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AGRICULTURAL EXPERIMENT STATION

THE COMBINE HARVESTER IN MINNESOTA

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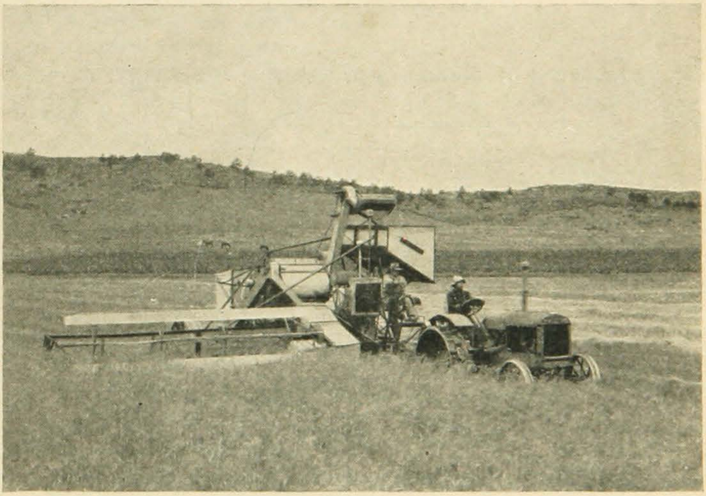

UNIVERSITY FARM, ST. PAUL

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THE COMBINE HARVESTER IN MINNESOTA

A. J. Schwantes,[1] G. A. Pond,[2] A. C. Arny,[3] and C. H. Bailey[4]

and

R. H. Black,[5] L. A. Reynoldson,[6] and W. R. Humphries[7]

INTRODUCTION

The material presented in this bulletin is the result of studies of the combine harvester conducted by the University of Minnesota Agricultural Experiment Station in co-operation with the United States Department of Agriculture during the harvest season of 1928.

History of Development

The combine harvester-thresher cuts and threshes the grain in one operation. The idea of performing all of these operations at one time is not new. Patents on such machines were granted in the United States as early as one hundred years ago. In 1836 a combine harvester was patented in Kalamazoo, Michigan. This machine was built and two years later was used to harvest 30 acres of wheat. Several other machines were built and used in the North Central States, including one in Minnesota in 1884.

None of these were highly successful, however, because usually they were too large and too expensive for the average-sized farm and the threshed grain contained too much moisture to keep well. Many of the records indicate that the grain heated in storage. Some reported that the grain did not ripen evenly and that it was not ready to thresh when it should be cut. These are the major difficulties today.

Farmers began to use combines extensively in California about 1880. Large fields, a shortage of labor, and dry weather during the harvest season encouraged their development and use. For a long time they were used only on the Pacific Coast. Some of these machines cut a swath 40 feet wide. In 1888 steam power was first used to propel them. During the World War the combine method was introduced east of the Rocky Mountains and has been gradually moving eastward since.

The season of 1927 marked the beginning of its use in Minnesota, when 11 combines were used. In 1928, 38 more were used. About a fourth of these are scattered across the southern half of the state, but most of them are in the northwestern part.

[1] Division of Agricultural Engineering.
[2] Division of Farm Management and Agricultural Economics.
[3] Division of Agronomy and Plant Genetics.
[4] Division of Agricultural Biochemistry.
[5] Grain Cleaning Investigations, U. S. Dept. Agr.
[6] Bureau of Agricultural Economics, U. S. Dept. Agr.
[7] Bureau of Public Roads, U. S. Dept. Agr.

Description

The combine harvester-thresher is essentially a threshing machine with a header attached to one side in such a way that the cut grain is conveyed directly to the cylinder of the thresher. The size is designated by the width of the swath. The width of the cylinder and the size of the separator are in proportion to the width of the cut. Combines used in Minnesota and neighboring states are smaller than the older types used in the Pacific Coast states. About 60 per cent of the Minnesota machines have a 10- or 12-foot cut; 40 per cent, a 16-foot cut.

Practically all the machines have an auxiliary motor for operating the cutting and threshing mechanism. A tractor is generally used for drawing the machine in the field, altho horses may be used. A two-plow tractor is sometimes used for the 10- or 12-foot size; a three-plow tractor is necessary for the 16-foot size.

The grain is usually collected in a tank mounted on the machine. On the smaller machines the tank holds 30 bushels; on the larger machines, about 60 bushels. When the tank is full, the grain is spouted into the wagon or truck tank and hauled to the granary or elevator. If the operator prefers, the grain may be deposited directly into a wagon tank hitched to the side of the combine and drawn along with it.

Where the straw is not needed for feed or bedding, it is spread evenly over the ground by a device attached to the rear of the combine. It is thus returned to the land at once. The straw may be deposited in a windrow behind the combine or by means of another attachment it may be deposited in bunches. Straw that is to be used is usually picked up with a hay loader and hauled to the farmstead. A buck rake is sometimes used for gathering up the straw if it is stacked in the field.

The windrower has been designed very recently and was used for the first time in Minnesota in 1928. It consists of a cutting mechanism only. The cut grain is carried by means of a platform canvas to one end of the platform or by means of two canvases to the center of the platform and is deposited on the stubble in the form of a windrow 2½ or 3 feet wide. The machine is made in sizes comparable to the size of the combine and is drawn by a two-plow tractor or by a 3- or 4-horse team. Power to drive the cutting and conveying machinery is taken from the ground by means of a "drive" or "bull" wheel.

Windrowing is resorted to when the threshed grain would not be dry enough to keep in storage because of green weeds, or uneven ripening of the grain, or early harvesting. When the grain has become dry enough in the windrow it is picked up by an attachment to the cutter bar and threshed with a combine. The knife, or sickle, and reel are removed. Thus the same machine may be used for "straight combining" (cutting and threshing in one operation) or for picking up grain from the windrow and threshing. The cutting mechanism of some combines may be detached and used as a windrower. When this is done, the pick-up is attached directly to the combine in place of the regular header platform. Various types of pick-up attachments are available.

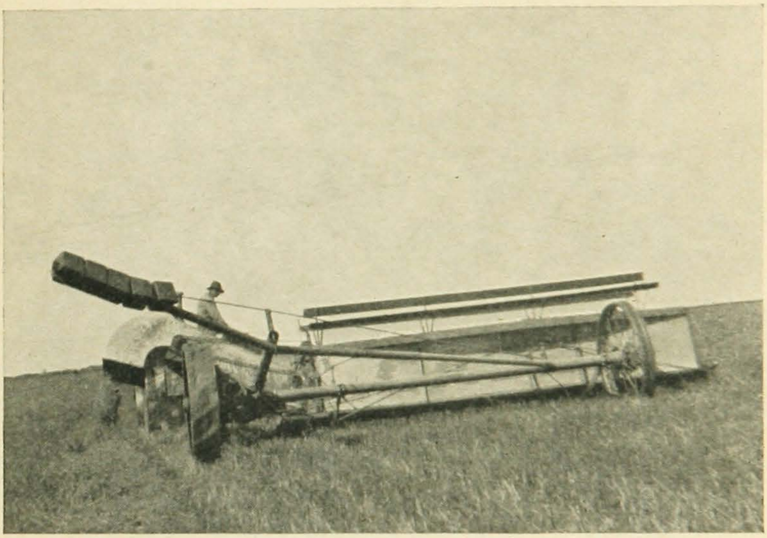

Fig. 1. The windrower cuts a swath 12 or 16 feet wide and deposits the grain on the stubble in a row 2½ or 3 feet wide.

The combine has been used in Minnesota for harvesting all small grains altho in the west it was used primarily for wheat.

The combine has been extensively used to harvest flax. Flax should be ripe before it is harvested, because a high moisture content of the stems may interfere with threshing. Succotash is readily handled with a combine. Many of the combines in Illinois are used for harvesting soybeans.

Lodged grain is easier to handle with a combine than with a binder. The combine can be set to cut close to the ground and pick up lodged grain fully as well as the binder. It is then conveyed directly to the thresher with no possibility of subsequent losses.

Object and Method of Study

Because the combine method of harvesting is new and untried under Minnesota conditions and is different from the binder method, many new problems are arising, hence efforts have been made to determine the problems involved and to find a solution for them.

The data regarding crops were obtained largely from experimental plots of several varieties at the Central experiment station, University Farm, St. Paul, and at branch stations at Waseca, Morris, and Crookston. All yields were determined by removing and threshing immediately six regularly distributed square-yard areas of the standing grain from each plot.

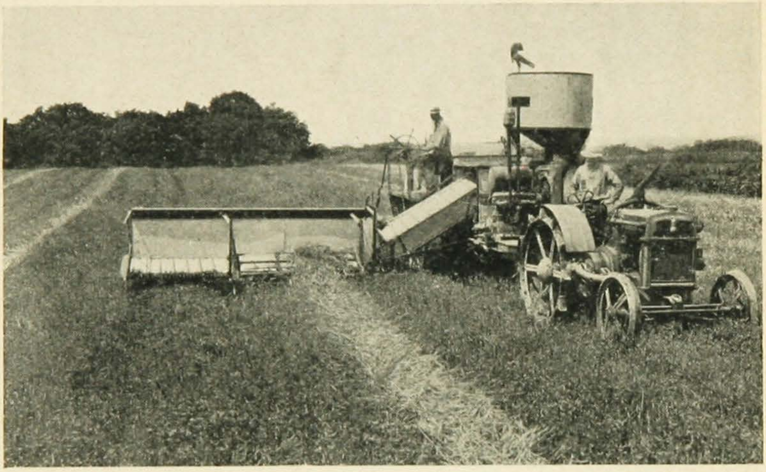

Fig. 2. Combining from the windrow is accomplished by means of a "pick-up" attachment to the regular combine with the reel and knife removed.

All the data concerning the windrow method of combine harvesting were taken in co-operation with farmers in the vicinity of Crookston and Kent. Determinations of losses were made on farms in the Red River Valley while harvesting was in progress. Cost figures were obtained from records kept by twelve combine operators during the harvesting season. These were supplemented by information regarding these farms and the experiences of the farmers in operating combines.

All moisture determinations were made in duplicate with the Brown-Duval tester in the biochemistry laboratory at University Farm or in a laboratory maintained for that purpose at Fargo, North Dakota, by the United States Department of Agriculture. Except when moisture determinations were made immediately, the samples were shipped and stored in sealed metal cans so that the moisture content of the grain to be tested might not change before the testing was done. Records of early attempts to harvest grain with the combine indicate that the outstanding reason for failure was that the grain had a tendency to heat in storage.

MOISTURE AS A FACTOR IN GRAIN HARVESTED WITH A COMBINE

Plump, hard spring wheat kernels that are sound and normal will ordinarily remain sound and cool throughout the fall and winter if they do not contain more than 14.5 per cent of moisture. With shrunken or soft or sprouted grain, the safe moisture limit is probably 0.5 to 1.0 per cent lower than that. The relation of moisture content and soundness is discussed by Bailey and Gurjar.[8] Moreover, hard spring and durum wheats can not be graded No. 1 if they contain more than 14 per cent moisture.

The safe maximum limit is lower for oats and barley than for hard spring wheat—not more than 13.5 per cent.

Combine users in the North Central states would have little to worry about if all grain could be harvested when the moisture content is 14 per cent or less.

The most important reasons why some grain harvested with a combine has a high moisture content are: (1) Harvesting before the grain is dead ripe, (2) harvesting too early in the morning, (3) harvesting in damp weather, (4) many weeds, and (5) uneven ripening. One or more of these conditions are likely to give trouble unless precautions are taken.

Harvesting Before Grain Is Dead Ripe

Methods of determining when standing grain is ready for harvest with the binder vary considerably. Light yellow heads; the upper leaves and the upper two or three internodes of the stems and kernels too firm to be cut easily with the thumbnail; and the turning brown of practically all the bolls of flax, were taken as indications that the crop was ready for harvesting with the binder.[9]

Moisture determinations of oats, barley, and wheat at binder harvest time were made at University Farm, St. Paul, and at the branch stations at Morris and Crookston.

The percentages of moisture at the time of binder harvest for oats, barley, and wheat are given in Table I. At Crookston, Glabron and Trebi barley contained slightly above and just below 40 per cent moisture, respectively. At University Farm, Trebi barley became slightly more mature than was intended; all other varieties except Anthony oats contained more than 30 per cent moisture. The grain of the three varieties of barley, Gopher oats, and Marquis wheat contained 28 per cent moisture or more. Anthony oats at University Farm and Morris,

[8] Bailey, C. H. and Gurjar, A. M. "Respiration of stored wheat." J. Agr. Res. vol. 12, pp. 685-713. 1918.

[9] Arny, A. C. and Sun, C. P. "Time of cutting wheat and oats in relation to yield and composition." J. Am. Soc. Agron. vol. 19, pp. 410-39. 1929.

Marquis wheat at Morris, Gopher oats and the two wheat varieties at Crookston were not tested until they were well past the stage at which they could have been harvested with the binder. This explains the lower moisture content of these grains.

