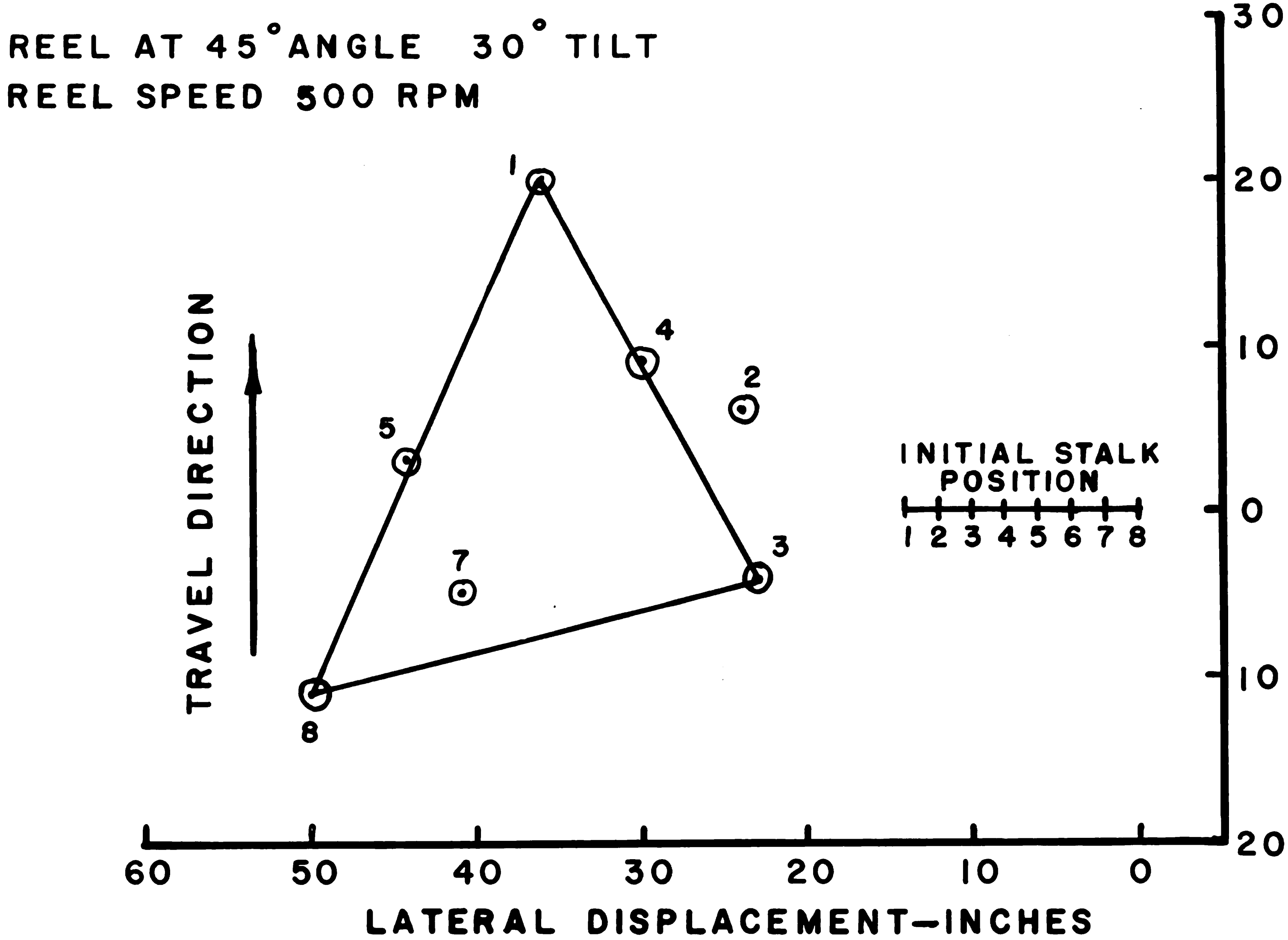

Fig. 19 Comparison of area of distribution pattern with initial area for alfalfa stalks.

