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Investigation of Combine Header Losses During Grain Sorghum Harvest

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INVESTIGATION OF COMBINE HEADER LOSSES DURING GRAIN SORGHUM HARVEST

BY

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INVESTIGATION OF COMBINE HEADER LOSSES

DURING GRAIN SORGHUM HARVEST

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head of the Major Department Date

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INTRODUCTION

Since ancient times man has been growing and harvesting grain sorghums. As near as historians can estimate, it has been cultivated and used for human consumption in Africa, India and China for nearly 4,000 years. For centuries it has been one of the staple foods for the enormous populations in these regions with warm climates.

The source and exact date of the introduction of grain sorghum into the United States has not been agreed upon, but it is generally agreed that it was sometime during the middle of the nineteenth century. The taller cane varieties were widely grown for syrup, sugar, and forage, but the strictly grain varieties were not accepted in the corn belt region until in the 1950's. It was at this time that the shorter varieties, those which could be harvested with a conventional combine, were sufficiently improved to compete with corn as a grain crop.

Grain sorghum's characteristics; being more resistant to drought than corn, responding well to irrigation, producing yields which correspond to those of corn, and being more resistant to the corn root-worm than corn, have made good arguments for raising it as a corn replacement. Grain sorghum also has a feed value which is competative with that of corn.

The one inherent disadvantage of grain sorghum is that, being a member of the grass family, the seed does not dry to any great extent until a killing frost or some artificial means has stopped plant growth. As a result, the plant dries out as rapidly, if not more rapidly, than the grain. Any high velocity wind occurring just prior to grain maturity can cause tremendous lodging due to the weakened stalk which must support the heavy, filled grain head. In ancient times, or in some of the underdeveloped countries today, where all harvesting would be accomplished by hand labor this fact has very little consequence. At present in a highly mechanized agricultural system, such as is found in the United States, this trait has created serious harvesting problems.

In areas where grain sorghum had been established as a major crop, one harvest season with high winds and resultant high lodging losses discouraged many farmers. This caused them to revert back to corn. This was unfortunate when one considers the potential yields and income from this crop, especially in areas which obtain only a marginal amount of moisture or where the amount of rainfall varies greatly from year to year.

One way of solving the problem of lodging is to harvest early at high moisture content. This is acceptable in many areas, but in some areas such as Central South Dakota many farmers are of the opinion that they cannot justify the expense of drying equipment and instead wait for the sorghum to mature naturally. If a machine or header attachment could be developed which would decrease losses under normal conditions, many farmers would plant more acres of grain sorghum.

Waelti (8) studied machine losses throughout the combine and shatter losses, but as yet no one has concentrated studies on the header area alone. On the basis of the potential of this crop, it seems that if the farmers could be assured of binning their crop even if it lodges, they would be more interested in raising grain sorghum.

A severe windstorm in October, 1965, resulted in severe lodging of grain sorghum in South Dakota. Many farmers reported high losses. A Hamlin County, South Dakota Agricultural Extension Agent told of a farmer reporting yields of up to 75 bushels per acre before the winds. After the winds he had difficulty obtaining yields of 35 bushels per acre.

Objectives

The objectives of this study were:

1. Design a row crop header attachment which will reduce header losses under normal conditions, and also under lodged conditions.
2. Test the above design by evaluating machine component losses.

3. Evaluate machine component losses under both normal and heavily lodged conditions using a conventional header and different commercial header attachments.
4. Carry out an economic analysis for the header attachment which performs best to determine if it is feasible for a farmer to purchase this attachment.

REVIEW OF LITERATURE

Before 1927 most of the grain sorghum was harvested by using a corn knife or some other sharp instrument to cut the heads from the plant. A 1927 survey showed that 50% of the crop was still being hand topped (3). This method was very efficient as far as minimizing grain losses, but was very time consuming and required considerable physical labor. A few farmers tried using mechanical headers, but for some unknown reason they never became widely accepted for grain sorghum harvesting.

When the combine was introduced, a popular method of harvesting grain sorghum was to bind it with a corn binder and shock the bundles until the heads were dry. As soon as the grain was dry enough for storage the heads were cut off by holding the bundles over an upward facing sicklebar on the combine. This left the fodder for feed, but was still a very slow procedure. Straight combining was an efficient method if the crop was standing, but lodged heads presented a real problem.

After a killing frost, which is necessary to allow the grain to dry, the mature grain sorghum heads usually begin to lodge within a week or ten days (12). Whenever dry windy conditions occur immediately following a freeze, the period is decreased even more.

Several methods have been tested whereby an artificial means of killing the foliage was used to start the drying at an earlier date. This was done in an attempt to harvest the dry, storable grain before high winds caused much lodging. This reasoning is substantiated by a 10 year summary of hourly wind observations from the United States Weather Bureau Station at Huron, South Dakota (7). During the years 1951-1960 there were an average of 9.8 hourly observations of winds greater than 25 miles per hour in the month of August, 20.5 during the month of September, and 31.9 during the month of October. This indicates that if the harvest is completed before the month of October the probability of high winds is less than if normal curing time was allowed.

In 1929 Conrad and Sterniman (1) experimented with root cutting as a means of killing the plant so that it would dry. They developed a deep tillage tool to perform this operation, but sometimes the roots had to be cut as much as seven inches below the surface to get a good kill without tipping the plant. This deep tillage required a large power unit, and therefore considerable fuel expense. Another draw back was that alternate sets of two rows had to be left blank to allow the tractor to pass through the field. This meant only one-half of the available acreage was being utilized to grow the crop.

Fowler (4) reported one farmer's success with spraying his sorghum with a dinitro solution. Dinitro is a defoliating chemical which stops plant growth. After the seed was mature he used an aerial sprayer to apply a solution containing one quart of dinitro in every fifteen gallons water-dinitro solution. The spray was applied in two successive trips over the same area in order to obtain double coverage. The farmer was able to harvest before a killing frost without resorting to artificial drying, but his cost of $4.50 per acre was somewhat prohibitive.

Narrow row planting has become more widely accepted, and one benefit seems to be that it encourages less lodging. Texas farmers (2) went to extremely narrow rows by blocking some of the openings in a grain drill. The spacings were ten inches and the only cultivation used was a propane "flame cultivation" seven to fourteen days after planting. Along with higher yields they found that much less lodging occurred than in fields planted on wider spacings.

In a 1964 study, Waelti (8) found that it was feasible to harvest grain sorghum at high moisture contents to reduce both shatter and reel losses. The main drawback he listed was that artificial drying was required. Because damage to material harvested at high moisture contents is considerable, the grain may need to be separated from cracked grain and foreign material in order to dry it economically. In Iowa, many farmers reached the same conclusion after the 1957 season. Many farmers had been switching to grain sorghum, and with good growing seasons had been making a good profit. In 1957, a high percentage of the Iowa sorghum crop was laid flat by high winds occurring just before harvest. Many farmers had fair success using pick-up reels and pick-up guards, but it was very difficult to obtain greater than 75% recovery (2, 10). Many farmers returned to corn, but the majority realized that if they harvested at 20% moisture content and artificially dried the grain they could continue to show a profit (9, 11). When harvesting high moisture grain sorghum it was important to use low cylinder speeds and wider concave openings in order to reduce the amount of damaged grain which was difficult to dry (3).

EXPERIMENTAL DESIGN AND TEST PROCEDURE

Criteria for 1965 Harvest

Design Chosen

The design used for the 1965 harvest was a randomized complete block design. This particular design was chosen because of its simplicity of analysis, reliability and its adaptability to field plot work. Variability among blocks does not affect differences between treatments (6). The total design consisted of four blocks with three treatments, each treatment being replicated three times within each block. This made a requirement of nine plots within each block.

Harvest dates, October 6, October 11, October 15 and October 29, were set up as blocks. The grain sorghum moisture content of the four blocks was respectively; 25%, 18%, 15% and 15%. The treatments were various header designs for the test combine. Treatment one was the conventional grain head. Treatment two was Flexo-Guards (Mfg. trade name) attached to the conventional head. Treatment three was row crop snouts, designed by the author, attached to the conventional head.