TABLE I

MOISTURE CONTENT OF OATS, BARLEY, AND WHEAT AT BINDER HARVEST TIME

Crop and variety	University Farm	Morris	Crookston
	per cent	per cent	per cent
Oats			
Gopher	32.0	28.0	22.4*
Anthony	23.6*	18.0*	....
Barley			
Velvet	30.5	....	....
Glabron	....	30.5	41.8
Trebi	27.8	28.2	39.7
Svansota	34.5	29.5	28.0
Wheat			
Marquis	31.8	19.0*	20.5*
Mindum	34.8	28.0	19.7*

* Grain left standing in the field after it could have been harvested with the binder without lowering of yield or quality.

The natural tendency of an operator who is accustomed to harvesting with the binder is to use the combine as soon as possible after he would normally cut with the binder. Such a practice must result in moist grain. Obviously, harvest should be delayed until the moisture content of the grain has dropped to about 14 per cent. The time necessary to bring about the reduction, the resulting losses, and the effect of this delay on quality will be discussed later.

Harvesting Too Early in the Morning

The moisture content of standing grain fluctuates. Normally, it rises during the night and drops again during the morning hours.

Figure 7 shows the results of moisture determinations of standing grain made at hourly intervals on three days. Invariably the moisture content was higher in the morning than later in the day. Usually harvesting should not begin until 10 or 11 o'clock in the morning and sometimes not until noon. There are exceptions to this, however, as on August 10, when the moisture content was 14 per cent at 7 o'clock. On the other hand, on August 31 the combine could not have been used safely before 5 o'clock in the afternoon. This is an extreme condition, due partly to previous wet weather. It is generally true that the moisture content begins to rise after sundown. Straw becomes damp in the late afternoon and evening an hour or more before the moisture content of the grain goes above 14 per cent. When harvesting grain with the combine, it is easy to have wet grain, even in good weather, by cutting too early in the morning and too late in the evening.

Harvesting Too Soon After Rains

Rainy or cloudy weather may prevent the normal decrease in moisture content of standing grain during the day. The effect of a light rain does not last long if clear drying weather follows. On the other hand, if cloudy weather follows prolonged rainy periods it may take a long time for grain to dry out sufficiently to harvest safely with the combine.

Weeds Are a Hindrance

Weeds are one of the outstanding hindrances to successful combine operation. The majority do not ripen until after the grain is harvested, altho seeds have formed in most of them. These seeds contain from 20 to 60 per cent of moisture, depending upon the relative maturity of the plants. The percentage of moisture varies with the season and the locality, and the variety of weed.

It is impossible to cut the crop without including a considerable portion of the weed plants. The result will be not only weed seeds in the threshed grain, but also pieces of stems and leaves. If these materials are stored with the grain, the excess moisture in the weed seeds is rapidly transferred to the grain, and if the amount of moist weed seeds is considerable, the grain becomes damaged in storage. This damage may more than offset the savings possible from the use of the combine.[10]

The effect of weeds on the moisture content of grain is shown in Figure 3, which represents the moisture content of samples taken from a field of barley at Kent, Minnesota, and illustrates the conclusions drawn from similar tests on other fields. The solid lines show the moisture content of barley kernels from heads that were picked at random from various parts of the field and threshed by hand. At 2 o'clock on August 14 the combine was started in the field. Samples containing weed seeds and other green materials were taken from the combine and the moisture content was determined. The grain contained 5 or 6 per cent more moisture than the hand-threshed samples of clean barley, and while the moisture content of that harvested with the combine was too high for safe storage, that of the clean grain was seldom much above 14 per cent, indicating that in this case weeds alone were responsible for the high moisture content.

Weed material in grain is objectionable from another standpoint. The small particles fill up air spaces that normally exist in clean grain,

[10] Black, R. H. and Boerner, E. G. "Preventing damage in spring wheat harvested with combines." U. S. Dept. of Agr. Mimeograph U. S. G. S. A.—GI—No. 43. June, 1928.

and greatly reduce the possibility of air circulating through it. Such a condition will seriously interfere with ventilating and drying.

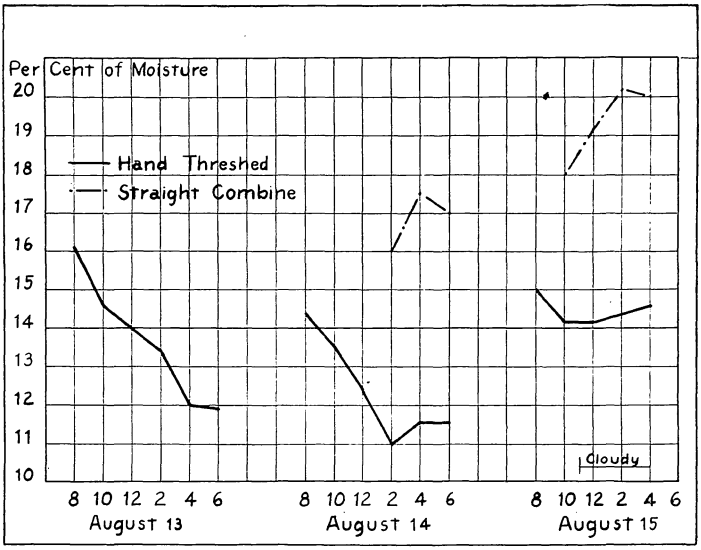

Fig. 3. Green weed seeds and plants generally have a much higher moisture content than grain. The solid lines show the moisture content of grain that is free from weed seeds because it was threshed by hand. Broken lines show the moisture content of grain harvested with a combine from the same field, but including weed seeds. The moisture in the weed seeds is soon transferred to the grain.

Uneven Ripening

When fields do not ripen evenly it is necessary to harvest while part of the crop is still green. In some cases harvesting can be delayed for several days. This will allow most of the crop to become ripe or nearly so. At other times part of the crop is so far behind that it would be impossible to harvest it without including considerable immature grain. While this condition does not always exist and may not be serious, it must be recognized as an important cause of moist grain. Frequently this factor is of so little importance that it can be readily overcome by using the combine only after the ripe grain is relatively dry.

RAINFALL DURING HARVEST

As rainfall is one of the important factors in the operation of the combine, the daily precipitation in Minnesota when most of the grain was harvested in 1928 and each of the four preceding years is given in Table II.

TABLE II

Daily Rainfall July 18 to August 21 at Four Locations in Minnesota, 1924-28, Inclusive

Month and day	St. Paul 1928	St. Paul 1927	St. Paul 1926	St. Paul 1925	St. Paul 1924	Waseca 1928	Waseca 1927	Waseca 1926	Waseca 1925	Waseca 1924	Morris 1928	Morris 1927	Morris 1926	Morris 1925	Morris 1924	Crookston 1928	Crookston 1927	Crookston 1926	Crookston 1925	Crookston 1924
July 18	...	...	T	...	0.01	...	...	...	0.25	T	...	0.11	...	0.19	0.50	...	0.37	...	...	0.03
19	0.20	...	0.03	T	...	...	...	...	...	...	0.16	...	0.08	...	...	...	...	...	...	0.12
20	T*	0.16	0.47	...	0.06	...	...	...	...	1.17	...	0.04	...	...	0.20	0.23	0.83	0.17	T	...
21	T	0.04	0.41	...	0.34	0.08	...	0.02	...	0.03	...	...	0.12	...	0.48	...	...	0.09	...	1.24
22	...	...	0.02	...	...	...	...	...	...	...	...	...	...	...	0.10	0.05	...	0.04	...	...
23	...	...	0.15	0.06	0.04	...	...	0.03	0.09	0.10	...	...	0.26	0.13	...	...	...	0.21	0.04	0.05
24	0.27	...	0.26	0.15	0.04	...	...	...	...	...	...	...	...	...	...	...	...	...	0.11	...
25	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
26	0.03	...	...	0.18	...	0.09	...	...	0.05	...	...	...	...	...	...	0.08	...	...	...	T
27	...	0.30	T	...	0.01	...	...	0.06	...	0.18	...	0.05	...	...	0.15	...	0.16	...	T	...
28	T	T	0.10	...	...	...	T	0.45	...	...	...	...	0.02	...	...	0.11	...	...	...	...
29	...	...	0.59	T	0.48	...	...	0.30	...	0.29	...	...	...	...	...	...	...	...	0.09	0.31
30	...	...	0.02	0.11	0.60	...	...	0.18	0.16	0.02	...	0.36	...	...	...	0.01	...	...	...	0.19
31	0.02	0.02	...	0.07	...	...	T	...	0.03	...	...	...	...	...	...	...	0.04	...	...	...
Total July 18-31	0.52	0.52	2.05	0.57	1.58	0.17	T	1.04	0.58	1.79	0.16	0.56	0.48	0.32	1.43	0.48	1.40	0.51	0.24	1.94
August 1	0.97	...	...	...	0.07	3.80	...	...	...	†	1.16	...	...	...	0.04	0.03	...	...	...	...
2	0.15	...	...	...	0.09	0.43	...	...	...	...	0.07	...	...	...	0.61	...	...	T	...	...
3	0.01	...	T	...	0.24	0.16	...	0.09	T	...	...	...	0.58	...	...	...	...	0.15	...	0.03
4	...	T	0.12	...	...	...	...	0.02	...	...	...	...	0.34	...	...	...	0.01	...	...	...
5	...	...	T	...	0.65	...	...	...	0.11	...	...	...	...	...	0.17	...	...	0.10	0.07	0.60
6	1.66	T	...	...	0.22	...	...	...	...	...	0.05	...	...	...	0.06	0.04	0.26	0.58	0.02	...
7	...	T	...	...	T	...	0.06	...	T	...	...	0.21	...	...	...	...	T	...	T	...
8	...	0.01	0.50	T	T	...	T	...	...	...	...	0.10	0.76	0.11	...	...	...	...	0.08	0.40
9	...	...	...	...	...	...	...	...	...	...	...	...	0.11	...	...	...	...	0.02	0.01	...
10	...	...	...	...	0.39	...	...	...	...	...	...	...	...	...	0.06	...	...	...	...	0.16
11	...	...	0.01	...	...	...	...	0.32	T	...	...	...	0.14	...	...	...	...	...	0.02	T
12	...	...	0.02	...	...	...	...	...	...	...	...	...	0.21	...	...	...	...	...	...	0.02
13	...	...	0.10	...	...	...	...	0.05	...	...	...	...	0.07	...	...	1.22	...	...	...	...
14	...	...	...	...	0.07	0.28	...	...	...	...	...	...	...	...	0.15	0.06	...	0.09	...	0.03
15	0.99	...	1.01	T	0.74	...	...	0.65	...	...	...	...	...	...	...	...	T	0.06	...	...
16	0.29	1.04	...	...	...	0.09	0.99	...	...	...	0.52	0.07	...	...	0.35	0.31	0.47	...	0.08	...
17	...	0.09	...	...	0.02	...	T	0.33	0.24	...	...	0.02	0.01	...	...	T	0.14	0.19	...	...
18	0.12	0.22	0.85	0.14	0.59	...	T	...	...	...	0.06	...	0.75	0.58	0.55	0.02	...	...	0.53	...
19	0.10	...	1.20	....	0.51	...	T	0.33	0.24	...	0.06	...	0.75	0.58	0.55	0.02	...	...	0.53	...
20	0.35	...	0.45	...	...	1.19	...	0.07	...	...	0.77	...	0.03	...	...	...	...	...	...	...
21	...	...	...	...	2.73	....	T	...	...	...	...	...	0.08	...	1.30	...	0.05	0.14	...	0.39
Total Aug. 1-21	4.64	1.36	4.26	0.14	6.32	6.11	1.08	2.32	0.35	...	3.08	0.40	4.03	0.69	3.44	1.68	0.93	1.49	0.81	1.65
Total July 18-Aug. 21	5.16	1.88	6.31	0.71	7.90	6.28	1.08	3.36	0.93	...	3.24	0.96	4.51	1.01	4.87	2.16	2.33	2.00	1.05	3.59

* Trace. † No record for month.

A comparison of the rainfall for the other years with that for 1928 indicates how nearly average was the latter and what must be expected over several years. The rainfall during the harvest season of 1928 was not far from the average. For the five years rains occurred more frequently during the third week of August than during the three preceding weeks.

On clear hot days the relative humidity of the air is low and moisture passes rapidly from the grain to the air, particularly if air movement is brisk. By relative humidity is meant the amount of moisture in the air at any time compared with what it could hold at that temperature if completely saturated. Conditions for drying are usually less favorable in cloudy weather than in clear weather.

HOW MANY DAYS FROM USUAL BINDER HARVEST TO A SAFE COMBINE HARVEST TIME?

Binder harvest time is not arbitrary and the moisture content of most grains is about 30 per cent at that time. For best results it is desirable not to harvest with the combine until the moisture content is reduced to about 14 per cent.

Moisture determinations of standing grain at University Farm, Morris, and Crookston at two-day intervals after binder harvest time, show that eight to ten days at University Farm and Morris, and with one exception nearly twice that long at Crookston was necessary for the grain to reach a 14 per cent moisture content. The longer time required at Crookston was due to heavy rainfall.