SUMMARY

Although extensive work has been done on the guard, knife section and reciprocating mechanism of mower, little development has been done on the swath board and grass stick. Consequently, the mower frequently clogs, both at the inner shoe due to a poor job of dividing and at the outer shoe as forage catches on the board or stick.

In addition, the manner in which the board and stick deposit the windrowed layer of hay on top of the swath is undesirable. This two-layer accumulation of hay dries at a slower rate than the rest of the swath. If a conditioner is used, the double thickness of hay interferes with the effectiveness of the conditioner as the rolls must be set on non-uniform spacing and the center portion of the swath receives little conditioning.

Therefore, a divider pick-up reel 15 in. long driven in by a hydraulic motor was mounted at the outer end of the cutter bar. The reel was positioned at an angle to the bar in order that material picked up by the reel was thrown onto the swath. The ratio of the peripheral speed to the ground speed was approximately 3 to 1.

Tests were conducted at 400, 500, and 600 R.P.M. The reel was positioned at a 45° angle and 30° angle with the cutter bar, and at 0° and 30° of tilt from the horizontal.

Alfalfa stalks from 14 in. strips at right angles to the line of travel were tagged at 2 in. intervals.

After reel operation, the displacements of the tagged stalks from the standing forage were measured.

Displacements of corresponding stalks were averaged, tabulated and two of the averaged tests were plotted.

The table of averages of the plots reveal which sections of forage receive severe separation. The inner stalks are accelerated farther forward than the outer stalks. This occurs because the inner end of the reel is positioned directly above the point of cutting. The separation effect did not appear to be a function of reel speed. The mean of the distribution pattern moves rearward with an increase of reel speed.

The alfalfa from a 2 in. by 14 in. area was distributed on top of the swath over an area of approximately 30 in. by 24 in. The width of path cleared by the divider was 11 to 15 in.

The angularity of the reel with the line of travel or degree of tilt did not appear to affect the distribution significantly.

In tangled alfalfa, only partial separation occurred and occasionally, the forage would wrap on the reel.

CONCLUSIONS

1. The powered divider was effective in clearing a path of 11 to 15 in. wide.
2. The distribution pattern was good. The width of the distributed material on top of the swath was 2½ ft.
3. The forage does not receive uniform acceleration. Average parallel separation was about 20 to 24 in.
4. Qualitative tests did not indicate any setting of the reel as critical. Visual observation of random field tests in alfalfa up to 30 in. high indicated an improvement in distribution with a 30^{o} tilt from the horizontal.
5. Rotational speeds between 400 to 600 R.P.M. does not significantly affect parallel separation.
6. An increase of reel speed shifts location of distribution from forward to rearward of initial stalk position.
7. The divider distributed the forage over an area 13 times greater than the initial area.
8. The reel lacks sufficient positive capacity for long viney alfalfa. This forage receives insufficient acceleration for distribution. Tangled forage may cause wrapping.
9. Wind restricts the effectiveness of the divider by reducing its distribution pattern. Path width could be

maintained by changing the arcing position of the fingers to carry forage directly over and back of the reel without accelerating the forage into the air.

RECOMMENDATIONS FOR FURTHER STUDY

1. Development of a cone-shaped reel enabling the foremost edge of the cone to be positioned parallel to the cutter bar.
2. Design of a divider composed of two flat belts to provide positive gripping and accelerations.
3. Incorporate a mechanical drive directly from the mower.
4. Conduct tests to determine relationships between accelerations and distribution for various length and conditions of forage.
5. Investigate the improvement of drying conditions for various distributions.

APPENDIX

EXPERIMENTAL RESULTS

TABLE I

AVERAGE DISPLACEMENT OF ALFALFA STALKS FOR COMPARATIVE STALK POSITION AT 45° ANGLE-0° TILT

RPM	Stalk Position	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
	1	35	16	
	2	29	13	
	3	30	6	
400	4	27	8	
	5	35	3	
	6	32	1	
	7	32	1	
	8	Missed		
	1	25	13	
	2	26	9	
	3	34	10	
500	4	29	4	
	5	22	4	
	6	28		3
	7	30		5
	8	25		5
	1	18	6	
	2	16	3	
	3	25		16
600	4	23		4
	5	27		7
	6	27		13
	7	15		12
	8	-----		

