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WHEAT STORAGE RESEARCH AT HUTCHINSON, KANS., AND JAMESTOWN, N DAK
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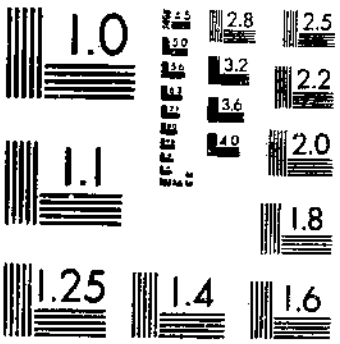

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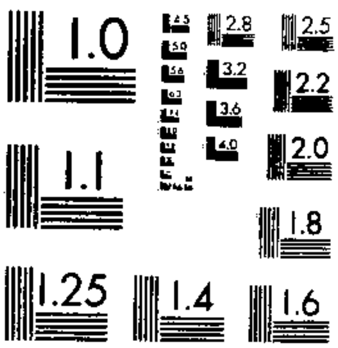

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Wheat Storage Research

at Hutchinson, Kans., and Jamestown, N. Dak.

By J. L. Schmidt

Technical Bulletin No. 1113

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CONTENTS

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Wheat Storage Research

at Hutchinson, Kans., and Jamestown, N. Dak.[1]

By J. L. Schmidt, *associate agricultural engineer, Agricultural Engineering Research Branch, Agricultural Research Service*

Cooperative wheat storage research was started in 1941 at Hutchinson, Kans., in the hard red winter wheat area, and at Jamestown, N. Dak., in the hard red spring wheat area, by the United States Department of Agriculture [2] and the Kansas and the North Dakota Agricultural Experiment Stations at the request of the Commodity Credit Corporation for assistance in the management of government-owned wheat in storage. Field work was concluded in 1946. Used in the study were a large number of Commodity Credit Corporation steel bins of typical farm-type construction, of 1,000- to 5,000-bushel capacity.

The study dealt with engineering and entomological problems affecting the safe storage of wheat.

Engineering research [3] included bin construction, bin floor designs, measurement of wheat temperatures, grain ventilation, and related

[1] Submitted for publication Oct. 4, 1954. This is the final report on these studies. Various findings previously have been reported in technical journals, in mimeographed form, or in the following publications of the U. S. Department of Agriculture:

Shedd, C. K., and Cotton, R. T. STORAGE OF SMALL GRAINS AND SHELLED CORN ON THE FARM. U. S. Dept. Agr. Farmers' Bul. 2009, 30 pp., illus. 1949.

Stahl, B. M. GRAIN BIN REQUIREMENTS. U. S. Dept. Agr. Cir. 835, 23 pp., illus. 1950.

Walkden, H. H., and Schwitzgebel, R. B. EVALUATION OF FUMIGANTS FOR CONTROL OF INSECTS ATTACKING WHEAT AND CORN IN STEEL BINS. U. S. Dept. Agr. Tech. Bul. 1045, 20 pp., illus. 1951.

[2] The cooperating agencies of the U. S. Department of Agriculture are now represented by the Agricultural Engineering Research Branch, Agricultural Research Service; Biological Sciences Branch, Agricultural Marketing Service; and Grain Division, Commodity Stabilization Service.

[3] Engineering studies at Hutchinson were under the immediate supervision of W. R. Swanson, assistant agricultural engineer, until June 1943, and of E. R. Gross, associate agricultural engineer, from November 1943 to October 1946. Studies at Jamestown were under the immediate supervision of M. G. Cropsey, junior agricultural engineer, until August 1941, and then of B. M. Stahl, associate agricultural engineer. General supervision of the engineering phases of wheat storage investigations was by H. J. Barre, formerly senior agricultural engineer, until 1943, then by W. V. Hukill, principal agricultural engineer. Dr. Barre was assisted by C. F. Kelly, formerly associate agricultural engineer, until the fall of 1942, and then by J. L. Schmidt, assistant agricultural engineer. Mr. Schmidt maintained a central file of data at Ames, Iowa, and was responsible for the analysis of the data and preparation of this report.

F. C. Fenton, head, Department of Agricultural Engineering, Kansas State College, and W. T. Promersberger, head, Department of Agricultural Engineering, North Dakota State College, gave valuable advice on the conduct of the engineering studies in their States.

activities. Entomological research [4] dealt with analyses of insect abundance and species and their effective control by fumigants. Preservation of wheat in bins by improved management practices was a joint responsibility.

Wheat storage structures and labor and equipment for handling wheat and maintaining bins and other property for use in these studies were provided by the Commodity Credit Corporation through the Kansas and North Dakota State and county agricultural stabilization and conservation committees.[5]

This report deals primarily with agricultural engineering phases of the investigations, but includes a section on management studies, which were a joint responsibility of engineers and entomologists. Pertinent data relating to insects are included as criteria for evaluating all storage results.

OBJECTIVES

The general objectives of the research studies were: (1) To determine the types of storage structures that will preserve the quality of wheat stored on farms and the market grades of wheat that can be safely stored for long periods; (2) to determine accurately the condition and changes in the condition of wheat during storage in typical bins, so that conditions which might adversely affect wheat storage in similar bins can be foreseen and corrected before harm results; (3) to develop and test methods of conditioning grain by cleaning and turning and of cooling by means of natural ventilation so as to reduce insect damage and avoid injurious local concentrations of moisture; (4) to determine the relation of bin size to the cost of storage; (5) to determine the effect of various grain moisture contents, temperatures, and dockage and foreign material percentages on the "storability" of grain and on insect activity; and (6) to determine the identity, importance, and habits of insects infesting stored wheat and the best fumigants and fumigation practices for their control.

MATERIALS

TYPES OF BINS

All the grain bins first used for the wheat storage studies at Hutchinson and Jamestown were of circular corrugated galvanized-steel construction (fig. 1). Later, because of material shortages created by World War II, prefabricated wood bins and several types of experimental and temporary grain bins were added to the bin sites for structural and quality studies. Approximately 200 storage bins of various types and sizes were available for research work at each station. The bins available for the studies are listed in table 1.

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[4] Entomological investigations were made under the immediate supervision of H. H. Walkden, senior entomologist, and R. B. Schwitzgebel, formerly entomologist, and under the general supervision of R. T. Cotton, principal entomologist, Biological Sciences Branch, Marketing Research Division, Agricultural Marketing Service.

[5] E. A. Ellison, formerly grain storage specialist, Grain Division, Commodity Stabilization Service, aided in the conduct of this research in many ways.

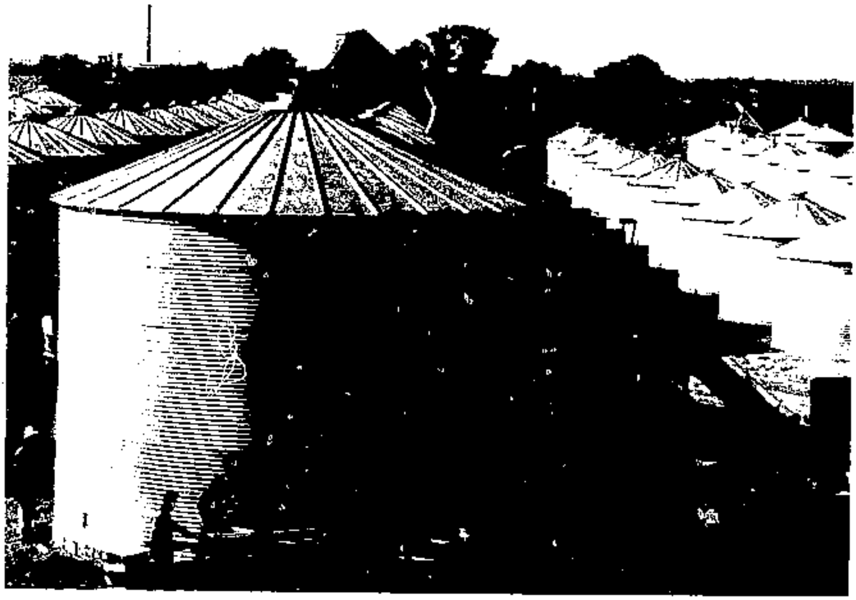

FIGURE 1.—Part of the experimental steel bins at Hutchinson, Kans. The same types were used at Jamestown, N. Dak. The bin in the foreground has a capacity of 5,000 bushels; those at the right, 1,000 bushels, and at the left, 2,740 bushels.

ARRANGEMENT OF BINS

The steel bins were so spaced that grain could be turned from one bin to the next in the same row, or into a bin in an opposite row, by using one farm elevator, thus eliminating unnecessary trucking. Wood bins and temporary bins were added after the original steel bins were erected in 1941.

SOURCE AND CONDITION OF THE WHEAT

Wheat from terminal elevators was placed in experimental storage at the bin sites as follows:

Year	*Hutchinson, Kans.*	*Jamestown, N. Dak.*
1941	288,510 bu. in 148 bins	286,200 bu. in 111 bins.
1942	71,360 bu. in 26 bins	25,772 bu. in 20 bins.
1943	35,090 bu. in 24 bins	18,450 bu. in 7 bins.

It was wheat of the condition that may be acquired by the Commodity Credit Corporation (CCC) for storage at any time. It graded mostly No. 2 and No. 3, but a few of the bins were filled with No. 1 and No. 4 wheat. It was low-moisture-content wheat, averaging 11.3 percent at Hutchinson and 12.4 percent at Jamestown.

Some of the wheat used in short-time experiments was disposed of at end of 1 year and some was sold from time to time to meet war needs. However, a large part was held in storage until 1944 and 1945, and some until 1946.

TABLE 1.—*Types and capacities of bins available for wheat storage studies, Hutchinson, Kans., and Jamestown, N. Dak.*

Bin type and description	Bin capacity	Hutchinson		Jamestown	
		Bins	Total capacity	Bins	Total capacity
Standard steel bins:	*Bushels*	*Number*	*Bushels*	*Number*	*Bushels*
14' dia. x 8' high	1,000	84	84,000	70	70,000
12' dia. x 11' high	1,000	1	1,000		
14' dia. x 11' high	1,350	2	2,700		
18' dia. x 8' high	1,650	2	3,300		
18' dia. x 11' high	2,250	2	4,500		
18' dia. x 13.5' high	2,740	85	232,900	103	282,220
22' dia. x 13.5' high	4,100	2	8,200		
22' dia. x 16' high	5,000	2	10,000		
Bolted steel tank:					
21.5' dia. x 16' high	4,600	1	4,600		
Experimental concrete block:					
12' x 24' x 8'	2,000	1	2,000		
Prefabricated and precut wood bins:					
12' x 16' x 10'	1,600	11	17,600		
Special wood bins:					
8' x 16' x 8', with roll roofing on shed-type roof	850			2	1,700
15.3' dia. x 8' high, 12-sided (4' x 8' panels)	1,150			1	1,150
14' x 14' x 8', with roll roofing on gable roof	1,250			1	1,250
15.3' dia. x 10' high, 12-sided (4' x 10' panels)	1,350			1	1,350
12' x 18' x 10.5', with shingled gable roof	1,800			2	3,600
14' x 16' x 10.5', with shingled gable roof	1,860			4	7,440
15.5' x 15.5' x 10', tongue-and-groove, corner-locked 2" plank	2,000			1	2,000
15.5' x 15.5' x 18', tongue-and-groove, corner-locked 2" plank	3,300			7	23,100
Special bins other than wood:					
10.5' dia. x 6' high, 2 layers of roll roofing cemented together, externally supported by 2" x 4" studs	400			1	400
15' dia. x 4' high, pressed wood walls, kraft-paper roof	700	1	700	2	1,400
18.5' dia. x 4' high, pressed wood walls, kraft-paper roof	1,000			1	1,000
12.5' dia. x 10' high, wallboard walls, kraft-paper roof	1,000			2	2,000
14.5' dia. x 8' high, wallboard walls, kraft-paper roof	1,000			1	1,000
19' dia. x 10' high, wallboard walls, kraft-paper roof	2,250			2	4,500
11' x 15' x 8' of insulation board, with roof of insulation board covered by roll roofing	1,050			1	1,050
12' x 20' x 7' high, wallboard walls	1,200			1	1,200
16' x 38' x 3.5' at peak; a rick, roll roofing as floor and cover	500	1	500		
16' dia. x 4' high, 4" x 4" wire mesh lined with kraft paper	750	1	750		
16' dia. x 8' high, 4" x 2" wire fencing lined with roll roofing	1,400	1	1,400		
18' dia. x 7' high, 18 panels of 6" x 6" wire mesh bolted at joints and lined with kraft paper, canvas roof	1,500	1	1,500		
Total		198	375,650	203	406,360

SAMPLING OF WHEAT IN STORAGE

Successive average wheat samples, taken from the bins at Hutchinson and Jamestown, were analyzed [6] for the commercial grade factors—test weight, moisture content, foreign material, total damage, dockage, fat acidity, protein content, germination percentage, and for kind and number of insects—to show any changes in the condition of the stored wheat. In addition, numerous special samples were taken for grade determinations, individual moisture readings, or insect counts.

[6] Wheat grade factors, protein content, fat acidity, and germination were determined by the Agricultural Marketing Service, now Grain Division, Commodity Stabilization Service, U. S. Department of Agriculture.

An average sample from a bin of wheat consisted of a mixture of small portions of wheat taken by probe along 9 specified lines down through the wheat. The positions of these lines were 1 vertical at the center; 4 diagonal lines beginning off-center about one-third of the distance of the bin radius and directed to the floor-wall junction on the north, east, south, and west sides of the bin: and 4 shorter diagonal lines beginning off-center at about one-half the distance of the bin radius and directed to a point on each of the 4 walls at about two-thirds the distance above the floor. The sampling errors, calculated from 78 duplicate wheat samples, for estimating the various quality factors in a bin with this method of sampling were as follows:

Factor:	*Sampling error [1] at the 5-percent level*
Test weight	±0.46 pound per bushel
Moisture content	±0.30 percent
Dockage	±0.10 percent
Foreign material	
Total damage	±0.36 percent
Fat acidity [2]	±4.40 units
Protein	±0.66 percent
Germination	±8.30 percent

[1] The errors also include any errors in determining the factors.
[2] See p. 19 for definition of fat acidity.

In addition to the observations to determine changes in quality factors, wheat temperatures were taken periodically to study the effect of several factors such as presence of insects, bin size, cooling practices, seasonal temperature changes, and the mean annual temperature differences between storage locations.