TABLE III

Days After Usual Binder Harvest Time Before Oats, Barley, and Wheat Reached a 14 per Cent Moisture Content

Crop and variety	University Farm			Morris			Crookston		
	Dates ripe for binder harvest	Dates grain reached 14 per cent moisture	Days from binder to combine harvest time	Dates ripe for binder harvest	Dates grain reached 14 per cent moisture	Days from binder to combine harvest time	Dates ripe for binder harvest	Dates grain reached 14 per cent moisture	Days from binder to combine harvest time
Oats									
Gopher	7/24	8/5	11	7/30	8/6	7	8/6	8/10	4
Anthony	8/1	8/9	8	8/8	8/13	5	....	....	..
Barley									
Velvet	7/24	8/9	15	....	....	..	....	....	..
Glabron	....	....	..	7/30	8/8	9	8/1	8/23	18
Trebi	7/24	8/11	17	7/30	8/13	9	8/1	8/23	18
Svansota	7/24	8/9	17	8/6	8/13	7	8/10	9/5	23
Wheat									
Marquis	8/1	8/9	8	8/6	8/8	2	8/15	9/1	17
Mindum	8/1	8/11	10	8/8	8/15	7	8/18	9/5	18

Table III gives the dates when binder harvest and combine harvest could be safely started, and the number of days intervening. When there is little or no rainy weather during this period, there is a continual decrease in moisture content; if rain intervenes, the moisture content may rise and the time required for the grain to be fit for harvesting with the combine is prolonged. Figure 4 illustrates a case of this kind. The moisture content of Svansota barley on this plot was 34.5 per cent on July 24. There were light rains on July 24 and 26, with a trace on the 28th. As the rains were light and of short duration and were interspersed with periods of clear weather, they interfered little with the natural and fairly regular lowering of the moisture content to 15.4 per cent by July 30. From July 30 to August 3, inclusive, rain fell each day. The grain took on moisture so that on August 3 the percentage was 26.2. August 4 and 5 were clear and there was a rapid lowering of the moisture content. A rainfall of 1.66 inches on August 6 reduced the rate of loss and the content reached 14 per cent some time between August 7 and 9. This shows how weather conditions affect the rate of drying after binder harvest time.

The moisture content of Velvet barley was reduced to 14 per cent on the same day as that of Svansota; that of Trebi two days later. Velvet was lodged 80 per cent, at an angle of 65 degrees; Svansota 90 per cent, at an angle of 90 degrees; and Trebi at an angle of 72 degrees before the grain was ready for binder harvest.

All varieties of the same cereal required about the same time to reach the stage for safe harvesting with the combine. The long time required for barley to mature at University Farm and Crookston was due to lodging and to prolonged rainy periods. These wet periods are apparently more serious, from the standpoint of prolonging the drying time, when they occur late. Referring again to Figure 4, intermittent light rains late in July, the first few days after binder harvest time, interfered little with the natural decrease in moisture content of the grain, but subsequent rains actually delayed combine harvesting about seven days.

HOW DOES THE RIPENING PERIOD TO COMBINE HARVESTING TIME AFFECT YIELDS?

Under average conditions, eight to ten days elapse from the time grain may be harvested with the binder until it can be safely harvested with the combine. During this period, which in unfavorable weather may be fifteen to twenty days, both the grain and the straw pass the dead ripe stage, usually by two or three days. This subjects the crop not only to all the tests it is required to meet when harvested with the binder at the usual time but also to the necessity of resisting lodging, crinkling (breaking over of the upper part of the stems), and shattering for varying periods after becoming dead ripe. The part broken over remains attached to the lower part of the stem, which is still more or less erect. Crinkling often results in the head, or panicle, touching the ground, hence losses of grain are greater than by lodging.

With the combine, questions naturally arise regarding the ability of the different crops and the recommended varieties of each to stand these additional tests, particularly resistance to crinkling and shattering. If they are able to stand this additional time in the field without serious loss in yield and quality, they will continue to be grown in sections of the state where combines prove practical. If not, other varieties must be developed to replace them.

TABLE IV

DECREASE IN YIELDS AND IN PERCENTAGE BETWEEN USUAL BINDER HARVEST TIME AND TIME GRAIN REACHED 14 PER CENT MOISTURE, WITH PROBABLE ERRORS IN PER CENT, AND ODDS THAT DIFFERENCES ARE SIGNIFICANT

Location and crop	Variety	Yield at binder harvest time	Decrease in yield before moisture in grain was lowered to 14 per cent		Probable errors	Odds that differences are significant
		bu.	bu.	per cent	per cent	
University Farm						
Oats	Gopher	102.4	17.5	17.1	5.23	10:1
	Anthony	81.1	4.3	5.3	5.30	Less than 1.1
Barley	Velvet	53.7	14.0	26.1	9.30	7:1
	Trebi	74.1	20.8	28.1	4.40	175:1
	Svansota	64.6	17.0	26.3	6.87	26:1
Wheat	Marquis	42.8	6.3	14.7	4.62	8:1
	Mindum	48.6	7.7	15.8	7.38	3:1
Crookston						
Oats	Gopher	87.8	9.6	10.9	3.75	3:1
Barley	Glabron	44.9	20.7	46.1	3.82	∞:1‡
	Trebi	70.2	17.7	25.2	4.55	332:1
	Svansota	50.5	9.1*	18.0	1.38	∞:1‡
Wheat	Marquis	28.5	4.4	15.4	2.43	825:1
	Mindum	38.9	9.6†	24.7	4.96	142:1
Morris						
Oats	Gopher	87.3	22.7	26.0	5.11	175:1
	Anthony	94.2	...	...	4.75	....
Barley	Trebi	50.0	11.5	23.0	5.24	54:1
Wheat	Marquis	22.5	...	...	6.02	....
	Mindum	29.8	4.5	15.1	3.61	31:1

* Grain did not reach less than 14.8 moisture content during the time yield determinations were made.

† Grain did not reach less than 14.6 moisture content during the time yield determinations were made.

‡ ∞ Infinity.

With a few exceptions, yields of the different varieties of oats, barley, and wheat when ready for binder harvest are given in Table IV for University Farm, Crookston, and Morris. The decrease in yield is also given, both in bushels and in per cent of the original yield, during the period required for the grain to reach a 14 per cent moisture content.

In determining the yield per acre on experimental plots there are always variations due to factors that can not be controlled. The errors may be relatively large in some cases and small in others. Table IV gives the errors that occurred in making yield determinations of the different varieties, the figures in the last column indicating to what extent the data in the column on "decrease of yield" are likely to be affected by these errors. Where there is a marked difference in odds, as 825:1 for Marquis wheat at Crookston, the decrease in yield as shown is significant. On the other hand, where odds are low, as 3:1 for Mindum wheat at University Farm and Gopher oats at Crookston, the decreases are less likely to be significant unless they are consistent throughout the experiment and the total is large.

The time required for each of these varieties to reach 14 per cent moisture and the dates on which this occurred are given in Table III. The rainfall for any particular period is given in Table II.

Yields of Oats Varieties

As indicated in Table IV, the yield of Gopher oats at University Farm at binder harvest time was 102.4 bushels per acre. During the time (July 24 to August 5) required for the grain to reach 14 per cent moisture, there was a decrease in yield of 17.5 bushels per acre, or 17.1 per cent. The yield determinations during the eleven-day period shows a fairly regular decrease and the total is large. There probably was a significant decrease, altho the odds are only 10:1 that this was the case.

The crop was dead ripe on August 1 and the first shattering was noted on August 3. It was ready for harvesting with the combine on August 5. At the first harvest, on August 3, Anthony oats yielded 81.1 bushels per acre; on August 9, when the moisture content of the grain was 14 per cent or less, the yield was 76.8 bushels. The difference is 4.3 bushels, or 5.3 per cent, in favor of the early harvest. However, on the probable-error basis, this difference appears insignificant. The heavy rainfall, 1.66 inches, on August 6 resulted in additional crinkling, but no shattering was noticed until August 11.

At Crookston, on August 6, the yield of Gopher oats was 87.8 bushels per acre. On August 10, when the grain contained 14 per cent moisture or less, the yield was 78.2 bushels per acre—9.6 bushels less than at the first harvest. This difference is small and is probably not significant.

The yield from the first harvest of Gopher oats at Morris, on July 30, was 87.3 bushels. The lodging was 50 per cent. On August 1, 1.16 inches of rain fell but caused little crinkling, as the grain and the straw were not yet ripe. However, as ripening progressed, crinkling and shattering took place. This lowered the yield on August 6, when the grain reached 14 per cent moisture, to 64.6 bushels per acre—a reduction of 22.7 bushels per acre, or 26 per cent. The odds are 175:1 that this difference is significant.

Anthony oats showed no significant lowering of yield at Morris during the five-day period required for the moisture content of the grain to fall from 18 per cent to 14 per cent or less.

The indications are that oats must be harvested with the combine as soon as possible after reaching 14 per cent moisture content in order to avoid heavy losses from crinkling and shattering. After the crop is dead ripe, rain increases these losses.

Yields of Barley Varieties

At University Farm, Velvet barley had lodged 80 per cent at an angle of 65 degrees and the other two varieties somewhat more before binder harvest. The decreases in yields during harvest were fairly consistent and large. Therefore, altho the odds are only 7:1, there was probably a significant decrease in yield.

Lodging of the grain and unfavorable weather prolonged the time between the first harvest, July 24, and the time when the moisture content reached 14 per cent.

Except that Velvet barley lodged slightly less than Trebi and Svansota, at University Farm, the varieties in the test were similar. Weeds grew more rapidly in the lodged barley than in the erect oats.

As shown in Table IV, the yield of Glabron barley at the first harvest at Crookston was 44.9 bushels per acre. During the twenty-two days required for the grain to reach 14 per cent moisture, the yield was lowered 20.7 bushels, or 46.1 per cent. There was a significant lowering of yield between usual binder harvest time and the time it was ready to harvest with the combine, owing to crinkling and shattering during the first part of the period and to these and lodging during the last part.

At Crookston the decreases in yield were less for Trebi and Svansota than for Glabron. However, the high odds indicate that the differences in yield at binder and combine harvest time are significant.

At University Farm and Morris there was a high percentage of lodging before the barley was ready for binder harvest. This prolonged the time required for the grain to reach the 14 per cent moisture stage and made possible more crinkling and shattering before the crops were ready for the combine. At Crookston, crinkling and shattering were responsible for lowered yields.

Yields of Wheat Varieties

There was a decrease of 6.3 bushels per acre, or 14.7 per cent, for Marquis; and 7.7 bushels, or 15.8 per cent, for Mindum between binder and combine harvest time at University Farm. Decreases were fairly regular and the totals were large; therefore the decreases may be considered significant.

The rainfall of 1.66 inches on August 6 did not cause marked crinkling. With Marquis wheat, slight shattering was first noticed on August 13, four days after the grain had reached a 14 per cent moisture content. Shattering was not general even as late as October 1. Because of crinkling on and after August 15, many of the spikes lying on or near the ground were not picked up in the harvesting operations.

During the long period required at Crookston for Marquis and Mindum wheat to reach a 14 per cent moisture content owing to unfavorable weather, there was a decrease in yield of 4.4 bushels, or 15.4 per cent, for Marquis; and of 9.6 bushels, or 24.7 per cent, for Mindum. The high odds of 825:1 and 142:1 indicate that these differences are significant. Crinkling was principally responsible for the loss during the first part of the period, and crinkling and lodging during the last part.

The weather was exceptionally favorable for drying the grain and harvesting with the combine from August 6 to 15 inclusive, at Morris. The moisture content of the Marquis wheat was reduced from 19 per cent on August 6 to 13.4 per cent on August 8. Determinations indicate that there was no reduction in yield during that time. When the first yield determination was made Marquis had lodged 10 per cent and on August 15 this had increased to 50 per cent. Crinkling was not extensive until after the grain had reached a 14 per cent moisture content.

During the seven days required for Mindum wheat at Morris to reach 14 per cent moisture or less, the yield had lowered 4.5 bushels, or 15.1 per cent. The data indicate a significant decrease in yield between binder and combine harvest time.

Mindum was lodged 75 per cent when the first determination was made. Lodging and crinkling, which took place after the straw was completely mature, account for the decrease in yield. Shattering was slight.

When wheat stands in the field for two weeks after it is dead ripe, considerable loss in yield must be expected.

Yields of Flax Varieties

Yield determinations were made on several varieties of flax at Waseca (Table V). On August 6 yields were determined for the four varieties ready for binder harvest, and on August 11 for all varieties included in the test. Damont is not wilt resistant, consequently the stand was thin and yields were low because of wilt disease.

TABLE V

YIELDS OF FLAX VARIETIES HARVESTED AT THE USUAL TIME WITH THE BINDER AND ON SUBSEQUENT DATES, WASECA, 1928

Variety	No.	Yields per acre on					Decrease in yields per acre 8/6 to 9/8		Odds that differences are significant
		8/6	8/11	8/17	8/24	9/8			
		bu.	bu.	bu.	bu.	bu.	bu.	per cent	
Linota	191	22.1	19.3	20.2	19.1	20.3	1.8	8.2	2:1
Redwing	188	20.9	17.8	18.4	17.2	17.5	3.4	16.3	19000:1
Rio	195	...	19.6	18.3	17.6	18.5	1.1	5.6	1:1
Winona	182	19.2	16.0	16.3	16.7	15.7	3.5	18.2	∞:1*
Buda	194	...	17.6	18.2	17.1	17.6	0.0	...	....
Bison	199	19.1	19.0	17.1	17.2	16.4	2.7	14.1	7:1
Damont	...	...	7.7	7.1	5.3	2.3	5.4	70.1	∞:1*
Rainfall one date to next, in.	...	...	0.0	0.37	4.19	1.11	..	...	....