TABLE II

AVERAGE DISPLACEMENT OF ALFALFA STALKS FOR COMPARATIVE STALK POSITION AT 45° ANGLE-30° TILT

RPM	Stalk Position	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
	1	24	22	
	2	24	22	
	3	39	21	
400	4	38	22	
	5	19	13	
	6	22	27	
	7	24	0	
	8	38	5	
	1	25	26	
	2	20	21	
	3	22	1	
500	4	26	6	
	5	36		1
	6	34		6
	7	34		6
	8	43		9
	1	32	13	
	2	24	19	
	3	19	4	
600	4	30	9	
	5	23	6	
	6	30	11	
	7	47	10	
	8	60	4	

TABLE III

AVERAGE DISPLACEMENT OF ALFALFA STALKS FOR COMPARATIVE STALK POSITION AT 30^{o} ANGLE-0^{o} TILT

RPM	Stalk Position	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
	1	32	8	
	2	34	14	
	3	33	4	
400	4	33	1	
	5	24	13	
	6	37	12	
	7	16	6	
	8	19		4
	1	21	21	
	2	33	10	
	3	31	10	
500	4	31	10	
	5	24	9	
	6	19	11	
	7	25	8	
	8	29		10
	1	23	3	
	2	40	9	
	3	38	4	
600	4	35	13	
	5	37	3	
	6	31	2	
	7	40	2	
	8	41		10

TABLE IV

AVERAGE DISPLACEMENT OF ALFALFA STALKS FOR COMPARATIVE STALK POSITION AT 30° ANGLE-0° TILT

RPM	Stalk Position	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
	1	21	17	
	2	27	8	
	3	24	9	
400	4	34	7	
	5	33	4	
	6	35	20	
	7	29	5	
	8	42		2
	1	33	19	
	2	24	29	
	3	29	16	
500	4	23	6	
	5	24		2
	6	28		5
	7	26		2
	8	37		8
	1	30	23	
	2	20	17	
	3	28	12	
600	4	29		1
	5	29		2
	6	37		8
	7	52		11
	8	44	1	

TABLE V

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 400 R.P.M., 45° ANGLE-0° TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	Lost		
2	21	24	
3	31	3	
4	27	4	
5	30	1	
6	28	0	
7	22		4
8	Missed		
9	37	18	
10	29	4	
11	23	13	
12	24	14	
13	43		1
14	36		0
15	4		13
16	Missed		
17	33	14	
18	26	11	
19	35	1	
20	29	9	
21	28	9	
22	33		2
23	18		3
24	Missed		

TABLE VI

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 500 R.P.M., 45° ANGLE-0° TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	25	26	
2	22	14	
3	31	18	
4	20	3	
5	16	3	
6	20		3
7	Lost		
8	32		14
9	27	25	
10	26	8	
11	38	13	
12	36	11	
13	24		2
14	42		6
15	29	0	
16	42		2
17	22	17	
18	29	4	
19	32		2
20	31		2
21	25	11	
22	23	0	
23	31		10
24	2	0	

TABLE VII

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 600 R.P.M., 45^{o} ANGLE-0^{o} TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	16	3	
2	13	5	
3	32		21
4	30		50
5	26		9
6	23		7
7	19		17
8	Missed		
9	18	10	
10	19	6	
11	21	8	
12	12	2	
13	24		8
14	20		12
15	11		6
16	26		12
17	20	4	
18	17		3
19	21		35
20	26		11
21	32		5
22	39		20
23	Missed		
24	Missed		

TABLE NO. VIII

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 400 R.P.M., 45° ANGLE-30° TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	19	2	
2	26	7	
3	30		2
4	32	11	
5	24	0	
6	20	20	
7	18	13	
8	25	31	
9	19	41	
10	28	34	
11	41	33	
12	37	26	
13	15	6	
14	29	32	
15	26	7	
16	51		2
17	34	0	
18	17	26	
19	45	10	
20	46	28	
21	19	33	
22	18	38	
23	27		20
24	36		8

