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Rain-Induced Harvest Losses in Swathed and Standing Wheat

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Grain quality and/or grain yield losses can occur when rain or a combination of rain and high humidity delay wheat harvest. Losses in grain quality can result from sprouting and from reduction in test weight. Sprouting causes a degradation of grain proteins and starches, so flour quality is reduced (Gordon et al., 1977) and the grain price deteriorates to the value of feed grain. Yield losses can result from shattering, from a reduction in test weight, and from sprouting in heads (spikes) in a windrowed crop that make contact and become rooted in the soil, and, therefore, are not picked up and threshed.

Climatic conditions in North Dakota during harvest of hard red spring wheat are normally characterized by low rainfall, low humidity, and warm temperatures (Ramirez, 1972; 1973). These conditions favor rapid grain drying with little chance for biological damage to the grain. However, there is a 50% probability of receiving at least 0.1 inch rain per week during weeks 30 through 35 (last week in July to September) and a 15% probability for 0.60 inches during the same time period (Ramirez, 1973). Also, seeding occasionally is delayed in the spring, causing harvest to be extended into a cooler period of the year and a less favorable drying period.

Although losses in grain yield and quality are rain-induced, these losses do not necessarily occur because a standing or windrowed crop is wetted by rain (Wellington and Durham, 1958). The water concentration in non-dormant hard red spring wheat grain must be increased to about 45 to 49%, oven-dry basis,[1] before sprouting is initiated (Bauer and Black, 1983). The time required to overcome dormancy after drying to 12 to 14% water concentration differs with hard red spring cultivars (Bauer and Black, 1983). Wheat grain remains dormant[2] during and after the grain filling period until drying reduces the water concentration to about 12 to 14%.

The vegetative parts of the spike can act as a water reservoir from which the grain can imbibe (absorb) water. The amount of water absorbed by saturated spike vegetative tissue (glumes, rachis, etc.) and in the interstitial areas among the spikelets is sufficient to increase the water concentration in the grain by about 50 percentage units[3], assuming all the water is transferred from the spike vegetative parts to the grain. At maturity, the grain accounts for about 72% of the total dry matter of the spike of hard red spring wheat (Bauer and Black, 1983).

Timgalen wheat grain (Australian soft white wheat) imbibed water at a rate of about 1.9 percentage units per hour in a linear manner from 14% water concentration to saturation at about 100% concentration (Gordon et al., 1977) when the spikes were misted five minutes every hour (except 10 minutes the first hour) and in the interim kept in a high relative humidity environment. Water absorption rate by the intact spike was about six times more rapid than the imbibition rate of the grain itself over the first 10 hours of wetting. Spikes with an initial water concentration of about 14% became saturated at 130 to 150% water concentration, oven-dry basis, in 11 to 12 hours. (Each pound of spikes absorbed 1.3 to 1.5 pounds of water.) Wared hard red spring wheat absorbed water at a rate of 1 percentage unit per minute over a 50-minute period under a constant misting rate (Bauer and Black, 1983). Grain of Olaf wheat imbibed water at a maximum rate of 1.7 percentage units hour in spikes misted to 145% water concentration (Bauer and Black, 1983).

Hard red spring wheat is harvested by the swath-combine and the straight combining (simultaneous cutting and threshing) methods in the northern Great Plains of the United States and Canada. The advantages provided by the swath-combine method over straight combining are: (a) the crop is better protected from wind, hail, and frost when it is in windrows; (b) green weeds are eliminated as a threshing problem; (c) grain water concentration is equalized where field ripening is not uniform because of soil and topographic differences; (d) the cost to artificially dry grain to assure safe storage may be eliminated or reduced, and (e) potential losses from sawfly infestations are reduced (Dodds, 1967). But the swath-combine method requires additional equipment, such as a swather and combine pickup attachment, as well as labor and fuel to operate the swather.

Field and laboratory studies were conducted to develop capacity to forecast the extent of expected crop losses from rainfall events that delay threshing. This report gives the results of a field study conducted to evaluate the effect of varying amounts of rain on grain yield and quality of ripe, standing and windrowed, hard red spring wheat.

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[1]Percent water concentration oven-dry basis, is calculated as:

$$\frac{\text{weight of water in plant tissues}}{\text{weight of oven-dry plant tissue.}} \times 100$$

Plant tissues are dried at 156°F (69°C) and the weight of water is the difference between the fresh and oven-dry weight. The calculation, therefore, is based on a common, constant tissue water base.