* ∞ Infinity.

Rains of 1.19 and 1.65 inches, respectively, fell on August 20 and 22 and lighter rains on August 19 and 23. No lodging occurred up to September 8, the date on which the last determinations were made, and decreases in yields were due to loss of bolls. Decreases between August 6 and September 8 for Redwing, Winona, and Damont may be considered statistically significant. There was no decrease in the yield of Buda from August 11 to September 8.

No general lowering of the weight per bushel of the seed of any of the varieties occurred during this comparatively long period.

Summary of Crops

Barley was less adapted than oats for harvesting with the combine, as far as lodging was a factor. All varieties lodged badly at University Farm and Morris before they were ready to harvest with the binder. The lodged barley reached the 14 per cent moisture stage somewhat later than did Gopher oats, the straw of which stood erect. Crinkling and shattering, particularly after heavy rains, caused most of the reduction in yields.

Oats lodged less than barley but crinkling and shattering started soon after they became dead ripe and were the main factors responsible for reductions in yields.

Both varieties of wheat lodged less than the barley varieties and crinkled and shattered less than either barley or oats. This enabled the wheat to stand in the field through heavy storms after it was dead ripe with less marked decreases in yield. The losses that occurred were due to crinkling and consequent loss of spikes rather than to shattering.

Loss of bolls caused most of the reduction in yields of flax.

SEPARATING WEED MATERIALS FROM GRAIN HARVESTED WITH A COMBINE

Attention has already been called to the increase in moisture content caused by weeds in grain harvested with a combine. Figure 3 shows a variation in moisture content of about 6 per cent between grain that contains weeds, threshed with a combine, and grain that contains no weeds, threshed by hand from the same field. The green weed seeds should be separated from the threshed grain while threshing with the combine or soon after, because the excess moisture from the weed seeds will be transferred to the grain if they are allowed to remain together for some time.

Many green weed seeds are of approximately the same diameter as the wheat kernels, but are shorter. Seeds of lamb's-quarters, sweet clover, wild buckwheat, and ragweed retain their hulls during the combine threshing operation unless they are fully matured.

Several grain-cleaning attachments were used in 1928 in an attempt to remove the larger weed seeds. These attachments were of disk and cylinder type and separate grain kernels on the basis of their length. Results were not entirely satisfactory, but information obtained indicates possibilities that should be developed by further research work. One device that removed these seeds was operated on sixty lots of wheat that contained an average total dockage of 7.5 per cent, of which the small-seed dockage ranged from 2 to 17 per cent. The average moisture in the sixty lots of wheat was 15.7 per cent. This caused the wheat to grade No. 4 and made it unsafe for storage. The average moisture of the wheat after passing through the cleaner was 14.4 per cent. The wheat would grade No. 2, and would be worth 8 cents per bushel more than before cleaning. Most of it was then safe for storage.

Another method of removing green weed seeds, practiced by several farmers in the spring wheat area, is to clean the wheat and other grains with a fanning mill or other grain-cleaning device within 24 hours after harvest. Half of the moisture is usually transferred from the weed seeds to the wheat during the first 24 hours, altho transference is usually not complete for about a week.

THE WINDROW METHOD OF COMBINE HARVESTING

The windrower illustrated in Figure 2 has been described. During the harvest season of 1928, 60 per cent of the Minnesota combine owners used the windrow method. The ready acceptance of this method is due largely to the natural reluctance of most farmers to delay harvesting operations for a week or ten days after binder harvest time. This necessary delay is feared by some because of the possibility of losses through shattering, crinkling, and lodging. These losses vary with different varieties but, in general, the yields are not much lower at the time for straight combine harvesting than at the time for binder harvesting.

Losses due to lodging are much higher when harvesting with the binder than when harvesting with the combine. The combine harvester picks up lodged grain fully as well as the binder. When lodged grain is cut with the binder and bound, subsequent losses are heavy because bundles can not be made properly. As there is no possibility for losses after cutting with the combine, lodging becomes much less important.

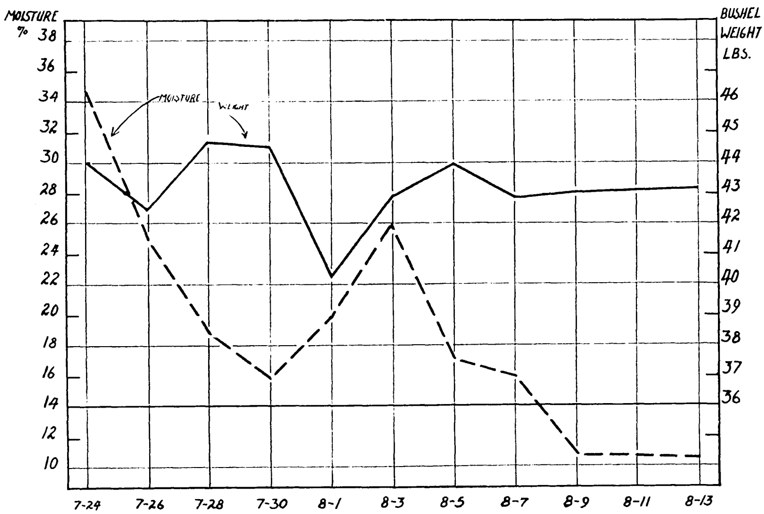

Fig. 4. Moisture Content and Weight per Bushel of Standing Grain of Svansota Barley at University Farm

Given at two-day intervals

With the windrower, however, the grain can be cut and laid in the windrow about the time that it would normally be cut with the binder. The risk of windrowing is probably no greater than that of shocking.

If ripening is uneven or if the field is weedy, the windrow method offers additional advantages. In a weedy field it is difficult to use the straight combine method without getting moist grain. Delaying harvest beyond the time when the grain is dead ripe is of little value and may even be detrimental, because most of the weeds continue to grow taller after the grain has ripened. At the same time the heads of grain bend over nearer to the ground. This makes it necessary to cut lower in order to get all the heads and a larger part of the weed plants is included.

It is evident, therefore, that windrowing is almost indispensable in very weedy fields. Observations were made during the 1928 harvest season on fields where the grain was dry enough for harvesting with a combine but a thick stand of weeds made it practically impossible. It was necessary to use the windrow method, altho the grain had a moisture content well below 14 per cent.

How Grain Is Laid in the Windrow

Two sizes of windrowers were used in Minnesota in 1928—those cutting a 12-foot and those cutting a 16-foot swath. In general they were of two types: One delivered the grain to the center of the platform by means of two canvases, one on each end and running in opposite directions. An opening about 2½ feet wide in the middle of the platform allowed the grain to drop on the stubble. The other had only one canvas, carrying all the grain to one end of the platform and over the drive wheel, dropping it on the stubble through a hood.

Care should be used not to deposit the windrow in the wheel track, where it will lie close to the ground because the stubble underneath has been broken down. In this position it will not dry readily after a rain because the air can not circulate underneath it.

The windrow will be held up by straight standing stubble. Rapid drying is facilitated and little loss results in the picking-up operation.

Grain in the windrow is overlapped in such a way that the heads are on top and the butts underneath. The windrow is about 2½ feet wide, the thickness depending on the width of the swath and the thickness of the stand. The combine with a pick-up should follow the windrow in the same direction the windrower went in making it.

Rate of Drying in Windrow

It has been shown that most small grains have a moisture content of approximately 30 per cent at binder harvest time and that under normal weather conditions from eight to ten days are required for the grain to reach a moisture content of 14 per cent if it is left standing. If the windrower is used to cut the grain at normal binder harvest time, it is desirable to pick up the windrows and thresh them with the combine as soon as the grain is dry enough for safe storage.

To determine the time required for the moisture of grain in the windrow to be reduced to 14 per cent, tests were made in fields of wheat and barley at Crookston and Kent, Minnesota. Figure 5 shows the data obtained on a field of barley at Crookston. This field was cut with a 16-foot windrower on August 2.

On part of the field the windrow was laid on stubble about 15 inches high and on another part the stubble was only about 9 inches high. Part of the field was left uncut.

The weather from August 2 to August 11 was dry and warm. The relative humidity was low and conditions were favorable for rapid drying. The days were bright and clear and there was little dew.

When this barley was windrowed it had barely reached the binder harvest stage, having a moisture content of 36 per cent. Samples were taken daily from the windrows and from the standing grain in the same field and moisture determinations were made. The solid line in the figure shows the moisture content of the uncut grain each day until it reached 14 per cent. This would have been ready for straight combining on August 11, just nine days after binder harvest time. This confirms the results obtained on the plots at University Farm, Morris, and Crookston experiment stations that were previously reported.

There was practically no difference in the rate at which the grain dried on stubble of two different heights. Six days were required to bring the moisture content of the windrows to 14 per cent.

The comparison in this case is interesting. Only two or three days longer were required for the standing grain to be ready for harvesting with the combine than for the grain in the windrows. There were few weeds in this field and the grain had ripened evenly, therefore straight combine harvesting could have been done on August 11 with perfect safety and the cost of windrowing have been saved. The windrowing operation, on the other hand, made it possible to use the combine on August 8 instead of August 11 and thus get the barley under shelter three days earlier.

These data apply only to clean fields. If the fields are weedy the windrow method is much better. In straight combining, the weed materials raise the moisture content of the mixture to a point that makes storage unsafe, even tho the moisture content might be 14 per cent or less when combined. By the windrow method, however, the weed seeds have dried before combining and thus do not affect the moisture content of the threshed grain.

The rate of drying in the windrow depends somewhat on the stage of ripeness at time of cutting. A field of wheat near Crookston was windrowed at a moisture content of 21 per cent, on August 7. Three days later both the windrows and the standing grain were ready for the combine. There was no advantage in windrowing this field—there were no weeds.

The two fields cited suffice to illustrate the general results obtained on all fields studied in that way. These results indicate that if there are no weeds and the crop ripens evenly there is little advantage in using the windrower. In general, grain cut at binder harvest time and put in the windrow does not reach a moisture content of 14 per cent much sooner than if it is left standing.

Height of Stubble for Windrowing

Grain that is laid in the windrow is carried on the stubble and should not settle down so it will touch the ground. The height of the stubble is significant. Naturally, the height of the stubble depends somewhat on the length of the straw. If the straw is not to be saved, it is best to cut as high as possible to avoid running the excess straw through the separator and possibly decreasing the efficiency of threshing.

In the studies mentioned the stubble was usually cut at two different heights—9 inches and 15 inches. Figure 5 shows that within reasonable limits the rate of drying is not affected by the height of stubble. If the stubble is too high in proportion to the length of the straw, the heads with short stems will drop to the ground. Very high stubble is more flexible and therefore can not hold up a windrow as well as shorter stubble. The most satisfactory height is about one third the total length of the straw.

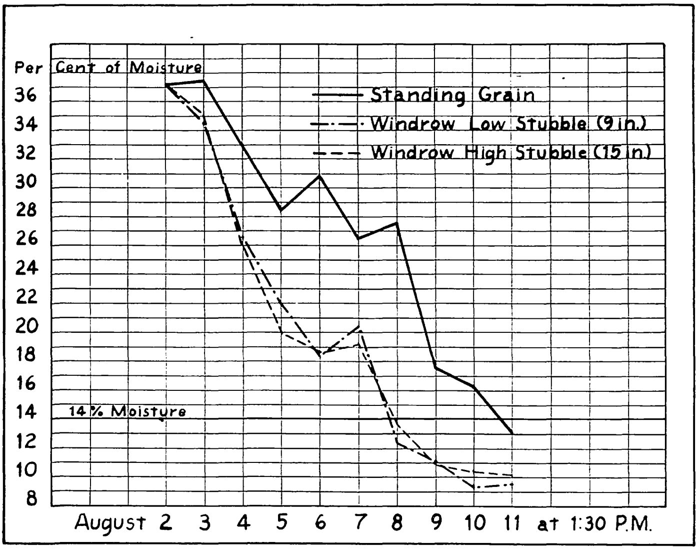

Fig. 5. Under normal conditions grain that is laid in the windrow at binder harvest time requires almost as long to dry out sufficiently for combining as that left uncut.

Will the Stubble Hold Up the Windrow?

During the harvest season of 1928 there was an opportunity to compare the behavior of grain in the windrow during and after heavy rains with that of grain from the same field that had been cut with the binder and shocked. About 100 acres of a 160-acre field of Durum wheat was cut and shocked on August 22 and 23; the other 60 acres was cut with the windrower on August 25 and 26. The wheat was dead ripe, and altho no moisture determinations were made at time of cutting, the moisture content was thought to be below 14 per cent. The field was very weedy, hence it was impossible to use the straight combine method. On August 26 about 4 inches of rain fell and on August 28 another 2 inches. In the meantime and until August 29 the weather was damp and cloudy. After that it was clear.

Shock threshing was begun on the afternoon of September 2. The grain threshed from the shocks on that day had 18 per cent moisture. Shock threshing was continued on September 3 and 4 and threshing with the combine from the windrow was begun at 3 o'clock on September 3. Moisture determinations were made hourly of samples from the threshing machine, from the combine, and from standing wheat that had been dead ripe for two weeks. Figure 6 shows the results of these tests.