Randomization Procedure

Plots within a block were picked for order of harvest on a particular date by using a random number table. The most desirable procedure would have been to randomly assign a treatment to a plot, but in this manner all the plots could not have been harvested in one day. Moisture contents can be very critical and day to day changes can be quite large depending on weather conditions. For this reason each treatment was picked at random as to whether the entire treatment would be applied first, second or third. The randomizing procedure was repeated for each harvest date. Figure I shows the results of this randomization procedure.

Plot Layouts

Plots were laid out in lengths of 43.56 feet. The grain sorghum was planted in 30 inch rows. Plot width was 10 feet. This gave a plot size of 0.01 acres. Buffer strips of four rows each were left between each plot, with 25 foot strips before and 15 foot strips after each plot. The strips before and after the plot were required to keep the machine under operating load throughout the test distance.

Determination of Machine Losses

Before tests were performed, a 30-inch by 60-inch frame was placed in each plot three times at random across two rows. All seeds on the ground within these areas were collected and designated as field shatter. Trial runs

Block 1	1 F	8 C	4 S	3 F	9 C	6 S	2 F	5 S	7 C
Block 2	9 S	3 F	8 S	5 C	1 F	2 F	4 C	6 C	7 S
Block 3	9 C	2 F	7 C	4 S	3 F	5 S	6 S	1 F	8 C
Block 4	1 F	8 C	7 C	4 S	6 S	5 S	9 C	2 F	3 F

Figure I. 1965 Plot Arrangement

C = Conventional Header
F = Flexo-Guards
R = Row Crop Snouts

were made before final tests were performed to determine where tailings fell. Bright red paint was sprayed at the base, on the heads, and upper stalks of several plants. After this was accomplished the machine was operated over this area at test speeds. All tailings fell in the same area where they were cut. Based on the trial runs, all samples were taken between the plot boundaries.

A canvas tarplin was carried in place over each plot to catch all tailings from the machine. These were placed in bags and later processed. All loose grain in the tailings constituted rack and shoe losses, while unthreshed grain was classified as cylinder loss. After the plot was harvested, the 30-inch by 60-inch frame was again placed randomly at three different locations. All loose grain was collected and consisted of both cutter bar loss and field shatter. Field shatter, obtained previously, was subtracted from this total to obtain cutter bar loss. Whole heads, either cut or uncut, were picked up and later threshed and weighed. These constituted reel loss.

Grain was collected at the clean grain spout of the combine over the plot distance to obtain tank yield. Whenever possible, a component of loss was collected by the same person or persons throughout the tests. This was done in an effort to reduce variation in sampling.

All samples were weighed in the laboratory and moisture contents obtained by oven drying. After moisture contents were determined, all weights were adjusted to 12% moisture content. All calculations were carried out using 56 pounds per bushel.

CRITERIA FOR 1966 HARVEST

Design Chosen

On the basis of the 1965 harvest, tests in 1966 were conducted using only two treatments. Treatments were a conventional header and a commercially manufactured row crop gathering attachment. In an attempt to gain more precision in detecting differences, observations were paired. This gave more degrees of freedom for purposes of statistical analysis. Variance existing from pair to pair could also be eliminated (6). The number of pairs used was 10. This was the maximum number of pairs that could be harvested in one day and the minimum number in order to retain enough degrees of freedom for precision.

Randomization Procedure

Plots in each pair were assigned the numbers one and two, one being on the left when progressing from plot one to plot ten in order. A combination of 10 ones and twos was obtained using a random number table. The numbers obtained were assigned in order selected to plots one through ten respectively. This number was used to determine which plot from each pair would be harvested first.

The time element involved in harvesting 20 plots required harvesting 10 using one treatment and then the remaining 10 using the other treatment. In the event that time of day could have an effect on harvest loss, the treatment that was used first on one harvest date was used last on the next harvest date. Figure II shows the results of this randomization procedure.

Plot Layout

Row spacing and machine size in 1966 remained the same as for the 1965 harvest. Plot dimensions were 43.56 feet by 10 feet which gave an area of 0.01 of an acre. Buffer strips of four rows were left between each group of 10 pairs. Strips of 30 feet were left at the ends of each plot to insure that the machine was operating under normal load.

Determination of Machine Losses

To reduce sampling time in obtaining field shatter losses and cutter bar losses, 4-mil polyethylene sheets were placed in each plot. These sheets were 36 inches by 60 inches. The 36-inch width was used to allow the sheets to follow the contour of the ground when placed length wise between 30-inch rows. Three sheets were placed randomly on each plot before any shatter had occurred.

Harvest 1 C First		Harvest 2 R First		Harvest 3 C First	
5 C | R	6 C | R	5 R | C	6 R | C	5 R | C	6 R | C
4 C | R	7 C | R	4 C | R	7 C | R	4 C | R	7 C | R
3 R | C	8 R | C	3 R | C	8 C | R	3 R | C	8 R | C
2 R | C	9 C | R	2 C | R	9 R | C	2 R | C	9 C | R
1 R | C	10 R | C	1 C | R	10 R | C	1 C | R	10 R | C

Figure II. 1966 Plot Arrangement

C = Conventional
R = Row Harvester

Figures III and IV show the plastic sheets in place before and after harvest. Just prior to harvesting the plots, all grain was collected from the sheets to determine field shatter. A canvas was held in place to collect all tailings within the plot areas in order to obtain header losses from the ground. These tailings were discarded at the ends of the plots. The grain was collected from the plastic sheets after harvesting to determine cutter bar loss. All unthreshed heads in the plot were collected and later threshed and weighed. The sum of threshed heads and cutter bar loss was designated as header loss.

Grain tank yields were collected over the entire plot. The same person took tank yields for each group of pairs in an attempt to reduce sampling error. By using plastic strips and not processing the tailings, the tank yield was the only area where different persons taking samples could cause variation. All samples were processed and corrected to 12% moisture content in the same manner as were the samples the previous year.

Figure III. Plastic Sheet Shown before Harvesting

Figure IV. Plastic Sheet Shown after Harvesting

TEST EQUIPMENT

Combine

Harvest tests were conducted with a John Deere 45 self-propelled combine equipped with a conventional grain head. The reel had been modified from original equipment on the basis of previous studies. The original reel consisted of four 4-inch batts while the modified reel consisted of six 16-inch batts. The diameter of the modified reel was 53½ inches.

Straw walker covers were installed prior to testing to prevent stalks from falling through the large openings. When this occurs, many of the stalks lodge in the openings and decrease separating efficiency.

Sieve and wind settings were adjusted to do the most efficient job of saving and cleaning the grain. Concave clearances were 3/8 inches for front and 1/8 inches for rear in all tests.

Instruments to Monitor Machine Speeds

Cylinder speed was set at 780 RPM for all tests during both seasons. Previous to the 1965 tests a direct current generator tachometer was installed at the end of the cylinder shaft as shown in Figure V to monitor cylinder speed. Voltage was recorded by an oscillograph which was powered by a 12 volt DC to 110 volt AC inverter. Cylinder

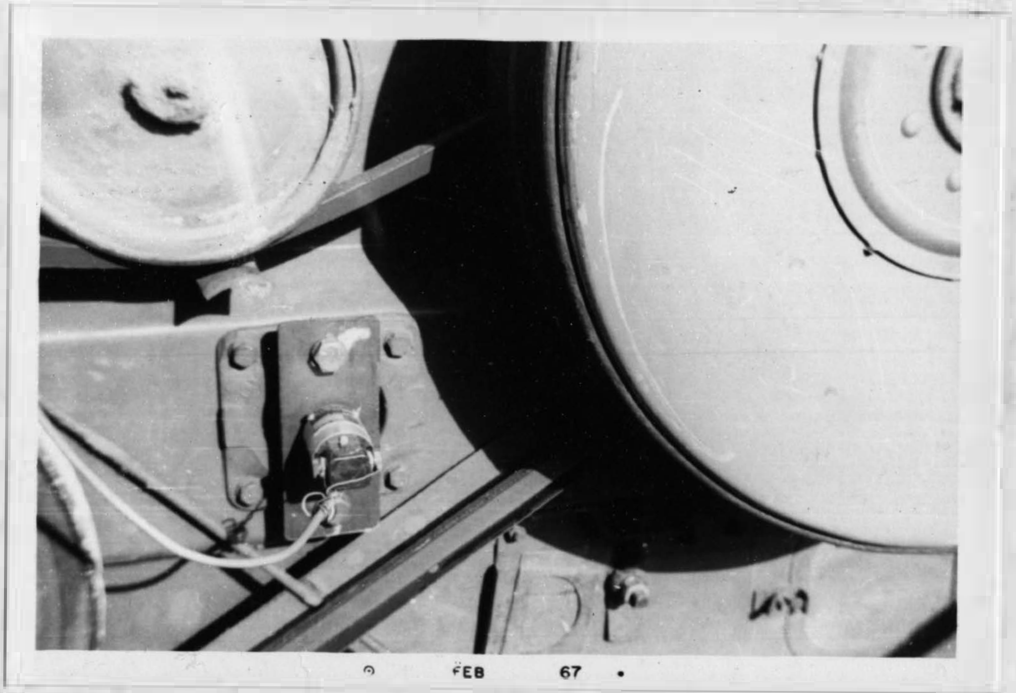

Figure V. Generator Tachometer in Place

speeds remained quite constant throughout all tests. Based on this information, cylinder speed was checked with a hand tachometer before each group of pairs was harvested during the 1966 tests.