Plant water concentration often is expressed on a fresh weight basis and is calculated as:

$$\frac{\text{weight of water in plant tissue}}{\text{fresh weight of plant tissue.}} \times 100$$

In this method, the calculation is based on a shifting tissue water base.

[2]A definition of dormancy is that the seed will not germinate when placed under optimum conditions of water, temperature, and light.

[3]This means that the weight of water increased by half the weight of oven-dry grain. When expressed on an oven-dry basis, changes in grain water concentration represent only changes in water quantity.

MATERIALS AND METHODS

Field experiments were conducted in 1979, 1980, and 1981 on privately-owned farm fields. The swath-combine and straight combine methods of harvesting were compared each year by measuring grain yield, test weight, and grain nitrogen (protein) concentration. In addition, comparisons also were made among three swathing stubble heights in 1980 and between two swathing widths in 1981. Farm-sized swathers and combine were used in all harvesting procedures.

When rainfall did not occur to wet the crop, water was sprinkler irrigated on the windrows and the standing crop to simulate rain. The amount of water applied by sprinkler was measured with cans placed on the sprinkled area. Rain was measured with a standard rain gauge. Data in Table 1 indicate the amount of rain and supplemental water applied during each experiment.

The combine-threshed grain was collected in bags, oven-dried at 156°F, cleaned, weighed, and yields calculated on the basis of 60 pounds per bushel. Test weight measurements were made with official test weight apparatus on a sub-sample randomly removed from the total sample. Grain nitrogen concentration was measured by a micro-Kjeldahl procedure (Shuman et al., 1973). All measurements are expressed in terms of oven-dry grain.

Following threshing, a square meter (1.2 square yards) area was vacuumed near the center of each plot to pick up grain that had fallen to the soil surface. The kernels were separated from the soil and straw, oven-dried, then counted and weighed.

1979

The experiment was initiated September 7 in a field seeded to several hard red spring wheat cultivars in 6-inch rows.[4] Each plot of standing and windrowed crop was an area 10.5 feet wide and 60 feet long .The swath stubble height was about 9 inches. Each treatment of six threshing dates and two harvesting methods (straight and swath-combine) was repeated three times. Except for 0.82 inches rain, all water applied on a given day was sprinkler-irrigated on the plots over a period of 45 minutes at a rate of about an inch per hour (Table 1).

1980

The experiment was conducted in a field of Wared hard red spring wheat seeded in 6-inch rows.[5] Swathed plots were cut on August 7 at stubble heights of 4, 9, and 14 inches. Each plot of standing and win-

[4]This was the only field in the area that had not been harvested when notice was received of financial support to conduct the study.

Table 1. Interval between swathing and threshing, and amount of water applied to windrows and standing grain.

		Year					
		1979		1980		1981	
Method	**Threshing**[1]	**Interval**[2]	**Water**[3]	**Interval**[2]	**Water**[3]	**Interval**[2]	**Water**[3]
	date	days	inches	days	inches	days	inches
Swath	1	10	0.82[4]	—	—	6	0.06
	2	13	1.57	18	4.32[5]	10	1.40
	3	17	2.32	21	5.42[5]	16	2.34
	4	20	3.08	29	6.76[6]	22	3.14[9]
	5	24	3.83	35	7.86[6]	28	4.39
	6	29	4.58	53	10.03[8]	34	5.79[10]
Straight	1	14	0.82	—	—	6	0.06
	2	17	1.57	21	5.42[5]	10	1.40
	3	20	2.33	28	7.86[6]	16	2.34
	4	24	3.08	35	8.96[6]	22	4.26[9]
	5	28	3.83	40	9.11[7]	28	5.46
	6	32	4.64	53	10.55[8]	34	6.91[11]

[1]See Table 2 for the threshing dates.
[2]From date of swathing to threshing.
[3]Sum of rainfall and water applied by sprinkler system.
[4]Except for the 0.82 inches, all water was applied by sprinkler.
[5]Of this total, 4.32 inches was rain.
[6]Of this total, 5.66 inches was rain.
[7]Of this total, 5.81 inches was rain.
[8]Of this total, 6.15 inches was rain.
[9]Windrows were covered with plastic sheets during a 1.12-inch rain event.
[10]Of this total, 0.19 inches was rain from 4 storms.
[11]Of this total, 1.31 inches was rain from 5 storms.

drowed crop was an area 10.5 feet wide and 45 feet long. Each treatment of six threshing dates and of harvesting methods (straight and swath-combine of three stubble cutting heights) was repeated three times. However, because of threshing problems, data of the first threshing date are not included in the text. During the test period, windrowed and standing crop plot areas were wetted with more than 10 inches of water, with slightly more than 6 inches from rain (Table 1). Water sprinkled on the plots on a given day was applied over a period of 45 minutes at a rate of about 1.5 inches per hour.