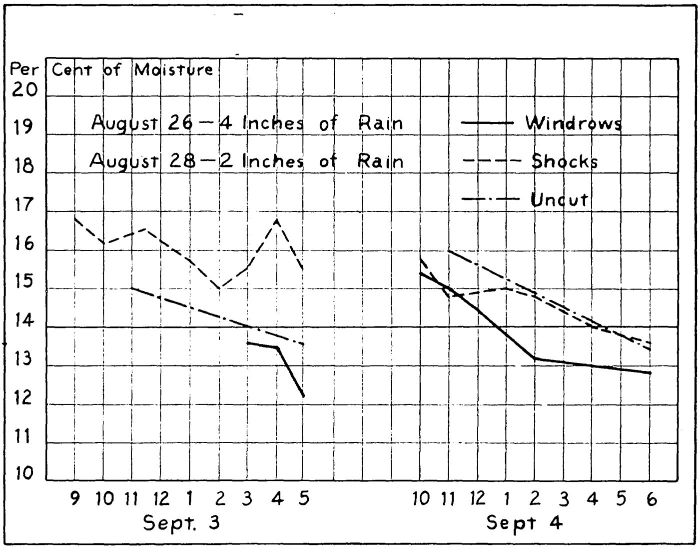

Fig. 6. Comparison of Rate of Drying After Heavy Rains of Wheat in Windrows, in Shocks, and Standing

It was impossible to begin work with the combine before 3 o'clock on September 3 because the ground was too soft from recent heavy rains. The moisture content of wheat threshed with the combine was consistently lower than that of wheat threshed from the shock. The windrows were well up on the stubble. There was no difficulty in picking up the windrows and it was still possible for air to circulate freely under them.

Figure 6 shows the relation between the moisture content of standing grain and the windrows. In general, there is the same variation throughout the day in grain in windrows as in standing grain. The shocks dry slowly after a heavy rain.

Data on other fields indicate that not quite so much moisture is taken on during the night by grain in the windrow as by uncut grain, hence combining might be possible earlier in the morning from the windrow than from standing grain. On the other hand, standing grain dries more rapidly after rains than grain in windrows.

Windrowing on a field of wheat was done on a windy day with a machine that carried the grain over the bull wheel and dropped it from a height of several feet. When the machine traveled at right angles to the direction of the wind, the wind made a narrow windrow, compact and heavy. These windrows settled to the ground and required more time to dry than those that were held up on the stubble.

LENGTH OF COMBINE DAY

In order to be able to plan work ahead, it is necessary to know the time of day when standing grain has reached approximately 14 per cent moisture, and at about what time in the evening the moisture content again becomes too high for safe storage.

This depends on how heavy a dew has fallen and on the relative humidity of the air. Clear weather during the early morning hours accompanied by a rising temperature makes the air capable of taking up more moisture. This results in a relatively rapid drop of moisture in the grain and makes it possible to begin harvesting early.

Hourly moisture determinations of the standing grain after it had reached 16 per cent or less on some previous day were made at University Farm and at Crookston. Some of the days chosen were more favorable for combining than others.

Figure 7 shows the variation in moisture content of Anthony oats on three days. On August 10 samples were taken hourly from a plot at University Farm on which oats had reached a moisture content of 13.8 per cent at 1 p.m. on August 9. The solid line in the figure shows that while the moisture content had risen during the night, it was down to 14 per cent by 7 a.m. and remained low until 9 p.m. The dew was light and disappeared by 7 a.m. Bright sunshine caused a rapid rise in temperature. The relative humidity of the air dropped rapidly after the dew was off and remained low throughout the day.

On this day, which was exceptionally favorable for combining, the work could have been started by 7 o'clock or slightly earlier and probably could have been continued after 9 o'clock, when the last moisture determination was made.

At Crookston the grain of Anthony oats had reached a moisture content of 14 per cent on August 20. Moisture determinations were made at hourly intervals on August 24 and 31. These data are representative of conditions when grain has reached the combine stage but stands in the field several days after that time. On August 24 the moisture in the grain was 17.6 per cent at 7 a.m. and had dropped to 14.4 per cent by 9 o'clock, when the dew had disappeared.

With the weather clear, the temperature rising slowly, and the relative humidity comparatively low for the morning hours, indicating that the moisture in the bulk of the grain harvested during the day would be well below 14 per cent, the combine could have been started at 9 a.m. and continued for an hour or two after 7 p.m.

On August 31 the grain again had a relatively high moisture content in the morning and dropped more slowly during the day, as on the other two days. The temperature at 7 a.m. was low and the air was

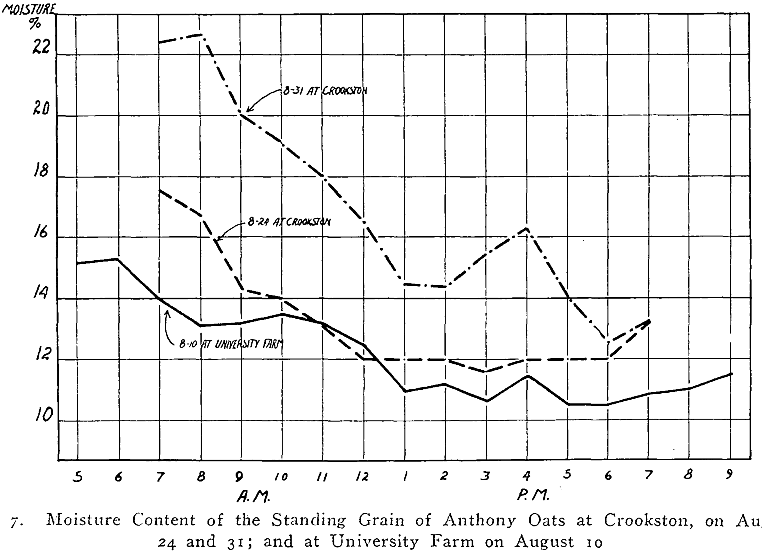

Fig. 7. Moisture Content of the Standing Grain of Anthony Oats at Crookston, on August 24 and 31; and at University Farm on August 10
Given at hourly intervals

almost saturated with moisture, the relative humidity being 94 per cent. The temperature rose slowly, however, and with this rise came a decrease in humidity. It would hardly have been possible to begin harvesting with the combine before 5 p.m. on that day.

The moisture content always rises during the night, but this rise is not always the same. When the dew is heavy it rises, and combining must be delayed longer in the morning than if the dew is light.

On four days out of the ten over which the work extended, weather conditions were so unfavorable that the grain either reached the 14 per cent stage so late in the afternoon that little combining could be done or it did not reach that stage at all.

The combine could have been started at 6 a.m. on Marquis wheat and at 7 a.m. on Anthony oats at University Farm on August 10 and used well into the night.

On five days out of the ten, the combine could have been started between 10 a.m. and 2 p.m. On one of these days, August 6, rain fell at 4 p.m. On the other four days combining could have continued until 7 or 8 p.m., or later.

These limited data, confirmed by results obtained in North Dakota during the summer of 1928,[11] indicate that the moisture content of standing grain, otherwise fit for combining, may be 14 per cent or below for 6 to 8 hours during a good combining day. In order to utilize this time to best advantage, arrangements should be made to keep the combine working continuously from the time the moisture content goes below 14 per cent to the time it goes above that in the evening.

Records kept during the 1928 harvest season on 12 combines operating in Minnesota showed that these machines worked, on the average, 5.6 hours a day. These combines were of 3 sizes—10-, 12-, and 16-foot cut. The 10-foot machines averaged 13.5 acres a day; the 12-foot and the 16-foot sizes averaged 17.5 and 23.25 acres, respectively. Expressed in acres per hour this is 2.4 acres for the 10-foot machines and 3.4 and 4.3 acres, respectively, for the 12-foot and 16-foot machines. The average rate of all machines was 0.26 acre an hour per cutting foot. The usual starting time was 9:30 a.m. and the usual quitting time 6:30 p.m. The extremes were 8 a.m. and 8 p.m. On this basis the average acreages covered per day would be 21, 25, and 33.25, respectively, for the 10-, 12-, and 16-foot machines.

The average acreage per cutting foot was higher with the windrowers than with the combines, being 0.38. The usual length of the operating day for the windrower was about 9 hours. Windrowing may be done at almost any time regardless of weather conditions, except during rains, therefore the limited daily performance is not significant.

QUALITY OF GRAIN HARVESTED WITH A COMBINE

It is not evident that the use of the combine harvester introduces any problems involving the quality or grade of grain that are not already familiar to the grain producers of Minnesota. The grain is at least as ripe and mature when harvested in this way as when the ordinary binder is used. With the binder, provision must be made for subsequent drying. This is accomplished by placing the bundles in shocks, where evaporation takes place more or less readily, as bundles may be wet by rains. If good drying weather follows, no serious dam-

[11] Stoa, T. E. Unpublished data obtained at the North Dakota Experiment Station in 1928.

age results, but if the rain is prolonged and drying is prevented, the grain may become damaged in the shock.

With the straight combine method of harvesting, the grain is usually left standing a week or ten days after normal binder harvest time, to allow the moisture content of the grain to become low enough that it may be stored without danger of spoiling. When grain is dried in the windrow, conditions are practically the same as when the binder method is used.

When wheat becomes wet in the field and remains damp for several days, the grain first acquires a "bleached" or light colored appearance. If the grain is in a shock or a windrow, sprouting or germination may follow. Germination may be serious or slight. If grain is threshed with the combine while moist, there will be trouble in warehousing and shipping. The same condition will exist in the case of straight combining if the grain has not been allowed to stand long enough to dry out.

Weight per bushel is a factor in determining the market grade of most grains; hence where the crop is hauled directly from the field to the elevator it is a factor in determining price. A definite relation exists between weight per bushel and moisture content (see Figs. 4 and 8). It will be noted that as the moisture content decreases the weight per bushel increases, and vice versa. Grain with a high moisture content is graded low not only because of its moisture, but also because the weight per bushel is low. This is another important reason for having the moisture content of grain down to 14 per cent or lower.

The relation between moisture content and weight per bushel was fairly close for both Marquis and Mindum wheat at each location

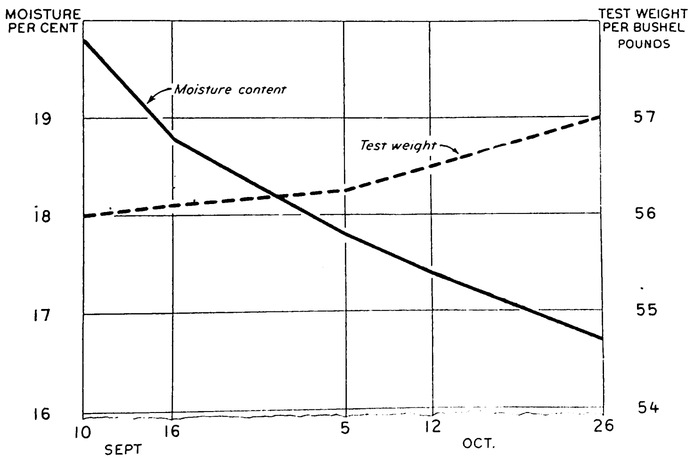

Fig. 8. The wheat stored in a ventilated bin was cut during the three days preceding September 10 and was thoroly cleaned before being put in the bin. During the forty-seven days that it was in the ventilated bin, it decreased 3 per cent in moisture content and increased one pound in weight per bushel.

where these determinations were made. Altho there was some relationship for oats and barley throughout each test, it was not so close as for wheat.

STORING GRAIN HARVESTED WITH A COMBINE

If the moisture content of grain harvested with a combine is 14 per cent or less at time of harvesting, no special precautions need be taken in storing. It will behave exactly like grain threshed from the stack or shock after it has been cured and dried.

If it is necessary to harvest with a combine grain that contains a little too much moisture, the grain can usually be safely stored in properly ventilated bins. At Jamestown, North Dakota, one lot of 800 bushels of wheat containing 19.8 per cent moisture on September 10, 1927, was thoroly cleaned to remove all weed seeds and shrunken wheat and was then stored in a bin equipped with horizontal 4x6-inch ventilators open to the outside air at both ends and placed 20 inches apart. This wheat was in good condition for seed on April 14. The decrease in moisture and the increase in test weight up to October 26 are illustrated in Figure 8. Storing wheat of high moisture content is, however, a dangerous practice, particularly if non-ventilated bins are used.

Grain harvested with a combine should always be cleaned before it is stored if it contains green weed seeds. It can not be safely stored even in ventilated bins.

Figures 9 and 10 show the details of construction of horizontal ventilators in a bin for the storage of moist grain.[12] Ventilators of this kind may be placed in almost any bin if both ends are exposed to outside air circulation.

The ventilators, which are 4x6 inches in cross-section, are placed 24 inches apart on centers horizontally and 20 inches on centers vertically. With this spacing, 5 per cent of the bin is occupied by ventilators. A board or pole the length of the ventilator may be used to learn how the ventilators can best be put in place and removed from the bin. This should be done before the ventilators are constructed.