An estimated 12,000 samples were taken from the wheat while in storage, and approximately 50,000 determinations of test weight, moisture, dockage, foreign material, total damage, protein content, fat acidity, or germination were made. In addition, approximately 250,000 temperature observations of wheat in storage were made and recorded.

STORAGE IN STEEL BINS

The commercial bins used were built of preformed galvanized corrugated-steel wall sheets, bolted together on the site. Lead washers were used under the bolts to make them watertight, and, with few exceptions, calking compound was used to seal wall and floor-wall joints. The bins were equipped with galvanized sheet steel floors having watertight preformed joints laid directly on the earth fill of the concrete block foundation.[7] The underside of the floor was covered with a thick coating of asphaltic paint.

There was no serious damage to the steel bins caused by grain pressures or by storms. Leakage of rainwater into most of the bins, however, caused some spoilage of grain. Many of the bins were also subject to snow leakage, blown in through roof ventilators, damaged roof inspection doors, and under eaves. The snow was usually found and removed during wheat inspections and caused no appreciable damage.

[7] In 1950 the use of concrete blocks for bin foundations was discontinued by the CCC, and a metal foundation ring that was partly buried in the ground was substituted. This change saved considerable labor and material and eliminated additional anchorage.

At Hutchinson 119 steel bins, having calked floor and wall joints, were examined, after emptying for spoilage caused by leakage of rainwater. Spoilage was found in 110 bins, including 58 with leaks through the wall joints, especially the vertical joints; 51 with leaks at the floor-wall joint; 20 with leaks at the frame of the emptying door; and 19 with leaks through uncalked roofs. Leakage at more than one of these sources was found in many bins (figs. 2 to 4). The wheat in these bins had been stored from 1 to 5 years with insect infestation kept under control.

The extent of spoilage caused by water leakage through wall joints, floor-wall joints, and around doorframes was not separately recorded. However, the total amount found in the bins at these sources ranged from a trace to a maximum of 50 bushels in 1 bin. Two bins had from 25 to 30 bushels of spoiled grain; 2 from 15 to 20 bushels; 5 from 10 to 15; 30 from 5 to 10; 60 from a trace to 5; and 10 bins had only a trace. Spoilage caused by roof leaks averaged 2.7 bushels per bin, ranging from a trace to 12 bushels.

The extent of spoilage in the bins varied with the length of time the wheat was stored. The average amount of spoilage in bins in which wheat was stored 1 year was 0.9 bushel; 2 years, 4.0 bushels; 3 years, 5.2 bushels; and 4 to 5 years, 12.6 bushels.

Average spoilage in twenty-six 1,000-bushel bins after 2 and 3 years of storage was 5.2 bushels per bin, as compared with an average of 4.6 bushels per bin in forty-five 2,740-bushel bins, in which the wheat was stored for the same length of time. The 2,740-bushel bins were of a newer design than the 1,000-bushel bins.

Calking the steel-sheet joints in the bins at Hutchinson, during or after erection, did not appear to improve materially the tightness of the bin, unless the steel sheet had been damaged and a normal joint could not be made. The average amount of spoiled wheat owing to water leakage in 6 uncalked bins was 5.2 bushels per bin after 2 and 3 years of storage as compared to 4.5 bushels per bin in 28 similar bins that had been calked during or after erection. The compound used for calking the bins had a tendency to dry, and after 1 or more years the expansion and contraction of steel sheets cracked it and thus at times caused a source of leakage owing to failure of calking. Also, when the calking compound is applied with a calking gun during erection, extreme caution is required to assure an even and continuous layer of compound between the sheet joints, because any breaks or unevenness in the compound may permit entry of water as it runs down the side of the bin (fig. 5).

Not only does water leakage cause some spoilage, but it also influences insect life in stored wheat. Grain of high moisture content is highly attractive to insects, and is also difficult to fumigate effectively. Insect infestations in leaky bins may easily double the total amount of damaged grain found. Combined insect-damaged and water-spoiled wheat found in one bin at Hutchinson, after 4 years of storage, exceeded 100 bushels, and in another bin, after 5 years of storage, 80 bushels.

At Jamestown, 17 bins in which wheat had been stored for 1 year were emptied and examined for evidence of spoilage because of rainwater leakage. While 16 contained wheat spoiled by rain, 2 of the bins showed only a trace of spoilage. The spoiled wheat ranged from

FIGURE 2.—Spoiled wheat in steel bin caused by water leakage around doorframe. Wheat in storage 5 years.

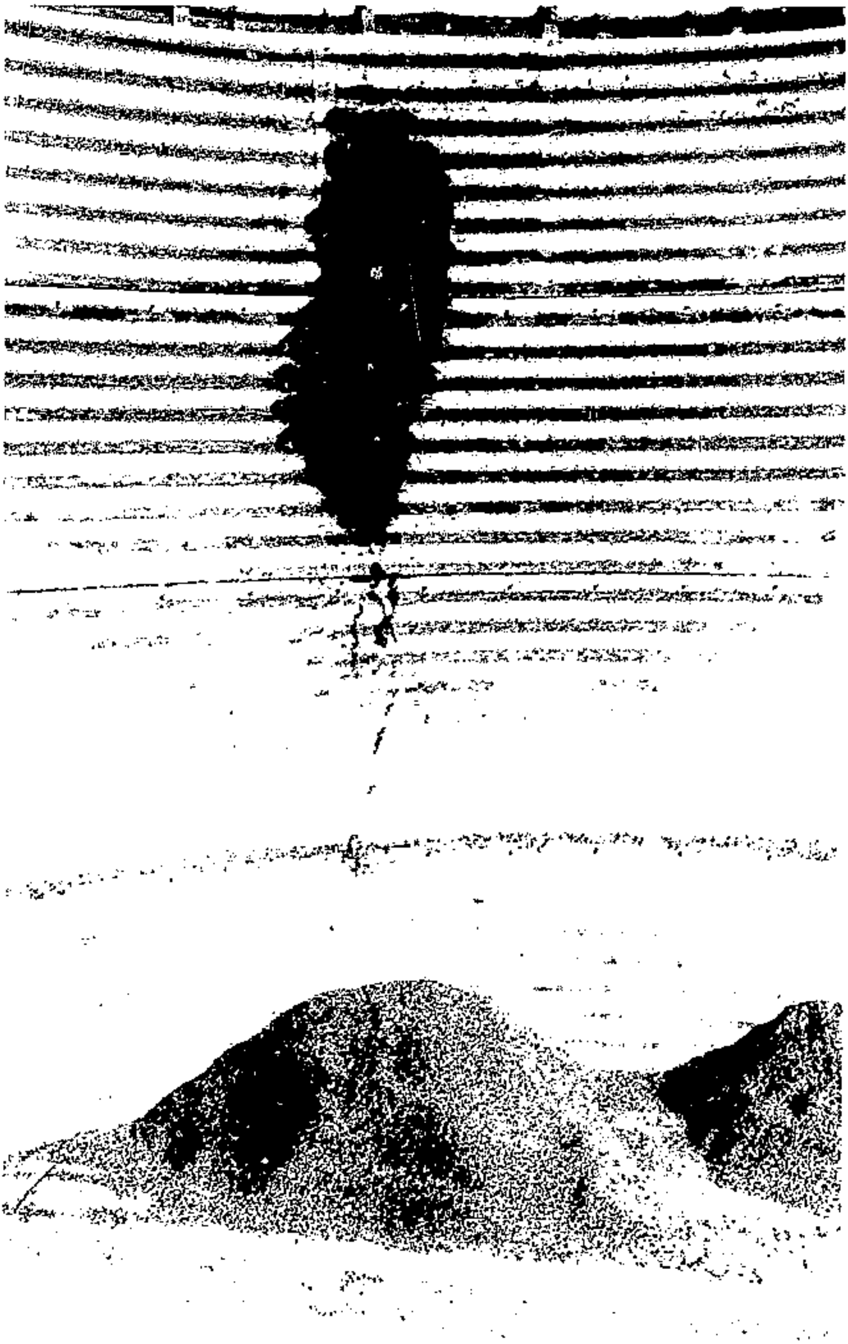

FIGURE 3.—Caked wheat along wall and floor below loose roof clip bolt. Wheat in storage 2 years.

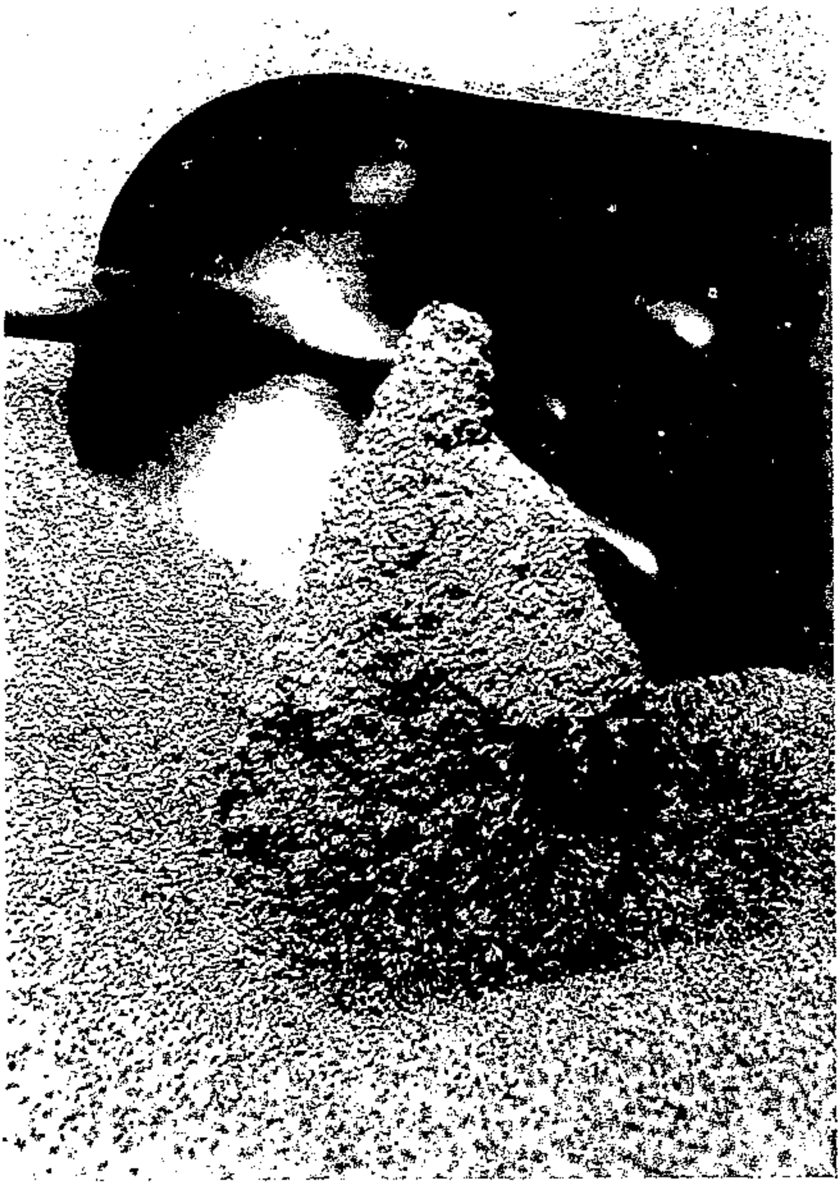

FIGURE 4. Spoiled grain below water leak in removable roof section. Wheat in storage 4 years.

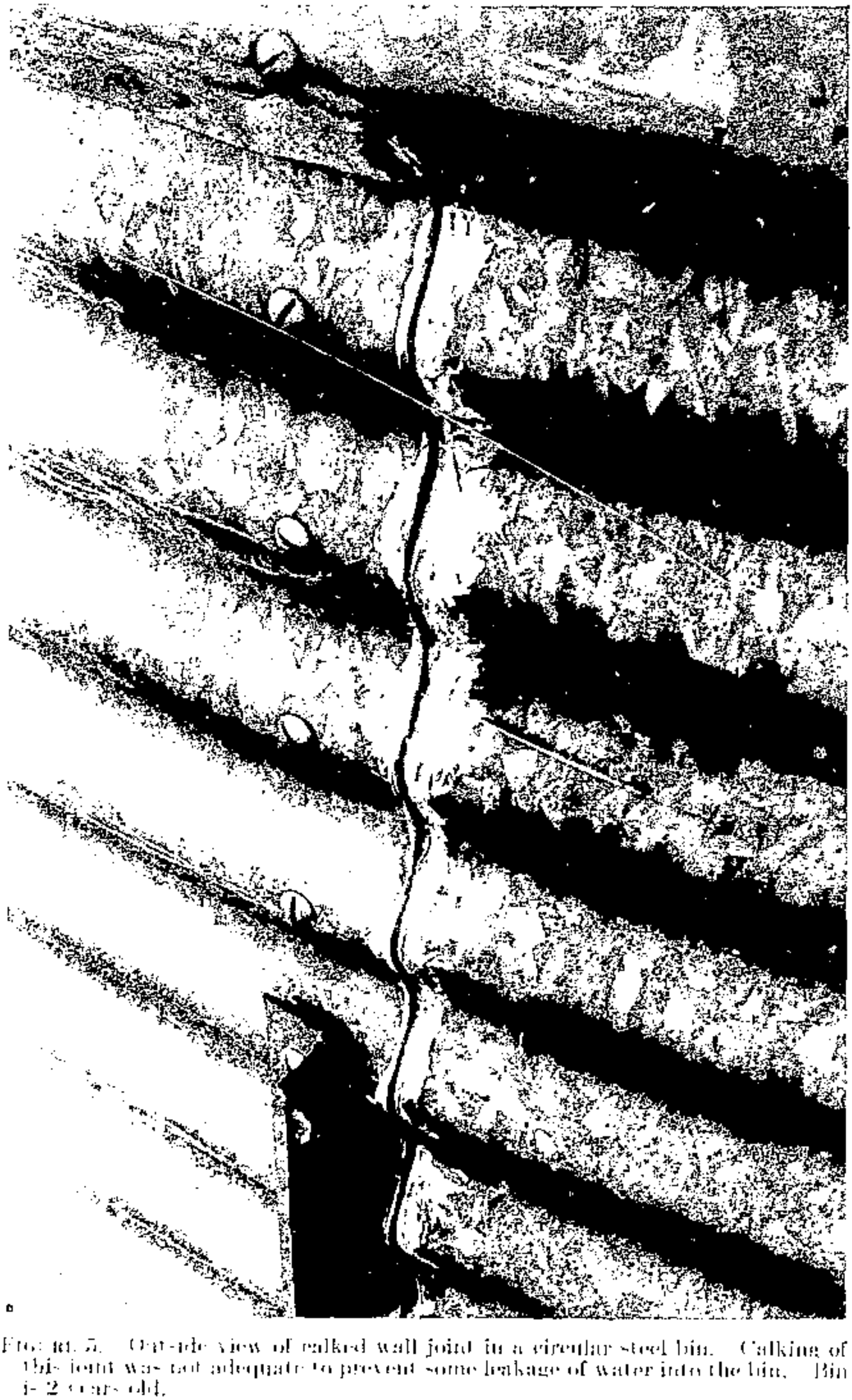

FIGURE 5.—Outside view of calked wall joint in a circular steel bin. Calking of this joint was not adequate to prevent some leakage of water into the bin. Bin is 2 years old.