The number of damaged kernels (sprouted and discolored) was determined from a 0.5 pint subsample randomly removed from the total sample. Examination of kernels was made under magnification by one person. The kernel was classed as sprouted when the radicle (rudimentary root) was visible and as discolored when dark blemishes were observed. When the kernel was both sprouted and discolored, it was classed as sprouted.

1981

The experiment was conducted in a field of Olaf hard red spring wheat seeded in 6-inch rows. Swathed plots were cut August 18 leaving a stubble height of about 9 inches. All plots were 50 feet long. The standing crop plots and one set of plots of swathed crop were 10.5 feet wide, and the other set of plots of swathed crop was 15 feet wide. Each treatment of six threshing dates and of harvesting methods (straight and swath-combine of two swath widths) was repeated four times.

Water sprinkled on the plots was applied over a 2.5 to 2.75-hour period, usually beginning about 4 o'clock in the afternoon (Table 1). Following the second threshing, the windrows were covered with clear plastic sheeting at about 9:00 a.m. (CDT) on the day after sprinkling to reduce the water evaporation rate. The plastic sheet was left on the windrows for 24 hours after the second threshing date, for 55 hours after the third threshing date, and for 78 hours after each of the fourth and fifth threshing dates.

The number of sprouted and of discolored kernels was determined under magnification from a constant volume subsample of about 200 kernels. The system to determine damage was identical to the one described above in 1980. The same person made the examinations in 1980 and 1981.

Straw water concentration was determined on a subsample collected at threshing by weighing the straw before and after oven-drying at 156°F.

[5]Because of drouth in the area and hail at the ARS field station, no suitable dryland-managed wheat fields were available for the experiment. The field selected was irrigated and had not been damaged by hail.

RESULTS AND DISCUSSION

The amount of water required to saturate a mature crop is relatively small. To illustrate: the water in the grain and straw of a hard red spring wheat crop yielding 50 bushels per acre, saturated to 150% water concentration, weighs about 9000 pounds. (Straw and grain weight are about equal in a crop which yields 50 bushels per acre; Bauer and Zubriski, 1978). Nine thousand pounds of water is equivalent to 0.04 inches rain falling on one acre. (An inch of water over an acre weighs 113.26 tons). However, a standing crop of spring wheat seeded in 6 to 7-inch rows will not be saturated by 0.04 inches rain because not all the raindrops will strike the crop. If one assumes that only 25% strike the crop and that all the rain striking the crop is absorbed and none is evaporated, then the amount of water needed could be supplied by 0.16 inches rain.

The amount of rain required to saturate a windrow is greater than is required for the standing crop because the windrow concentrates the tissue into a small area. The quantity of tissue in a windrow will vary with the quantity produced per unit area, stubble cutting height, and with swath width. The amount of rain needed to saturate yard-wide windrows of a crop of various yields, cut with a swather of various widths, is shown in Figure 1. Assuming all the rain falling on the windrows is absorbed and none is evaporated, a yard-wide windrow of a 30-bushel-per-acre crop cut with an 18-foot swather could be saturated with about 0.21 inches of rain. (Highest recorded stage average wheat yield in North Dakota is 28.6 bushels per acre in 1971; Smith, 1978).

