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Combine Harvesters in Missouri

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Combine harvesters were first used in Missouri in the late 1920's. Most of these machines were of 9-, 10-, and 12-foot sizes, with a few cutting swaths as wide as 15 and 16 feet. In 1935, machines cutting only 5-foot swaths were used in the state, and in 1939 still smaller machines cutting swaths as narrow as 40 inches were introduced. These smaller machines were lower in price, were mounted on rubber tires, and in the main were power-take-off driven. With the introduction of smaller machines the advantages of combining were extended to small farms. Combines have been used successfully for harvesting and threshing practically all small grain and seed crops grown extensively in Missouri. In 1940, approximately one-quarter of the wheat acreage and one-tenth of the oats acreage in the State were combined.

In order to secure more definite information on costs of operation and on the practicability of the combine for Missouri conditions, field surveys were made following the harvest seasons of 1937, 1938, and 1939. More than 200 combine owners were interviewed, and a complete season's records were obtained in 182 cases. The information thus secured is summarized and presented in this bulletin.

Crops Harvested

Many different crops are harvested satisfactorily by combines in Missouri. Table 1 gives the acreages of various crops combined in

TABLE 1.—CROPS HARVESTED IN ONE YEAR BY THE 182 COMBINES SURVEYED.

	Acres	% of Total
Wheat	41,326	86.09
Oats	3,165	6.60
Barley	1,929	4.02
Timothy	480	1.00
Lespedeza	319	0.67
Sweet Clover	265	0.55
Soybeans	240	0.50
Rye	118	0.25
Flax	52	0.11
Red Top	30	0.06
Sorgo	21	0.04
Kafir	20	0.04
Alsike Clover	16	0.03
Alfalfa	10	0.02
Red Clover	10	0.02
	48,001	100.00

*The authors acknowledge valuable assistance received from Xzin McNeal, formerly research assistant in agricultural engineering, in making the field survey reported in this bulletin.

one year by the 182 machines included in the survey. It will be noted, however, that wheat makes up the largest part of the acreage harvested. Small acreages of other crops were probably harvested by other machines not included in the survey.

Capacity of Combines

The acreage that a combine can harvest in a day will vary with the weather, the condition of the ground, and the condition of the crop. The average acreage harvested per day by the various sizes of combines varied from 7.6 acres for the small 40-inch machines to 25.3 acres for the 12-foot machines. See Table 2. The average acres cut per day per foot of cutter bar for the various machines ranged from 2.1 to 2.8.

TABLE 2.—ACRES CUT PER DAY AND PER YEAR.

Size of Combine	No. of Machines	Average Acres Cut Per Day	Average Acres Per Day, Per Foot of Cutter Bar	Average Total Acres Cut Per Year	Estimated Maximum Acreage of Wheat and Oats to be Cut Per Year
40-inch	8	7.6	2.3	108	125
5-foot	53	13.8	2.8	238	236
6-foot	40	14.4	2.4	206	240
8-foot	52	18.1	2.3	297	320
10-foot	11	20.9	2.1	306	332
12-foot	18	25.3	2.1	351	388

The maximum acreage of a particular crop that may be safely harvested in a season with a combine will depend primarily upon the size of the machine and the length of the harvesting season which varies somewhat from year to year. It has been found that wheat as well as many other crops can generally be left standing longer after maturity than was considered practical when combines were first used in the State. Table 2 gives the acreage harvested per year by the combines included in this study, as well as the owners' estimates of maximum average safe total acreage of wheat and oats that may be cut per year. The total acreage of all crops that a combine can harvest per year can be increased considerably if the combine is used to harvest crops that mature at different times, such as lespedeza or soybeans, in addition to small grains. The greater the total acres harvested per year, the lower the per acre cost of harvesting.

Custom Work Generally Satisfactory

Most of the machines included in this survey did a considerable amount of custom work. This, in the main, was profitable and satisfactory, both to the combine owners and to the farmers who hired their grain harvested. It will be noted from Table 3 that the custom work averaged from about one-third to about one-half of the total acreage harvested.

TABLE 3.—AMOUNT OF CUSTOM WORK DONE BY COMBINES ANNUALLY.

Size of Combine	No. of Machines	Average Amount Own Work, Acres	Average Amount of Custom Work: Acres	Average Amount of Custom Work: % of Total	Average Total Work, Acres
40-inch	8	52	56	51.8	108
5-foot	53	154	84	35.3	238
6-foot	40	103	103	50.0	206
8-foot	52	152	145	48.8	297
10-foot	11	189	117	38.2	306
12-foot	18	223	128	36.5	351

Custom Prices

Various prices have been charged for custom work, depending upon the grain and the ground. Some operators have charged a flat rate per bushel, some a flat rate per acre, and some a certain amount per bushel plus a certain amount per acre. Probably the majority have charged by the acre, because the acreage of the field or fields is generally known, and the total charge is therefore easily determined. Some common rates for combining wheat have been $1.00 per acre plus 10 cents per bushel, $1.00 per acre plus 8 cents per bushel, 12 to 16 cents per bushel, and $2.00 to $4.00 per acre. Probably the "per acre plus a per bushel" charge would be most satisfactory over widely varying conditions, particularly where the acreage of the fields is known and the bushels threshed can be measured or determined easily.

Dependability of Combines—Repair Costs

Modern combines are very well constructed, and the loss of time due to breakdowns and repairs is usually quite small. The later models are better-built and more fool-proof and trouble-free than the earlier models. The average time lost per season due to breakdowns and repairs for the 182 machines included in this survey was six hours. Most delays were caused by minor breaks which were repaired at home or at a nearby repair shop.

TABLE 4.—AVERAGE ANNUAL REPAIR COST.

Size of Combine	No. of Machines	Average Age of Combines, Years	Average Acres Cut	Average Annual Repair Cost*	Average Annual Repair Cost Per Acre
40-inch	8	1.0	108	$ 2.16	$0.020
5-foot	53	1.5	238	9.81	0.041
6-foot	40	1.5	206	10.95	0.053
8-foot	52	1.6	297	10.14	0.034
10-foot	11	6.5	306	15.81	0.052
12-foot	18	2.9	351	19.28	0.055

*Includes cost of parts and expert hired labor.

Table 4 gives the average annual cost of repair parts and expert hired labor as reported by the owners of the machines. Most of the machines are rather new. These figures therefore cannot well be considered as typical of average annual repair costs during the life of the machines, since larger repair costs may be expected as the machines become older.

In making estimates of repair costs on a combine, various methods may be used. It may be assumed that the total repair costs during the lifetime of the machine will be a certain amount, say twenty per cent of the purchase price. The average annual repair cost would then be this amount divided by the estimated life of the machine. Such estimates are probably somewhat too high for machines receiving good care and cutting less than the average acreage per year. For the older model combines, which were obviously inferior mechanically to the newer models, ten cents per acre was considered a good estimate for repair cost under average conditions. Newer models which are more ruggedly built, less complicated, better lubricated, and mounted on pneumatic tires, may reasonably be expected to have considerably lower repair costs, possibly as low as 3 to 5 cents per acre.