It should be noted that the ventilators will be supported at the center on 1x6-inch brackets nailed to 2x4-inch vertical supports. These brackets should be designed so that the ventilators will be held close to the supports. At the top of these supports 1x4-inch ties should be provided, which may be left in place. The top ends may be extended to the roof or ceiling of the building. The ventilators and center supports can be removed. In operation, the doors covering the ends of the ventilators should be closed at night and during rainy periods.

[12] Working drawings of a ventilated grain bin may be obtained from the Division of Agricultural Engineering, University Farm, St. Paul, Minn.

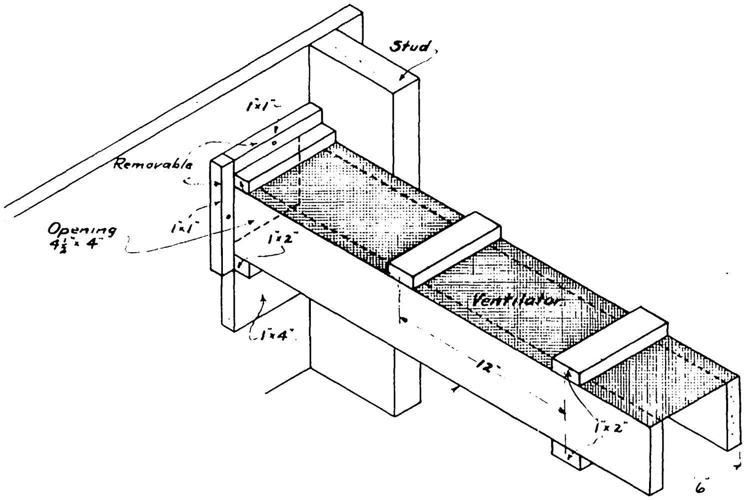

Fig. 9. Detail of Ventilator for Ventilated Bin

If the ventilators last seven years with slight repairs, the construction cost will be about equal to an annual cost of one cent per bushel of grain stored.

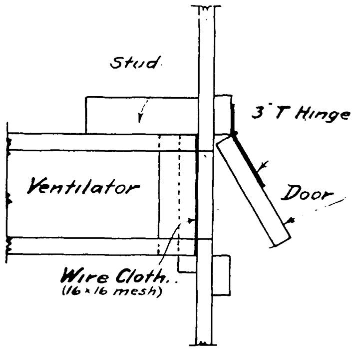

Fig. 10. Horizontal Section of Ventilator

HARVESTING AND THRESHING LOSSES WITH COMBINES, WINDROWERS AND PICK-UPS

More interest is exhibited in the harvesting and threshing job a combine does than in any other feature connected with its operation, probably because of the skepticism of many persons that such a machine can perform two major operations as one and do the work as efficiently as two highly perfected machines—the binder and threshing machine—

can perform them separately. When it is considered that harvesting methods are the same for a combine as for a binder or header; and in threshing, separating and cleaning methods are identical in the combine and the stationary machines, why should the work of the combine not be as efficient as that of other harvesting and threshing machines? Each time the grain is handled for a separate operation, losses are bound to occur. With a combine these losses, occurring in the field, are represented by heads cut and left in the stubble and kernels and unthreshed heads carried over with the straw from the threshing unit. With a binder, similar cutting losses occur and, in addition, heads are dropped from the packers and the bundle carrier. Heads are lost where the bundles drop, in shock bottoms, and from bundle wagons. When grain is threshed with a separator, losses are similar to those with a combine.

Counts have been made in grain fields of the heads left after straight combining or windrowing and picking-up, and blanket tests have been

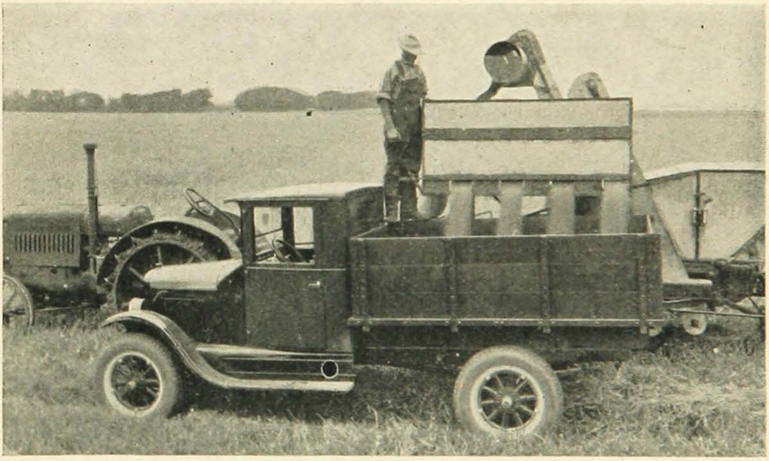

Fig. 11. The threshed grain is collected into a tank on the combine that holds from 30 to 60 bushels. When the tank is full, the grain is emptied into a truck or wagon tank and hauled to the granary or the elevator.

made while machines were in operation to determine losses occurring when different crops were harvested with a combine. When compared with losses occurring in fields of bound grain and with stationary threshing machines, these losses show that for nearly all crops the combine, under ordinary conditions, saves more grain.

Harvesting Losses

Heads cut and dropped in front of the sickle or thrown out by the reel are the principal source of loss in combine harvesting. Small losses may occur where the grain is of uneven height or the crop is lodged, as some heads will be missed by the sickle. The greatest loss occurs in grain of uneven height, partly lodged grain, on rough land, in very weedy fields, and in windy weather. Large losses may occur with a careless operator. Losses from these sources will occur whether the crop is straight combined or windrowed and picked up, but they vary, as will be pointed out later.

Because of extremely bad weather during the 1928 harvesting and threshing season, it was impossible to make many observations in fields and tests on machines for all crops. Sufficient information was obtained on most crops, however, that general comparisons can be made for straight combining, and for windrowing and picking up. Comparisons are also possible with results obtained from combine owners in other states.

In straight combining wheat, harvesting losses were as low as 1.2 per cent and as high as 7.6 per cent. While some machines showed high losses, the majority would be considered low. On fields of wheat that were windrowed and picked up, losses were less than on fields that were straight combined. The lowest loss recorded was 0.4 per cent and the highest 5.4 per cent. A possible explanation of this difference is that the pick-up attachment picks up some of the heads that are cut and dropped by the windrower or thrown over by the reel, as in straight combining. Losses occurring with this method of harvesting wheat may be greater than with straight combining when heavy winds occur after windrowing and before the swath has time to settle.

Similar losses occurring when binders are used to harvest wheat are 6.1 per cent in the Great Plains, 3.0 per cent in South Dakota, 3.6 per cent in Illinois, and 2.8 per cent in Indiana.

Losses in harvesting rye by either method on the farms visited were practically the same as those for wheat.

Farmers in other regions who harvested barley with a combine have, as a rule, had comparatively heavy losses, and those visited in 1928 were no exception. Barley, of all the small grain crops, seems to be hardest for combine operators to handle without heavy loss. Occasionally, however, the loss is only normal. The principal difficulty seems to be that the straw and heads are very brittle. This causes the heads to break or snap off and fall on the ground when harvested.

The smallest loss in any of the barley fields that were regularly harvested with the combine amounted to 3.1 per cent—half that in any field that was windrowed and picked up.

The harvesting loss is lower for oats than for barley, but higher than for wheat. The windrow and pick-up method showed a lower loss on some fields than did straight combining. The lowest loss for the former method was 2.1 per cent. Only one field was found that was straight combined. The loss amounted to 6.0 per cent, which was higher than the average loss for windrowing and picking up.

Flax, whenever tests are made, shows a lower harvesting loss than any other crop. The habit of growth is responsible for this—the plant branches, and the heads, when cut, hold one another. This prevents them from falling on the ground. Field losses were less for straight combining—0.3 per cent as compared with 0.4 per cent for windrowing and picking up.

In many fields the grain was badly lodged. Under such conditions harvesting with a combine is slower and losses are greater. Most combine operators believe that the machine handles lodged grain as well as a binder, or better. The following example illustrates the comparative harvesting efficiency of a combine and a binder, together with the heavy loss that can occur when grain is lodged. In 1928 many farmers who used binders had difficulty because their grain was badly lodged. On one farm a large field of grain was almost flat. The owner, who used binders, found after several attempts that he could not harvest the crop—it appeared to be a total loss. As a last resort he hired a combine owner to go into the field. The crop was straight combined and a count made in the field showed a harvesting loss of 25 per cent, one-fourth of the crop. About 75 per cent of the crop was saved. If the owner had been forced to depend only on the binder, the loss would have been complete. With extension pick-up guards on the combine the loss would possibly have been less.

While tests on combines indicate that harvesting losses are higher in the Red River Valley and adjoining regions than in the Great Plains generally, many are operating with exceedingly low losses. There is a possibility, therefore, that many machines showing large losses in 1928 could be operated another year more efficiently under the same harvest conditions.

Threshing Losses

Threshing losses usually average slightly higher with combines than with threshing machines, owing chiefly to the inexperience of the combine operators. Practically the only grain lost in threshing is that carried over because of too strong an air blast or too heavy a layer of straw and weeds, or in unthreshed heads.

During the harvest season, especially where combines are comparatively new, it is common to see men following the machine and looking for threshed grain carried over with the straw. If only a few kernels are found scattered along the ground it should not be considered a loss, as a bushel of wheat, for example, contains about a million kernels. All free grain found on the ground over which the machine has passed is not necessarily carried over with the straw or chaff—some combines allow a considerable quantity to escape from the feeder house and some may have resulted from shattering.

In straight combining the greatest threshing losses occur in lodged grain, when it is necessary to handle a large bulk of straw; and in weedy grain, which causes the machine to run slower. Under similar conditions with a windrower and pick-up outfit, losses are about the same as in straight combining. In a weedy crop, however, the windrow and pick-up method is better if the weeds are dry.

Blanket tests on machines in wheat showed threshing losses in straight combining as low as about 0.1 per cent and as high as 1.2 per cent. When grain was threshed from the windrow, losses were greater than in straight combining. The highest single loss for this method amounted to 1.7 per cent.

Threshing losses in rye amounted to 2.6 per cent on one machine tested when straight combining. This was higher than for machines picking up. Two machines picking up showed losses of 2.4 and 0.6 per cent, respectively.

Threshing losses in barley for straight combining showed a wide variation—from 0.2 to 4.0 per cent. For picking up, the greatest loss was only half that of the other method. However, no loss was as low as in straight combining.

Machines tested on oats were all picking up except one, which showed a loss of 1.1 per cent. For the others, losses ranged from 0.3 to 7.2 per cent. Two blanket tests made on the same machine show the influence of wind on the efficiency of the outfit. These tests emphasize to inexperienced operators the fact that combining is not merely a matter of pulling the combine around the field. The first test, made on a day with no wind, showed a loss of 0.4 per cent; the next test, made in the same field on a very windy day, showed a loss of 2.7 per cent.

Most of the tests in flax were made on machines that were straight combining. Threshing losses were all below 1.0 per cent (with the exception of those of one machine, which were 3.6 per cent), the lowest being 0.2 per cent. The highest loss in picking up was 5.2 per cent.

Only one machine was tested on buckwheat; two were tested on sweet clover. All were picking up and showed losses less than 1.0 per cent. One machine on emmer, also picking up, showed 2.7 per cent loss.

ADJUSTMENT AND CARE OF THE COMBINE

Altho the combine is complicated, it can readily be operated and properly cared for by one accustomed to handling agricultural machinery. It is to be expected that the man who has never operated a threshing machine will not at once be able to do a good job of threshing under all conditions.

Improper adjustment of the separator results in cracked or poorly cleaned grain and loss of grain both in the head and after it has been threshed. Grain in the tank or wagon as well as the straw and chaff coming from the machine should be examined frequently to determine the quality of the work.

The cracking of grain is caused by insufficient clearance between cylinder and concave teeth, excessive speed of cylinder, or excessive tailings. Many grains crack when dry, consequently a minimum number of concaves should be used and the cylinder speed should not be excessive. Bent or loose teeth and end play in the cylinder also causes crackling.

Loss of grain in the head is due to improper cylinder and concave adjustment. The concaves are set too low, the cylinder is running below rated speed, or too few concave teeth are used. Such a condition should be corrected in the order named. There is always danger of overloading the sieves when too many concaves are used because the straw is chopped more, and more material is thrown on the sieves.

The secret of clean and efficient separation lies in the operator's ability not to overload the sieves. Assuming that the proper sieves are used for the crop being harvested, sufficient air should be admitted to keep the material on the sieves "fluffed" and thus allow the grain to fall through on the screen or grain pan below. The careful operator examines his sieves frequently to see that they are working properly. Overloaded sieves may be the result of insufficient air blast and agitation, use of too many concaves, especially if the straw is easily broken, low cylinder speed, or excessive rate of travel.

Difficulty in separation increases with the amount of weeds. Green weeds passing through the cylinder are usually broken into small pieces. Unless they are gotten rid of quickly they are returned to the cylinder in the tailings and will clog the sieves. When the crop is weedy, a strong air blast should be used even tho a small amount of grain is lost.