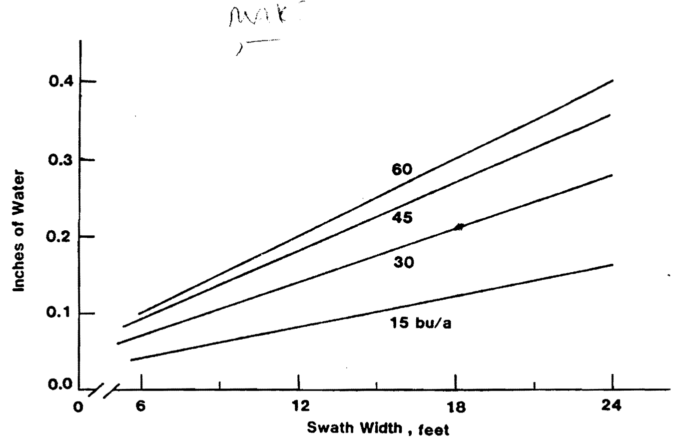

Figure 1. Inches of Water Needed to Wet Yard-wide Windrows of Wheat Tissue of Varying Grain Yield and Swath Width to 150% Water Concentration.

Grain Yield

Harvested grain yield differed between the straight and swath-combining methods only in 1979

(Table 2) and then only at the first and sixth threshing dates. (Data from windrows formed with a 10.5-foot swath cut at about a 9-inch height were used for the comparison). On the first date, yields were higher on straight combined plots and on the sixth date on the swath-combined plots. (The low yield in the windrow at the first threshing date is attributed to experimental error.) The amount of grain loss by shattering in 1979, as measured by the amount vacuumed from the plots (Table 3), generally reflected the same trend as the threshed yield in that shattering losses were highest with straight combining by the sixth threshing date.

Shattering losses in Olaf wheat in 1981 also were higher on straight combining than on windrows at the fourth and fifth threshings, but they were lower at the sixth threshing (Table 3). The reason for the apparent reduced loss at the sixth threshing date is that more of the grain that had been shattered from the standing crop sprouted, rooted, and became anchored to the soil, and therefore was not vacuumed up.

The ease of shattering differs among varieties. Shattering in standing grain is caused by the impact of heads striking other heads through wind action and/or by the impact of raindrops or hail. Wind is not a causative factor of shattering in a windrowed crop. Less shattering occurs from raindrop or hail impact in the windrowed than standing crop because fewer heads are exposed to direct hits.

Table 2. Grain yield comparisons between swath and straight combine methods of cutting hard red spring wheat.

	Year					
	1979		1980		1981	
	Method		Method		Method	
Threshing[1]	**Swath**[2]	**Straight**	**Swath**[2]	**Straight**	**Swath**[2]	**Straight**
date	bu/ac[3]		bu/ac[3]		bu/ac[3]	
1	27.7 d	34.9 a	—	—	27.2 a	28.8 a
2	30.9 bc	32.6 ab	30.9 a	35.0 a	26.7 a	28.1 a
3	32.1 bc	33.1 ab	30.0 a	28.0 a	28.2 a	27.1 a
4	29.6 cd	31.7 bc	32.1 a	32.9 a	26.2 a	23.3 a
5	31.5 bc	31.3 bc	36.4 a	34.6 a	24.1 a	23.1 a
6	30.8 bc	23.7 e	34.5 a	34.8 a	22.0 a	22.9 a

[1]Threshing dates:
1979 Swath: 9/17, 9/20, 9/24, 9/27, 10/01, 10/04;
1979 Straight: 9/21, 9/24, 9/27, 10/01, 10/04, 10/09;
1980 Swath: 8/25, 8/28, 9/5, 9/11, 9/29;
1980 Straight: 8/28, 9/4, 9/11, 9/16, 9/29;
1981 Swath: 8/24, 8/28, 9/3, 9/9, 9/15, 9/21;
1980 Straight: 8/24, 8/28, 9/3, 9/9, 9/15, 9/21.
[2]Stubble height 9 inches, cut with 10.5 foot swather.
[3]Within a year, yield data followed by the same letter do not differ at the 5% confidence level.

Table 3. Grain vacuumed from the ground comparing swathed and straight combine methods of cutting hard red spring wheat.

	Year					
	1979		1980		1981	
	Method		Method		Method	
Threshing[1]	**Swath**[3]	**Straight**	**Swath**[3]	**Straight**	**Swath**[3]	**Straight**
date	bu/ac		bu/ac		bu/ac	
1	4.2 b[2]	2.0 bc	—	—	0.4 e[2]	0.8 e
2	1.6 c	2.8 bc	1.4 a[2]	2.4 a	0.6 e	0.7 e
3	2.8 bc	1.5 c	8.7 a	10.6 a	1.6 de	1.8 de
4	2.0 bc	1.8 c	4.5 a	7.6 a	1.8 de	4.8 ab
5	2.9 bc	3.6 bc	—	—	1.8 de	3.6 bc
6	3.0 bc	6.9 a	16.8 a	10.0 a	5.2 a	2.7 cd

[1]See Table 2 for threshing dates.
[2]Within a year, data followed by the same letter do not differ at the 5% confidence level.
[3]Stubble height 9 inches, cut with a 10.5 foot swather.