It is a good plan to overhaul a combine thoroughly sometime before harvest begins. It is usually wise to replace parts that show considerable wear even though they might last another season. Such practice may increase repair costs somewhat but it is good insurance against breakdowns and delays during harvest.

Fuel, Oil, and Grease Used in Combining

The quantities of fuel, oil, and grease used by combines of different sizes and by the tractors pulling them are shown in Table 5. Five-foot combines used an average of 17.5 gallons of fuel per day in cutting 13.8 acres. The smaller 40-inch combines used an average of 12.5 gallons per day in cutting 7.6 acres. There was a rather wide spread in the amount of fuel used by machines in this group, ranging

TABLE 5.—QUANTITIES OF FUEL, OIL, AND GREASE USED PER DAY.

Size of Combine	No. of Machines in Group	Gallons of Fuel			Quarts of Oil			Lbs. Pressure Gun Grease	Average Acres Cut Per Day
		Combine Engine	Tractor Engine	Total	Combine Engine	Tractor Engine	Total		
40-inch	8	...	12.5	12.5	...	1.3	1.3	.8	7.6
5-foot	53	...	17.5	17.5	...	1.7	1.7	1.4	13.8
6-foot	16	9.6	15.3	24.9	0.7	1.5	2.2	1.8	15.6
6-foot with power takeoff	24	...	20.3	20.3	...	1.6	1.6	1.8	13.7
8-foot	51	12.8	15.8	28.6	1.0	1.4	2.4	2.3	18.1
8-foot with power takeoff	1	...	20.0	20.0	...	2.0	2.0	2.3	20.0
10-foot	11	12.7	15.8	28.5	1.1	1.9	3.0	2.1	20.9
12-foot	18	19.3	19.6	38.9	1.5	1.9	3.4	2.9	25.3

from 8 to 18 gallons per day. This was due largely to the fact that many of the small combines were pulled by tractors much larger than necessary.

Life of Combines

The length of useful life of a combine has a very definite bearing upon its cost of operation and the feasibility of owning it. Table 6 gives the average of the owners' estimates of the useful life of their combines. It will be noted that most of these combines are only one to three years old, and therefore the estimates may not be as valuable as similar estimates would be a few years later after the owners have had more experience with them. The owners of the older machines, however, estimate longer lives for their machines than the owners of the new machines, indicating that the estimates are in the main conservative.

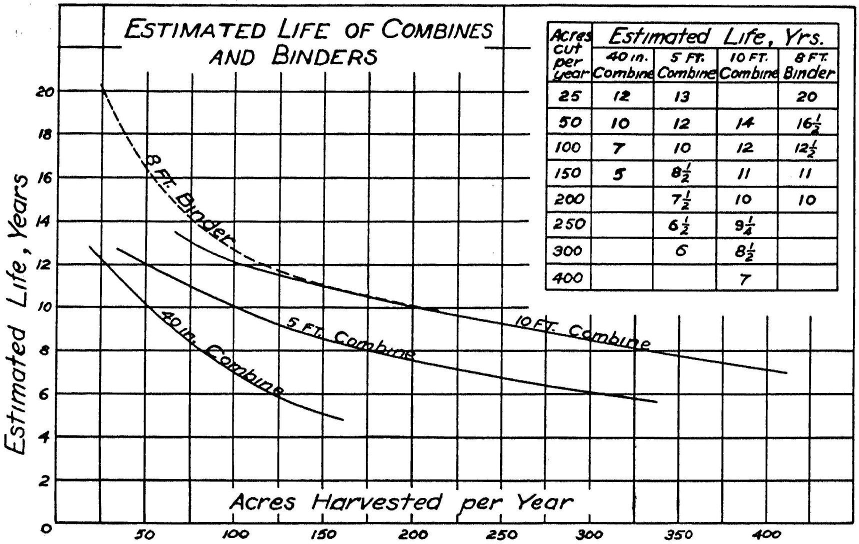
TABLE 6.—LIFE OF COMBINES.

Size of Combine	No. of Machines	Average Age of Combines, Years	Average Acres Cut Per Year	Owners' Estimate of Life	
				Years	Acres
40-inch	8	1.0	108	6.8	734
5-foot	53	1.5	238	7.1	1690
6-foot	40	1.5	206	8.5	1751
8-foot	52	1.6	297	9.4	2792
10-foot	11	6.5	306	10.3	3152
12-foot	18	2.9	351	9.1	3194

The length of life of combines, like that of most other farm machines, is determined not only by the amount of work they do per year, but also by their rate of becoming obsolete or out-of-date due to the production of newer and improved models.

The life of any individual machine may vary quite widely from the average, depending upon the care it receives, the conditions under which it works, and the amount of repairs the owner considers advisable to put on it. By increasing the amount of repair work done, it would be easily possible to make a machine last longer than average.

The table and curves of Fig. 1 may be used as a basis for estimating the length of life of combines and binders when cutting different acreages per year. The curves and tables for combines are based upon data obtained in the 1937-39 survey of 182 combines, and those for binders are based upon data obtained from a survey of 113 binders in 1928 and 1929 and reported in Missouri Agricultural Experiment Station Bulletin 286.



Acres cut per year	Estimated Life, Yrs. 40 in. Combine	5 FT. Combine	10 FT. Combine	8 FT. Binder
25	12	13		20
50	10	12	14	16½
100	7	10	12	12½
150	5	8½	11	11
200		7½	10	10
250		6½	9¼	
300		6	8½	
400			7	

Fig. 1.—Estimated life of combines and binders.

Cost of Harvesting With Combines

The average costs of harvesting, along with certain other pertinent data, for the 182 combines included in this study, are given in Table 7. The various items of cost for each individual case, were calculated as follows:

I. Overhead Costs

1. Annual Depreciation, first cost of the machine divided by the years of life, as estimated by the owner.
2. Annual Interest, 5 per cent of average value, or half of purchase price.
3. Annual Taxes and Insurance, 1 per cent of average value, or half of purchase price.
4. Annual Housing Cost, $3.00 for 40-inch sizes, $4.00 for other sizes.
5. Annual Repair Cost, as reported by the owners.

II. Operating Costs

1. Fuel, Oil, and Grease, as reported by the owners.
2. Power Costs, $2.00 per day for 1-plow tractors,
   $2.50 per day for 2-plow tractors,
   $3.00 per day for 3-plow tractors.

III. Labor Costs

$3.00 per day for 1-man outfit; $5.00 per day for 2-man outfits ($2.00 for tractor operator, and $3.00 for combine operator.)

TABLE 7.—RESULTS OF SURVEY OF 182 COMBINES.