3 pounds to 2 bushels, with the average 0.4 bushel per bin, as compared with 0.9 per bin at Hutchinson. Less rainfall and greater care in erecting and calking the bins at Jamestown are factors believed responsible for the difference shown. Normal annual rainfall at Jamestown is about 20 inches as compared with about 28 inches at Hutchinson.

CHANGE IN WHEAT CONDITION IN LONGTIME STORAGE

In general the condition of the relatively dry wheat stored in farm-type bins at Hutchinson and Jamestown did not change while in storage unless damaged by insect infestation or rainwater leakage. Wheat was stored in watertight bins at Jamestown for as long as 4½ years and at Hutchinson for 5 years without change in the average grade. After 2 or more years of storage, however, many of the bins contained small areas of deteriorated or partly deteriorated wheat at the surface. These areas were caused by an increase in surface moisture, but in their entirety they represented less than 2 percent of the total amount of wheat in the bin. When the bins were emptied, the wheat in these areas was mixed with the rest of the wheat without materially affecting the average grade. The size of the bin did not appear to affect the condition of the wheat, except that surface spoilage was less pronounced in the smaller bins.

CHANGES IN WHEAT GRADE FACTORS

Data obtained on successive average and special wheat samples taken from the steel bins at Hutchinson and Jamestown were analyzed to show natural changes in the individual grade factors and in the protein content, fat acidity, and viability (percent germination) of the wheat while in storage. Except for the grade factor of total damage and for the special sample factors, only successive average data were used in the analyses. These data were collected on wheat that was stored undisturbed for at least 3 years and in which insect damage was prevented.

Test Weight

Successive average test weights taken from 34 bins at Hutchinson and 52 at Jamestown for 33 months show the effect of length of storage on wheat test weight (tables 2 and 3). The test weights given in the tables are averages of several bins grouped as to bin size and moisture content of the wheat and, in the case of Hutchinson, as to the crop year of the wheat. Also included in the tables are the correlation and regression coefficients for the relationship between the length of storage (months) and the successive average test weights for each group of bins.

According to the correlation analyses of the data in tables 2 and 3, 14 of the 15 groups of bins showed a decrease in the average test weight while in storage, but this trend was statistically significant in only 5 groups. Except for 1 group of bins at Jamestown, these significant decreases were in groups of bins filled with wheat of higher moisture contents. The rate of test weight decreases as seen by the regression coefficients, however, were small and commercially negligible. Unless the test weight of the wheat when placed in storage is near the grade borderline, these changes in test weights would not affect the commercial grade over several years of storage.

TABLE 2.—*Changes in test weight of 1940 and 1943 wheat stored at different moisture contents in steel bins of 3 different capacities at Hutchinson*

Length of storage (months)	Average test weight per bushel							
	1940 wheat; moisture content of—				1943 wheat; moisture content of—			
	10 percent	11 percent		12 percent	9 percent	10 percent	11 percent	12 percent
	Six 2,740-bushel bins	Four 1,000-bushel bins	Eight 2,740-bushel bins	Two 5,000-bushel bins	Two 1,000-bushel bins	Two 2,740-bushel bins	Four 2,740-bushel bins	Six 1,000-bushel bins
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0	60.2	58.2	58.5	58.6	63.2	60.8	60.0	60.6
3	60.3	58.2	58.4	58.8	62.9	60.9	59.8	60.3
6	60.1	58.2	58.2	58.5	63.0	61.0	59.8	60.2
9	60.2	58.3	58.4	58.4	62.4	60.6	59.6	60.2
12	60.3	58.4	58.5	58.8				
15	60.4	58.4	58.4	58.5				
18	60.1	58.2	58.1	58.4	62.6		50.7	60.0
21	60.0	58.1	58.3	58.1				
24	60.1	58.1	58.2	58.1				
27	60.3	58.3	58.3	58.6				
30	60.1	58.2	58.5	57.6	62.8	61.2	50.7	60.0
33	60.0	57.9	58.3		63.0			
Correlation coefficient [1]	−.424	−.429	−.240	−.685*	−.154	.651	−.587	−.832*
Regression coefficient [2]	−.005	−.005	−.003	−.024	−.003	.012	−.007	−.017

[1] * = Significant at the 5-percent level.
[2] The average change in test weight per month of storage.

TABLE 3.—*Changes in test weight of 1940 wheat stored at different moisture contents in steel bins of 2 different capacities at Jamestown*

Length of storage (months)	Average test weight per bushel						
	11-percent moisture wheat		12-percent moisture wheat		13-percent moisture wheat		14-percent moisture wheat
	Seven 1,000-bushel bins	Three 2,740-bushel bins	Nine 1,000-bushel bins	Twenty 2,740-bushel bins	Seven 1,000-bushel bins	Three 2,740-bushel bins	Three 1,000-bushel bins
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0	57.7	57.1	57.1	57.4	56.5	58.1	55.6
3	57.5	57.1	57.0	57.2	56.4	58.2	55.4
6	57.6	57.6	57.1	57.3	56.5	58.2	55.2
9	57.6	57.4	57.0	57.3	56.3	58.2	55.2
12	57.7	57.2	56.9	57.3	56.4	58.1	55.2
15	57.6	57.4	56.8	57.3	56.6	52.0	54.8
18	57.5	57.3	56.0	57.2	56.3	58.0	54.8
21	57.5	57.1	56.9	57.2	56.3	58.0	55.0
24	57.4	57.2	56.9	57.1	56.3	58.0	54.8
27	57.5	57.2	57.0	57.1	56.5	57.9	54.7
30	57.5	57.3	57.0	57.4	56.4	58.0	54.6
33	57.5		56.9		56.3		55.1
Correlation coefficient [1]	−.638*	−.057	−.472	−.375	−.339	−.808**	−.783**
Regression coefficient [2]	−.005	−.001	−.004	−.004	−.003	−.008	−.022

[1] * = Significant at the 5-percent level; ** = significant at the 1-percent level.
[2] The average chang in test weight per month of storage.

Moisture Content

Successive bin average wheat moisture contents for the same set of bins as used in the test weight analysis at Hutchinson and Jamestown are given in tables 4 and 5. The data show slight changes in the average moisture content of wheat while in storage. But these indicated moisture changes, like the changes in test weights, were small and not important commercially.

TABLE 4.—*Changes in the moisture content of 1940 and 1943 wheat stored in steel bins of 3 different capacities at Hutchinson*

Length of storage (months)	Average wheat moisture content: 1940 wheat				1943 wheat			
	Six 2,740-bushel bins	Four 1,000-bushel bins	Eight 2,740-bushel bins	Two 5,000-bushel bins	Two 1,000-bushel bins	Two 2,740-bushel bins	Four 2,740-bushel bins	Six 1,000-bushel bins
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	10.6	11.4	11.3	12.1	9.2	10.5	11.0	12.1
3	10.6	11.3	11.2	12.1	9.2	10.3	11.0	11.9
6	10.6	11.4	11.3	12.2	9.3	10.7	11.3	12.1
9	10.6	11.2	11.3	12.1	9.6	10.7	11.3	12.2
12	10.9	11.4	11.4	12.1				
15	10.7	11.3	11.3	12.0				
18	10.7	11.4	11.5	12.2	10.4		11.1	11.9
21	10.8	11.6	11.4	12.0				
24	10.8	11.2	11.1	12.0				
27	10.7	11.3	11.2	12.0				
30	11.0	11.6	11.4	11.9	10.0	10.8	11.2	12.0
33	10.8	11.7	11.4		9.3			
Correlation coefficient [1]	.690*	.474	.150	−.667*	.443	.605	.320	−.288
Regression coefficient [2]	.008	.007	.002	−.006	.016	.012	.004	−.003

[1] * = Significant at the 5-percent level.
[2] The average change in moisture content per month of the storage.

TABLE 5.—*Changes in the moisture content of 1940 wheat stored in steel bins at 2 different capacities at Jamestown*

Length of storage (months)	Average wheat moisture content						
	Seven 1,000-bushel bins	Three 2,740-bushel bins	Nine 1,000-bushel bins	Twenty 2,740-bushel bins	Seven 1,000-bushel bins	Three 2,740-bushel bins	Three 1,000-bushel bins
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	11.6	11.8	12.6	12.4	13.2	13.1	14.1
3	11.6	11.9	12.7	12.6	13.3	12.9	14.2
6	11.7	12.1	12.7	12.5	13.4	13.0	14.3
9	11.7	11.9	12.7	12.6	13.3	13.1	14.3
12	11.6	11.9	12.4	12.6	13.0	13.0	14.0
15	11.7	11.9	12.8	12.5	13.1	13.0	14.2
18	11.7	12.1	12.8	12.6	13.2	13.1	14.2
21	11.7	12.2	12.6	12.5	13.2	12.9	14.0
24	11.9	12.0	12.7	12.6	13.3	13.2	14.0
27	11.8	12.0	12.5	12.6	13.0	13.2	14.2
30	11.8	11.3	12.7	12.5	13.2	12.9	14.2
33	11.8		12.7		13.3		14.2
Correlation coefficient [1]	.789**	.208	*.029	.257	−.189	.183	−.131
Regression coefficient [2]	.007	.003	.000	.002	−.002	.002	−.001

[1] ** = Significant at the 1-percent level.
[2] The average change in moisture content per month of storage.

Although the average wheat moisture content in a bin changed but little during storage, there is a considerable movement of moisture within the stored grain mass. This moisture migration results in a concentration of moisture in the upper layers of the wheat and occurs in unventilated bins after a period of storage, even though they were filled originally with wheat of uniform moisture.

The concentration of moisture in the upper layers of grain is the result of differences in, and the constant changing of, wheat temperatures within the bin. During the fall and winter the wheat in the center of the bin is the warmest and the wheat near the walls and in the upper portion of the bin is the coldest. The warmer, moisture-laden air from the center rises in the form of convection currents to the bin surface. When this warm moisture-laden air comes in contact with the colder wheat near the bin surface, moisture is deposited in this colder grain, thereby increasing its moisture content. The moisture accumulation is greater in a dish-shaped layer directly below the bin surface and slightly south of the bin center. Rarely does the increased moisture area extend to the bin walls. Maximum thickness at the center of the layer may range from 1 to 3 feet.

The process of moisture concentration usually starts during the latter part of September or in early October as soon as the air temperature reduces the bin-surface wheat temperature below that of the wheat in the bin center. It continues until the air temperature again raises the bin-surface wheat temperatures above that in the center of the bin, usually in March or April. From March to September the wheat temperatures in the center of the bin are cooler, which reverses the convection currents. A part of the moisture in the upper layers of grain is again redistributed through the grain bulk, some of the moisture in the top layer is given to the air, and a small amount of drying takes place in this wheat. However, the drying from loss of moisture to the air and redistribution downward in the grain is usually less than the wetting, and after a few years of storage top-layer wheat may have moisture contents that are 1 to 3 percent, or even more, above the bin average moisture content. If the bin average moisture content is near the limit for safe storage, the concentration of moisture in top-layer wheat can, and often does, result in spoilage. This wetter grain is also ideal for insect development.

Because of the smaller wheat bulk and the more rapid cooling of the wheat in the bin center, moisture concentration in the upper layers in 1,000-bushel bins is usually less than in the larger 2,740-bushel bins when both are filled with the same moisture content wheat (fig. 6).

A series of special samples taken from a number of bins at Jamestown demonstrated this moisture concentration and its effect on the quality of the wheat as it remains in storage. These samples were taken 1 foot and 4 feet below the surface in June 1944, June 1945, and December 1945. All this wheat was placed in storage during July 1941 in 1,000-bushel and 2,740-bushel bins. It was well mixed and had an average moisture content of 12.5 percent when placed in storage. The average test weight was approximately 57.5 pounds in the 1,000-bushel bins and 56.2 pounds in the 2,740-bushel bins. Total damage averaged approximately 0.8 percent. The average moisture content, test weight, total damage, and protein content for these special samples are compared in table 6 for the different sampling dates.