An event marker on the oscillograph was used to indicate the beginning and end of each test run. With this information ground speed was calculated and found to be 1.4 ± 0.1 miles per hour for the 1965 tests. In 1966 the machine was operated at the same gear speed ratio and throttle setting as during the 1965 tests.

Designs Tested

The header configurations tested in 1965 were a conventional sickle bar header, a conventional header with Flexo-Guards attached and a conventional header with row crop snouts attached. In 1966, Hesston row crop attachments were compared to a conventional header.

Flexo-Guards

Flexo-Guards are guard extensions with wires that extend from the tips backward over the sicklebar as shown in Figure VI. The front attachment is by means of a metal loop that fits over the tip of the original guards. This is shown in Figure VII. The angle iron at the rear of the guards in Figure VII fits next to an angle iron below the rear edge of the sickle bar. Two spring

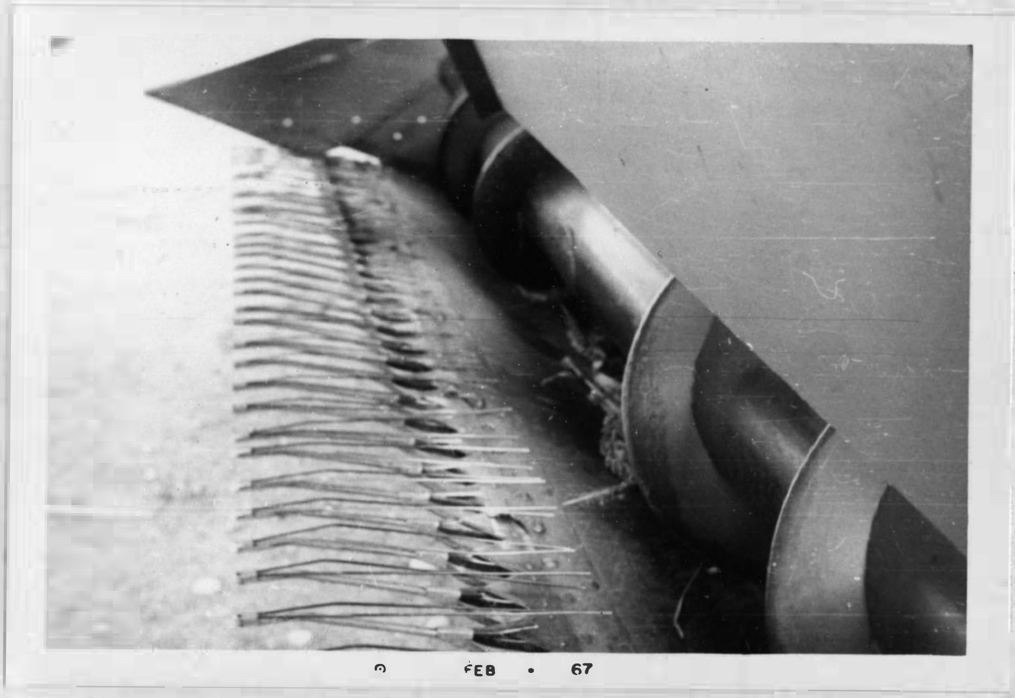

Figure VI. Flexo-Guards Mounted on Machine

Figure VII. General View of Flexo-Guard Unit wire clips for each section are placed around the rods, below the guard angle and fasten to the cutter bar angle. They are commercially produced by Richardson Manufacturing, Cawker City, Kansas.

Row Crop Snouts

The row crop snouts tested were designed by the author for these tests. The snouts were designed to lift lodged stalks and to prevent cut heads from being thrown on to the ground or into the sickle. The points were positioned at a point below and ahead of the sickle bar. The back portion was sloped downward over the sickle bar to return heads kicked forward by the feeder auger and to keep cut heads out of the sickle. A 12-inch width of cut was allowed for each row.

They were fabricated from heavy galvanized sheet metal 18 1/2 inches by 30 inches, two 3/8-inch steel rods 24 inches long and a 15 inch 3/4 by 3/4 by 1/16 angle iron. After the point was formed the back 6 inches was bent downward to cover the guards. The framework was then shaped to the snout, welded together and the snout attached to it by pop-riveting. The cross pieces seen in Figure VIII are 1/16 inch strips of strap iron. The general shape of the snout can be seen in Figure IX.

The two end snouts were fabricated from the same size sheets. The curved part was made from one-half the sheet,

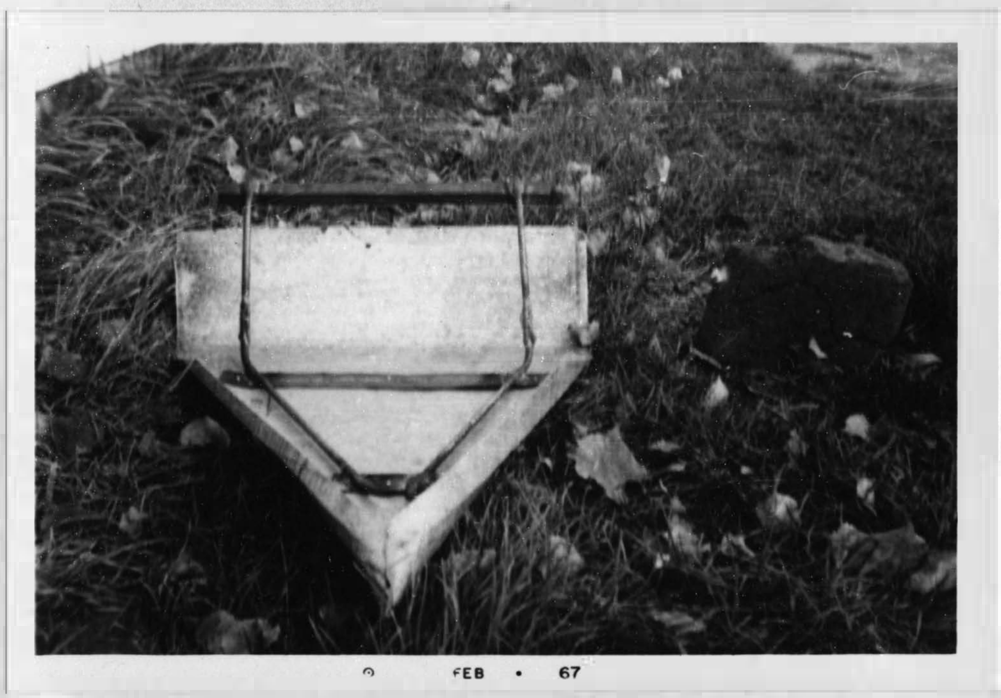

Figure VIII. Framework of Row Crop Snout

Figure IX. View Illustrating Slope at Rear of Row Crop Unit while the remaining one-half was bent upward to be bolted on the combine divider. The undermounting was one-half of the mounting for the center snouts. Figure X is a general view of an end snout. The machine with snouts mounted in operating position is shown in Figure XI.

Row Harvester

For the 1966 tests a Hesston Row Harvester manufactured by Hesston Manufacturing Company, Hesston, Kansas was tested. The most significant feature of this unit is the set of three gathering belts with lugs for each row. This particular model was mounted on pivot rods bolted beneath the sickle bar. This arrangement permitted each row unit to be independent and free floating if an obstruction was encountered. Figure XII shows the arrangement of the belts and the slide that clamps onto the rod beneath the sickle bar. Figure XIII is a general view of the attachment. It is shown in operation under lodged conditions in Figure XIV.