Size of Machine	40-inch	5-foot	6-foot	8-foot	10-foot	12-foot
Number of Machines	8	53	40	52	11	18
Average Cost	$384	$650	$899	$1178	$1214	$1476
Owner's Estimate of Life						
Years	6.8	7.1	8.5	9.4	10.3	9.1
Acres	734	1690	1751	2792	3152	3194
Average Years Used	1	1.5	1.5	1.6	6.5	2.9
Estimated Yearly Capacity, Wheat & Oats, Acres	125	236	240	320	332	388
Own Crops Harvested, Acres in 1 Yr.	52	154	103	152	189	223
Custom Crops Harvested						
Acres in 1 Year	56	84	103	145	117	128
Per Cent of Total	51.8	35.3	50.0	48.8	38.2	36.5
Total Acres Harvested in 1 Year	108	238	206	297	306	351
Total Days Used in 1 Year	14.1	17.3	14.5	16.3	14.7	14.5
Average Acres Cut Per Day	7.6	13.8	14.4	18.1	20.9	25.3
Average Acres Per Day Per Foot of Cutting Width	2.3	2.8	2.4	2.3	2.1	2.1

Average Costs of Combining.

I. Average Overhead Costs	Per Year	Per Acre	Per Year	Per Acre	Per Year	Per Acre	Per Year	Per Acre	Per Year	Per Acre	Per Year	Per Acre
1. Depreciation	$57.82	$0.69	$97.27	$0.47	$108.09	$0.58	$128.63	$0.50	$123.13	$0.46	$175.34	$0.59
2. Interest	9.60	0.09	16.26	0.08	22.48	0.12	29.45	0.11	30.35	0.10	36.90	0.11
3. Taxes & Insurance	1.92	0.02	3.25	0.02	4.48	0.02	5.89	0.02	6.07	0.02	7.38	0.02
4. Repairs	2.16	0.02	9.81	0.04	10.95	0.05	10.14	0.03	15.81	0.05	19.28	0.05
5. Housing	3.00	0.03	4.00	0.02	4.00	0.02	4.00	0.01	4.00	0.01	4.00	0.01
Total overhead costs	74.50	0.85	130.54	0.63	150.00	0.79	178.11	0.67	178.44	0.64	242.90	0.78
II. Average Operating Costs												
1. Fuel	1.34	0.18	1.86	0.14	2.33	0.16	2.95	0.16	2.95	0.14	4.18	0.16
2. Oil and Grease	.32	0.04	.46	0.04	.55	0.05	.70	0.05	.79	0.06	.93	0.06
3. Tractor Cost (other than fuel, oil and grease)	2.31	0.32	2.55	0.20	2.52	0.18	2.60	0.15	2.63	0.14	2.75	0.11
Total operating costs	3.97	0.54	4.87	0.38	5.40	0.39	6.25	0.36	6.37	0.34	7.86	0.33
III. Average Labor Costs, Tractor & Combine Operator (or operators)	3.00	0.41	3.00	0.23	3.00	0.22	4.07	0.23	5.00	0.26	5.00	0.21
Total Acre cost	...	$1.80	...	$1.24	...	$1.40	...	$1.26	...	$1.24	...	$1.32

TABLE 8.—COST OF COMBINING AS AFFECTED BY ACRES CUT PER YEAR.
(Data from 53 Five-Foot Combines).

Acres Per Year	No. in Group	Estimated Life of Combine, Years	Avg. Acres Per Year	Avg. Acres Custom Work Per Year	Avg. Acres Cut Per Day	Overhead Costs			Operating Costs (Including Labor)			Total Average Cost	
						Per Day	Per Acre	% of Total Acre Cost	Per Day	Per Acre	% of Total Acre Cost	Per Day	Per Acre
51-100	3	7.7	90	7	12.0	$16.40	$1.37	62.6	$9.88	$0.82	37.4	$26.28	$2.19
101-150	11	7.6	138	23	13.4	12.00	0.90	60.4	7.97	0.59	39.6	19.97	1.49
151-200	7	8.3	182	48	11.5	7.46	0.65	48.9	7.84	0.68	51.1	15.30	1.33
201-250	12	8.0	226	57	13.2	6.99	0.53	46.1	8.19	0.62	53.9	15.18	1.15
251-300	8	6.5	274	74	14.9	6.95	0.47	46.1	8.25	0.55	53.9	15.20	1.02
301-350	4	6.0	337	127	13.0	6.02	0.46	42.2	8.15	0.63	57.8	14.17	1.09
351-400	5	5.4	362	179	15.4	6.84	0.44	43.1	8.87	0.58	56.9	15.71	1.02
401-450	2	5.0	418	244	18.7	7.05	0.38	48.7	7.54	0.40	51.3	14.59	0.78
Over 450	1	5.0	600	600	15.0	3.99	0.27	33.3	8.16	0.54	66.7	12.15	0.81

Table 8 shows the costs of operating the 5-foot combines included in the survey, grouped according to the acreages cut per year. It will be noted that in general the higher the acreage cut per year, the lower the cost per acre, and that the costs varied from $2.19 per acre for the group cutting between 51 and 100 acres per year to 78 cents per acre for the group cutting between 401 and 450 acres per year.

Tables 7 and 8 give average costs of combining for the machines included in this study. It is recognized, of course, that costs on a particular farm, or for a particular set of conditions may vary quite widely from the average. The one single factor having the greatest effect on the acre cost of combining, is the number of acres cut per year. This is because a large part of the total cost of operating a combine is made up of overhead costs (depreciation, interest on investment, taxes, insurance and housing) which are practically the same whether many or few acres are cut per year. When many acres are cut then the proportion of overhead costs charged to each acre is small.

Estimating Cost of Harvesting with Combines

Using information and data obtained from this survey, estimates have been made of costs of harvesting with combines of different sizes when used for different acreages annually. These estimates are given in Tables 9, 10, and 11, and are also shown graphically in Fig. 2.

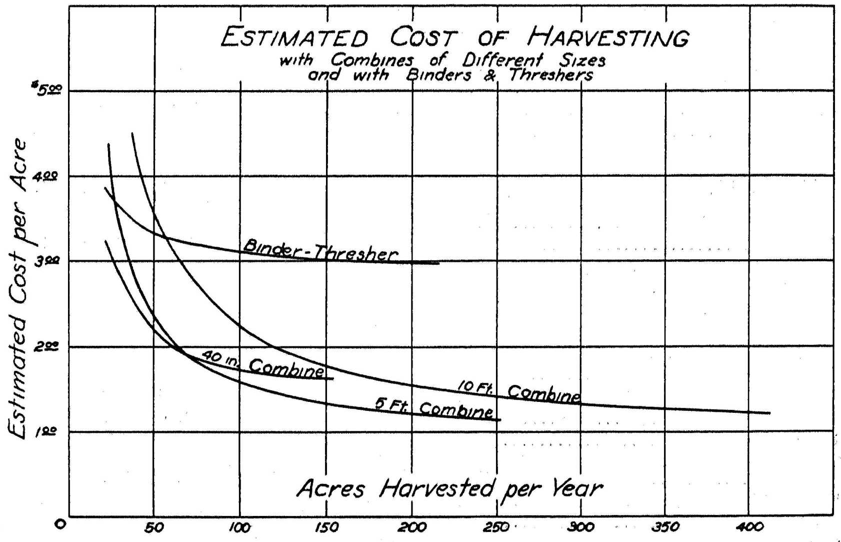


Fig. 2.—Estimated cost of harvesting and threshing by different methods. For prices and values of various items see Tables 9, 10, 11, and 12.