Harvested grain yields in 1980 from windrows on 4-inch stubble averaged 5.2 bushels per acre higher than on 9-inch stubble and 8.9 higher than on 14-inch stubble (Table 4), about 14 to 23% difference. Further, yields on 4-inch stubble were consistently higher than on 14-inch stubble at all threshing dates, and higher than on 9-inch stubble on all except the sixth threshing. The lower harvested yields on taller stubble are attributed to more extensive windrow:soil contact, allowing more of the sprouting grain to root and become anchored to the soil. The taller stubble is less rigid and bends more easily under windrow weight allowing more of the windrow to lie on the soil instead of being supported above the soil surface. Also, on the 14-inch stubble, much of the windrow fell through the stubble during the first rain. Windrows are pushed into and through stubble by the energy that is transferred from raindrop impact and the added weight of absorbed water.

Table 4. Effect of stubble height on grain yield, 1980.

Threshing[1]	Stubble height, inches 4	9	14
date		bu/ac	
2	36.3 b[2]	30.9 cd	29.0 de
3	35.0 bc	30.0 de	29.9 de
4	41.5 a	32.1 bcd	30.8 cd
5	41.2 a	36.3 b	30.0 de
6	35.8 b	34.5 bc	26.2 e
Average	38.0 a[3]	32.8 b	29.1 b

[1]See Table 2 for threshing dates.
[2]Among these three columns, yield data followed by the same letter do not differ at the 5% confidence level.
[3]Within this row, yield data followed by the same letter do not differ at the 5% confidence level.

The volume and length of straw in the windrows are reduced as stubble cutting height increases. The lower the volume of straw in relation to stubble height the more easily the windrow can fall down through the upright stubble. In 1980, the average height of Wared wheat was 28 inches, so the proportion of stubble height to straw length was 1:6, 1:2, and 1:1 for 4-inch, 9-inch, and 14-inch stubble, respectively. The volume of tissue in the windrows from a given cutting height will vary with swath width. Crop height, stubble cutting height, and swath width (spike population) need to be considered to determine the ideal windrow volume to be supported on a given stubble. However, consideration may need to be given to the ratio of total plant material-other-than-grain to grain for maximum efficiency in separating grain from straw as these pass over the combine straw-walker (Reed et al., 1970). In 1980, 4.32 inches of rain was received before the first windrows were picked up and threshed (Table 1). The initial 2.02 inches fell in one storm within three days after swathing, and this was followed by another 1.0 inches a week after the first storm.

Although the short stubble gave better support to windrows and provided a yield advantage over taller stubble in a wet harvest year like 1980, some of the yield advantage gained at harvest with short stubble may be offset in some succeeding years because short stubble has less snow-trapping capability than tall stubble. With less snow-trapping there is a reduction in the water storage potential for the next crop. This is illustrated from four years' data developed at Mandan.[6] On 14-inch stubble, each inch of stubble above 2 inches height increased the average available soil water content 0.15 inches in the upper 3 feet of soil from late autumn to spring seeding, a total of 1.80 inches, while on 8-inch stubble, each inch of stubble above 2 inches height increased the soil water content about 0.09 inches in the upper 3 feet over the same time period. The long-term average contribution to wheat grain yield from an inch of stored soil water at seeding is about 2.4 bushels per acre (Bauer, 1972).

Swath width, 10.5 versus 15 feet, had no effect on grain yield in 1981 (Table 5).

Table 5. Measurement comparisons between windrows from 10.5- and 15-foot swaths, 1981.

Measurement	Swath width, feet 10.5	15
Grain yield (bu/ac)[1]	25.7 a	25.7 a
Test weight (lbs/bu)	55.9 a	55.1 b
Grain nitrogen (% N)	3.33 a	3.37 a
Number sprouted (%)[2]	4 b	5 a
Number damaged (%)[2]	10 a	7 b

[1]Within a row, the data followed by the same letter do not differ at the 5% confidence level.
[2]Percent of the total number of kernels in the sample.