TABLE IX

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 500 R.P.M., 45° ANGLE-30° TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	18	37	
2	17	36	
3	19	0	
4	21	0	
5	32		10
6	32		8
7	22		7
8	39		10
9	20	22	
10	Caught		
11	24	6	
12	27	8	
13	33	3	
14	37		4
15	39	0	
16	43		7
17	36	20	
18	24	6	
19	23		4
20	30	9	
21	44	3	
22	x		
23	41		5
24	50		11

TABLE X

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 600 R.P.M., 45° ANGLE-30° TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	45	29	
2	20	10	
3	19		2
4	30		4
5	10	33	
6	23		19
7	42		21
8	Missed		
9	23	2	
10	30	6	
11	42		3
12	46	24	
13	27		21
14	36	3	
15	49	13	
16	54		12
17	26	7	
18	23	42	
19	19	17	
20	14	6	
21	31	8	
22	31	14	
23	51	40	
24	66	3	

TABLE XI

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 400 R.P.M., 30° ANGLE-0° TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	33	26	
2	37	26	
3	37	0	
4	Lost		
5	15	34	
6	44	13	
7	9	25	
8	18	6	
9	Lost		
10	27	16	
11	22	13	
12	30	5	
13	34	0	
14	39		3
15	20	0	
16	20		14
17	32		9
18	40	1	
19	41	0	
20	36		3
21	23	5	
22	27	15	
23	20		8
24	47		39

TABLE XII

DISPLACEMENT OF ALFALFA STALKS AT REEL SPEED OF 500 R.P.M., 30^{o} ANGLE-0^{o} TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	17	23	
2	27	16	
3	42	14	
4	32	18	
5	34	13	
6	26	12	
7	40	8	
8	42		13
9	20	27	
10	29	7	
11	25	0	
12	24	11	
13	16	9	
14	12	25	
15	15	16	
16	31		14
17	26	14	
18	44	8	
19	27	16	
20	36	0	
21	23	6	
22	18		4
23	21	0	
24	15		3

TABLE XIII

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 600 R.P.M., 30° ANGLE-0° TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	14	4	
2	43	17	
3	33	14	
4	18	26	
5	34	2	
6	16	9	
7	50	3	
8	Missed		
9	15	7	
10	40	21	
11	50		6
12	52		0
13	63		8
14	55		19
15	43	4	
16	43		0
17	40		3
18	37		10
19	32	3	
20	3	22	
21	15	19	
22	21	16	
23	28	0	
24	39		21

TABLE XIV

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 400 R.P.M., 30° ANGLE-30° TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	18	21	
2	23	0	
3	25	8	
4	31	0	
5	Lost		
6	35	27	
7	46	3	
8	Missed		
9	28	11	
10	30	15	2
11	26	11	
12	35	0	
13	42	8	
14	33	31	
15	19	18	
16	58		6
17	18	18	
18	27	10	
19	31	7	
20	37	20	
21	24	0	
22	38	2	
23	22		6
24	26	3	

TABLE XV

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 500 R.P.M., 30^{o} ANGLE-30^{o} TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	20	41	
2	Lost		
3	27	0	
4	20		3
5	18		6
6	22		4
7	30	18	
8	Missed		
9	35	22	
10	30	28	
11	39	18	
12	22		2
13	31	0	
14	34		5
15	30	0	
16	37		5
17	23	16	
18	17	30	
19	20	31	
20	26	22	
21	24	0	
22	27		6
23	19		4
24	38		11

TABLE XVI

DISPLACEMENT OF ALFALFA STALKS AT REEL

SPEED OF 600 R.P.M., 30^{o} ANGLE-30^{o} TILT

Stalk Number	Lateral (Inches)	Forward (Inches)	Rearward (Inches)
1	19	21	
2	18		3
3	19	0	
4	38	0	
5	26		13
6	40		5
7	46		9
8	Missed		
9	26	42	
10	21	34	
11	26	8	
12	29		2
13	34	0	
14	41		11
15	Lost		
16	32	6	
17	45	25	
18	22	21	
19	40	29	
20	19	41	
21	28	7	
22	31		10
23	28		13
24	26		4

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