The prices used in the tables for labor, and certain other items will vary somewhat from year to year in different localities. In the event that prevailing local prices differ widely from those used, the acre costs can be adjusted accordingly.

TABLE 9.—ESTIMATED COST OF COMBINING WITH 40-INCH COMBINES, PULLED BY 1-PLOW TRACTORS.

Acres Harvested Per Year	25	50	100	150
Cost New	$385	$385	$385	$385
Estimated Life, Years	12	10	7	5
Annual Depreciation	$32	$39	$55	$77
Annual Interest, Insurance and Taxes	$12	$12	$12	$12
Annual Housing Cost	$3	$3	$3	$3
Annual Repair Cost	$6	$8	$12	$15
Total Annual Overhead Cost	$53	$62	$82	$107
Days Used Per Year (7 acres per day)	3.6	7.1	14.3	21.4
Daily Overhead Cost	$14.70	$8.70	$5.70	$5.00
Labor Cost Per Day	$3.00	$3.00	$3.00	$3.00
Tractor Cost per Day (Other than Fuel and Oil)	$2.00	$2.00	$2.00	$2.00
Fuel, Oil, and Grease Cost Per Day	$1.50	$1.50	$1.50	$1.50
Total Daily Costs	$21.20	$15.20	$12.20	$11.50
Cost Per Acre	$3.03	$2.17	$1.74	$1.64

TABLE 10.—ESTIMATED COST OF COMBINING WITH 5-FOOT COMBINES.

Acres Harvested Per Year	25	50	100	150	200	250
Cost New	$650	$650	$650	$650	$650	$650
Estimated Life, Years	13	12	10	8.5	7.5	6.5
Annual Depreciation	$50	$54	$65	$76	$87	$100
Annual Interest, Insurance and Taxes	$20	$20	$20	$20	$20	$20
Annual Housing Cost	$4	$4	$4	$4	$4	$4
Annual Repair Cost	$10	$11	$13	$16	$19	$20
Total Annual Overhead Cost	$84	$89	$102	$116	$130	$144
Days Used Per Year (14 acres per day)	1.8	3.6	7.1	10.7	14.3	17.8
Daily Overhead Cost	$46.70	$24.70	$14.40	$10.80	$9.10	$8.10
Labor Cost Per Day	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00
Tractor Cost Per Day (Other than Fuel and Oil)	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Fuel, Oil, and Grease Cost Per Day	$2.32	$2.32	$2.32	$2.32	$2.32	$2.32
Total Daily Costs	$54.52	$32.52	$22.22	$18.62	$16.92	$15.92
Cost Per Acre	$3.90	$2.32	$1.59	$1.33	$1.21	$1.14

TABLE 11.—ESTIMATED COST OF COMBINING WITH 10-FOOT COMBINES.

Acres Harvested Per Year	50	100	150	200	300	400
Cost New	$1300	$1300	$1300	$1300	$1300	$1300
Estimated Life, Years	14	12	11	10	8½	7
Annual Depreciation	$93	$108	$118	$130	$153	$186
Annual Interest, Insurance and Taxes	$39	$39	$39	$39	$39	$39
Annual Housing Cost	$5	$5	$5	$5	$5	$5
Annual Repairs	$18	$20	$24	$28	$36	$44
Total Annual Overhead Cost	$155	$172	$186	$202	$233	$274
Days Used Per Year (21 acres per day)	2.4	4.8	7.1	9.5	14.3	19.0
Daily Overhead Cost	$64.60	$35.83	$26.20	$21.26	$16.29	$14.42
Labor Cost Per Day	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00
Tractor Cost Per Day (Other than Fuel and Oil)	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Fuel, Oil, and Grease Per Day	$3.74	$3.74	$3.74	$3.74	$3.74	$3.74
Total Daily Costs	$75.84	$47.07	$37.44	$32.50	$27.53	$25.66
Cost Per Acre	$3.61	$2.24	$1.78	1.55	$1.31	$1.22

Cost of Combining Compared to Cost of Binding and Threshing

It will be noted from Tables 9 to 12 and from Fig. 2 that the binder-thresher method is cheaper for smaller acreages. For less than about twenty acres per year the binder-thresher method is cheaper on the average. For harvesting small acreages per year the small combine is cheaper than larger ones. For acreages above 60 to 70 per year, the harvesting cost is cheaper with 5-foot combines than with 40-inch machines.

TABLE 12.—ESTIMATED HARVESTING AND THRESHING COSTS, BINDER-THRESHER METHOD (8-FOOT HORSE-DRAWN BINDER AND CUSTOM THRESHER).

Acres Harvested Per Year	25	50	100	150	200
Cost of Binder, New	$250	$250	$250	$250	$250
Estimated Life, Years	20	16½	12½	11	10
Annual Depreciation	$12.50	$15.20	$20.00	$22.70	$25.00
Annual Interest, Insurance and Taxes	$7.50	$7.50	$7.50	$7.50	$7.50
Annual Housing Cost	$3.00	$3.00	$3.00	$3.00	$3.00
Annual Repair Cost	$2.00	$3.00	$5.00	$7.50	$10.00
Total Annual Overhead Cost	$25.00	$28.70	$35.50	$40.20	$45.50
Binder Overhead Cost Per Acre	$1.00	$ .57	$ .36	$ .27	$ .23
Labor, Cutting, Cost Per Acre (16 acres per day @ $3.00 per day)	.19	.19	.19	.19	.19
Labor, Shocking, Cost Per Acre (1 man hour per acre @ $2.00 per day)	.20	.20	.20	.20	.20
Twine, 1.7 pounds @ $0.09	.15	.15	.15	.15	.15
Oil	.01	.01	.01	.01	.01
Horse Labor Cost Per Acre @ 10c per hour (4 horses cut 16 acres per day)	.25	.25	.25	.25	.25
Threshing Cost, 13 bushels per acre @ 15c per bushel	1.95	1.95	1.95	1.95	1.95
Total Harvesting and Threshing Cost Per Acre	3.75	3.32	3.11	3.02	2.98

It should be kept in mind that these conclusions are general and are based on average conditions. Changes in the cost of labor and the yield in bushels per acre as well as the prices of fuel and machinery will change the costs of harvesting by the different methods.

Where labor costs are lower than those used in Tables 9 to 12, the costs of the binder-thresher method would be lowered more than the costs of the combine method. Probably the factor which might make the greatest change in the relative costs of the two methods, is the yield in bushels per acre. Reasonable variations in yields do not usually change the cost of combining, but threshing costs vary largely in proportion to the yield. The figures for cost of the binder-thresher method in Table 12 are based on threshing costs for an average yield of 13 bushels per acre. The costs for higher yields will on the average be considerably more and the costs for lower yields may be considerably less. Sometimes in the case of extremely poor grain yielding only a few bushels per acre, the whole crop might not be worth as much as the cost of binding, shocking and threshing.

Frequently under such conditions a combine can be used to advantage, and the grain will more than pay the cost of combining.

Except for small acreages, it may be concluded in general that costs of combining are much lower than binder-thresher costs. This fact, together with the lower labor requirements, probably accounts in large part for the increased use of combines in recent years.