Test Weight

Test weight of grain harvested by straight combining was equal to that harvested by the swath-combine method in 1979 and higher at most threshing dates in 1980 and 1981 (Table 6).

The differences in test weight between harvesting methods likely is associated with differences in water evaporation rate. For a given amount of water applied to the tissues, the more rapidly this evaporates the less water is imbibed by the grain. Water evaporation rate from spikes of the standing crop is considered to be faster than from spikes in windrows because of better air circulation. Seeds swell when they take up water and remain partially swelled after drying. This irreversible change in seed

[6]Unpublished data, Bauer.

Table 6. Test weight comparisons between swathed and straight combine methods of cutting hard red spring wheat.

	Year					
	1979		1980		1981	
	Method		Method		Method	
Threshing[1]	Swath[3]	Straight	Swath[3]	Straight	Swath[3]	Straight
date	lbs/bu		lbs/bu		lbs/bu	
1	58.1 a[1]	57.6 a	—	—	59.2 a[3]	58.1 b
2	57.4 a	57.9 a	56.5 cd[2]	57.4 ab	56.9 de	57.3 cd
3	57.4 a	57.4 a	56.2 d	58.0 a	55.2 g	57.6 bc
4	57.0 a	58.1 a	55.3 e	58.2 a	55.2 g	56.5 e
5	57.2 a	58.7 a	55.2 e	57.0 bc	54.4 h	56.3 ef
6	56.7 a	57.8 a	54.2 f	57.9 a	54.3 h	55.7 fg

[1]See Table 2 for threshing dates.
[2]Within a year, test weight data followed by the same letter do not differ at the 5% confidence level.
[3]Stubble height 9 inches, cut with 10.5 foot swather.

Table 7. Effect of stubble height on grain test weight and grain nitrogen (N) concentration, 1980.

	Stubble height, inches			
Measurement	4	9	14	Standing
Test weight (lbs/bu)[1]	55.0 bc	55.5 b	54.8 c	57.7 a
Grain N, field (%)[2 5]	2.25 b	2.32 b	2.34 b	2.52.a
Grain N, good (%)[3]	2.26 ab	2.16 b	2.35 a	2.32 a
Grain N, damaged (%)[4]	2.52 b	2.55 b	2.40 c	2.91 a

[1]Within any row, measurement data followed by the same number do not differ at the 5% confidence level.
[2]Grain N concentration of kernels as threshed in the field.
[3]Grain N concentration of kernels not discolored or sprouted.
[4]Grain N concentration of sprouted and discolored kernels.
[5]Grain N times 5.7 equals percent protein.

size is the cause of lowering of test weight (Ciha, 1981). The extent of swelling likely is related to the amount of water absorbed above an unknown minimum amount rquired to initiate expansion.

Because of the warm, dry weather that prevailed in 1979 when the experiment was conducted, the water sprinkled on the plots evaporated in less than a day. Hence water uptake by the grain was minimal and no change in test weight occurred.

In 1980 test weight was consistently higher in the standing crop than the windrowed crop. Test weight was first measured after 4.32 inches rain had wetted the crop, so the test weight change that occurred from this amount of rain is unknown. Also, test weight of grain from windrows on the 14-inch stubble was about 0.7 pounds per bushel lower than grain from 9-inch stubble windrows (Table 7) but did not differ from that of the 4-inch stubble. A larger portion of the windrow on the 1-inch stubble made soil contact, so evaporation rate likely was slower than in windrows on the 9-inch stubble.

After the second threshing in 1981, the windrows were covered with clear plastic sheets about 16 hours after wetting to reduce the rate of evaporation from the windrows relative to the standing crop. The effect of this treatment is apparent in the lower test weights, as shown in data in Table 6. Also, the lower test weight associated with the 15-foot swaths compared to the 10.5-foot swaths in 1981 (Table 5) appear to be a reflection of a slower evaporation rate in the larger windrows.

Grain Protein

Grain nitrogen concentration (protein) differed between harvesting methods in 1980 (Table 8) but not in 1979 and 1981. The difference at the fourth threshing in 1979 was not found at the other threshing dates. In 1980, the grain nitrogen was lower in the 9-inch stubble swathed crop than standing crop, an average of 0.20 percentage units over the five threshing dates. But, there was no difference in grain nitrogen concentration among the three swath stubble-cutting heights as threshed in the field (Table 7), that is, before separation of "good" from "damaged" kernels. Further, the concentration was lower in the "good" kernels on the 9-inch stubble and was higher in the "damaged" kernels of the standing crop than any of the windrowed crop (Table 7). No reason can be given for this anomalous outcome.