Figure X. Row Crop End Snout in Position on Machine

Figure XI. Row Crop Snouts Mounted on Machine

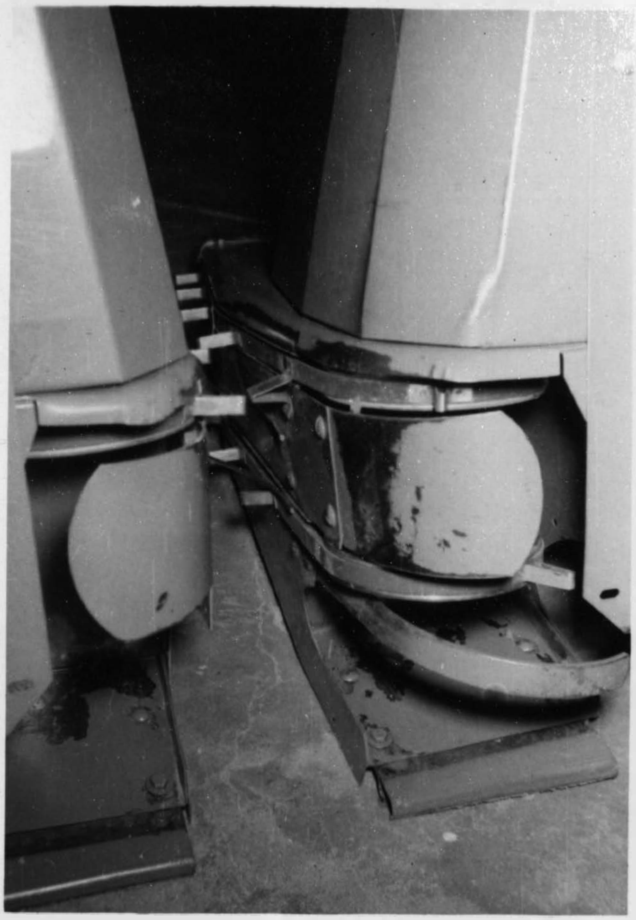

Figure XII. Rear View of Row Harvester Unit

Figure XIII. Row Harvester Unit

Figure XIV. Row Harvester Units in Operation

PRESENTATION OF DATA

The losses in the following tables have been presented as percentages of total yield in order to facilitate comparisons.

Table 1 presents reel loss, header loss and total loss from the different header designs during the 1965 tests. Reel losses consisted of whole heads which were not harvested. Header loss consisted of reel loss and cutter bar shatter. Total loss consisted of field shatter, cutter bar loss, reel loss, cylinder loss and rack and shoe losses.

Block by treatment totals used in performing analyses of variance are presented in Tables 2, 3 and 4. Analyses of variance summaries are presented in Tables 5, 6 and 7.

The 1966 header losses for the conventional header and the Hesston Row Harvester are presented in Table 8. Values used in performing tests on the 1966 data are presented in Table 9.

Figure XV is a graph of loss vs. plot number for 1966 harvest dates. Figure XVI is a graph of loss vs. yield for October 4, 1966.

Table 1. 1965 Losses as Per Cent of Total Yield

			Reel Loss[1]	Header Loss[2]	Total Loss[3]
October 6		1	6.93	10.35	11.59
Harvest	Conventional	2	8.86	14.81	18.14
		3	10.90	13.06	14.78
Moisture		1	2.66	5.58	6.16
Content	Flexo-Guard	2	4.68	6.29	7.53
25%		3	4.07	4.89	5.90
		1	3.44	3.90	5.58
	Row Crop	2	2.51	4.05	6.24
		3	2.76	4.78	6.58
October 11		1	20.69	25.52	27.75
Harvest	Conventional	2	16.81	21.20	25.19
		3	20.69	25.05	27.54
Moisture		1	43.91	47.30	49.13
Content	Flexo-Guard	2	30.71	37.17	39.87
18%		3	22.77	28.30	30.41
		1	18.30	25.92	29.81
	Row Crop	2	23.45	27.85	30.84
		3	13.45	17.50	21.31
October 15		1	29.33	31.59	34.72
Harvest	Conventional	2	25.44	30.14	33.53
		3	18.93	19.94	23.47
Moisture		1	25.43	30.52	36.90
Content	Flexo-Guard	2	16.92	20.67	25.03
15%		3	26.14	32.36	35.13
		1	30.63	32.27	37.01
	Row Crop	2	32.34	37.85	40.91
		3	35.83	39.78	42.64

Table 1. (Continued)

			Reel Loss[1]	Header Loss[2]	Total Loss[3]
October 29		1	43.70	48.04	55.92
Harvest	Conventional	2	38.42	46.04	51.28
		3	42.05	48.32	53.31
Moisture		1	55.17	62.14	65.47
Content	Flexo-Guard	2	48.48	54.97	59.38
15%		3	32.96	39.77	46.33
		1	42.25	48.77	56.26
	Row Crop	2	39.57	43.85	48.20
		3	32.87	36.72	46.25

1. Whole heads which were not harvested.
2. Reel loss plus cutter bar loss.
3. All machine component losses.

Table 2. Block by Treatment Sum of Squares for Reel Loss

Treatments	BLOCK 1 Reps. 1	2	3	BLOCK 2 Reps. 1	2	3	BLOCK 3 Reps. 1	2	3	BLOCK 4 Reps. 1	2	3	Treatment Totals $X_{i\cdot}$	$\sum_j X_{ij}^2$
Conventional	6.93	8.86	10.90	20.69	16.81	20.69	29.33	25.44	18.93	43.70	38.42	42.05	282.75	8,403.8391
Flexo-Guard	2.66	4.68	4.07	43.91	30.71	22.77	25.43	16.92	26.14	55.17	48.48	32.96	313.90	11,531.8798
Row Crop	3.44	2.51	2.76	18.30	23.45	13.45	30.63	32.34	35.83	42.25	39.57	32.87	277.40	8,790.5920
Block Totals $X_{\cdot j}$		46.81			210.78			240.99			375.47		874.05	
$\sum_i X_{ij}^2$		316.6287			5,594.0884			6,749.9197			16,065.6741			28,726.3109

Table 3. Block by Treatment Sum of Squares for Header Loss

Treatments	BLOCK 1 Reps. 1	2	3	BLOCK 2 Reps. 1	2	3	BLOCK 3 Reps. 1	2	3	BLOCK 4 Reps. 1	2	3	Treatment Totals $X_{i\cdot}$	$\sum_i X_{ij}^2$
Conventional	10.35	14.81	13.06	25.52	21.20	25.05	31.59	30.14	19.94	38.04	46.04	48.32	334.06	11,291.5320
Flexo-Guard	5.58	6.29	4.89	47.30	37.17	28.30	30.52	20.67	32.36	62.14	54.97	39.77	369.96	15,385.0238

Table 3. (Continued)

Treatments	BLOCK 1 Reps. 1	BLOCK 1 Reps. 2	BLOCK 1 Reps. 3	BLOCK 2 Reps. 1	BLOCK 2 Reps. 2	BLOCK 2 Reps. 3	BLOCK 3 Reps. 1	BLOCK 3 Reps. 2	BLOCK 3 Reps. 3	BLOCK 4 Reps. 1	BLOCK 4 Reps. 2	BLOCK 4 Reps. 3	$X_{i.}$	Treatment Totals $\sum_i X_{ij}^2$
Row Crop	3.90	4.05	4.78	25.92	27.85	17.50	32.27	37.85	39.78	48.77	43.85	36.72	323.24	11,514.2974
Block Totals $X_{.j}$		67.71			255.81			275.12			428.62		1,027.26	
$\sum_i X_{ij}^2$		646.0957			7,901.7207			8,766.2640			20,876.7728			38,190.8532