It should be remembered, however, that there are other important factors to be considered in choosing the harvesting method to be employed, such as saving and use of the straw, the timeliness of harvest, and threshing, availability of labor, conflict with labor requirements of other crops grown on the farm, the boarding of harvest and threshing crews, etc.

Grain and Seed Losses

Questions are frequently asked regarding the amounts of grain lost by combines as compared with amounts lost with binders and threshers. Tests have been made by various experiment stations and the U. S. Department of Agriculture. It has been found that losses vary quite widely with all methods of harvesting, and depend largely upon the condition of the grain, the weather or the season, and particularly upon the adjustment of the machines. Combine losses on the average are slightly lower than binder and thresher losses on wheat and most small grains and seeds. On oats the losses will probably average slightly higher with combines than with binders and threshers. Oats usually do not stand as well after maturing as wheat, and if they cannot be combined promptly, the losses may be higher. For certain crops like lespedeza and soybeans the combine method of harvesting saves more seed than any other method.

Adjustment of Combine is Important

The skill with which a combine is adjusted and operated probably affects the losses more than any other single factor. Many farmers who have not had previous experience with threshing equipment are somewhat hesitant to make adjustments as long as the combine is operating reasonably well. Also many operators are not aware of the losses.

Combine Instruction Book Valuable

An operator will soon feel repaid for his efforts in learning how to make quick checks for losses and how to make adjustments to prevent them. The instruction book furnished with a new machine is most helpful in learning exactly how the machine should work and how to make the various adjustments. This booklet should be carefully studied by the operator and it should be kept carefully for future reference.

How the Combine Works

Adjustments.—The main operations performed by a combine are cutting, threshing or shelling, separating and cleaning.

Threshing or Shelling.—Threshing or shelling is done by the cylinder and concave. The threshing action should be just severe enough to remove the grain or seed from the heads or seed pods, but not so severe as to crack the seed or to break up the straw unnecessarily. Too severe threshing not only requires somewhat more power but it may overload the sieves or cleaning screens with small pieces of weeds and straw and prevent the clean grain from falling through. Grain is then carried on through the machine and lost on the ground.

The threshing action of the cylinder is controlled by the speed of the cylinder, the spacing between the cylinder and the concave, and, on some machines, by the number of concave bars. Many of the later model combines have provisions for quickly changing the speed of the cylinder without changing the speed of other parts of the machine. On such machines the severity of threshing action is therefore quickly and easily controlled. The clearance between the cylinder and the concave or stationary threshing bars is likewise quickly and easily changed on most late model combines.

Separating.—The threshed grain and much loose chaff fall through a grate just beneath the cylinder and are carried to the cleaning apparatus by a grain pan or a slat drag conveyor called a raddle. The straw is fed, with the aid of the beater, onto the straw rack where it is agitated thoroughly and carried toward the rear of the machine. The loose grain shaken from the straw finds its way onto the top sieve of the cleaning apparatus beneath, usually by means of a return pan. At the rear of the machine the straw falls from the straw rack onto the straw spreader or onto the ground.

Sometimes all loose grain is not shaken out of the straw but is carried on over with it and is lost on the ground. This is usually caused by overloading the straw rack, making it carry such a volume of straw that the grain cannot sift through. Common causes of such overloading are pulling the combine in too high a tractor gear, and cutting the straw too close to the ground. Where the grain is down and it is necessary to cut low in order to get all the grain, only a part swath should be cut or the combine should be pulled in a lower gear, particularly if there is evidence of overloading the straw rack.

Cleaning.—The cleaning apparatus consists of a set of sieves or screens and a fan which produces an air blast. The screens have adjustable openings in them. They are mounted in a box-like compartment beneath the straw rack and are given an end-shaking motion, usually by the same mechanism that drives the straw rack. The

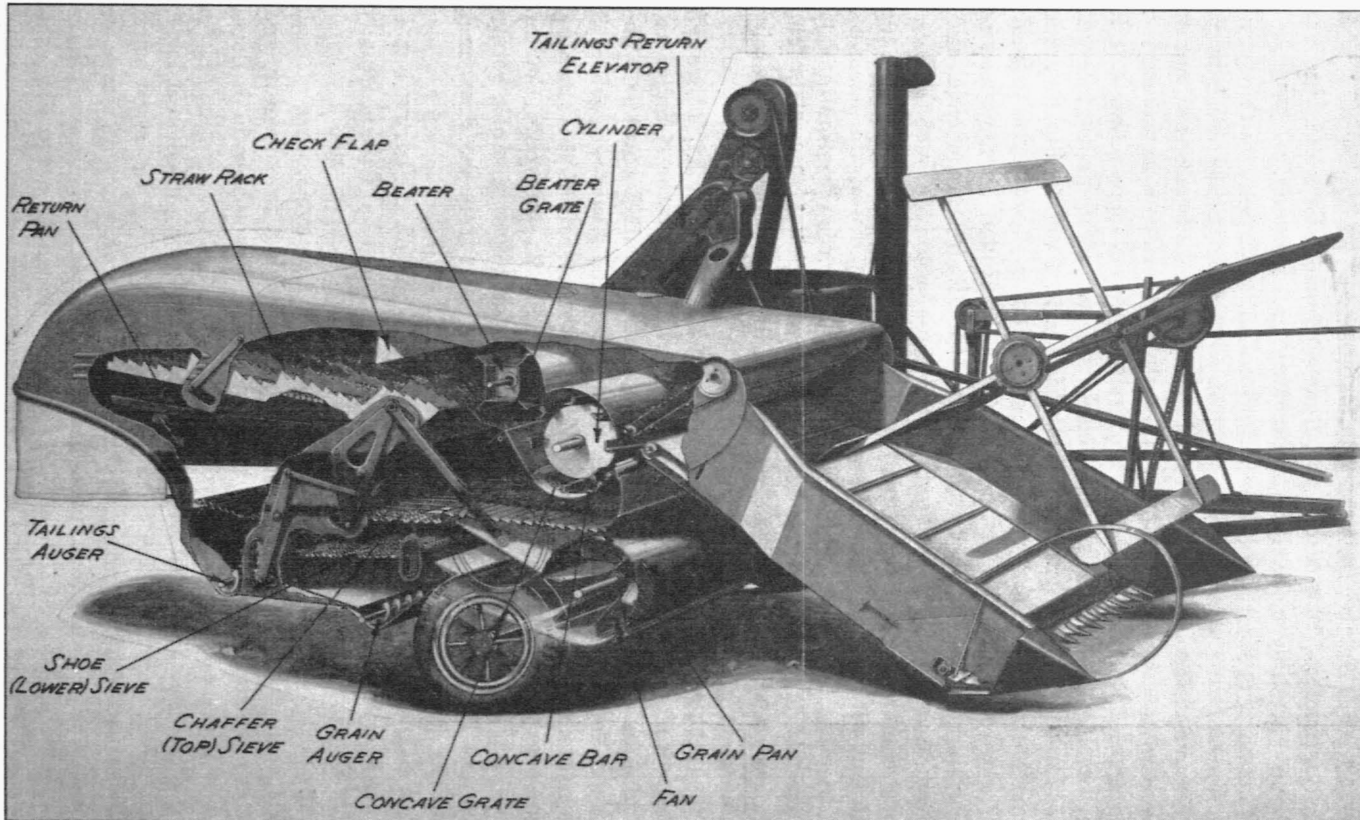


Fig. 3.—Cross-sectional view of a typical combine, showing arrangement of the various units inside the machine.