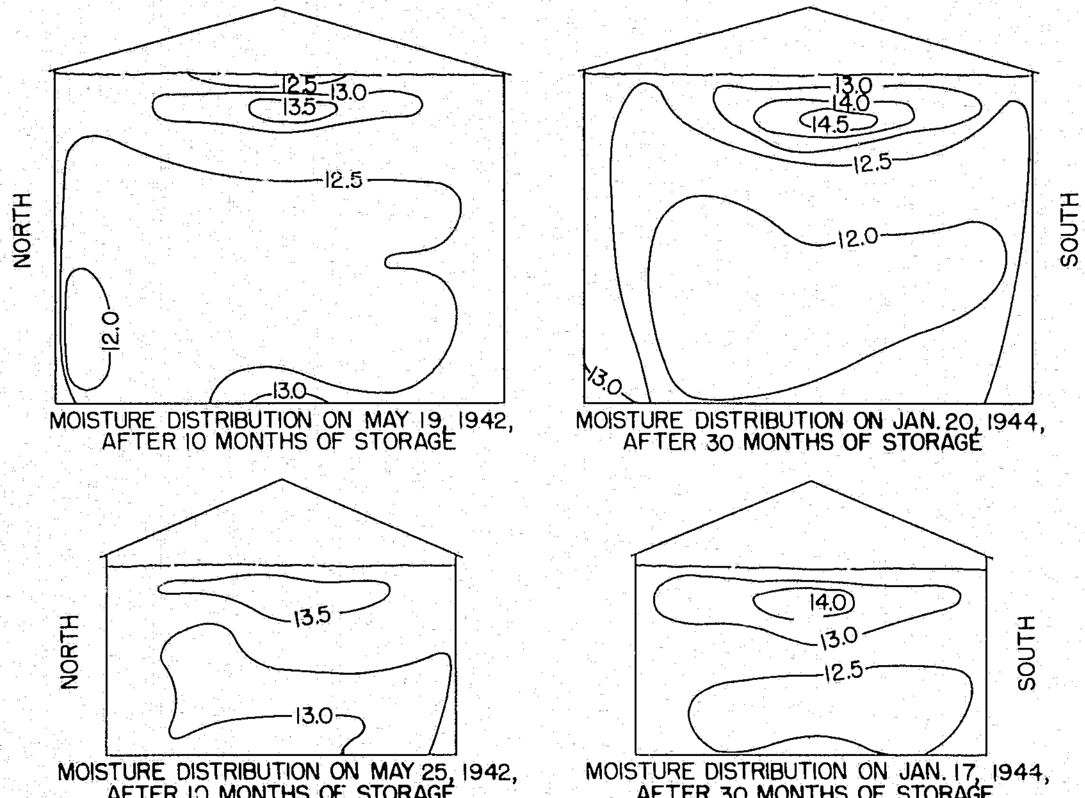

FIGURE 6.—Moisture distribution in wheat placed in storage July 1941 in steel bins at Jamestown: Upper bins, 2,740-bushel capacity; lower bins, 1,000-bushel capacity.

Several of the wheat samples in table 6, taken 1 foot below the surface during June and December 1945, graded Sample because of a musty odor. These included one 1,000-bushel bin in June 1945, three 2,740-bushel bins in June 1945, and four 2,740-bushel bins in December 1945. Only one 2,740-bushel bin graded Sample at the 4-foot level, and this was in December 1945. The total damage of the Sample grade wheat ranged from 0.2 to 18.0 percent. The highest moisture content recorded for any wheat sample was 16.0 percent in a 2,740-bushel bin 1 foot below the surface in December 1945. The original average moisture content in this bin was 12.2 percent, and 4 feet below the surface the moisture content was still 12.5 percent in December 1945.

TABLE 6.—*Comparison of the average percentage of moisture content, test weight, total damage, and protein content of wheat 1 foot and 4 feet below the surface in 1,000- and 2,740-bushel steel bins after 0, 3, 4, and 4½ years of storage at Jamestown*

Date of sampling	Length of storage	1 foot below surface: Moisture content	1 foot below surface: Test weight	1 foot below surface: Total damage	1 foot below surface: Protein content	4 feet below surface: Moisture content	4 feet below surface: Test weight	4 feet below surface: Total damage	4 feet below surface: Protein content
1,000-BUSHEL BINS [1]									
	Years	*Percent*	*Pounds*	*Percent*	*Percent*	*Percent*	*Pounds*	*Percent*	*Percent*
July 1941 (original)	0	12.6	57.5	0.6	15.9	12.6	57.5	0.6	15.9
June 1944	3	13.4	57.3	.7	16.2	[2] 13.1	57.5	.6	16.2
June 1945	4	13.5	56.1	1.0	16.3	12.4	57.2	.8	16.2
December 1945	4½	13.7	56.2	1.2	16.0	12.2	57.6	.9	16.0
2,740-BUSHEL BINS [1]									
July 1941 (original)	0	12.4	56.2	0.9	16.2	12.4	56.2	0.9	16.2
June 1944	3	13.4	56.0	.9	15.9	12.6	56.4	1.1	16.0
June 1945	4	13.9	54.5	1.6	16.7	12.7	55.6	1.0	16.5
December 1945	4½	14.6	53.5	6.6	16.4	12.4	56.0	.6	16.0

[1] June 1944 averages include six 1,000-bushel and eight 2,740-bushel bins. June 1945 and December 1945 averages each include eleven 1,000-bushel and fourteen 2,740-bushel bins. The average original grade factors in the table are from the larger number of bins. The average original grade factors for the smaller number of bins were about the same.

[2] Recorded data for this sampling seemed to be in order. No explanation is given for this higher-than-expected average moisture content. Similar effects of this sampling were observed in germination percentage.

Dockage and Foreign Material

The amount of dockage or foreign material in wheat does not change during storage if it is kept free of insect infestation. Storage does not affect these factors but they can affect the wheat in storage, especially in the storage of damp grain requiring ventilation. Excessive dockage or foreign material increases the resistance to airflow through the wheat, thereby requiring more power for drying and cooling high-moisture grain containing such matter. It is also known that high dockage and foreign material hinder effective fumigation by preventing the fumigant gases from passing down through the wheat.

Total Damage

Increases in total damage are not natural changes that occur to the wheat kernel with age but are changes that are brought about by prestorage conditions or by careless storage practices. Consequently, increases in total damage while in storage can be held to a minimum if good structures are provided and good management practices are followed.

Of the several types of damage included under total damage, part of those present before storage include frost and weather-damaged and other materially damaged kernels. Other types of damage, such as heat damage, sprouted or molded kernels, sick wheat, and insect damage, can be the results of storage.

Increases in heat damage are usually the result of storing damp wheat. This can be avoided by proper drying and handling before storage. Such damage is seldom a problem when storing dry wheat.

Sprouting and mold damage to dry stored wheat are often the result of water and snow leakage into the bin. This type of damage can be avoided by storing wheat in tight bins and by making frequent inspections for possible leaks. Sprouting and mold damage often occur from the moisture migration, described on page 14.

Insect damage may occur while storing either damp or dry wheat in climates that are favorable to insect life. In the storage of dry wheat at Hutchinson, almost all increase in total damage was caused by insect activity. Frequent fumigation, however, held this damage to a minimum. Out of 143 bins of dry wheat that were stored undisturbed from 2 to 5 years, only 6 bins had a total damage increase large enough to lower the grade of wheat, and then by only 1 or 2 grades. Of these 6 bins, 4 were 1,000-bushel bins and 2 were 2,740-bushel bins. The wheat in 3 of the 1,000-bushel bins (one painted white) had been in storage for 5 years, and in 2 of these (both unpainted) the wheat was not fumigated during the last 3½ years of storage. The painted bin was fumigated when needed. The fourth 1,000-bushel bin of wheat was in storage 3 years; it was fumigated when needed. Wheat was in storage for 4 years in the two 2,740-bushel bins. One of these bins was painted white and the wheat was not fumigated; the other was fumigated when needed.

With effective fumigation and management practices, the increase in total damage from insect activity can be held to a minimum and the commercial grade of the wheat need not change. As shown in table 7, an increase in total damage occurred in all bins whether stored for 2 or 5 years. These increases were not great and did not affect the commercial grade except in the 6 bins mentioned above.

TABLE 7.—*Changes in average percentage of total damage in 143 bins of dry wheat stored from 2 to 5 years at Hutchinson*

Length of storage (years)	Bins	Total damage		
		Initial	Final	Increase
	Number	*Percent*	*Percent*	*Percent*
2	17	1.2	1.9	0.7
3	88	.6	1.1	.5
4	17	1.4	2.3	.9
5	21	.5	1.6	1.1

It requires intense insect infestation to increase total damage enough to lower the commercial grade of the wheat by one or more grades. Under such circumstances the most detrimental effect is the objectionable odor imparted to the wheat by the insects.

In 143 bins of wheat 10 were eventually graded Sample because of objectionable odor attributable to insects. In 6 of these bins the insects did not increase the total damage enough to lower the grade, but the wheat was graded Sample in 4 of them because of a sour odor and in 2 of them because of a commercially objectionable foreign odor, the latter being due to residual fumigant gases. In the 4 remaining bins the wheat graded Sample because of a sour odor, but insects had actually increased the total damage sufficiently to lower the grade in 3 of them from No. 1 to No. 3 and in 1 enough to change the grade from No. 1 to No. 2.

Analyses of special samples to show differences in total damage within bins are shown in table 6.

Protein Content

Neither the size of the bin nor the moisture content of the wheat seems to affect the protein content while in storage (regression coefficients, tables 8 and 9). According to the magnitude of the correlation coefficients, only 1 group of bins showed that the protein content changed while in storage. This group was the eight 2,740-bushel bins at Hutchinson (table 8) filled with 1940 wheat at 11-percent moisture content. The protein content in this group changed from 11.1 percent to 11.4 percent during the 33 months of storage. Actually, this was a

TABLE 8. *Effect of length of storage on the protein content of 1940 and 1943 wheat stored at different moisture contents in steel bins of 3 different capacities at Hutchinson*

Length of storage (months)	Average protein content							
	1940 wheat; moisture content of—				1943 wheat; moisture content of—			
	10 percent	11 percent		12 percent	9 percent	10 percent	11 percent	12 percent
	Six 2,740-bushel bins	Four 1,000-bushel bins	Eight 2,740-bushel bins	Two 5,000-bushel bins	Two 1,000-bushel bins	Two 2,740-bushel bins	Four 2,740-bushel bins	Six 1,000-bushel bins
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	10.5	11.3	11.1	11.6	13.9	13.5	13.4	12.1
3	10.5	11.3	11.1	11.3	13.9	13.7	13.3	12.5
6	10.7	11.5	11.3	11.9	14.2	13.7	13.5	12.9
9	10.7	11.5	11.3	12.0	14.4	13.8	13.7	13.0
12	10.6	11.4	11.1	11.9				
15	10.8	11.4	11.3	11.7				12.6
18	10.8	11.2	11.3	12.4	14.0		13.5	12.6
21	10.6	11.3	11.3	11.8				
24	10.6	11.4	11.3					
27	10.6	11.3	11.3	11.5				
30	10.9	11.6	11.4	11.8	13.9	13.5	13.4	12.9
33	10.6	11.7	11.4		14.2			
Correlation coefficient [1]	.316	.410	.767**	.174	.067	-.035	.053	.492
Regression coefficient [2]	.004	.005	.008	.005	.0008	-.0003	.0006	.015

[1] ** = Significant at the 1-percent level.
[2] The average change in protein content per month of storage.

TABLE 9.—*The effect of length of storage on the protein content in 1940 wheat stored at different moisture contents in steel bins of 2 different capacities at Jamestown*

Length of storage (months)	Average protein content of wheat with moisture content of—						
	11 percent		12 percent		13 percent		14 percent
	Seven 1,000-bushel bins	Three 2,740-bushel bins	Nine 1,000-bushel bins	Twenty 2,740-bushel bins	Seven 1,000-bushel bins	Three 2,740-bushel bins	Three 1,000-bushel bins
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	15.7	16.0	15.8	15.9	15.7	15.7	13.7
3	16.0	16.2	15.9	16.3	16.0	15.7	13.7
6	15.7	16.1	16.1	16.2	16.1	15.7	13.6
9	16.4	16.5	16.3	16.5	16.6	15.6	14.4
12	15.9	15.9	16.4	16.1	16.3	16.2	13.7
15	16.0	15.9	16.2	16.0	16.0	15.6	13.7
18	15.8	16.0	15.9	16.2	16.0	16.0	13.9
21	15.9	16.0	16.0	16.1	15.9	15.8	13.6
24	16.0	16.1	16.2	16.0	16.0	15.7	13.6
27	15.8	16.0	15.9	15.8	15.9	15.8	13.6
30	15.9	16.5	16.2	15.9	15.9	16.1	14.0
33	16.2	....	16.5	....	16.5	....	13.7
Correlation coefficient	.195	.114	.398	−.492	.112	.388	−.075
Regression coefficient [1]	.004	.002	.008	−.010	.003	.008	−.002

[1] The average change in protein content per month of storage.

smaller change than occurred in the group of bins at Hutchinson filled with 12-percent moisture-content 1943 wheat. However, the increase in protein content with length of storage was consistent, while the indicated protein content of the 12-percent moisture-content 1943 wheat increased and decreased with successive samples—probably because of sampling errors—and consequently the correlation was not significant.

Further evidence against any change in the percent protein content of wheat as the result of size of bin and moisture content while in storage is shown from the special wheat samples taken 1 foot and 4 feet below the surface of the 1,000- and 2,740-bushel bins at Jamestown (table 6). The differences between the protein averages at the 2 depths are nonsignificant, but the differences between the moisture averages for June and December 1945 are significant.

Protein studies on the wheat stored at Hutchinson and Jamestown dealt only with the changes in the quantity of the protein. No attempt was made to measure any chemical changes in the quality of the protein of the wheat while in storage.

Fat Acidity

Fat acidity is expressed as the number of milligrams of potassium hydroxide (KOH) required to neutralize the free fatty acids extracted from 100 grams of wheat calculated on a dry basis. It is usually expressed as fat acidity units.

It has been shown by a previous report that the fat acidity units increase with the length of storage and that the size of the increase is related to the moisture content of the wheat.[5]

[5] KELLY, C. F., STAHL, B. M., SALMON, S. C., and BLACK, R. H. WHEAT STORAGE IN EXPERIMENTAL FARM-TYPE BINS. U. S. Dept. Agr. Cir. 637, 245 pp., illus. 1942.

According to the significant correlation coefficients in tables 10 and 11, fat acidity of wheat increased while in storage in all the groups of bins except those at Hutchinson filled with 9- and 10-percent moisture-content 1943 wheat. If more intermediate samples had been taken in the 10-percent moisture-content group, it probably would also have shown a significant correlation between the length of storage and fat acidity increase.

The regression coefficients show, when the size of the bin is disregarded, that the rate of fat acidity increase is greater for the higher moisture-content wheat (table 10).

The fat acidity data taken at Hutchinson were not sufficient to analyze the effect of bin size on the increase in fat acidity, since the different moisture contents were not divided appropriately among the various sizes of bins on the site.

Similar greater increases in fat acidity with the storage of higher moisture-content wheat were noted in the Jamestown bins (table 11). The only contradiction to greater fat acidity increases in higher moisture-content wheat was that of the 13-percent moisture wheat in the 1,000-bushel bins. According to the Jamestown studies, bin size did not affect the rate of increase in fat acidity.

The rate of fat acidity increase at a given moisture content was lower at Jamestown than at Hutchinson. This was presumably caused by the lower annual temperatures in the North Dakota area. Eleven-percent moisture wheat at Jamestown had about the same rate of fat acidity increase while in storage as that of 10-percent moisture wheat at Hutchinson.