Table 4. Block by Treatment Sum of Squares for Total Loss

Treatments	BLOCK 1 Reps. 1	BLOCK 1 Reps. 2	BLOCK 1 Reps. 3	BLOCK 2 Reps. 1	BLOCK 2 Reps. 2	BLOCK 2 Reps. 3	BLOCK 3 Reps. 1	BLOCK 3 Reps. 2	BLOCK 3 Reps. 3	BLOCK 4 Reps. 1	BLOCK 4 Reps. 2	BLOCK 4 Reps. 3	$X_{i.}$	Treatment Totals $\sum_j X_{ij}^2$
Conventional	11.59	18.14	14.78	27.75	25.19	27.54	34.72	33.53	23.47	55.92	51.28	53.31	377.22	14,324.1074
Flexo-Guard	6.16	7.53	5.90	49.13	39.87	30.41	36.90	25.03	35.13	65.47	59.38	46.33	407.24	18.238.6004
Row Crop	5.58	6.24	6.58	29.81	30.84	21.31	37.01	40.91	42.64	56.26	48.20	46.25	371.63	14,896.2561
Block Totals $X_{.j}$		82.50			281.85			309.34			482.40		1,166.09	
$\sum_i X_{ij}^2$		924.6630			9,385.0499			10,964.3458			26,184.9052			47,458.9639

Table 5. Analysis of Variance for Reel Loss

Source	df	SS	MS	F
Blocks	3	6,075.8261	2,025.2754	65.56**
Treatments	2	64.7554	32.3777	0.31
Exp. Error	6	623.0875	103.8479	3.36*
Samp. Error	24	741.4363	30.8932	
Total	35	7,505.1053		

Table 6. Analysis of Variance for Header Loss

Source	df	SS	MS	F
Blocks	3	7,290.4157	2,430.1386	73.67**
Treatments	2	99.6845	49.8422	0.43
Exp. Error	6	696.2587	116.0431	3.52*
Samp. Error	24	791.6302	32.9846	
Total	35			

Table 7. Analysis of Variance for Total Loss

Source	df	SS	MS	F
Blocks	3	8,945.6274	2,981.8758	103.58**
Treatments	2	61.1256	30.5628	0.29
Exp. Error	6	635.0759	105.8460	3.68*
Samp. Error	24	690.9104	28.7879	
Total	35	10,332.7393		

*Significant at the 95% level.
**Significant at the 99% level.

Table 8. 1966 Header Loss as Per Cent of Total Yield

Pair	October 4 -- M.C. 24%		October 7 -- M.C. 19%		October 17 -- M.C. 19%	
	Conventional	Row Harvester	Conventional	Row Harvester	Conventional	Row Harvester
1	5.50	1.45	10.89	1.77	38.41	7.28
2	10.66	3.67	8.12	3.27	35.41	9.58
3	9.22	4.22	11.42	3.98	33.41	9.56
4	14.57	8.40	11.86	4.75	40.51	11.41
5	13.33	4.79	8.34	4.76	48.08	16.58
6	7.81	4.92	11.90	4.12	26.34	7.52
7	15.38	4.35	15.78	6.54	32.76	13.27
8	12.76	6.54	7.08	3.26	30.27	7.78
9	12.72	3.21	11.50	1.20	28.65	7.73
10	10.27	1.58	7.74	3.18	34.11	6.96
Ave.	11.22	4.31	10.46	3.68	34.80	9.78

Table 9. Values Used for t Test at 95% Confidence Level

	$\bar{d}$	S_D^2	$S_{\bar{d}}^2$	t
Oct. 4	6.91	6.5086	0.6509	8.5678**
Oct. 7	6.78	5.9018	0.5902	8.8223**
Oct. 17	25.02	21.6400	2.1640	17.0040**