threshed grain and chaff which fall through the grate just beneath the cylinder, and the loose grain and chaff which are shaken from the straw rack onto the return pan, together with any partly threshed material, all come to the top screen which is called a chaffer. The openings in the chaffer should be adjusted as large as possible without letting coarse particles of trash and pieces of straw fall through to the lower screen. The threshed grain and the part heads and incompletely threshed material should fall through. (The air blast coming up from beneath and through the openings in the chaffer should keep the chaff floating and moving to the rear of the combine where it falls to the straw spreader or ground.) If the chaff settles down on the chaffer, the grain may not be able to sift through. Also too much chaff will fall to the lower screen where it will be more difficult to remove. More grain is usually lost because of too little air blast than because of too much.

The lower screen or sieve has smaller holes than the chaffer. Clean grain should fall through this lower screen to the grain auger beneath, but part heads and incompletely threshed material should not. This material should be carried to the back of the screen where it falls into the tailings auger, and is then returned by the tailing elevator to the cylinder for rethreshing. The clean grain which falls through to the grain auger is elevated to the grain bin or sacker.

The proper functioning of the cleaning apparatus is controlled by adjustments of the size of the openings in the screens, the slope of the screens, the amount and direction of the air blast, and by the height of a tail board at the back of the screens.

On many of the larger models of combines there is a recleaner, consisting of a fan and a second set of screens somewhat smaller than the first. It resembles a small fanning mill. On machines having such a recleaner, the adjustment of the main cleaning mechanism is not quite so critical, since any chaff and similar material left in the grain can be removed by the recleaner.

Tailings

The condition and amount of material returned by the tailings elevator for rethreshing is one of the best indications as to whether the various adjustments are properly made. Too much partly threshed grain in the tailings indicates too low a cylinder speed or too wide spacing of the cylinder and concave. Too much threshed grain in the tailings indicates that for some reason the grain could not fall through the screens. This may be due to one or possibly two of the following reasons: (1) Size of openings in screens adjusted too small. (2) Insufficient air blast to keep chaff floating on the chaffer. (3) Too strong an air blast, blowing the grain off the screens into the tailings auger.

Too much cracked grain and small bits of straw in the tailings may be caused by too severe threshing action at the cylinder, or by improper adjustment of the screens and fan. Small pieces of straw returned in the tailings will be still further reduced in size by the cylinder and become even more difficult for the cleaning apparatus to remove.

In the case of spike-tooth cylinders, end play in the cylinder bearings or improper spacing of the cylinder endways, allowing unequal spacing between the cylinder teeth and concave teeth, may cause a high percentage of cracked grain as well as a considerable amount of partly threshed grain in the tailings.

Constant Speed Important

For most satisfactory operation of the combine, the cylinder and the straw rack and other moving parts in the machine should operate at uniform speed. If the cylinder runs too fast it may crack grain and unnecessarily tear up straw, and thus overload the cleaning apparatus. If it runs too slowly it may not completely thresh the grain from the heads. If the straw rack runs either too slowly or too fast, it cannot work the straw to the rear of the machine as fast as it should. Straw thus accumulates on the rack, and the volume on the rack may become so great that the loose grain cannot sift through but is carried on through the machine and is lost. Likewise, improper speed of shake of the cleaning shoe and improper speed of the fan will cause grain to be lost over the screens. If the combine is power-take-off operated it is most important that the tractor engine be operated at a steady speed. Reducing the speed of the tractor engine would cause the parts of the combine to operate slower, with consequent loss of grain. If the ground is too rough, then the tractor should be shifted to a lower gear, keeping the engine speed the same. Likewise, if the grain is so heavy as to overload the tractor, causing the engine speed to drop, then the operator should shift the tractor to a lower gear, or steer out slightly and cut a narrower swath. Good combine operation depends largely upon the judgment and skill of the tractor driver.

Loose Grain on the Ground

Loose grain on the ground behind the combine may be caused by shatter before the passage of the machine. This can be checked, of course, by looking for loose grain on the ground in the standing grain. Loose grain may also come from leaks in the grain auger or elevator. Such leaks are more common in old machines.

The most common cause of excessive amounts of loose grain on the ground is improper adjustment or operation of the combine. The loose grain may be carried over with the straw or with the chaff from the cleaning shoe. To determine which, one may walk along beside the machine while it is working and reach in and collect samples coming off the straw rack and off the chaffer. If the grain is coming off the straw rack, the straw rack is probably overloaded or not operating at the proper speed. Overloading may be prevented, of course, by pulling the combine at a slower speed or by taking a part swath. If grain is coming off the rear of the chaffer, the trouble may be caused by overloading the chaffer with small bits of straw which in turn may be caused by too severe threshing action at the cylinder. Or it may be caused by too small adjustment of the openings in the chaffer, or by too little or too much air blast. Too little air blast might let the chaffer load up with chaff to such an extent that the grain could not sift through. An extremely strong air blast might blow the grain through the cleaning shoe and out behind.

Part heads, or partly threshed grain coming off the chaffer might be stopped and caused to fall into the tailing auger by adjusting the openings in the chaffer extension, or by raising the tail board at the rear of the chaffer.

Adjustments for Threshing in Green Weeds

Green weeds growing in the ripened grain sometimes present serious difficulties for the combine. In extremely bad cases, the best solution is to use the windrow method. See page 20. Usually, however, a combine can be adjusted to do satisfactory work in spite of the weeds. The weeds cause difficulty in two ways: (1) The juice from the weeds gets on the grain and raises the moisture content of the grain, possibly causing difficulties in storage; and (2) bits of green weed leaves and stems settle down on the sieves, forming a sort of blanket through which the grain cannot pass. Considerable grain is then carried over with the green weed leaves and stems onto the ground behind the combine.

To avoid these difficulties caused by green weeds, the speed of the cylinder and the spacing of the cylinder and concaves should be so adjusted that the weeds are crushed and torn up as little as possible. The weeds are thus passed onto the straw rack and on through the machine to the ground behind and cause a minimum of damage or trouble. It may be advisable under certain extreme conditions to sacrifice a few kernels of grain, leaving them in the head unthreshed, rather than to thresh them out thoroughly if this would at the same time tear up the green weeds too much.

Having the cylinder adjusted for as gentle threshing action as is practical, the operator should next give attention to the chaffer and fan. The parts of weed leaves and stem should not be allowed to settle down on the chaffer and clog it, but should be kept floating. This means a rather wide adjustment of the openings in the chaffer and a strong enough blast of air to keep the material floating and moving.