Adjusting for Different Crops

Observations were made in 1928 on combines operating on 45 fields of grain in the Red River Valley. The machines were tested under known conditions of adjustment to determine the amount of grain lost. These tests were made by catching the straw and chaff from the machine on a large canvas while a definite amount of grain was being threshed. The grain was then separated from the straw and chaff and later was cleaned and weighed. The amount recovered divided by the amount threshed gave the percentage of loss by the machine. These losses do not include the grain in the unthreshed heads that passed through the machine.

There is quite a variation in threshing losses on different crops and on the same crop under different conditions.

Wheat.—The use of the combine is perhaps better understood for wheat than for any other grain. The equipment used and its adjustment are more standardized and threshing losses are consistently lower. These losses ranged from 0.1 to 1.7 per cent of the crop, comparing favorably with threshing losses in other regions where similar tests have been made.

The speed of the cylinder has much to do with the amount of grain lost. This varies with the condition of the crop, but under normal conditions the rated speed of the machine should be maintained for best results. For wheat this is usually about 1,000 revolutions per minute on most machines. On the machines tested the cylinder speed deviated but slightly from the rated speed, showing an average of 1,015 revolutions per minute.

Four rows of concaves will generally dc satisfactory threshing. With some varieties of wheat and under humid conditions it is more difficult to knock the kernels from the heads. In such cases more concaves must be used. It should be remembered, however, that the least number consistent with good threshing insures cleaner and more efficient work with less power. On the combines tested, from four to six rows of concave teeth were used. The same number was usually placed in the front and in the rear of the concave circle. Several operators, however, claimed that the straw was more quickly disposed of by placing all the concaves in front. With such a setting the loss was 0.1 per cent on one machine and 1.2 per cent on another.

For wheat, two sieves are generally used in the separator shoe and two in the recleaner, altho one is often satisfactory. When the straw is clean and not much broken one sieve will work very well. In the separator shoe, the common practice is to use one coarse and one medium sieve, depending upon the equipment supplied with the machine; in the recleaner the adjustable lip, or mesh sieve, is used on top, with the small lip, mesh, or round-hole screen below. Some operators give little attention to the setting of the adjustable sieve. If the opening is too large the material falls through it in a pile to the screen or grain pan below before proper cleaning is possible. This sieve should be set so that a large part of its surface is covered with material at all times. This adjustment can be determined only when the machine is in operation, with the material passing over it.

Wheat is the heaviest of the small grains harvested with a combine and ordinarily requires more air blast in its separation than the other grains. The blinds on the separator fans are generally opened one-half or more and the recleaner fan is set for a maximum amount of air. When green weeds are numerous, a stronger blast of air is required in the separator shoe.

Grain is sometimes lost because of an excessive rate of travel. This is especially true in heavy or lodged grain or where weeds are troublesome. Under such conditions the large amount or the nature of the material overloads the machine and grain is carried out with the straw and chaff. Combines running at from 2.5 to 3 miles per hour will do good work if the adjustment and the equipment used are correct.

The influence of the speed of the cylinder and the rate of travel is well shown on a field of windrowed wheat that was picked up and threshed five days after it was cut. The straw was very heavy and was cut 36 inches. The tractor was moving at 3 miles per hour, and the cylinder was running 85 revolutions below rated speed. A test showed that there was a loss of 1.7 per cent. A second test was made after the rate of travel had been reduced to 2 miles per hour, and the cylinder speed increased to 1,000 revolutions. This showed a loss of less than 1.0 per cent. Four rows of concaves were used. One lip sieve was used in the separator and one adjustable and one small lip sieve were used in the recleaner. The separator fan was half open and the maximum amount of air was used in the recleaner.

Rye.—Rye is easy to thresh and the equipment and adjustments for wheat are usually well suited for this crop. Rye straw is long and should be threshed with the least possible number of concaves, as the straw will be badly broken and make unnecessary work for the sieves. When damp, the straw wraps around the moving parts. For this reason the speed of the cylinder should be well up to normal. If, by a slight increase in speed, fewer concaves will do the work properly, this adjustment should be made.

A machine using five rows of concaves was tested in straight combining in a field of damp rye. The crop was badly infested with green weeds, and a light rain on the morning of the test made the straw tough. Altho the air temperature was above 90 degrees, the heads of rye carried a moisture content of 15.2 per cent. The equipment used and its adjustment were similar to those for wheat. The machine was traveling at the rate of 2.6 miles per hour and the cylinder was running at 1,000 revolutions per minute. The test showed a loss of 2.6 per cent, much of which was doubtless due to the bulk of chopped material on the sieves because of too many concaves. If the rye had dried more after the rain the loss should have been much less.

There was a similar loss on a machine picking up a windrowed field of rye. The cylinder of this machine was running at 50 revolutions below normal speed and three rows of concaves were used. On another machine with normal speed and with two rows of concaves there was a loss of 0.6 per cent.

Barley.—Barley is one of the easiest crops to thresh when dry and one of the hardest to thresh when damp. When thoroly dry it may be threshed with one row of concaves. When damp, the grain is hard to knock from the heads and six rows of concaves are sometimes necessary. A considerable amount of light chaff is to be disposed of, including the beards, and if the adjustable sieve is used it should be opened more than for wheat.

The machines tested were using from one to four rows of concaves and the speed of the cylinder was close to rated speed. One sieve was generally used in the separator shoe and one in the recleaner.

Threshing loss was lowest where the equipment and its adjustment were practically the same as those used for wheat. Two sieves were used in the separator shoe with the air set for half the maximum blast. One row of concaves was used and the cylinder was running at approximately 1,000 revolutions per minute. The rate of travel was 2.6 miles per hour. The crop yielded 25 bushels per acre and was cut 12 inches high, with 16 inches of straw going through the machine. Less than 0.5 per cent was lost by this machine. There was considerable loss on a machine traveling 3.5 miles per hour, which is too fast for efficient separation under average conditions.

In threshing barley that had been windrowed, the machines used four rows of concaves. One sieve was used in the separator shoe. In the recleaner one adjustable sieve was used and on one machine operating in a very weedy field a medium lip sieve was used below the adjustable sieve.

Oats.—A dry, clean field of oats may be satisfactorily harvested with the combine, using one or two rows of concaves. Special attention should be given to the amount of air over the sieves, as oats are light and are easily blown away. One operator, in harvesting oats after having completed his wheat harvest, failed to reduce the air blast and much of his crop went out the rear end of the machine. High winds blowing through the machine have the same effect. With one machine tested in a high wind the loss was 7 per cent and with another 2.7 per cent; with a similar machine in a neighboring field on a calm day the loss was less than one per cent. These machines were operating with one or two lip sieves in the separator shoe and one adjustable sieve in the recleaner. The air in the separator shoe was from one-fourth to one-half the maximum.

Oats shatter badly soon after they are mature and the straw falls over. For this reason oats should be harvested with a combine as soon as they are ripe.

Emmer.—Requirements for emmer are similar to those for oats. Threshing has been successful on clean dry fields without the aid of concaves and with the cylinder running slightly under rated speed. The heads of emmer are very brittle when dry and are easily threshed. One or two rows of concaves are generally used with a light supply of air and the cylinder running below the rated speed.

A field of windrowed emmer showed a loss of 2.7 per cent. The crop had been cut with 10 inches of straw and was fairly dry when picked up. The cylinder of the machine was running 70 revolutions above rated speed and 3 rows of concaves were used. The blinds on the separator fan were closed, so the amount of air in the machine was not sufficient.

Buckwheat.—Buckwheat is easily cracked and care should be taken not to have the cylinder speed excessive or to raise the concaves too high. One row of concaves is usually sufficient and the sieves used are similar to those used for wheat. Only a slight loss should occur in combining buckwheat, as it is one of the most easily threshed crops. The following equipment and adjustment should meet ordinary requirements: One row of concaves, speed of cylinder 920 revolutions per minute, two sieves in separator, and air at half blast.

Sweet clover.—In using a combine to harvest sweet clover the rate of travel should be less than for wheat, to prevent crowding the feed. The plants are bulky and contain a high percentage of moisture, so the cylinder, sieves, and elevators are easily clogged.

This crop is well adapted to the windrow method of harvesting as most of the moisture is given up by the plants in the windrow and the crop is more readily handled by the machine. Threshing is often done with no concaves, altho when the plants are tough a few rows must be used. As the seeds are very light, little air should be used. On the machines tested, the air passage in the separator shoe was closed. Ordinary sieves were used and the cylinders were run close to rated speed. The loss was less than one per cent on these machines. Sweet clover, even after it is windrowed, is bulky, and an extra man is frequently required to feed it into the machine. If the feed beater is retarded by the plants, it should be removed.

Flax.—In combining flax the average threshing loss was 1.2 per cent for the machines tested, including 3.6 per cent in one machine operating on a rough weedy field of badly lodged flax. In other sections losses have been as high as 7 to 8 per cent of the crop under similar conditions. Damp flax wraps around moving parts, hence the cylinder should be kept at rated speed. The average speed for the machines tested was slightly above 1,000 revolutions. Four rows of concaves were used, most of which were set high more thoroly to knock the flax from the bolls. The adjustable sieve, set close, and the small round-hole screen were used in the recleaner. The adjustable or the medium lip sieve was used in the separator shoe. As flax is light and easily blown away, little air is required in its separation. All the machines were operated with the air drafts closed. One operator used extra metal blinds on the separator fan more completely to reduce the amount of air. This resulted in poorly cleaned flax.

The loss was greater in threshing flax from the windrow than in direct combining. One test, made during a high wind, showed a loss of more than 5 per cent. Part of the loss may have been due to partly open blinds on the separator fan.

On the machines tested, the cylinder speed averaged 977 revolutions per minute. Four rows of concaves were used in two of the machines and six rows in another machine. One adjustable sieve was generally used in the separator shoe, and one adjustable with the round-hole or the slotted flax screen was used in the recleaner.

Care of the Combine

A new machine should be started carefully and according to instructions given by the manufacturers. It should be run empty for several hours before starting on a crop, and should not be crowded for the first few days of work. The bearings should be allowed to fit in gradually, with no undue strain on them. They should be examined frequently for heating. The press of work at harvest time, when the machine is purchased late in the season, should not interfere with breaking it in properly.

Older machines should be put in good running condition before harvest begins, otherwise they may break during harvest and cause serious delay. Some part of the combine may be damaged during the storage season and often this can be detected only by starting the machine.

The machine should be oiled and greased several times a day while it is in operation. The day's work will be shortened considerably if this is done while the machine is running. The efficient operator soon learns the location of points to be oiled and the frequency of oiling, and takes advantage of all stops. He knows that high-speed shafts require more attention than slower moving ones, and are more likely to overheat. He feels the bearings as he makes the rounds and notes any undue heating. Occasionally a grease or oil hole will clog and if not detected in time a burned bearing will result. If no additional oil or grease is used in a reasonable time, the hole should be examined for stoppage.

Care of the combine after the day's run is important. Canvases and belts should be removed and left, over night, inside the rear of the machine, out of danger from damage by the weather. In humid regions grain and chaff should be removed after the day's run because of the possibility of rain. In regions of considerable rainfall during the harvest season or when the season extends into the late fall or winter, a large tarpaulin to protect the entire machine in bad weather is suggested.

Before the combine is purchased a suitable storage place should be considered. On some farms machinery storage is inadequate for the combine because of its size. Often removing some of the units makes it possible to store the machine in a space that would otherwise be too small. A shelter with a concrete floor is best.[13] A dirt or cinder floor should be well drained.

Careful operators clean their machines thoroly inside and out before putting them away for the winter. Dirt and chaff on or in the machine retain moisture, as is evidenced by the sprouted grain too frequently seen on combines in operation. If this is left on the machine it will eventually rust the metal and rot the wooden parts. Even tho the combine is housed over winter, it is well to give it a coat of good paint. The sickle, chains, bearings, and other metal parts should be coated with heavy transmission oil as a protection from dampness. The header unit should be well protected, as the slats of the reel and the cutting mechanism are particularly susceptible to damage from exposure to the weather. The belts and canvases should be removed and stored in a dry place away from possible damage by rats and mice. A coat of neatsfoot oil on the belts helps to prevent checking and hardening.

COMBINE HARVESTING COSTS

One of the most important advantages claimed for the combine method of harvesting over the binder and thresher method is the saving in time and labor and the consequent reduction in cost. To determine costs of combine operation and to make possible a comparison of these with costs of binder and thresher operation, records were obtained in 1928 from 12 combine operators. Daily records were kept, covering acres cut; hours of labor; use of tractors, trucks, and horses; gasoline consumption, and similar data.

Four of the combines studied were 10-foot size, three 12-foot, and five 16-foot. Three operators of 10-foot machines used 12-foot windrowers with them. Two operators of 12-foot machines and three operators of 16-foot machines used 16-foot windrowers. The 5,000 acres of crops covered by these reports includes 1,188 acres of wheat, 1,306 of barley, 1,637 of flax, 650 of other small grains, and 219 of timothy, red clover, and sweet clover.