** Significant at the 99% level.

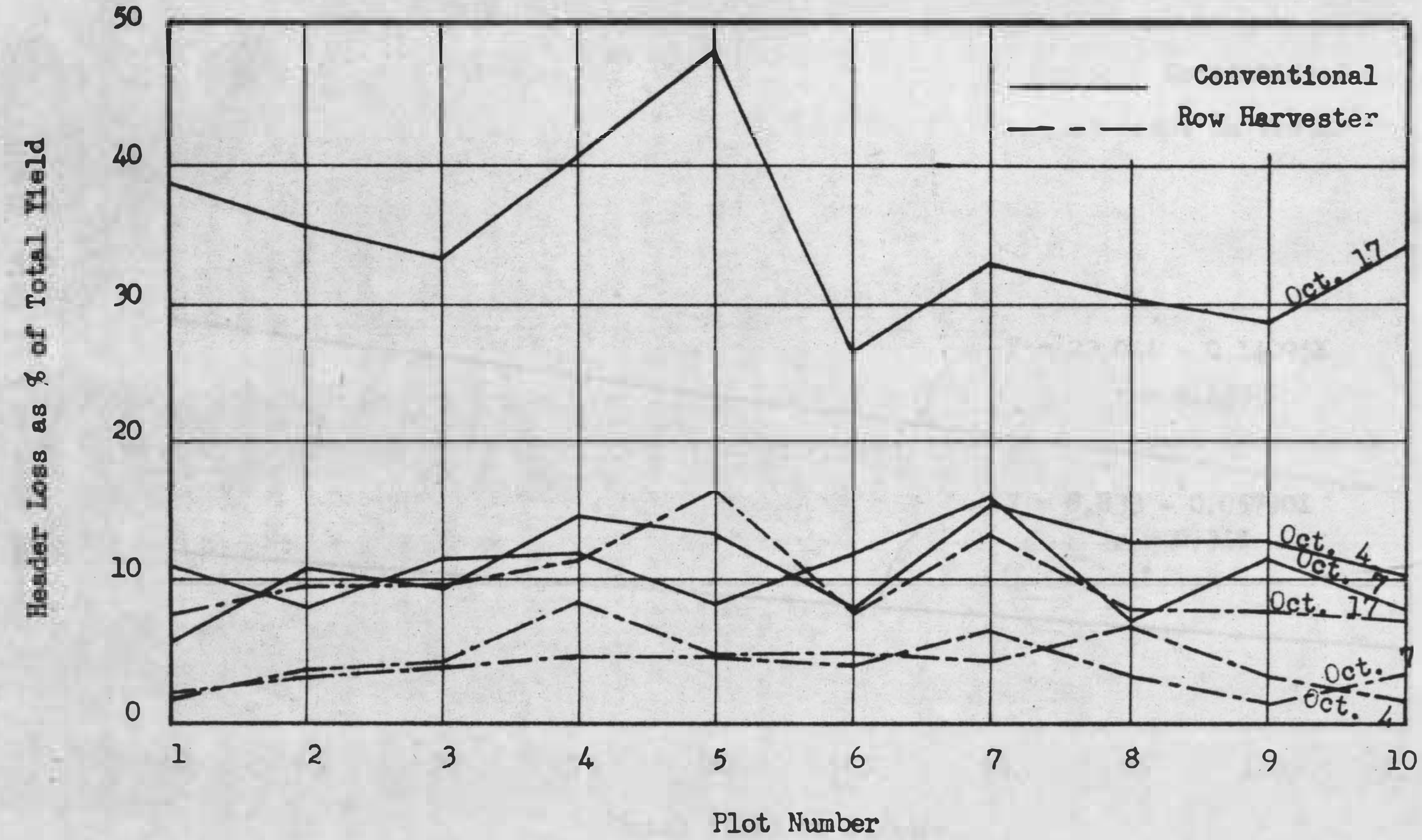

Figure XV. Graph of 1966 Header Loss Per Plot for Each Harvest Date

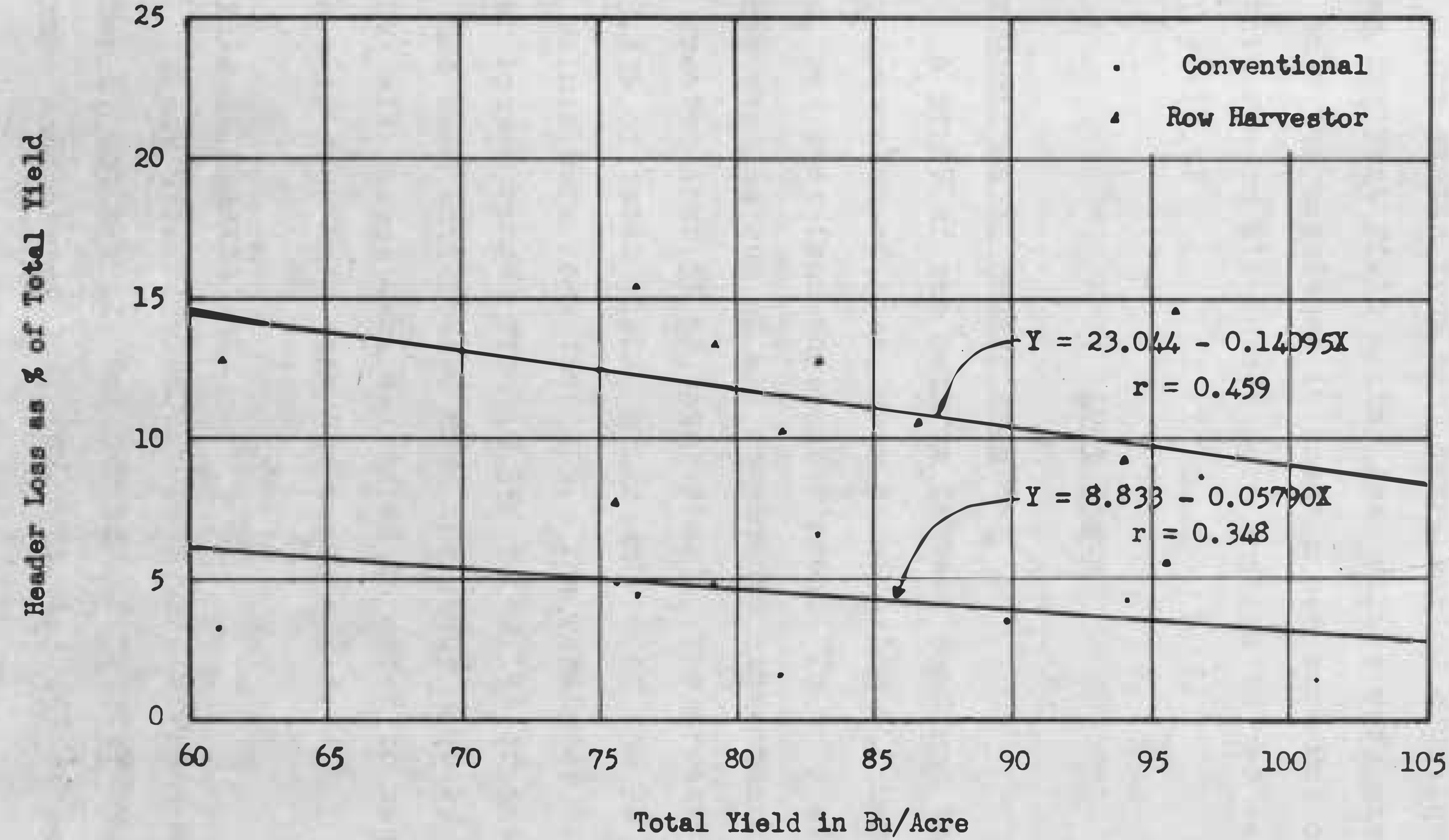

Figure XVI. Plot of Header Loss vs. Total Yield for October 4, 1966

ANALYSIS OF DATA AND RESULTS

The yields from both years varied considerably across the test field making loss values very misleading when only the magnitude in bushels per acre was considered. For this reason all losses were changed to per cent of total yield.

1965 Tests

Study Confined to Header Area

A study of the data in Table 1 confirms that the major component of loss, when considering all harvest dates, was that from the header area. In only six instances was the sum of all components other than header loss greater than 5% of total yield. The greatest loss was 9.53% of total yield, while only 6 of the 36 header loss values were less than 10%. The remainder of the header losses ranged from 10.35% to 62.14% of total yield. This had been anticipated from the study made by Waelti (8) but all losses were evaluated in order to substantiate this from more than one years tests.

Analysis of Observations

Tests were carried out on four different dates, October 6, October 11, October 15 and October 29, at moisture contents of 25%, 18%, 15%, and 15% respectively.

Losses from the header area at these levels are presented in Table 1. Under standing conditions, 25% moisture level, there appeared to be an indication that both the Flexo-Guards and the row crop snouts would be better than the conventional header. At this level the percentage loss for both was less than one-half that of the conventional header.

When the crop was standing it was noted that both attachments kept cut heads from falling into the sickle where they would be cut and partially lost with the conventional header. Another benefit was that whole heads which were kicked forward by the feeder auger were caught and returned instead of being permitted to fall to the ground.

There was a severe windstorm on October 7 which caused very heavy lodging. The three harvests following this date were conducted under heavily lodged conditions. Figures XVII and XVIII illustrate the amount of lodging just previous to the October 15 harvest. Under these conditions one treatment was not consistently any better than another of the treatments. Even in the event that one had been consistently better, at the magnitude of loss experienced, none of them would have been acceptable. Losses ranged from 27% to 57% of total yield which is far from desirable.

Figure XVII. Lodged Conditions, October 28, 1965

Figure XVIII. Severe Lodging in Length of One Plot, October 28, 1965

When the lodged stalks were tangled one of the snouts was buckled downward. Care had to be exercised in order to avoid catching them in the ground. If snouts of this type were to be used they would need more reinforcing and possibly a free floating mounting arrangement.

Either of these attachments in heavy lodging will have little benefit and may yield higher losses than with the conventional header. This appeared to be a result of their inability to either lift and/or gather the lodged stalks.

Statistical Analysis

A statistical analysis for the randomized complete block design was performed on reel loss, header loss and total loss. This was performed in order to determine if any significant difference in treatments existed. All analyses were performed using the hypothesis of no difference. Equations and procedures for analyzing data from both seasons were taken from Steele and Torrie (6).

As indicated from observing the data in Table 1 and the treatment sums in Tables 2, 3 and 4, the analysis of variance for each loss, Tables 5, 6 and 7 did not show any treatment differences to be significant. The F values for the three analyses were; 0.31, 0.43 and 0.29. In order to show significance at the 95% confidence level, an F value of at least 5.14 would have been required.

Block sums, shown in Tables 2, 3 and 4 were considerably different. The analysis of variance showed block differences to be highly significant. The randomized complete block design is set up so that block differences do not effect treatments. Differences between plots in each block, Appendix B, were greater than is desirable. At the level of loss involved, this would not have changed the interpretation of the results.

Summary of 1965 Tests

Header losses were the major component of machine loss in all tests performed.

Under standing conditions either the Flexo-Guards or the row crop snouts could be of benefit. A statistical analysis showed no differences between treatments. This was due to the high losses encountered with all treatments under severely lodged conditions.

1966 Tests

Selection of Unit to be Tested

Flexo-Guards and row crop snouts were not used during the 1966 tests. On the basis of the 1965 tests it was concluded that an attachment with gathering devices should be developed and tested. After preliminary studies were made, it was decided to test a Hesston Row Harvester. The degree of refinement was more than could be achieved by designing and building a similar unit in the limited time available.

Losses Compared to 1965 Tests

Field shatter was collected along with header shatter, but due to the minute quantities obtained, they were not included in any of the analysis.

A comparison of Table 1 with Table 8 shows that header loss when using the conventional header did not differ greatly between the two harvest seasons. For the 1965 season under standing conditions the overall average loss was 12.74% while with lodged conditions it was 32.87%. The 1966 averages were 10.84% for standing conditions and 34.80% for lodged conditions.

Lodging during the 1966 harvest was caused by moderate to strong winds several days after a killing frost. The third test was delayed until a degree of lodging occurred which was about the same as the 1965 lodging which was caused in early October by severe winds. Figure XIX shows the lodged conditions just prior to the October 17, 1966 harvest.

Analysis of Observations

Figure XV illustrates that on any given harvest date the row crop attachment had considerably less loss than the conventional header. It also illustrates that under the

Figure XIX. Lodged Conditions October 17, 1966 heavily lodged conditions the row crop attachment performed as well or better than the conventional header under standing conditions. The high percentage loss for the conventional header in plots four and five can possibly be attributed to severely lodged conditions. The plants in these plots were lodged more severely than in the rest of the field.

Inspection of Table 8 shows that some individual values of the conventional header were less than the row crop, but on the average the row crop under heavily lodged conditions had less loss than the conventional under any of the conditions tested.