Windrowing

Windrowing is sometimes advisable where there is a heavy growth of green weeds, or where the grain or seed crop does not ripen uniformly. Under such conditions the grain or seed crop can be cut and left in windrows from a few days to a week or two and allowed to cure before threshing. The crop is picked up from the windrow with a combine equipped with a pick-up attachment instead of a sickle. Where the crop growth is heavy and the cutter bar can be operated high leaving a high stubble, the windrow will lie on top of the stubble, allowing air to circulate well. This will hasten curing and also hasten redrying in case of rain before threshing can be accomplished.

Windrowing is not practiced as much now as it was when the combine was first introduced into Missouri. There are probably two main reasons for this: (1) Experience has indicated that danger from storm damage is not so great as was at first thought, and in many cases the grain may just about as well be left standing until such time as it can be combined direct; and (2) windrowing requires an additional operation and increased expense.

With the coming of the smaller combines, and with many old binders in the country which can be readily converted into satisfactory windrowers, the practice of windrowing may increase. The capacity of the smaller combines in acres cut per day or per season, may be increased considerably by windrowing. A small 4- or 5-foot combine may be able to handle the grain grown on 7- or 8- or even a 10-foot swath if the vegetative growth is not too heavy and it is first windrowed and allowed to cure thoroughly before threshing.

Crop Must be in Threshable Condition

Combining of grain that is damp or immature should not be attempted. Only poor work can be done and it will most likely be impossible to store the grain without heating and damage. Farmers using a combine for the first time are frequently impatient to start harvesting. After some experience, however, they learn that it is better to wait. Wheat usually stands well after ripening, and if rains come, harvesting can usually be delayed safely until both the ground and the grain are dry enough. Most lodging of wheat occurs before it is ripe enough to cut with a binder. Combines can generally harvest lodged grain better than binders, although the speed of harvesting is reduced considerably if the grain is down. Combining of wheat should usually be delayed for 7 to 10 days after it is ready to be cut with a binder.

Straw Problems

On many livestock farms straw provides bedding, and to a limited extent, feed. If combines are used for harvesting all the small grain crops on a farm, it may be necessary to buy straw or to gather the straw up from the field and save it. Sometimes it is possible to buy straw at satisfactory prices and leave the combined straw on the field to add to the organic matter in the soil. Some farmers cut enough grain with a binder to provide a straw pile, even though most of their crops are combined. Such straw piles are somewhat expensive, however, and in many cases it may prove cheaper and more satisfactory to buy straw or to save the straw after the combine.

If the straw is to be salvaged, it should be left in windrows behind the combine, rather than spread. It then can be picked up with a hay loader or a pick-up baler, or it may be gathered with a sweep rake and taken to a stationary baler. The cost of saving the straw will depend upon conditions, but will usually vary from $2.00 to $4.00 per ton. Although the cost of the straw thus saved is considerably more than the cost of hauling it from a straw pile, it is also worth more when baled and stored in a barn or shed convenient for use.

The forage or roughage harvester which is being developed by the implement industry gives promise of solving the straw and bedding problem on many farms. These machines can pick up straw from a windrow, chop it into short lengths, and deliver it into a wagon, trailer or truck. The chopped straw can then be hauled to the barn or shed and blown or elevated into the storage space. On many farms it may be practical to use these machines for gathering and chopping or shredding corn stalks left in the field after the corn has been picked. Shredded stalks, in the opinion of many, make better bedding material than straw, because of the more absorbent nature of stalks.

If the straw is to be left on the field it is better to spread it with a straw spreading attachment on the combine, particularly if the combine cuts a swath of more than 5 or 6 feet. Straw thus spread will be easier to plow under if the field is to be plowed. In case a legume crop is to follow the small grain, it is also better to have the straw spread evenly than to have it left in windrows.

Plowing Straw Under.—With suitable equipment on plows there is ordinarily little difficulty in plowing under straw left by the combine, particularly if it is spread rather than left in windrows. Large coulters of 17- or 18-inch diameter are much better than small coulters, and notched or scalloped coulter disks are generally better than plain round ones. Of course, sharp ones cut trash and straw much better than dull ones.

Adding Fertilizer Ahead of Plowing.—When large amounts of straw are plowed under late in the summer, there may be some detrimental effects on the following crop. This is due to the fact that the bacteria which feed upon the straw and cause it to rot, must have larger amounts of certain minerals and nutrients—nitrogen, phosphorus and calcium in particular—than are found in the straw. Since these elements are not found in sufficient quantities in the straw, the bacteria take them from the soil, leaving a deficiency for the growing crop, with resultant decreased yields, especially on soils of low fertility.

This trouble can be largely avoided and the decomposition of the straw somewhat hastened by applying a mixture of ammonium sulfate and limestone at the rate of about 65 pounds of each for each ton of straw as it is plowed under.* This material may be applied with a drill ahead of the plow, with a fertilizer distributor on the plow, or probably best of all with a simple hopper attachment fastened on the back of the tractor and just ahead of the plow.

This material gives the bacteria a balanced ration and they will then not draw on the reserves of plant nutrients in the soil to the detriment of the next crop.

Fertilizing the crop following the plowing under of the straw will also lessen the danger mentioned above. A 4-12-4 or a 4-16-4 fertilizer, drilled at a rate of about 200 pounds per acre with small grain, is commonly recommended.

Effect of Straw on a Legume Seeded in a Grain Crop.—Straw left on the ground by a combine seldom is heavy enough to smother clover or other young legume crops seeded in the grain, particularly if it is spread rather than left in windrows. In fact, the higher stubble left by a combine is frequently an advantage. Also, there are no spots smothered out by shocks when the grain is combined. It is true, of course, that there will be more straw and stubble in an early hay crop from a combined field than if the grain were cut with a binder.

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*Any other carriers of nitrogen and lime in the same proportions may be used. (See Missouri Agricultural Experiment Station Bulletin 369, *Artificial Manure Production on the Farm.*)

Types of Threshing Cylinders

The common types of threshing cylinders are spike-tooth cylinders, steel rasp-bar cylinders, steel angle-bar cylinders, and rubber-faced angle or beater-bar cylinders. Many manufacturers can provide cylinders of different types for their machines. The spike-tooth type was more commonly used on earlier models, but in recent years there has been a gain in popularity of the rasp-bar and beater-bar types. The tooth cylinders are possibly better adapted to a wider variety of threshing conditions, if the number of concave teeth and the spacing of concave and cylinder teeth are properly adjusted. There is a tendency for the threshing action to be a little more thorough or severe, however, resulting in a greater power consumption and an unnecessary and undesirable breaking up of the straw and green weeds, unless careful attention is given to adjustments. Spike-tooth cylinders are possibly not as well adapted to threshing grain infested with green weeds as other types of cylinders, because of the tendency of the teeth to cut the green weeds into small pieces.

Power Take-off Versus Auxiliary Engine

Most of the larger sizes of combines are equipped with auxiliary engines for driving the cutting, threshing, and cleaning mechanisms, while on most of the smaller models these mechanisms are driven with a power take-off shaft from the tractor. A combine with an auxiliary engine is without doubt better for certain conditions. The main reason of course that all combines are not equipped with auxiliary engines, is that for many farmers the added advantages would not justify the added expense of an engine. Fortunately, power take-off drives on the smaller sizes of combines (six-foot and under) have proved reasonably satisfactory under most conditions. A combine with an auxiliary engine has two main advantages over one with a power take-off drive: (1) It can be pulled with a smaller tractor; and (2) it is possible to reduce the travel speed when heavier straw or ditches are encountered without slowing the speed of the cylinder and other mechanisms of the combine.