Within any stubble height in 1980, nitrogen concentration in the "damaged" kernels averaged consistently higher than in the "good" kernels. The reason for the higher nitrogen concentration in "damaged" grain is that in the process of sprouting, carbohydrates are consumed in respiration and carbon dioxide is released. With the loss of carbohydrates, the apparent nitrogen concentration increases. Also one could expect protein synthesis taking place as germination begins. Proteins are not consumed during respiration but are utilized in the synthesis of other organic nitrogenous compounds (Meyer and Anderson, 1952).

Swath width, 10.5 versus 15 feet, had no effect on grain nitrogen concentration in 1981 (Table 5).

Grain Damage

Damage to grain, sprouting plus discoloration, was severe in the high rainfall year 1980, generally increasing with delay in threshing (Table 9, 10). At the initial threshing, damage was higher on the 9-inch than either the 4-inch or 14-inch stubbles. On the subsequent threshings, damage was as high or higher in grain on 4-inch stubble as on the taller stubbles. The relatively lower sprouting percentage on the 9- and 1-4 inch stubble is likely a reflection of sprouted grain becoming anchored to the soil and not being picked up and included in the threshed grain. Damage also was observed in grain harvested by the straight combine method (Table 10), but the severity of damage was roughly 50% less, supporting the premise that spikes on the standing crop dry faster than spikes in the windrows.

Table 9. Effect of stubble height and threshing date on percent damage to wheat grain, 1980.

	Stubble height, inches			
Threshing[1]	4	9	14	Average
date		percent		
2[2]	9 f [3]	24 cde[3]	7 f[3]	13 d[4]
3	27 cd	25 cde	16 def	23 c
4	35 bc	31 c	12 ef	26 c
5	48 ab	28 cd	23 cde	33 b
6	50 a	45 ab	51 a	49 a
Average	34 a[5]	30 a	22 b	

[1]See Table 2 for threshing dates.
[2]Dates: 8/25, 8/28, 9/5, 9/11, and 9/29
[3]Among these three columns data followed by the same letter do not differ at the 5% confidence level.
[4]Within this column data followed by the same letter do not differ at the 5% confidence level.
[5]Within this row, data followed by the same letter do not differ at the 5% confidence level.

Damage to kernels was less severe in 1981 than 1980 (Table 10). Differences between harvesting methods in 1981 were not significant until the fourth threshing. (Windrows were covered with plastic sheets after the second threshing). Covering the windrows with clear plastic sheets to reduce the

Table 8. Grain nitrogen concentration comparisons between swathed and straight combine methods of cutting hard red spring wheat.

	Year					
	1979		1980		1981	
	Method		Method		Method	
Threshing[1]	Swath[4]	Straight	Swath[4]	Straight	Swath[4]	Straight
date	% N		% N		% N	
1	2.82 bc[2]	2.79 bc	—	—	3.37 a[2]	3.47 a
2	2.93 ab	2.95 ab	2.30	2.48	3.37 a	3.27 a
3	2.85 bc	2.84 bc	2.36	2.54	3.21 a	3.38 a
4	2.72 c	3.09 a	2.25	2.49	3.40 a	3.26 a
5	2.77 bc	2.86 bc	2.40	2.70	3.36 a	3.27 a
6	2.81 bc	2.96 ab	2.31	2.42	3.28 a	3.49 a
Avg.			2.32 b[3]	2.52 a[3]		

[1]See Table 2 for threshing dates.
[2]Within a year, nitrogen concentration data followed by the same letter do not differ at the 5% confidence level.
[3]Nitrogen concentration was lower in the windrows than in the standing grain.
[4]Stubble height 9 inches, cut with 10.5 foot swather.

Table 10. Percent of damaged kernels in threshed grain in 1980 and 1981 as affected by date and cutting method.