Statistical Analysis

The hypothesis of no difference in population means for paired data was tested using the t test. The values of $t_{.01}$ for the three harvest dates were 8.57, 8.82 and 17.00 respectively (Table 9). This test showed that the difference in population means was highly significant. Statistically this means that there exists a considerable difference in losses incurred when using the Row Harvester as compared to the conventional header.

The Hesston Row Harvester performed better both when the crop was standing and when severe lodging had occurred. For standing conditions (October 4 and October 7) the average header loss was 10.84% of total yield for the conventional and 3.99% of total yield for the Row Harvester. When lodging occurred (October 17) the average header loss was 34.80% of total yield for the conventional and 9.78% of total yield for the Row Harvester.

Economic Analysis

A statistical analysis has much merit, but in some instances even when statistical significance is shown, economic feasibility does not exist. In order to avoid this possibility an economic analysis was conducted to determine the acres of grain sorghum a farmer would need to raise to justify the added cost of the Row Harvester.

The 99% confidence interval for the mean difference is $\bar{d} \pm t_{.01} S_{\bar{d}}$. This gives lower limit difference values under standing conditions of 4.29% for October 4 and 4.28% for October 7. Using the lower value of 4.28% and the average yield for three harvest dates of 80.25 bushels per acre gives a lower confidence limit of 3.44 bushels per acre difference in loss. Using a price of $1.00 per bushel, which is usually about the low market price, would give a savings of $3.44 per acre by using the Row Harvester.

The machine tested normally costs about $200 per row. Adding the cost for the drive unit and shipping costs, a four row unit would cost about $900. Assuming an average life for the units of 8 years with an annual ownership cost of 15% of purchase price gives an annual cost of ownership of $135. This would mean a farmer could expect to pay for the added cost of the Row Harvester by harvesting 39.2 acres.

Per cent losses were plotted against yields for each date in an attempt to predict percentage losses at different yields. Figure XVI is representative of the three harvesting dates.

A regression analysis, using procedures given by Wine (13), was conducted using the points from Figure XVI and the resulting equation lines were drawn. The pertinent regression values for the conventional header were; slope -0.14095, intercept 23.044 and an r of 0.459. Values for the Row Harvester were; slope -0.05790, intercept 8.833 and an r of 0.348. Slopes were tested at the 95% confidence level to determine whether they were different from zero. The F values were 2.17 for the conventional and 1.10 for the Row Harvester. The F at the 95% level is 2.32. This indicates that the regression line slopes were not statistically different from zero.

Assuming that the percentage losses calculated held for all yields, and applying to the 1959 - 1963 South Dakota average yield of 35.4 bushels per acre (5) gives a $1.47 per acre saving. This requires a break-even acreage of 91.8 acres.

When considering these values it must be realized that conservative values were chosen for all calculations, and that the losses are for standing crop conditions. Another factor to be considered is that the probability of high winds during the time when the grain matures is relatively high. Records were not available, but the author can recall at least two seasons when heavy lodging from high winds occurred in the period from 1961 - 1966 in the Brookings, South Dakota area. Length of time after a killing frost is another factor. In the period between the October 7 and October 17 harvest there were no severe winds, but some which were in the 10 - 20 mile per hour range.

This resulted in heavy lodging in a period of 10 days. If a farmer has a considerable acreage to cover with one machine he may not be able to complete his harvest in the one to two week critical period after a freeze.

Summary of 1966 Tests

The Hesston Row Harvester performed better than the conventional header on each harvest date. A statistical analysis showed that the difference in losses was highly significant for each harvest date.

An economic analysis indicates that South Dakota farmers could expect to pay for a Row Harvester by harvesting 91.8 acres of grain sorghum. In the event of severe lodging the acreage would be much less.

SUMMARY AND CONCLUSIONS

Header losses were the main component of loss when all 1965 harvest losses were evaluated. Only six plots of the 36 harvested had losses for all other components totaling more than 5% with 9.35% being the maximum. Six plots had header losses less than 10%. The maximum header loss was 62.14% of total yield.

A one year study indicated that Flexo-Guards and row crop snouts reduced header losses when the crop was standing, but were no improvement over a conventional header when lodging occurred. These units were not tested in 1966.

The Hesston Row Harvester reduced losses from 10.84% to 3.99% for standing conditions and from 34.80% to 9.78% when severe lodging was present. This was from a one year study.

A break-even analysis showed that, assuming percentage losses constant for any yield, an average South Dakota farmer could pay for the Row Harvester by raising 91.8 acres of grain sorghum. In the event that lodging occurred, his return to investment would be much greater.

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APPENDICES

APPENDIX A. CULTURAL PRACTICES

CULTURAL PRACTICES

1965 Crop

The test field had been planted to grain sorghum for the 1964 season. Stalks were chopped and plowed under late in the fall of 1964.

Variety NK 125 grain sorghum was planted May 28, 1965 using a till planter set for 30 inch row spacings with 40 pounds N and 50 pounds P per acre applied at planting. The rows were also banded with Propozine and good weed control was achieved.

The crop received one harrowing with a flextine harrow and one cultivation. It was irrigated three times by sprinkler irrigation with 100 pounds N per acre added through the irrigation water.

1966 Crop

Stalks were chopped and fall plowed. Twenty pounds K per acre was broadcast April 30 and NK 125 grain sorghum till planted May 24 and 25 with 33 pounds N and 46 pounds P applied at planting.

The field was sprayed with an oil and Atrazine solution. Rate was 1 pound of Atrazine per acre. This treatment along with two cultivations gave quite effective weed control.

Three sprinkler irrigations were applied during the growing season and 100 pounds N per acre was added through the irrigation water.

APPENDIX B. 1965 HARVESTING LOSSES AND YIELDS

Table 10. 1965 Harvesting Losses and Yields in Bu/A at 12% M.C.

Block	Treat.	Rep.	Losses: Shatter	Cutter bar+	Reel =	Header	Cylinder	Rack Shoe	Total	Yields: Tank	Total
Oct. 6		1	0.0149	1.8657	3.7857	5.6514	0.1562	0.5071	6.3296	48.2857	54.6153
Harvest	Conv.	2	0.0249	2.7960	4.1607	6.9567	0.2071	1.3336	8.5223	38.4643	46.9866
		3	0.0087	1.0622	5.3571	6.4193	0.2089	0.6279	7.2648	41.8929	49.1577
M.C.		1	0.0485	1.1505	1.5536	2.7041	0.1598	0.6900	3.6024	54.8571	58.4595
25%	Guard	2	0.0485	0.9788	2.8393	3.8181	0.1880	0.5182	4.5728	56.1429	60.7157
		3	0.0199	0.6020	2.9643	3.5663	0.1652	0.5516	4.3030	68.5893	72.8923
	Snout	1	0.0050	0.2798	2.0893	2.3691	0.2393	0.7800	3.3934	57.4107	60.8041
		2	0.0572	0.7550	1.2321	1.9871	0.1820	0.8352	3.0615	46.0179	49.0794
		3	0.0149	1.2587	1.7143	2.9730	0.2268	0.8739	4.0886	58.0893	62.1779
Oct. 11		1	0.3868	4.1132	17.6250	21.7382	0.2011	1.3180	23.6441	61.5536	85.1977
Harvest	Conv.	2	0.4838	3.0249	11.6071	14.6320	0.2689	2.0021	17.3868	51.6429	69.0297
		3	0.6902	4.1418	19.6607	23.8025	0.2470	1.4314	26.1711	68.8571	95.0282
M.C.		1	0.2400	1.8943	24.5536	26.4479	0.2218	0.5645	27.4742	28.4464	55.9206
18%	Guard	2	0.7836	4.3682	20.7679	25.1361	0.2321	0.8114	26.9632	40.6607	67.6239
		3	0.2488	2.6692	10.9822	13.6514	0.3268	0.4423	14.6693	33.5714	48.2407
		1	0.7488	4.7637	11.4464	16.2101	0.2277	1.4577	18.6443	43.8929	62.5372
	Snout	2	0.9589	3.0734	16.3571	19.4305	0.1961	0.9291	21.5146	48.2500	69.7646
		3	0.3246	2.1990	7.3036	9.5026	0.2398	1.5053	11.5723	42.7321	54.3044

Table 10. (Continued)