Factors of Cost

The most important factors of cost in combine harvester operation are man labor; tractor work; gasoline, oil, and grease; and interest and depreciation on the machine. A considerable variation was shown in

[13] A plan of a shed suitable for sheltering a combine harvester-thresher has been prepared by the Division of Agricultural Engineering and may be obtained from the Mailing Department, University Farm, St. Paul, Minn., for 10 cents.

the relative importance of each. Variations are due to differences in size of fields, condition of the grain, size of crew, familiarity of the operator with his machine, and similar causes. There was no significant difference in factors of combine harvester costs between different crops or between standing grain and grain in the windrow.

Man labor.—The most significant saving effected by the combine harvester method is in man labor. Less than half as much man labor per acre was expended as with the binder and thresher method, in northwestern Minnesota;[14] and less than one fourth as much in the southeastern part of the state.[15] This is a decided advantage, as extra labor is likely to be both scarce and high priced during the harvest season.

On two of the farms studied, one man drove the tractor and operated the combine. On most of the others there was one man on the tractor and one on the combine. On one farm two men were used regularly on the combine in addition to the tractor operator, and on two others, part of the time. The windrower was usually handled by one man, who operated both it and the tractor. On three farms, however, one man was used on each. In general, three men can handle a combine and haul the grain. On large farms the regular help will do the work without the necessity of exchanging help with the neighbors or hiring labor, which is high priced at harvest time. The housewife is relieved of the burden of boarding the larger crew needed with the binder and thresher.

There was a slight variation in man hours per acre for threshing with combines of different sizes, as shown in Table VI. With the 10-foot machines an average of 0.75 man hour was required per acre; with the 12-foot, 0.73; and with the 16-foot, only 0.60. The highest number of man hours per acre for threshing was 1.13 for a 10-foot machine.

TABLE VI

Factors of Cost and Performance in Combine and Windrowing Operations

Item	Method of harvesting				
	Straight combining			Windrowing and picking up	
Width of cut, ft.	10	12	16	12	16
Total acres	210	407	547	297	561
Acres per hour	2.4	3.4	4.3	3.9	5.3
Man hours per acre	0.75	0.73	0.60	0.31	0.33
Tractor hours per acre	0.45	0.31	0.24	0.26	0.20

[14] Unpublished data obtained by the Division of Farm Management and Agricultural Economics, of the Minnesota Agricultural Experiment Station, from 20 farms in Polk County, for 1926 and 1927.

[15] Pond, G. A. "A study of dairy farm organization in southeastern Minnesota." Minn. Agr. Expt. Sta. Tech. Bull. 44. 1927.

Windrowing requires about half the labor needed for combining. With 12-foot windrowers the average was 0.31 man hour; with the 16-foot machines, 0.33 man hour. This does not show a saving in man labor for the larger windrower because on three of the 16-foot windrowers two men were used, one on the windrower and one on the tractor; and all the 12-foot machines were operated by one man.

While the operation of hauling grain is not strictly part of combining, it should be considered here because man labor is needed for hauling simultaneously with combining. The average time per acre required for hauling grain on all farms was 0.48 man hour. On five of the farms horses were used exclusively; on four, motor trucks only were used. It is obvious that the time required for hauling depends almost entirely on the distance of haul, but a comparison of the time for hauling in both cases is interesting. Where horses only were used, the average time per acre was 0.59 man hour; where motor trucks only were used, the average was 0.36 man hour.

Power, fuel, and lubricants.—Tractors were used for drawing the combines in the field on all the farms where records were kept. Most operators used a three-plow tractor. This size will readily haul a 16-foot combine. Windrowers and small combines may be drawn by a smaller tractor, but generally the three-plow size is used for the smaller combines also. The threshing and cutting mechanism of the combines was operated by auxiliary motors of about 20-horsepower capacity, mounted on the combine. Table VI shows the average tractor hours per acre for machines of different sizes. There is a difference of from 0.45 tractor hour for the 10-foot machines to 0.24 hour for the 16-foot machines. The small and the large windrowers required only 0.26 and 0.20 tractor hour per acre, respectively.

No fuel or lubrication records were kept on the tractors. In arriving at costs, the three-plow tractors were charged at $1.00 per hour and the four-plow tractors at $1.20 per hour. The auxiliary engines used, on the average, 0.61 gallon of gasoline per acre, those on the larger combines used more. As the records for oil and grease consumption were not complete for all farms, the average rate on farms for which complete records were available has been used. This is 2 cents per acre.

Most of the combines studied were being used for the first time and none had been used more than one year, hence the cost of repairs was low, especially as most broken parts were replaced free by the dealer. In order to have a representative item of costs of repair, 10 cents per acre has been charged to all machines. This figure was obtained from a published study made by the United States Department of Agriculture in the Great Plains.[16]

Interest and depreciation.—The combine represents a considerable investment. The average purchase price of the 10-foot machines was $1,336; of the 12-foot machines $1,849; and of the 16-foot machines $2,216, including all extra equipment except windrower and pick-up. None of the machines had been in use long enough to provide an adequate basis for estimating the length of life. Two hundred fifty-seven combine operators interviewed in the Great Plains area estimated the life of their machines at an average of eight and three-tenths years. As the small combine has been on the market only a short time and improvements are being added each year, it seems probable that few of the combines now in use will be used more than seven years. Even tho not completely worn out, they are likely to be replaced by machines of newer type. One-seventh of the purchase price has therefore been computed as the annual depreciation. Interest at 6 per cent has been charged on the average investment during the life of the machine.

The length of life of the windrower has been estimated at seven years. The average purchase price of a 12-foot windrower was $250 and of a 16-foot machine $366. The pick-up attachments averaged $85 for the 10-foot machines, $92 for the 12-foot, and $111 for the 16-foot.

Total Costs of Harvesting and Treshing with a Combine

A summary of all costs involved in combine operation, with and without the windrower, is shown in Table VII for the various sizes and for hauling. The average cost per acre of hauling grain for all three groups was computed and the same figure was used for each group. The machine charge included interest, depreciation, and repairs on the combine and the equipment used with it, also the cost of gasoline for the auxiliary engine and oil and grease for it and the combine. All man labor was charged at 40 cents per hour. Gasoline for the auxiliary engine was charged at 22 cents per gallon and oil at 75 cents per gallon.

The comparison in the table is misleading because the larger combines were used more nearly to their capacity than the 10-foot machines. It will be remembered that the annual depreciation was calculated as one-seventh of the initial cost of the machine. This would be the same regardless of the number of acres cut, consequently the charge per acre for depreciation (which is a relatively large item) will decrease as the number of acres per year increases. The large difference between the

[16] Reynoldson, L. A., Kifer, R. S., Martin, J. H., Humphries, W. A. "The combined harvester thresher in the Great Plains." U. S. Dept. Agr. Tech. Bull. 70, pp. 27-9.

cost per acre of the 10-foot and the 12-foot machines is due almost entirely to the fact that the average 12-foot machine cut almost twice as many acres as the average 10-foot machine.

TABLE VII

Comparative Cost per Acre of Straight Combining and Windrowing and Picking up for the Same Acreage

(Acreages as found in study)

Item	Method of harvesting					
	Straight combining			Windrowing and picking up		
Width of cut, ft.	10	12	16	10	12	16
Av. no. of acres harvested	210	407	547	210	407	547
Man labor	$0.47	$0.48	$0.43	$0.59	$0.61	$0.56
Horse and truck work	0.17	0.17	0.17	0.17	0.17	0.17
Tractor work	0.44	0.31	0.27	0.70	0.52	0.48
Machine charge	1.85	1.06	1.40	2.14	1.30	1.64
Total cost	$2.93	$2.02	$2.27	$3.60	$2.60	$2.85

The matter of having a crop acreage large enough to keep the combine profitably employed during a large part of the harvest season is one that the prospective owner should carefully consider. Where the farm is not large enough to warrant the purchase of a machine, it may be advisable for two or more neighbors to purchase one co-operatively. Many operators do custom work for their neighbors, charging a certain rate per acre. The rate usually depends on how heavy the crop is and on the condition of the field and the crop.

Relatively large acreages were harvested by three of the machines studied in 1928. One of these was a 10-foot and the other two were 16-foot machines. The average of the three was 50 acres of grain per cutting foot. If all the machines had cut at this rate, the acreages and the costs would have been as shown in Table VIII. These figures emphasize the importance of keeping the combine profitably employed on a relatively large acreage.

TABLE VIII

Computed Average Cost per Acre of Straight Combining and Windrowing and Picking up for the Same Acreage

(Acreage adjusted to capacity of machine)

Item	Method of harvesting					
	Straight combining			Windrowing and picking up		
Width of cut, ft.	10	12	16	10	12	16
Av. no. of acres harvested	500	600	800	500	600	800
Man labor	$0.47	$0.48	$0.43	$0.59	$0.61	$0.56
Horse and truck work	0.17	0.17	0.17	0.17	0.17	0.17
Tractor work	0.44	0.31	0.27	0.70	0.52	0.48
Machine charge	0.75	0.78	0.77	0.87	0.92	0.88
Total cost	$1.83	$1.74	$1.64	$2.33	$2.22	$2.09

Table VIII indicates that the cost per acre would decrease as the size of the machine increases. This advantage may not be so large as these figures indicate. The tractors were charged at the same rate per hour on all farms regardless of the size of machine drawn or the amount of straw handled. More fuel would probably be required for the machines of wider cut. This would offset the slight advantage indicated in favor of the larger machines.

Comparison of Costs of Combine and Binder-Thresher

A comparison between combine harvester and binder-thresher costs is shown in Table IX. The data on costs of the combine have just been presented. The source of data on costs of binder-thresher has been referred to in the discussion of "man labor." All these data have been made comparable by using the same rates for man labor, horse work, tractor work, and other factors in cost as were used in the study of the combine.

TABLE IX

COMPARISON OF COSTS OF HARVESTING AND THRESHING BY DIFFERENT METHODS

Item	Machine used				
	10-ft. combine	12-ft. combine	16-ft. combine	8-foot binder and stationary thresher (N. W. Minn.)	7-foot binder and stationary thresher (S. E. Minn.)
Acres harvested	210	407	547	200	101
Man labor	$0.59	$0.61	$0.56	$1.40	$2.40
Horse and truck work	0.17	0.17	0.17	0.60	1.02
Tractor work	0.70	0.52	0.48	...	...
Machine charge	2.14	1.30	1.64	0.22	0.25
Twine	...	...	...	0.28	0.36
Threshing charge	...	...	...	0.95	1.50
Total cost (average acreage with windrower)	$3.60	$2.60	$2.85	$3.45	$5.53
Total cost (average acreage without windrower)	$2.93	$2.02	$2.27	...	...

Where there is a sufficient acreage of crops to use a combine effectively there seems to be a material saving in its favor. On 160- to 320-acre diversified farms, however, the acreage of crops to be harvested with the combine is too small to afford much advantage. It should be remembered that with the combine the straw is left in the field; with the stationary thresher the straw is stacked. In southeastern Minnesota most of the grain is hauled to the farmstead so that the straw may be stacked in the barnyard or blown into the mow of the barn. On livestock farms, where the straw is needed for feed or bedding, this is an important factor. If the straw is left in the windrow for a time or is spread out on the stubble until after harvest, its feeding value is greatly impaired. It can still be used for bedding. On the small-grain farms, on the other hand, where no use is to be made of the straw, there may be a decided advantage in having it spread on the land.

The cost per acre of harvesting is much higher on the dairy farms in southeastern Minnesota than on the small-grain farms of the Red River Valley. These dairy farms have small fields, a small acreage of grain, and a high yield of both straw and grain. Most of the grain is hauled to the farmstead instead of being threshed in the field, as is the custom on small-grain farms. Smaller threshing outfits are used and the working day is shorter because of the morning and evening chore time spent on livestock. The practice of doing custom work would be necessary in order to have a sufficient acreage of crops to make the use of a combine in this section economical. Methods of recovering the straw would have to be worked out.

A comparison of harvesting and threshing costs under two methods on a large farm in the Red River Valley is shown in Table X. In 1927 a 10-foot tractor binder was used. In 1928 this was replaced by a 10-foot combine harvester and a 12-foot windrower. In spite of an unusually wet harvest season and a heavier crop of grain and straw, the cost per acre was 70 cents lower when the combine harvester was used. By doing custom work for neighbors, the acreage was materially increased. One third more acres were handled in 1928 than in 1927 with the same amount of labor. In evaluating this comparison it should be remembered that in 1927 the straw was all recovered and stacked; in 1928 it was left in the field. The cost of recovering the straw might largely offset the saving from the use of the combine harvester.

TABLE X

COMPARISON OF COST OF HARVESTING AND THRESHING BY DIFFERENT METHODS ON THE SAME FARM

Item	Machine used	
	1927	1928
	10-foot tractor-binder and stationary thresher	10-foot combine and 12-foot windrower
Acres covered	303	419
Man labor	$1.30	$0.96
Horse work	0.39	0.21
Tractor work	0.35	0.69
Machine charge	0.21	0.96
Twine cost	0.27	...
Threshing charge	1.00	...
Total cost	$3.52	$2.82

An advantage of the combine method is that as soon as a field is harvested fall plowing can be started. Even tho harvesting operations are delayed by wet weather the labor force can be kept busy at this important operation. It is not necessary to wait for the threshing crew to clean the fields of grain shocks. This is especially important in the small-grain country where weeds are a serious menace to crops. Early fall plowing is an important factor in their control. Early harvesting leaves more time for this task.