	1980		1980	
	Method		Method	
Threshing[1]	Swath[4]	Standing	Swath[4]	Standing
date	percent		percent	
1	—	—	6 d[3]	9 bcd[3]
2	24	12	11 bc	10 bcd
3	25	11	11 bc	8 cd
4	31	13	14 ab	7 cd
5	28	25	19 a	8 cd
6	45	23	19 a	9 bcd
Average	30 a[2]	17 b	13 a[2]	8 b

[1]See Table 2 for threshing dates.
[2]Within a year, data of averages followed by the same letter do not differ at the 5% confidence level.
[3]Among these two columns, exclusive of the average values, data followed by the same letter do not differ at the 5% confidence level.
[4]Stubble height 9 inches, cut with 10.5 foot swather.

evaporation rate also likely raised the temperature in the windrows and contributed to increased damage. More of the damage was a result of microbial activity, as reflected by discoloration, than sprouting. (Data are not shown).

Grain damage (sprout plus discoloration) of less than 3% difference was statistically significant between the 10.5 and 15-foot swaths in 1981 (Table 5).

Water in Straw

Water concentration in the straw of the 1981 standing crop was consistently higher than in the straw from windrows (Table 11). At the same time, the water concentration in the grain, while differing significantly, differed by no more than two percentage units between the windrowed and standing crop. Apparently the straw of a standing crop continues to absorb water from the soil after it is mature. This can affect the ease of threshing grain to be straight combined.

SUMMARY

1. The amount of water needed to saturate a standing crop of wheat yielding 50 bushels per acre, grown in 6 or 7-inch spacing, could be supplied by 0.16-inch rain, provided that all the rain striking the tissue is absorbed by it and there is no water loss by evaporation.

2. Yard-wide windrows of a 30-bushel per acre crop cut with an 18-foot swather could be saturated with about 0.21 inches rain, provided there is no runoff from the windrow and no water loss by evaporation.

3. Harvested grain yields differed between straight combining and windrows formed with a 10.5-foot swather, leaving about a 9-inch stubble, in one year out of three and only at the sixth threshing date.

Table 11. Water concentration in the grain and straw at threshing as affected by cutting method, 1981.

	Grain			Straw		
	Cutting method			Cutting method		
	Swath (feet)			Swath (feet)		
Threshing[1]	10.5	15	Standing	10.5	15	Standing
date		% water			% water	
1	8[2]	8	10	10[2]	9	37
2	9	11	13	8	8	17
3	10	12	11	—	—	—
4	9	10	11	6	4	31
5	13	12	14	11	13	23
6	13	16	14	9	10	18
	11 b[3]	11 b	12 a	9 b[4]	9 b	25 a

[1]See Table 2 for threshing dates.
[2]Statistically the water concentration did not differ in the grain or straw within a given harvest.
[3]Within this row, data followed by the same letter do not differ at the 5% confidence level.
[4]Within this row, data followed by the same letter do not differ at the 5% confidence level.

4. Harvested grain yields on 4-inch stubble averaged 14 and 23% higher than on 9-inch and 14-inch, respectively. Long stubble, less rigid, allowed a greater opportunity for contact between the windrow and soil. Also, short stems more readily fell between or were driven between the stubble by raindrop impact and thus made contact with the soil. More anchoring (sprouting grain rooting in soil) occurred on 9-and 14-inch stubble than 4-inch stubble.

5. After each rain, the standing crop lost some of its erectness. Hence, the required cutting height of straight combining crop was lowered with each date to assure that all spikes were captured and threshed.

6. Test weight of grain harvested by straight combining was equal to or higher than that harvested by the swath-combining method. The reason likely is associated with water evaporation rate. Spikes of the standing crop likely dry faster than spikes in windrows, because of better air circulation. Test weight decreases because seeds swell when they take up water and remain at least partially swelled after subsequent drying.

7. Grain protein differed between cutting methods in one year of three. Protein in sprouted kernels was at a higher concentration than in kernels not observed to have sprouted. In the sprouting process, carbohydrates are consumed in respiration and carbon dioxide is released. Proteins are not consumed in respiration. Hence, an apparent increase in protein is measured because of a decrease in carbohydrate concentration.

8. Sprouting was severe in the windrows in a year when high rainfall occurred after swathing. In general, severity increased with increased delay in threshing. Sprouting also occurred in grain harvested by the straight combine method, but the severity of damage was about 50% less than in the windrowed crop.

9. Water concentration in the straw of the 1981 standing crop was consistently higher than in the straw in windrows at each threshing date, the smallest difference being 8 percentage units and the largest 27 percentage units. Simultaneously, the water concentration in the grain was higher in standing grain than windrowed by no more than two percentage units at any threshing date.

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