TABLE 10.—*The effect of length of storage on the fat acidity of 1940 and 1943 wheat stored at different percent moisture contents in steel bins of 3 different capacities at Hutchinson*

Length of storage (months)	Average fat acidity							
	1940 wheat, moisture content of—				1943 wheat; moisture content of—			
	10 percent	11 percent		12 percent	9 percent	10 percent	11 percent	12 percent
	Six 2,740-bushel bins	Five 1,000-bushel bins	Eight 2,740-bushel bins	Two 5,000-bushel bins	Two 1,000-bushel bins	Two 2,740-bushel bins	Four 2,740-bushel bins	Six 1,000-bushel bins
	Units	*Units*	*Units*	*Units*	*Units*	*Units*	*Units*	*Units*
0	18	23	22	18	20	14	10	17
3	19	25	21	19	20	16	21	17
6	19	23	24	23	22	9	18	16
9	18	21	23	23	22	15	20	18
12	24	27	21	24				
15	21	28	28	32				
18	29	31	31	36	17		28	21
21	26	37	31	31				
24	28	38	31					
27	26	31	31	34				
30	28	30	31	40	20	20	29	26
33	25	31	30		21			
Correlation coefficient [1]	.806**	.963**	.821**	.941**	−.144	.672	.902*	.909**
Coefficient of determination [2]	65	93	67	89	2	45	81	83
Regression coefficient [3]	.30	.51	.38	.73	−.02	.22	.38	.34

[1] *=Significant at the 5-percent level; **=significant at the 1-percent level.
[2] The percentage of total variation in successive samples accounted for by the length of storage.
[3] Average change in fat acidity per month of storage.

TABLE 11.—*The effect of length of storage on the fat acidity of 1940 wheat stored at different percent moisture contents in steel bins of 2 different capacities at Jamestown*

Length of storage (months)	Average fat acidity of wheat with moisture content of—						
	11 percent		12 percent		13 percent		14 percent
	Seven 1,000-bushel bins	Three 2,740-bushel bins	Nine 1,000-bushel bins	Twenty 2,740-bushel bins	Seven 1,000-bushel bins	Three 2,740-bushel bins	Three 1,000-bushel bins
	Units	*Units*	*Units*	*Units*	*Units*	*Units*	*Units*
0	18	17	21	14	21	20	13
3	21	20	23	20	23	22	18
6	19	20	20	22	21	22	17
9	19	18	21	21	23	21	18
12	24	25	28	26	27	27	23
15	23	18	25	21	24	23	23
18	28	27	30	29	36	33	29
21	25	26	30	26	28	28	27
24	32	28	36	30	32	34	32
27	25	27	28	26	28	32	29
30	25	22	29	24	28	25	27
33	25		29		29		35
Correlation coefficient [1]	.712**	.688**	.753**	.733**	.675**	.720*	.929**
Coefficient of determination [2]	51	47	57	54	46	52	86
Regression coefficient [3]	.27	.20	.33	.34	.28	.37	.58

[1] *=Significant at the 5-percent level; **=significant at the 1-percent level.
[2] The percentage of total variation in successive samples accounted for by the length of storage.
[3] Average change in fat acidity per month of storage.

The higher moisture content of the wheat at the bin center near the grain surface and the differences in wheat temperatures at the grain surface, the bin center, the south portion, the southwest portion, and the west portion led to the belief that these variations would cause differences in the fat acidity of wheat at these various locations. To check this, a series of spot samples were taken from the top half of the bin at each of these locations from thirteen 1,000-bushel bins and twenty-five 2,740-bushel bins at Hutchinson during June 1943 and again in January 1944. Wheat had been in storage in these bins for 2 and 2½ years. The differences among the fat acidity averages at the various locations in the bins were not statistically significant (table 12). However, no sample was obtained entirely from the top center area where moisture content had been increased by moisture migration.

TABLE 12.—*Average fat acidities and germination of wheat at various locations within 1,000- and 2,740-bushel bins after 2 and 2½ years of storage at Hutchinson*

Location of sample in bin	Average of thirteen 1,000-bushel bins after				Average of twenty-five 2,740-bushel bins after			
	2 years' storage		2½ years' storage		2 years' storage		2½ years' storage	
	Fat acidity	Germination	Fat acidity	Germination	Fat acidity	Germination	Fat acidity	Germination
	Units	*Percent*	*Units*	*Percent*	*Units*	*Percent*	*Units*	*Percent*
Surface [1]	36.0	47.1	37.6	37.3	34.2	57.4	34.9	48.7
Center [2]	32.9	51.5	36.4	37.8	33.2	58.0	34.6	48.2
South [3]	34.1	54.5	39.0	38.7	33.4	57.8	34.0	50.8
Southwest [3]	34.1	50.5	37.4	39.5	33.4	57.8	34.2	51.3
West [3]	36.2	44.1	36.4	39.6	32.3	58.8	33.8	49.5

[1] Wheat sample from top 1 to 2 inches.
[2] Wheat sample from center of bin, 2 inches to 7 feet below surface.
[3] Wheat sample 2 feet from south, southwest, or west wall, 2 inches to 7 feet below surface.

Special spot samples for fat acidity taken from the Jamestown bins gave similar results for wheat stored about 3 years. At Jamestown the spot samples were taken from only 2 locations at the bin center—1 foot and 4 feet below the surface.

The differences between the fat acidity averages after 3 years' storage were not statistically significant, but the fat acidity averages after 4 and 4½ years of storage were significantly different (table 13).

TABLE 13.—*Comparison of average fat acidities and germination of wheat 1 foot and 4 feet below the surface in 1,000- and 2,740-bushel bins after 3, 4, and 4½ years of storage at Jamestown*

Date of sampling	Length of storage	1 foot below surface: Moisture content	1 foot below surface: Fat acidity	1 foot below surface: Germination	4 feet below surface: Moisture content	4 feet below surface: Fat acidity	4 feet below surface: Germination
AVERAGE FOR 1,000-BUSHEL BINS [3]							
	Years	*Percent*	*Units*	*Percent*	*Percent*	*Units*	*Percent*
July 1941 (original)	0	12.6	22	90	12.6	22	90
June 1944	3	13.4	28	63	[4] 13.1	26	[4] 65
June 1945	4	13.5	42	60	12.4	34	85
Dec. 1945	4½	13.7	39	40	12.2	31	86
AVERAGE FOR 2,740-BUSHEL BINS [3]							
July 1941 (original)	0	12.4	20	90	12.4	20	90
June 1944	3	13.4	33	55	12.6	28	72
June 1945	4	13.9	41	45	12.7	36	78
Dec. 1945	4½	14.6	43	19	12.4	31	82

[3] See footnote 1, table 6, p. 16.
[4] See footnote 2, table 6, p. 16.

The findings at the 2 stations are similar. Neither set of bins at the 2 stations showed any distinct difference in the fat acidity of the wheat at various locations in the bins when stored less than 3 years.

Germination

Germination as used here refers to the viability of the wheat and is reported as the percentage of kernels developing strong sprouts in germination tests on average wheat samples taken from the bins.

Germination, like fat acidity, measures deterioration in wheat that is not accounted for by commercial grade standards. Both fat acidity and germination show changes with age, although the commercial grade of the wheat may remain the same.

The relationship between the decline in germination and length of storage was significant in all 8 groups of bins at Hutchinson filled with 9- to 12-percent moisture wheat in 1940 and 1943 (table 14). These rates of decrease in the 1940 wheat, when the size of the bin is disregarded, show a greater decline in the percent germination with an increase in moisture content. The exception is the 10-percent moisture wheat in the 2,740-bushel bins for 1943. However, data for this group were not so complete as for the other groups.

The 1,000-bushel bins at Hutchinson filled with 11-percent moisture 1940 wheat showed a greater rate of decrease in germination than the 2,740-bushel bins filled with the same moisture wheat (table 14).

Ordinarily this would be evidence that the germination decreased faster in smaller bins. However, the wheat stored at Hutchinson was subjected to heavy insect infestations and required applications of fumigants for their control, and it is known that certain fumigants will decrease the germination.[9] Although an attempt was made to minimize the effect of fumigants on germination by discarding data on bins that were fumigated with methyl bromide, the data in table 14 come from bins that had received applications of various fumigants at least once and in some cases many times. Consequently, the data show not only the decline in germination with increasing moisture content but also the effect of insect infestation and the application of the various fumigants. Were the bins naturally free from insects, statements regarding the effect of bin size on the rate of decrease in germination could be made.

TABLE 14.—*Effect of length of storage on germination of 1940 and 1943 wheat stored at different moisture contents in steel bins of 3 different capacities at Hutchinson*

Length of storage (months)	Average germination							
	1940 wheat: moisture content of—				1943 wheat: moisture content of—			
	10 percent	11 percent		12 percent	9 percent	10 percent	11 percent	12 percent
	Six 2,740-bushel bins	Four 1,000-bushel bins	Eight 2,740-bushel bins	Two 5,000-bushel bins	Two 1,000-bushel bins	Two 2,740-bushel bins	Four 2,740-bushel bins	Six 1,000-bushel bins
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	84	84	82	87	90	91	87	90
3					88	90	90	87
6	88		82		90	89	86	90
9	85	84	79	64	93	86	83	90
12	81	74	74	55				
15	79		75	45				84
18	83	61	67	56	88		76	70
21	81	63	70	53				
24	83	55	61					
27	81	32	62	44	79			
30	75	30	55	19	41	63	76	64
33	73	32	52					
Correlation coefficient [1]	-.773**	-.843**	-.970**	-.906**	-.771**	-.989**	-.905**	-.909**
Coefficient of determination [2]	60	71	94	82	59	98	82	83
Regression coefficient [3]	-.32	-1.48	-.98	-1.79	-.12	-.98	-.48	-.91

[1] ** = Significant at the 1-percent level.
[2] The percentage of total variation in the successive samples accounted for by the length of storage.
[3] Average change in percent germination per month of storage.

The percent germination decrease in stored wheat at Jamestown was similar to that found for the Hutchinson bins in that a greater decrease occurred in the storage of the higher moisture grains (table 15). One difference in the results from the 2 storage locations was the smaller rates of decrease in the percent germination of the wheat per month of storage. A comparison of the rate of percent germination decreases at the 2 stations indicates that the germination of wheat stored at Hutchinson decreased approximately 2½ times faster than that of wheat of similar moisture content stored at Jamestown.

[9] See footnote 1, p. 1.

The lower rates of decrease in percent germination of wheat stored in Jamestown are presumably caused by the lower temperatures in that area and to the low level of insect infestations and the few fumigations required for their control.

TABLE 15.—*Effect of length of storage on germination of 1940 wheat stored at different moisture contents in steel bins of 2 different capacities at Jamestown*

Length of storage (months)	Average germination of wheat with moisture content of—						
	11 percent		12 percent		13 percent		14 percent
	Seven 1,000-bushel bins	Three 2,740-bushel bins	Nine 1,000-bushel bins	Twenty 2,740-bushel bins	Seven 1,000-bushel bins	Three 2,740-bushel bins	Three 1,000-bushel bins
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	92	87	91	90	89	90	84
3							
6	92	88	91	88	87	86	
9							89
12	90						
15							86
18	92	89	90	87	89	94	85
21	89	87	88	82	88	82	83
24	90	88	88		88	76	75
27	90	89	85	82	82	77	69
30	90	86	86	83	84	81	67
33	90		81		75		70
Correlation coefficient [1]	−.673*	.00	−.859	−.838*	−.668*	−.870*	−.841**
Coefficient of determination [2]	45	0	74	70	45	76	71
Regression coefficient [3]	−.07	.00	−.25	−.26	−.28	−.39	−.64

[1] * = Significant at the 5-percent level; ** = significant at the 1-percent level.
[2] The percentage of the total variation in the successive samples accounted for by the length of storage.
[3] Average change in percent germination per month of storage.

The rates of percent germination decreases (tables 14 and 15) were computed from the linear relationship between the germinations and months of storage. The data used in these analyses were taken over a 3-year storage period, and the slow but consistent decrease in the germinations found for most groups of bins over this period indicates that the germination of stored wheat decreases at a constant rate. Sporadic germination tests made on bins of wheat that were stored longer than 3 years did not provide sufficient data either to prove or to disprove linearity.

Germination percentages were determined on the same set of special spot samples taken for fat acidity observations at Hutchinson and Jamestown (tables 12 and 13). Statistically, no significant difference was observed between the germinations from various locations within the top half of the bins at Hutchinson after 2 and 2½ years of storage. The same was true for the differences between the germinations at the 1-foot and 4-foot levels in the Jamestown bins (table 13) after 3 years of storage. Differences at the same 2 levels after 4 and 4½ years of storage were significant. These germination results from different parts of the bins are about the same as was found for the fat acidities after 3 or more years of storage.

Summary

Analyses showed the following changes in wheat grade factors:

There were few significant changes in the commercial grade factors of test weight and moisture content of the wheat stored over a period of years.

Total damage increased slightly while in storage. This increase resulted from rainwater leakage, insect activity, surface moisture, or a combination of these causes. Except for a few bins at Hutchinson, however, which were heavily infested with insects, the increases in total damage did not affect the grade of the wheat.

The protein content of the wheat did not change while in storage, even in portions where wheat deteriorated because of high moistures.

In general the fat acidity of the wheat increased and the germination percentage decreased while in storage. The extent of the changes in these factors was related to the moisture content of the wheat and to the climate where it was stored.

EFFECT OF BIN SIZE ON WHEAT QUALITY

The various successive measurements of test weight, moisture content, total damage, protein content, fat acidity, and germination on wheat samples showed no definite indication that the size of the bin was responsible for any of the changes occurring in these measurements of quality. If only the commercial grade factors of test weight, moisture content, and total damage are considered, any changes that did occur were just as likely to appear in a small bin as in a large bin.

Based on conflicting results in the fat acidity (table 13) and germination studies in various sizes of bins, it appears unlikely that bin size had much influence on the maintenance of quality in the stored wheat. However, there was a tendency for greater change in the fat acidity and germination in the surface wheat in 2,740-bushel bins than in 1,000-bushel bins (table 13). This difference was probably the result of the greater increase in surface moisture in the larger bins.

EFFECT OF FUMIGATION ON VIABILITY

Early in the investigations at Hutchinson it was noted that some of the bins that had been fumigated had a lower germination percentage than others. It was found that these differences were related to the kind of fumigant used (table 16).