Block	Treat.	Rep.	Losses							Yields	
			Shatter	Cutter bar	+ Reel	= Header	Cylinder	Rack Shoe	Total	Tank	Total
Oct. 15		1	0.2201	1.3458	17.5000	18.8458	0.2720	1.3739	20.7118	38.9464	59.6582
Harvest	Conv.	2	1.2587	4.3818	23.7321	28.1139	0.6146	1.2875	31.2747	62.0000	93.2747
		3	0.2313	0.8657	16.1964	17.0621	0.9630	1.8250	20.0814	65.4821	85.5635
M.C.		1	0.6754	3.8197	19.0536	22.8733	0.5946	3.5030	27.6463	47.2857	74.9320
15%	Guard	2	0.3333	2.8408	12.8036	15.6444	0.6834	2.2805	18.9416	56.7321	75.6737
		3	0.3570	4.5684	19.2143	23.7827	0.5012	1.1784	25.8193	47.6786	73.4979
		1	0.2637	1.5174	18.9821	20.4995	0.7236	1.4464	22.9332	39.0357	61.9689
	Snout	2	0.4552	4.2848	25.1786	29.4634	0.5255	1.4002	31.8443	46.0000	77.8443
		3	0.5647	3.0609	27.7500	30.8109	0.4359	1.2175	33.0290	44.4286	77.4576
Oct. 29		1	0.3172	3.1094	31.2857	34.3951	0.3064	5.0171	40.0358	31.5536	71.5894
Harvest	Conv.	2	0.2201	5.7774	29.1071	34.8845	0.3755	3.3709	38.8510	36.9107	75.7617
		3	0.9888	5.5970	37.5179	43.1149	0.3550	3.1019	47.5606	41.6607	89.2213
M.C.		1	0.1331	4.8420	38.3393	43.1813	0.3234	1.8573	45.4951	24.0000	69.4951
15%	Guard	2	0.4017	5.2637	39.3036	44.5673	0.3205	2.8553	48.1448	32.9286	81.0734
		3	1.8657	5.9751	28.9286	34.9037	0.3854	3.5053	40.6601	47.1071	87.7672
		1	0.6169	4.4515	28.8393	33.2908	0.4071	4.0914	38.4062	29.8571	68.2633
	Snout	2	0.3047	4.2998	39.8214	44.1212	0.5720	3.5003	48.4982	52.1250	100.6232
		3	0.2313	2.4963	21.3393	23.8356	0.3098	5.6460	30.0227	34.8929	64.9156

APPENDIX C. 1966 HARVESTING LOSSES AND YIELDS

Table 11. Shatter Loss Bu/A at 12% M.C.

Pair	Oct. 4 -- M.C. 24%		Oct. 7 -- M.C. 19%		Oct. 17 -- M.C. 19%	
	Conven.	Row Crop	Conven.	Row Crop	Conven.	Row Crop
1	0.00	0.06	0.00	0.00	0.01	0.34
2	0.00	0.06	0.00	0.00	0.04	0.20
3	0.00	0.00	0.00	0.00	0.05	0.11
4	0.00	0.01	0.00	0.01	0.09	0.07
5	0.00	0.00	0.00	0.00	0.07	0.20
6	0.00	0.00	0.01	0.00	0.20	0.24
7	0.00	0.01	0.00	0.00	0.04	0.03
8	0.00	0.01	0.00	0.00	0.01	0.04
9	0.00	0.01	0.01	0.00	0.13	0.10
10	0.00	0.00	0.00	0.00	0.03	0.09

Table 12. Cutter Bar Loss Bu/A at 12% M.C.

Pair	Oct. 4 -- M.C. 24%		Oct. 7 -- M.C. 19%		Oct. 17 -- M.C. 19%	
	Conven.	Row Crop	Conven.	Row Crop	Conven.	Row Crop
1	1.54	0.45	3.50	0.58	3.30	0.69
2	4.66	1.11	0.40	0.51	2.13	2.00
3	3.08	0.37	5.16	0.46	1.24	1.50
4	1.94	1.21	2.27	0.42	3.19	1.26
5	3.40	0.84	1.57	0.77	1.17	2.79
6	1.05	0.48	5.40	0.91	1.42	0.41
7	0.71	0.39	2.67	1.40	2.42	2.30
8	1.05	0.65	1.18	0.39	2.04	1.80
9	1.52	0.44	3.65	0.27	3.36	1.87
10	2.79	0.23	2.77	0.53	4.30	1.73

Table 13. Unthreshed Head Loss* Bu/A at 12% M.C.

Pair	Oct. 4 -- M.C. 24% Conven.	Oct. 4 -- M.C. 24% Row Crop	Oct. 7 -- M.C. 19% Conven.	Oct. 7 -- M.C. 19% Row Crop	Oct. 17-- M.C. 19% Conven.	Oct. 17-- M.C. 19% Row Crop
1	3.71	1.01	7.70	1.20	23.98	6.11
2	4.02	2.18	5.54	2.21	16.37	5.81
3	5.59	3.56	4.33	3.02	16.50	5.45
4	12.16	4.67	6.48	3.75	27.70	6.59
5	7.15	2.33	4.42	3.22	15.86	8.57
6	5.56	3.24	6.86	3.59	19.46	6.42
7	10.48	2.93	8.47	4.27	17.24	6.44
8	9.53	4.32	3.76	2.54	17.80	4.89
9	6.70	1.52	4.98	0.85	22.38	5.01
10	5.59	0.90	4.59	2.38	25.84	4.39

* For the conventional header this is Reel Loss.

Table 14. Header Loss Bu/A at 12% M.C.

Pair	Oct. 4 -- M.C. 24% Conven.	Oct. 4 -- M.C. 24% Row Crop	Oct. 7 -- M.C. 19% Conven.	Oct. 7 -- M.C. 19% Row Crop	Oct. 17-- M.C. 19% Conven.	Oct. 17-- M.C. 19% Row Crop
1	5.25	1.46	11.20	1.78	27.28	6.80
2	8.68	3.29	5.84	2.72	18.50	7.81
3	8.67	3.93	9.49	3.48	17.74	6.95
4	14.10	5.88	8.75	4.17	30.89	7.85
5	10.55	3.17	5.99	3.99	17.03	11.36
6	6.61	3.72	12.26	4.50	20.88	6.83
7	11.19	3.32	11.14	5.67	19.66	8.74
8	10.58	4.97	4.94	2.93	19.84	5.97
9	8.22	1.96	8.63	1.12	25.74	6.88
10	8.38	1.13	7.36	2.91	30.14	6.12

Table 15. Tank Yield Bu/A at 12% M.C.

Pair	Oct. 4 — M.C. 24%		Oct. 7 -- M.C. 19%		Oct. 17-- M.C. 19%	
	Conven.	Row Crop	Conven.	Row Crop	Conven.	Row Crop
1	90.18	99.46	91.61	98.57	43.75	86.61
2	78.21	86.45	66.07	80.36	33.75	73.75
3	85.36	89.11	73.57	83.93	35.36	65.71
4	82.68	64.11	65.00	83.57	45.36	60.89
5	68.57	63.04	64.82	79.82	18.39	57.14
6	80.89	68.93	90.71	104.82	58.39	83.93
7	69.46	65.18	59.46	81.07	40.36	57.14
8	72.32	71.07	64.82	86.96	45.71	70.71
9	62.68	52.86	66.43	92.50	64.11	82.14
10	73.21	70.54	87.68	88.57	58.21	81.78

Table 16. Total Yield Bu/A at 12% M.C.

Pair	Oct. 4 — M.C. 24%		Oct. 7 — M.C. 19%		Oct. 17-- M.C. 19%	
	Conven.	Row Crop	Conven.	Row Crop	Conven.	Row Crop
1	95.43	100.92	102.81	100.35	71.03	93.41
2	86.89	89.72	71.91	83.08	52.25	81.56
3	94.03	93.04	83.06	87.41	53.10	72.66
4	96.78	69.99	73.75	87.74	76.25	68.74
5	79.12	66.21	70.81	83.81	35.42	68.50
6	84.61	75.54	102.97	109.32	79.27	90.76
7	72.78	76.37	70.60	86.74	60.02	65.88
8	82.90	76.04	69.76	89.89	65.55	76.68
9	64.64	61.08	75.06	93.62	89.85	89.02
10	81.59	71.67	95.04	91.48	88.35	87.90