With the increasing need of a portable power unit for driving stationary machines like the ensilage cutter, blower elevator, feed grinder, baler, or hay hoist while the farm tractor is busy at other work, engines which can be used on a combine and then be easily and quickly removed for other work, may be expected to increase in number.

Suggestions on Combining Different Crops

The instruction book furnished with most new combines gives specific directions for adjusting the machine for harvesting different crops, as well as general suggestions on best methods of handling them. This book should be studied and kept for future reference.

Wheat usually causes few difficulties in combining and is generally combined direct. The windrow method may be used in cases of heavy weed growth, although it is usually not necessary. It is important not to begin combining until the grain is ripe and dry enough to avoid damage in storage. Usually 7 to 10 days of favorable drying weather are required after the wheat has reached the binder-cutting stage. The moisture content of wheat should generally not be more than 13 to 14 per cent when the wheat is put in storage.

Practically all varieties of wheat that are well adapted to Missouri conditions can be combined satisfactorily. There is little difference in such characteristics as uniformity of ripening, stiffness of straw, and resistance to shatter, except that bearded varieties generally shatter worse after ripening than beardless varieties.

Rye presents no particular problems in combining. It is handled in much the same manner as wheat. A closer setting of the cylinder and concaves, a somewhat closer adjustment of the sieves, and somewhat less air blast will likely be required than for wheat.

Barley is easy to thresh when dry, and hard to thresh when damp. Since barley has a tendency to shatter, farmers often start combining too early and storage troubles are likely to develop as a consequence. Dampness causes the same troubles with wheat and rye also, but to lesser degrees.

Oats are easily threshed, but the crop is subject to lodging after reaching the binder-cutting stage. After ripening, oats shatter badly and weeds are apt to grow rapidly, particularly in wet seasons. Therefore, they should be combined as soon after ripening as possible. Many farmers prefer to stop combining wheat, if necessary, in order to combine oats when they are ready, as wheat can stand longer than can oats. Where a large acreage of oats is to be combined, it is usually better to windrow a part of the crop.

Lespedeza may be combined direct or from the windrow. The direct method is generally better since it avoids unnecessary shattering caused by the extra handling with windrowing, and it is less expensive. Combining, it is generally agreed, is the best method of harvesting lespedeza seed. The sickle and other cutting parts should be in good condition because lespedeza, being wiry, is difficult to cut. Since lespedeza seed develops close to the ground, the cutter bar should usually be run as low as possible.

Sweet clover is one of the more difficult crops to combine because of its large, bulky, bushy growth, the uneven ripening of the seed, and its tendency to shatter after ripening. Cutting a hay crop, or pasturing and clipping, or simply clipping before blossoms set on, will prevent such a high, rank growth, cause more branching, and result in more even ripening of the seed. Windrowing is not favored because of the shattering and the difficulty in feeding the light, bulky plant material into the combine.

Red clover may be combined direct, or it may be cut and allowed to cure in the swath or in the windrow. It should be picked up and threshed, either from the windrow or swath, as soon as possible after it is dry. Direct combining is satisfactory only in dry years.

Alfalfa, on account of its uneven ripening and tendency to shatter, can seldom be satisfactorily combined direct, and then only in dry seasons. It is usually best to cut and windrow it, or leave it in the swath, later to be picked up with a pick-up attachment on the combine.

Timothy is usually best combined direct as soon as a majority of the seed is ripe. Timothy shatters badly if left standing long after the seed is ripe. The stalks and leaves may still be partly green, and if so, the cutter bar should be set to cut high in order to avoid taking in too much of the green material.

Red top. The suggestions made above for timothy apply also to red top.

Soybeans are usually harvested better as a standing crop than from the windrow. If they are windrowed and subjected to rain, the crop usually drys slowly and with difficulty, because the windrow is not well supported by a high and dense stubble. It is very important that the cylinder speed should be reduced and the clearance between the cylinder and concaves so adjusted as to prevent serious cracking of the beans.

Grain sorghums varieties which are adapted to Missouri conditions cannot under normal seasons be safely combined direct. Probably the best method is to cut the crop with a corn binder, shock it, and, after curing, thresh it with a combine. Vertical cutter-bar or topping attachments can be used for heading so that only the heads need to be run through the combine. The bundles are simply placed on the vertical cutter bar and the heads are cut off and threshed. The combine may be driven from shock to shock; or in some cases, the bundles have been hauled to the combine where they are topped, and then stalks are run through an ensilage cutter and put into a silo for silage.

Grain sorghums adapted to Missouri conditions usually ripen too slowly and unevenly to be combined direct. Normally, damp weather during September and October delays direct combining, resulting in excessive losses from shatter, bird damage, and weather. Excess moisture in the grain, particularly where stored in bulk, will cause severe damage to quality and to germination.

Summary

By personal survey following the harvest seasons of 1937, 1938, and 1939, a season's record of combining was obtained from each of 182 Missouri combine owners. In the great majority of cases, the combines were found to be economical and satisfactory in operation.

The average acreage of grain cut per day varied from 7.6 acres for 40-inch combines and 13.8 acres for 5-foot machines to 25.3 acres for 12-foot machines. The maximum acreage of wheat and oats that a farmer should expect to cut per year, was estimated by the owners to be 125 acres for 40-inch machines, 236 for 5-foot machines, and ranged up to 388 for the 12-foot sizes.

Custom work accounted for about one-third to one-half of the total work done by the machines surveyed. Custom work proved to be satisfactory in general to both the combine owners and the farmers hiring the work done.

The combines proved to be dependable and reasonably trouble-free, the average time lost per season on account of breakdowns being six hours. Repair costs varied from 2 to 5½ cents per acre.

The factor having the greatest effect on the cost of combining is the total acreages harvested per year. Analysis of records of 53 five-foot machines showed costs varying from 78 cents per acre for those cutting between 401 and 450 acres per year to $2.19 per acre for the group cutting less than 100 acres per year. The average cost for the 5-foot machines was $1.24 per acre, and the average acreage harvested per season was 238.

Tables of estimated costs of combining for various sizes of machines harvesting various acreages per year, are given. Comparisons are also made with estimated costs of the binder-thresher method of harvesting. The cost of combining with 40-inch combines pulled by one-plow tractors under average conditions, is estimated to vary from $1.64 to $3.03 per acre; the cost with 5-foot combines pulled by two-plow tractors, from $1.14 to $3.90 per acre; the cost with 10-foot combines from $1.22 to $3.61; and the cost with the binder-thresher method, form $2.98 to $3.75 per acre.

Grain and seed losses are variable, and depend largely upon the condition of the grain, the adjustments of the machines and the skill

with which they are operated. Combine losses on the average are somewhat lower than binder-thresher losses.

Information is given on the operation of the various parts of the combine. Suggestions are also made on the adjustment of the machines for various conditions and on the management of various grain and crops to be combined.