TABLE 16.—*Change in average wheat germination percentage in comparable bins treated with different fumigants at Hutchinson* [1]

Fumigant	Bins	Average change in germination
	Number	*Percent*
1-Dichloro-1-nitroethane-carbon tetrachloride mixture	14	−27.4
Chloropicrin-carbon tetrachloride mixture	15	−26.8
Chloropicrin-ethylene dichloride mixture	2	−23.5
Carbon disulfide-carbon tetrachloride mixture	4	−16.2
Carbon tetrachloride alone	9	−14.6
β-methylallyl chloride-carbon tetrachloride mixture	16	−10.1
Acrylonitrile-trichloroacetonitrile-carbon tetrachloride mixture	13	−3.4
Ethylene dichloride-carbon tetrachloride mixture	2	+2.5

[1] Check or untreated wheat in tests conducted over a 1-year period showed germination at start 95 percent and after 1 year 89 percent, a change of −6 percent.

At Jamestown a special fumigation study using a mixture of 3 : 1 ethylene dichloride-carbon tetrachloride containing 10 percent methyl bromide showed that the viability of the wheat was reduced materially by such treatment.[10]

EFFECT OF FUMIGATION ON FAT ACIDITY AND PROTEIN CONTENT

Fat acidity values and percent protein content of wheat after fumigation with the mixture containing 10 percent methyl bromide (used in Jamestown bins) are shown in table 17. Changes due to fumigation were not statistically significant.

TABLE 17.—*Average wheat fat acidity and protein content for three 2,740-bushel bins of wheat fumigated with a mixture containing 10 percent methyl bromide and for three similar bins of wheat not fumigated, Jamestown*

Date of sampling	Fat acidity [1]		Protein content [1]	
	Fumigated	Not fumigated	Fumigated	Not fumigated
	Units	*Units*	*Percent*	*Percent*
August 1941	[2] 22	21	[2] 15.3	16.6
November 1941	25	23	16.3	16.7
February 1942	24	21	15.9	16.8
May 1942	22	21	16.4	17.2
August 1942	27	27	16.0	16.9
November 1942	23	21	15.9	16.5
February 1943	31	31	15.8	16.7
May 1943	28	31	16.0	16.3
August 1943	36	34	16.1	16.7
November 1943	33	27	16.0	16.7
February 1944	26	26	16.3	17.0
June 1944	38	27	15.9	16.5

[1] Average of 3 bins.
[2] First fumigation November 1941. These figures represent fat acidity and protein content before fumigation.

EXPERIMENTAL FLOOR STUDIES

A study was made of the effectiveness of various types of floor construction and of materials in preventing the deterioration of wheat often found on floors of storage bins. Since the results of these tests are available in other publications only a brief summary is given here.[11]

All floors studied were in 14-foot diameter, 100-bushel steel bins. Twenty different floor designs were tested in 48 trials at Hutchinson and 21 floor designs in 39 trials at Jamestown. Tests ran from 1 to 3 years.

The main types of floors and foundations studied are shown in figure 7. Type A was standard for the steel bins. Types B, C, D, E, and F were experimental.

PERFORMANCE IN DIFFERENT LOCALITIES

Although the floors installed at Hutchinson and Jamestown were almost identical, there were noticeable differences between the 2 bin sites. At Jamestown there was excellent surface and soil drainage and the site was never flooded. At Hutchinson opposite conditions existed,

[10] See footnote 1, p. 1.
[11] GROSS, E. R. PERFORMANCE OF GRAIN BIN FLOORS. Agr. Engin. 26: 417–420, illus. 1945.
STAHL, B. M. STORAGE PERFORMANCE OF GRAIN BIN FLOORS. Agr. Engin. 27: 357–362, illus. 1946.

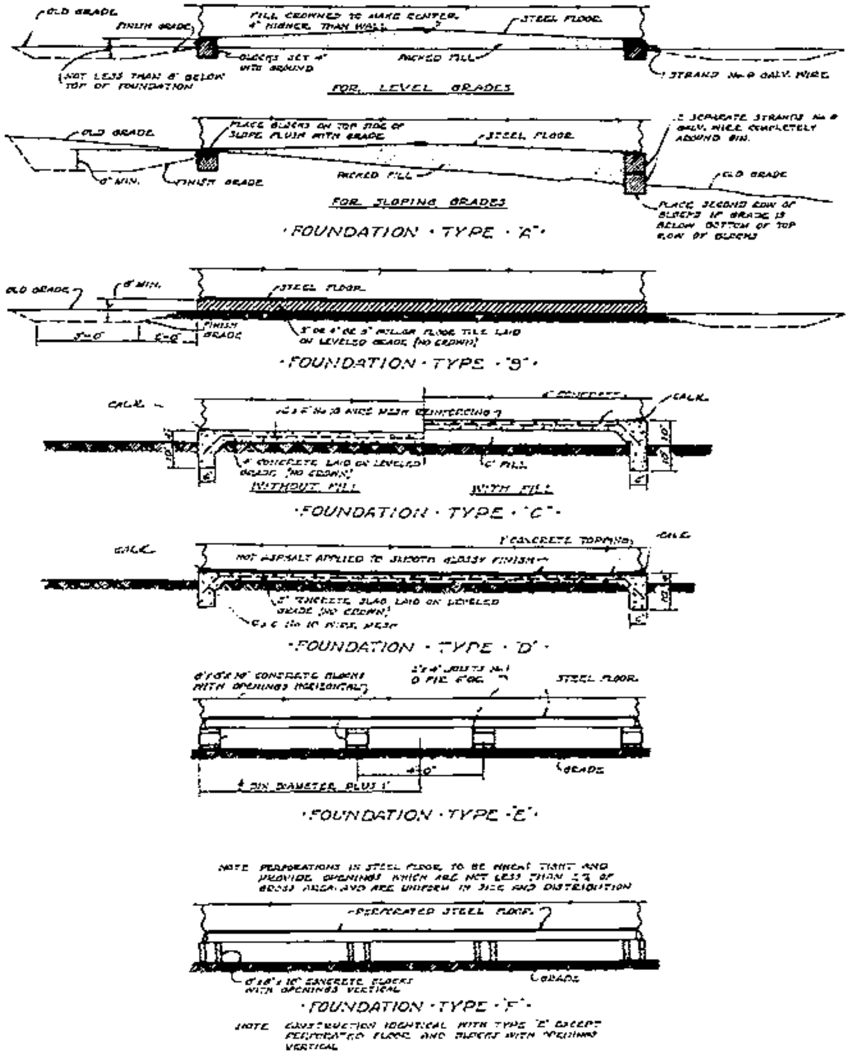

FIGURE 7.—Types of bin floors used in wheat storage studies.

although the floors were never inundated. Average precipitation at Hutchinson was 27.8 inches as compared to 19.5 inches at Jamestown. However, at Hutchinson precipitation was 39.0 inches in 1941 and 46.7 inches in 1942. Drifting snow was a more serious hazard at Jamestown than these records would indicate. Whenever snow accumulated against the bins used for experimental floor studies, it was shoveled or swept away before melting could occur.

With these relatively favorable conditions at Jamestown, much better results might be expected from the Jamestown tests than from the Hutchinson tests. However, the average amount of visibly spoiled wheat per floor test at the 2 bin sites was practically the same—3.7 bushels at Hutchinson and 3.8 bushels at Jamestown.

Also, floor performance as measured by the final moisture content of the wheat on the center of each floor showed approximately the same results for similar floor installation at both localities.

Seasonal fluctuations in the moisture content of the bottom 15 inches of wheat were observed at both localities. In these observations, the average moisture content of the wheat in January 1942, July 1942, and January 1943, as compared to the initial average wheat moisture content, was:

Date and probe samples:	Moisture content of wheat at— Hutchinson (Percent)	Jamestown (Percent)
June 1941, initial bin average	11.43	12.41
January 1942, bottom 15 inches in bin	11.20	12.52
July 1942, bottom 15 inches in bin	11.52	13.19
January 1943, bottom 15 inches in bin	11.24	12.41

The above conditions show that in the absence of roof or wall leaks no abnormal moisture change occurs in wheat on floors where there is no water leakage or penetration of moisture from the subfloor. The periodic changes of the wheat moisture content within 15 inches of the floor is explained by temperature gradients directing the movement of water vapor by convection currents from one section to another in the bulk of wheat.

RESULTS

1. Nine floor types proved effective in that no spoiled grain was found on the floors and floor moisture was adjudged to be within safe limits. They were (1) steel on earth, not calked; (2) steel on earth, calked; (3) steel on gravel; (4) steel on joists; (5) concrete with aluminum-foil overlay; (6) concrete with roll-roofing overlay; (7) single boards on joists; (8) double boards on joists; and (9) roll roofing on earth.

2. Six floor types that proved less effective in preventing grain spoilage or developed excessive moisture near the floor—both conditions prevailed in some cases—were (1) concrete on earth; (2) concrete on gravel; (3) concrete with board overlay; (4) concrete on tile; (5) concrete with 1 coat of emulsified asphalt; and (6) concrete with 2 coats of emulsified asphalt.

3. Four types considered uncertain, although no spoilage occurred but moisture was excessive in at least one trial, were (1) steel on tile; (2) perforated steel on joists; (3) 2-course concrete; and (4) concrete with aluminum-foil paper and board overlay.

4. Calking at the floor-wall joint was ineffective in floors where the platform extended beyond the bin wall. (Types B, C, and D.) These studies showed that calking has definite limitations as a remedy for poor floor design.

5. Flashing the platform floors proved effective in preventing spoilage caused by floor-wall joint leaks.

6. Moisture barriers are required for concrete floor designs, but are ineffective if the exposed concrete floor is not properly flashed or shielded above the moisture barrier.

7. Embedding the bin wall in the concrete floor makes a substantial floor-wall joint.

8. Floor materials of straw, roll roofing, and silo paper, as used in these tests, proved satisfactory in maintaining the quality of the wheat. The straw, however, must be sifted to remove wheat. Approximately 10 bushels of wheat was thus recovered from the straw floor in the Jamestown trial. A cover of kraft paper over the straw is a possible improvement in this type of floor. Paper floors are satisfactory but are subject to damage when the bin is emptied.

REMEDIES FOR DEFECTIVE FLOORS

Many farm storages have been erected on concrete or wood platforms that extend beyond the bin walls. Spoilage has always been observed in wheat stored on such floors. Some of the tests demonstrate that this can develop into a serious loss. Elaborate alterations are not required to remedy the defect in this type of floor. A strip of metal flashing attached to the bin walls by metal screws at the position shown in diagram *A* of figure 8 proved effective. This

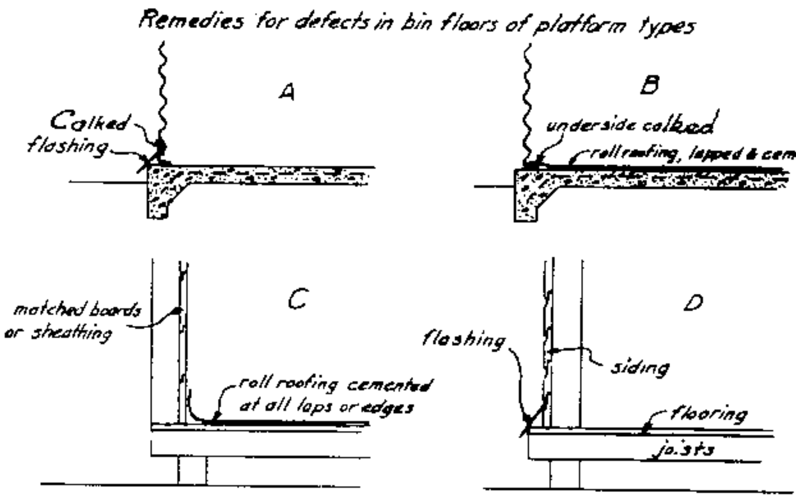

FIGURE 8. Remedies for defective bin-floor installations.

method of protecting the floor was adopted, even though somewhat difficult to install on a round bin, because it did not interfere with the tests on various floor treatments and coverings. Otherwise, the method illustrated in diagram *B* (fig. 8) would be more effective and simple.

If considerable shoveling is necessary, as in a bin used for feed storage, the roll roofing can be covered with boards or a concrete topping. A similar application of roll roofing (fig. 8, *C*) is suitable for bins having wood platform floors where external studding prevents the effective use of flashing. For rectangular bins having internal studding, flashing (fig. 8, *D*) is probably the simplest protection that can be used effectively.

MANAGEMENT STUDIES

Past experience in the storage of surplus wheat by farmers and by the Commodity Credit Corporation showed that sound management practices were necessary for prolonged storage of wheat in farm-type bins. The wheat-research investigations at Hutchinson and Jamestown were designed to obtain information on different methods of managing wheat of low-moisture content in storage. A sound management practice must fulfill the following requirements: (1) Prevent deterioration indefinitely, as measured by standard grade factors; (2) prevent loss caused by insects or rodents; (3) prevent spoilage from heating as the result of high moisture content and high temperatures, or both; and (4) maintain wheat in good condition for long periods at minimum cost.

OUTLINE OF TREATMENTS

Only steel bins were used in the management studies at Hutchinson and Jamestown. They were of different sizes, however, and some were ventilated. A total of 73 bins was used at Hutchinson and 90 at Jamestown.

The bins in the management studies, except for 2 bins filled with 1941 wheat at Hutchinson, were filled in June and July 1941 with 1940 crop wheat that had previously been stored in terminal elevators. It graded mostly No. 2 and No. 3, but a few of the bins were filled with No. 1 and No. 4 wheat. With few exceptions, test weight was the factor establishing the grade. Except for three 2,740-bushel bins at each station that were filled with wheat having high dockage, ranging from 3.0 to 6.0 percent, the wheat in storage contained dockage of 1.0 percent or less. The average moisture content of the wheat was 11.3 percent at Hutchinson and 12.4 percent at Jamestown. Wheat with such moisture contents is considered as dry and storable in these respective areas; consequently, the investigations did not include any provision for managing damp wheat in storage.[12]

The bins of wheat used in the management studies were originally assigned to 8 different treatments, each providing a possible management procedure. Later, a ninth treatment was added at Hutchinson. These treatments, designed mostly to protect stored wheat against damage caused by insects, excessive temperatures, or surface spoilage, fell into two categories—preventive and curative. *Preventive treatments* were designed to precondition the wheat to prevent the occurrence of the causes of damage, and *curative treatments* were designed to cure and recondition the wheat after the occurrence of the causes of damage. These treatments were as follows:

1. *No treatment* (check bins).—This wheat was placed in storage directly from terminal elevators without any kind of treatment or fumigation.
2. *Initial fumigation at Hutchinson and, if necessary, at Jamestown; no subsequent treatment* (preventive treatment).—At Hutchinson this wheat was fumigated with 3 gallons of carbon disulfide per 1,000 bushels of wheat when placed in storage. No further treatment was given. The insect-free wheat at Jamestown was not fumigated.

[12] "Damp wheat" is defined here as having too much moisture to store for long periods without spoilage in unventilated, tightly constructed bins; that is, wheat above 12 percent moisture in Kansas and above 14-percent in North Dakota.

3. *Oil spray on wheat surface* (preventive treatment).—The surface of the wheat was periodically sprayed with 2 quarts of paraffin oil in the 1,000-bushel bins and with 6 quarts in the 2,740-bushel bins. Its purpose was to seal the wheat surface against insect invasion.
4. *Periodic fumigation, June and September, later changed to August and October at Hutchinson, but August only at Jamestown* (preventive treatment).—This wheat was to be fumigated twice annually at Hutchinson whether or not it was weevily, and once annually at Jamestown.
5. *Turning in cold weather* (preventive treatment).—This treatment, also referred to as "turning in January," consisted of turning the wheat from one bin to another once a year during cold weather.
6. *Fumigation when necessary* (curative treatment).—This wheat was to be fumigated whenever the insect population was considered dangerously high.
7. *Turning and cleaning when necessary* (curative treatment).—This treatment consisted of running the wheat over a cleaning screen while turning it from one bin to another whenever it became infested with insects. The treatment was to be used when the insect population was considered dangerous or if excessive temperatures developed.
8. *Turning, cleaning, and fumigating when necessary* (curative treatment).—This treatment consisted of running the wheat over a cleaning screen when turning it from one bin to another and fumigating after turning and cleaning whenever it became infested with insects.
9. *Regular annual fumigation in October* (preventive treatment). At Hutchinson this treatment was added to the original management studies 18 months after the other treatments were started. It consisted of fumigating the wheat once each year during October whether or not the wheat was infested with insects.

Table 18 lists the number and type of bins originally assigned to each treatment at Hutchinson. It also shows the number of bins remaining in a treatment at the end of each 6 months of storage and gives the reason bins were removed from a treatment.

Insects were a major problem at Hutchinson, and all the treatments were applied to prevent damage to the wheat. However, in those treatments adequately controlling insects, wheat was stored safely for as long as 5 years before it was sold during the war to help meet the demand for wheat.

Insects were not a serious problem at Jamestown, and consequently treatments Nos. 2, 6, 7, and 8, all dealing with fumigation or cleaning for insects, were never applied. Treatment No. 3 (oil spray) was applied at Jamestown, however, but was discontinued, owing to the absence of insects. Treatment No. 4, periodic fumigation in August, was applied but only in order to study the effect of a fumigant on the viability of the wheat. Treatment No. 5 was applied to study the merits of turning in cold weather.

Wheat stored well at Jamestown. It remained in storage for as long as 4½ years before it was sold during World War II.

TREATMENT DATA AND DISCUSSION

No. 1. No Treatment

Check bins were established to determine how long low-moisture wheat could be stored safely at each station if unattended and untreated.

At Hutchinson three 2,740-bushel unventilated bins with calked floor and walls were used for check bins. These bins were filled with wheat during June 1941. Two of the bins were filled with No. 1 top quality wheat free of insects and with a moisture content slightly below 11.0 percent. The other was filled with No. 2 wheat with a moisture content of 11.6 percent and was slightly infested with insects.

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TABLE 18.—*Number of bins originally assigned to the various treatments at Hutchinson, and the number remaining per 6-month periods of storage*

Treatment No.	Treatment Description	Bin description: Size	Bin description: Ventilation [1]	Wheat type [2]	Number of bins as of— June 1941	Jan. 1942	June 1942	Jan. 1943	June 1943	Jan. 1944	June 1944	Jan. 1945	June 1945	Jan. 1946	June 1946	Reason for terminating bin treatment
		Bushels														
1	No treatment	2,740	None	a	3	2	2	2	2	2	2	0	----	----	----	Insects.
2	Initial fumigation, if necessary; no subsequent treatment.	2,740	do	a	6	6	6	6	1	1	1	0	----	----	----	Do.
		2,740	do	a′				3	3	0	----	----	----	----	----	Do.
		2,740	SL-t	a	2	2	2	2	1	1	1	1	1	0	----	Do.
		2,740	PL-t	a	2	2	2	2	1	1	1	0	----	----	----	Do.
		1,000	None	a	2	2	2	0	----	----	----	----	----	----	----	Do.
3	Oil spray, May and August	2,740	None	a	2	2	2	2	2	1	0	----	----	----	----	Do.
		2,740	SL-t	a	2	2	2	2	2	0	----	----	----	----	----	Do.
		2,740	PL-t	a	2	2	2	2	1	0	----	----	----	----	----	Do.
		1,000	None	a	2	2	2	2	0	----	----	----	----	----	----	Do.
4	Fumigation June and September later changed to August and October.	2,740	None	a	3	3	3	3	3	3	3	3	3	3	3	Sold wheat.
		2,740	SL-t	a	2	2	2	2	2	2	2	2	2	0	----	Do.
		2,740	PL-t	a	2	2	2	2	2	2	2	1	1	0	----	Do.
		1,000	None	a	2	2	2	2	2	2	2	2	2	1	1	Do.
5	Turning in January	4,100	None	a	1	1	1	1	0	----	----	----	----	----	----	Insects.
		2,740	do	a	3	3	3	3	3	3	3	0	----	----	----	Do.
		2,740	SL-t	a	2	2	2	2	0	----	----	----	----	----	----	Do.
		2,740	PL-t	a	2	2	2	2	0	----	----	----	----	----	----	Do.
		1,000	None	a	2	2	2	2	0	----	----	----	----	----	----	Do.
6	Fumigation when necessary	5,000	do	a	1	1	1	1	1	1	0	----	----	----	----	Insects and high moisture.
		5,000	SL-t	a	1	1	1	1	1	1	1	0	----	----	----	Do.
		2,740	None	a	5	5	5	5	3	3	3	3	3	3	1	Changed to treatment No. 9; sold wheat; insects.
		2,740	do	b	3	3	3	3	3	3	0	----	----	----	----	Difficult to fumigate.
		2,740	do	c	3	3	3	3	0	----	----	----	----	----	----	Changed to treatment No. 9.
		2,740	do. [3]	a′	----	----	----	2	2	2	2	2	2	2	0	Sold wheat.
		2,740	SL-t	a	2	2	2	2	2	2	2	0	----	----	----	Sold wheat; insects.
		2,740	PL-t	a	2	2	2	2	2	2	2	0	----	----	----	Sold wheat.
		1,000	None [3]	a	2	2	2	2	2	2	2	2	2	2	2	Sold wheat; insects.
		1,000	do	a	1	1	1	3	3	3	3	3	3	3	3	Do.
7	Turning and cleaning when necessary	2,740	None	a	3	3	3	3	3	3	0	----	----	----	----	Insects.
		1,000	do	a	2	2	2	2	2	2	0	----	----	----	----	Do.
8	Turning, cleaning, and fumigating when necessary.	2,740	None	a	3	3	3	3	3	3	3	1	1	1	0	Sold wheat.
		1,000	do	a	2	2	2	2	2	2	2	1	1	1	1	Do.
9	Regular annual fumigation in October [4]	2,740	None	a	----	----	----	[5] 5	5	5	5	4	4	1	0	Insects.
		2,740	do	c	----	----	----	[6] 3	3	3	3	0	----	----	----	Do.
		2,740	do	a	----	----	----	[6] 2	2	2	2	0	----	----	----	Do.
		2,740	SL-t	a	----	----	----	[5] 1	1	1	1	0	----	----	----	Do.
		2,740	PL-t	a	----	----	----	[5] 1	1	1	1	0	----	----	----	Do.
		1,000	None	a	----	----	----	[7] 2	2	2	2	0	----	----	----	Do.

[1] SL-t=Solid metal L-tube; PL-t=perforated metal L-tube.
[2] a =Hard Red Winter 1940 wheat with typical grade factors.
a′=Same as a, except 1941 wheat.
b =Same as a, except high dockage.
c =Same as a, except low test weight.
[3] Painted white.
[4] The bins of wheat in this treatment had originally been assigned to other treatments as indicated. They were fumigated for insects, however, before being tested in this treatment.
[5] Transferred from treatment No. 2, January 1943.
[6] Transferred from treatment No. 6, January 1943.
[7] Transferred from treatment No. 5, January 1943.

Although not considered a dangerous infestation when filled, within 3 months insect activity in this bin caused spot heating. It was necessary to fumigate the wheat during September to save it from excess insect damage.

The low-moisture, high-quality, insect-free wheat in the 2 remaining bins was in storage 3 years before requiring attention. At the end of the second year of storage a slight insect infestation was present, but this did not affect the grade of the wheat. At the end of the third year, however, the wheat was graded "weevily." Insects had increased to the point where it was necessary to fumigate. The wheat remained in storage another year after fumigation before the bins were emptied.

During the 4 years of storage the temperature of the wheat never reached a dangerous point, though localized spoilage caused by water leakage and insect activity, amounting to 60 bushels in one bin and 100 bushels in the other, was found in emptying the bins. Approximately one-half the damaged wheat found in these bins was caused by insects. The bulk of the wheat, however, was in good condition and still graded No. 1, though "weevily" (table 19).

TABLE 19. *Initial and final average grade of Hard Winter wheat stored undisturbed for 4 years and untreated for 3 years at Hutchinson*

Bin No.	Initial sample, June 1941: Grade	Test weight	Moisture content	Total damage	Fat acidity	Germination	Final sample, June 1945: Grade	Test weight	Moisture content	Total damage	Fat acidity	Germination
	No.	*Lb.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*No.*	*Lb.*	*Pct.*	*Pct.*	*Units*	*Pct.*
7-1	1 HW	61.0	10.7	0.2	18	86	1 HW weevily.	61.0	10.9	0.6	25	75
6-2	1 HW	61.1	10.7	.4	17	81	1 HW weevily.	61.0	11.2	2	24	83

At Jamestown, owing to the relatively few insects, wheat was stored without fumigation or turning in large and small steel bins, with or without L-tubes, for as long as 4½ years without change in the commercial grade and with a minimum amount of spoilage. (For description of L-tubes, see p. 57.)

Originally 12 bins of wheat were assigned as checks at Jamestown, but because the wheat in bins assigned to other treatments was not treated, 70 bins are discussed here. These 70 bins were filled during July 1941 with either Dark Northern Spring or Hard Amber Durum wheat. Most of the wheat in the bins graded No. 2 and No. 3 with some No. 1 and No. 4 (table 20). The moisture content averaged 12.5 percent. The final average grade sample from these bins was taken during February 1944 after 2½ years of storage. Although the wheat remained in storage from 3½ to 4½ years, only surface and spot samples were taken after February 1944.

The average grade of the wheat in these bins taken during February 1944, after 2½ years of storage, was the same as when first placed in storage in all except 6 of the 70 bins. In 5 of the 6 bins, the wheat had a lower or higher grade by 1 number, owing to a small change in

TABLE 20.—*Initial and final average grades of wheat stored untreated and undisturbed in 2,740-bushel and 1,000-bushel bins at Jamestown*

Size, description, and bin No.	Initial wheat sample, July 1941						Wheat sample, February 1944						Length of storage
	Grade [1]	Test weight	Moisture content	Total damage	Fat acidity	Germination	Grade [1]	Test weight	Moisture content	Total damage	Fat acidity	Germination	
2,740-bushel, no L-tube:	*No.*	*Lb.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*No.*	*Lb.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*Years*
J-1	3 DNS	56.0	12.3	0.2	19	96	3 DNS	56.0	12.5	0.3	24	92	3½
K-1	3 DNS	55.8	12.4	.5	22	90	3 DNS	56.1	12.5	.6	25	86	4½
K-2	3 DNS	56.0	12.3	.5	20	91	3 DNS	55.6	12.5	.8	27	89	4½
J-2	2 HAD	60.1	12.5	.2	18	90	2 HAD	60.7	12.6	1.4	21	77	4½
J-3	2 HAD	60.2	13.1	3.0	19	83	2 HAD	60.2	13.0	3.5	23	70	3½
K-3	2 HAD	60.2	12.2	1.7	17	85	2 HAD	60.0	12.4	2.6	19	78	3½
J-4	3 DNS	55.6	12.4	.7	22	90	3 DNS	55.8	12.4	1.5	28	84	4½
K-4	3 DNS	56.1	12.3	.6	19	95	3 DNS	56.0	12.6	.4	21	89	4½
K-5	3 DNS	56.0	12.7	.4	21	94	3 DNS	55.8	12.9	.3	26	84	3½
L-6	3 DNS	55.7	12.7	.4	20	93	3 DNS	55.8	12.9	.6	27	78	3½
L-7	3 DNS	56.2	12.5	.6	19	96	3 DNS	55.8	12.9	.4	----	88	4½
M-6	3 DNS	56.3	12.2	.4	19	92	3 DNS	56.5	12.2	.6	23	89	4½
L-5 [2]	1 DNS	58.6	12.5	.8	18	95	1 DNS	58.7	12.8	.4	25	92	4½
M-4 [2]	3 DNS	56.6	12.3	.7	18	88	3 DNS	56.9	11.8	.6	24	83	4½
M-5 [2]	3 DNS	55.5	12.3	.2	18	91	3 DNS	55.5	12.1	.3	20	91	4½
L-3	3 DNS	55.0	12.4	1.3	20	84	4 DNS	54.9	12.4	.8	26	77	4½
L-4	4 DNS	54.5	12.1	4.0	19	92	4 DNS	54.4	12.2	3.6	27	77	4½
M-3	3 DNS	55.3	12.0	2.5	18	86	3 DNS	55.2	12.0	.8	27	86	4½
L-1	2 HAD	61.0	12.3	0	14	91	2 HAD	60.8	12.2	.5	18	89	3½
L-2	2 HAD	59.7	12.7	2.5	18	87	S HAD	59.1	12.5	5.4	27	71	3
M-1	2 HAD	58.9	12.5	.8	15	89	2 HAD	59.5	12.5	2.4	22	78	3½
M-2	2 HAD	61.0	12.5	.7	18	85	2 HAD	60.7	12.5	2.0	23	73	3½
O-2	3 DNS	56.0	12.8	.2	19	94	3 DNS	55.5	13.1	.5	27	79	3½
O-3	3 DNS	56.0	11.8	.2	17	89	3 DNS	56.2	11.7	.3	23	84	4½
W-1	3 DNS	55.6	12.4	.8	21	90	3 DNS	55.7	12.6	1.2	23	84	3½
W-2	3 DNS	56.0	12.2	.2	22	94	3 DNS	56.3	12.4	.2	23	91	3½
W-3	3 DNS	56.0	12.1	.8	20	92	3 DNS	55.8	12.4	1.0	24	89	3½
P-1	3 DNS	55.6	12.2	.8	20	92	3 DNS	55.5	12.0	1.0	23	91	3
Q-1	3 DNS	55.7	12.6	1.1	22	91	3 DNS	55.5	12.9	1.0	24	84	3
P-2	3 DNS	55.7	12.2	.6	20	90	3 DNS	55.7	12.1	.5	25	86	3
Q-2	3 DNS	55.6	12.5	1.4	19	89	3 DNS	55.4	12.5	2.0	25	85	3
W-4	3 DNS	56.2	12.4	.2	22	93	3 DNS	56.1	12.6	.5	29	82	3
W-5	3 DNS	56.9	12.2	.7	18	92	2 DNS	57.0	12.2	.6	24	92	3
U-4	3 DNS	55.3	12.6	.1	21	92	3 DNS	56.6	12.6	.2	28	82	3½
U-5	2 DNS	57.0	12.7	.4	22	93	3 DNS	56.9	13.0	.8	29	78	3½
U-6	3 DNS	55.6	12.4	.2	22	89	3 DNS	55.3	12.3	.5	27	82	3½
N-6	2 HAD	60.1	11.8	.8	17	83	2 HAD	60.6	11.8	1.0	20	81	4½
N-7	2 HAD	60.0	12.4	1.5	19	81	2 HAD	60.0	12.3	1.0	24	70	4½
N-8	2 HAD	59.8	12.5	1.1	19	88	2 HAD	59.8	12.3	1.1	21	78	3½
N-3	2 HAD	60.0	12.2	1.6	15	86	2 HAD	60.2	12.3	1.0	----	----	4½
N-4	2 HAD	60.0	12.0	.5	18	88	2 HAD	60.2	11.9	1.0	20	84	3½
N-5	2 HAD	60.6	12.0	2.0	19	88	2 HAD	60.5	12.0	1.8	20	82	4½
Average	DNS	55.9	12.4	.7	19.9	91.5		55.9	12.5	.8	25.2	85.4	--------
	HAD	60.1	12.4	1.3	17.4	86.5		60.2	12.3	1.9	21.5	77.6	--------

2,740-bushel, solid L-tube:													
P-3	2 DNS	57.0	12.6	0.9	21	84	2 DNS	57.0	12.8	1.2	27	78	4½
Q-3	3 DNS	56.2	12.4	.2	21	90	3 DNS	56.0	12.3	.5	26	87	4½
P-4	2 DNS	57.5	12.9	1.5	23	93	3 DNS	56.8	12.9	1.2	25	87	4½
Q-4	3 DNS	56.0	12.0	1.5	18	90	3 DNS	56.1	12.3	1.0	25	88	3½
P-6	3 DNS	56.4	12.3	3.6	18	84	3 DNS	56.2	12.8	2.0	23	84	3½
Q-6	3 DNS	56.2	12.5	.5	22	92	3 DNS	56.3	12.5	.8	24	84	4½
P-7	2 HAD	59.5	12.1	2.5	22	82	2 HAD	59.6	12.3	1.5	23	79	3½
Q-7	2 HAD	60.2	12.2	2.4	20	81	2 HAD	60.2	12.2	1.8	[illegible]	83	4½
2,740-bushel, perforated L-tube:													
R-3	2 DNS	57.6	12.8	.8	20	94	2 DNS	57.7	12.7	.3	25	86	4½
S-2	3 DNS	56.0	12.6	.3	22	92	3 DNS	56.1	12.6	.7	25	87	4½
R-4	2 DNS	57.3	13.0	.1	23	93	2 DNS	57.1	12.3	.7	27	86	4½
S-3	3 DNS	55.8	12.6	3.3	22	93	3 DNS	56.7	12.6	.7	25	84	4½
R-6	3 DNS	55.4	12.6	2.5	22	93	3 DNS	55.6	12.8	1.5	23	82	4½
S-5	3 DNS	56.4	12.2	.4	20	90	3 DNS	56.4	12.0	.6	22	86	4½
R-7	2 HAD	60.3	12.3	1.7	19	85	2 HAD	60.0	12.2	1.5	21	75	4½
S-6	2 HAD	60.3	12.6	.5	17	82	2 HAD	60.6	12.4	2.8	22	84	4½
Average	DNS	56.5	12.6	1.3	21	90.7		56.5	12.6	1.0	24.8	84.9	
	HAD	60.1	12.3	1.8	19.5	82.5		60.1	12.3	1.9	22.5	80.2	
1,000-bushel, no L-tube:													
G-3	2 DNS	57.8	12.5	0.6	22	94	2 DNS	57.7	12.7	0.5	27	91	4½
H-3	1 DNS	58.4	12.5	.1	22	93	1 DNS	58.3	12.7	.3	30	88	4½
G-4	2 DNS	57.5	12.2	.7	24	90	2 DNS	57.9	12.6	.6	26	92	4½
H-4	2 DNS	57.6	12.3	.5	23	91	2 DNS	57.9	12.6	.6	26	92	4½
G-8	2 DNS	57.3	12.1	.1	22	91	2 DNS	57.2	12.0	.3	28	84	4½
H-7	3 DNS	56.8	13.0	.8	23	89	3 DNS	56.5	13.1	1.4	31	81	4½
E-4	2 HAD	59.7	12.9	2.0	19	86	2 HAD	59.5	13.1	2.4	27	73	4½
F-4	2 HAD	59.8	12.4	1.6	19	86	2 HAD	59.8	12.5	2.2	22	80	4½
E-5	3 DNS	56.8	13.1	.8	22	90	2 DNS	57.3	13.1	.7	34	87	4½
E-6	3 DNS	56.8	13.4	1.0	21	90	3 DNS	56.6	13.3	1.0	28	82	4½
E-7	3 DNS	56.5	12.7	.8	22	92	3 DNS	56.1	12.8	.5	30	87	4½
E-8	3 DNS	56.7	12.6	.3	22	88	3 DNS	56.5	12.7	.4	33	85	4½
Average	DNS	57.2	12.6	.6	22.3	90.8		57.2	12.8	.6	29.3	86.9	
	HAD	59.8	12.7	1.8	19.0	86.0		59.6	13.1	1.9	24.5	76.5	

[1] DNS=Dark Northern Spring; HAD=Hard Amber Durum; S=Sample.
[2] Wheat containing from 3- to 6-percent dockage.

test weight, easily attributed to sampling variation. The sixth bin, however, was "weevily" and graded Sample because of a musty odor. This bin and 6 others that still maintained their initial grade were emptied at the end of 3 years.

The remaining 63 bins were held in storage for an additional ½ to 1½ years, or a total of 3½ to 4½ years of storage. No heating occurred in any of these bins during storage, but surface damage occurred in a few as a result of increases in surface moisture.

During October 1944, after 3½ years of storage, the top 20 inches of the wheat was sampled for an official grade. The wheat near the grain surface in 18 of the 63 bins graded Sample owing to a musty odor. Bins having some wheat grading Sample included 35 percent of the 2,740-bushel bins with no L-tubes filled with Dark Northern Spring wheat and 48 percent of those filled with Hard Amber Durum wheat and 33 percent of the 2,740-bushel bins with solid L-tubes [13] filled with Dark Northern Spring and 50 percent of those filled with Hard Amber Durum. None of the surface wheat in the 2,740-bushel bins equipped with perforated metal L-tubes or in the twelve 1,000-bushel bins graded Sample.

The average moisture content of the surface wheat grading Sample was 14.0 percent in February 1944, as compared to the average moisture content of 13.4 percent in the surface wheat of similar bins grading better than Sample. Total damage in the Sample grade wheat averaged 12.6 percent as compared to an average of 3.6 percent in surface wheat grading better than Sample. Fat acidity of the Sample grade wheat averaged 38 units, as compared to an average of 31 units. Germination of the Sample grade wheat averaged 30 percent as compared to an average of 47 percent in the surface wheat above Sample grade.

The 18 bins with surface wheat grading Sample and 2 others were emptied at the end of 3½ years of storage. Wheat below the surface in all these bins was still in good condition. The Sample grade wheat, representing less than 2 percent of the wheat in the bin, was located in a dish-shaped area directly below the surface at the bin center. It seldom extended to the bin walls and was usually less than 2½ feet thick at the center. This Sample grade wheat, however, seldom caused a monetary loss. It was mixed with the good wheat when the bin was emptied and did not materially affect the grade of the entire bin of wheat.

The 43 remaining bins of wheat were held in storage for another year, or for a total of 4½ years. Wheat samples taken from the top center of these bins before emptying graded Sample in 4 bins because of a musty odor, but the top center in 29 of the bins still graded the same as when placed in storage 4½ years earlier. Ten of the bins had a grade lower by one number as compared to the original grade. No difference was found in the storage of wheat of different percent dockage or grades at Jamestown (table 20).

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[13] After this study was completed, methods were developed for cooling wheat, shelled corn, and other grains by slow ventilation when atmospheric temperature is lower than the grain temperature. This method is much more effective in preventing deterioration than the use of the L-tube described on p. 57.

No. 2. No Treatment After Initial Fumigation

Discussion of this treatment applies only to wheat stored at Hutchinson. None of the bins of wheat at Jamestown were fumigated for this treatment. Those bins at Jamestown originally assigned to this treatment were included in the check bins of treatment No. 1.

Thirteen 2,740-bushel steel bins and two 1,000-bushel steel bins were assigned to treatment No. 2. Four of the 2,740-bushel bins were equipped with either solid or perforated metal L-tubes (table 21).

Five of these bins were emptied after 1 year and 7 after 1½ years. Two bins were held for 3 years and 1 for 4 years. These 3 bins, like those in treatment No. 1, contained high-quality wheat free of insects and with a moisture content of 11.0 percent or less when placed in storage. There was no change in the commercial grade of the grain while in storage under this treatment that cannot be attributed to sampling error (table 21). Neither the size of the bin nor the presence of L-tubes increased or decreased the length of the storage period. No continued protective effect was noticed from the initial fumigation of carbon disulfide.

No. 3. Oil Spray on Wheat Surface

Treatment No. 3 consisted of a light paraffin oil sprayed over the surface of the grain as a preventive measure. It was hoped that a surface seal would prevent insect infestation for a long period of time. Eight bins of wheat at Hutchinson and 3 at Jamestown were set aside for this treatment. The bins at Hutchinson included six 2,740-bushel bins—four ventilated with L-tubes—and two 1,000-bushel bins. The 3 bins at Jamestown were 2,740-bushel bins without ventilators. At Hutchinson the wheat was fumigated with carbon disulfide as soon as placed in storage to make it insect-free before the first application of oil spray.

The first oil spray at Hutchinson was applied during November 1941; the second and third during May and September of 1942; and the fourth and fifth applications during June and August of 1943 to those bins of wheat still remaining in the treatment. Only one application of oil was sprayed on the wheat surface of the Jamestown bins, during June. Owing to the relative lack of insects at Jamestown, the treatment was discontinued. The condition of the wheat when released was as good as when placed in storage.

According to the results from the Hutchinson bins, applying a film of oil to the surface of the wheat to prevent insect damage was not successful. The 1,000-bushel bins remained in storage 2 years, but they were heavily infested and contained considerable insect damage in local areas when emptied. Most of the 2,740-bushel bins remained in storage an additional 6 months under this treatment before it was necessary to fumigate.

The failure of the oil-spray treatment at Hutchinson was largely attributable to the condition of the wheat when placed in storage. This wheat, though of good quality, had been previously stored in terminal elevators and was infested with insects when placed in storage. Although it was fumigated before the application of the oil, it is probable that the fumigation had not accomplished a 100-percent kill. Only one bin was insect-free when placed in storage, and this bin remained in storage 3½ years without dangerous insect

TABLE 21.—*Average initial and final grade, fat acidity, and germination and length of storage for the bins of wheat in the "no treatment after initial fumigation" at Hutchinson*

Size, description, and bin No.	Initial sample						Final sample						Length of storage[2]
	Grade[1]	Test weight	Moisture content	Total damage	Fat acidity	Germination	Grade[1]	Test weight	Moisture content	Total damage	Fat acidity	Germination	
	No.	*Lb.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*No.*	*Lb.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*Years*
2,740-bushel, no L-tube:													
5-2	1 HW	60.9	11.0	0.5	21	90	1 HW	60.8	11.0	0.4	28	72	3
6-3	1 HW	60.3	11.2	.7	27	80	2 HW	59.6	11.0	.3	28	71	1½
6-4	1 HW	60.1	11.3	(3)	25	79	1 HW	60.1	11.0	.2	28	71	1½
11-10	2 HW	58.3	11.6	2.5	27	78	2 HW	58.1	11.3	3.2	31	75	1
11-11	2 HW	58.3	11.5	2.0	24	76	2 HW	58.0	11.4	2.0	27	73	1
12-10	2 HW	58.5	11.5	2.4	22	80	2 HW	58.5	11.4	2.0	25	79	1
11-2	2 HW	58.7	11.4	.6	24	81	2 HW	58.6	11.3	.8	33	66	1½
12-1	2 HW	58.8	11.6	.1	29	83	2 HW	58.3	11.5	.7	36	50	1½
12-2	2 HW	58.0	11.7	.7	23	86	3 HW	57.4	11.8	1.3	40	36	1½
2,740-bushel, with solid L-tube:													
5-4	1 HW	60.3	11.7	1.2	23	82	2 HW	59.7	11.3	1.0	27	71	1½
6-5	1 HW	60.1	10.9	.2	23	82	1 HW	60.0	10.9	.5	25	66	4
2,740-bushel, with perforated L-tube:													
5-5	2 HW	58.0	11.8	.2	20	79	2 HW	58.4	11.5	.7	22	72	1½
6-6	1 HW	60.6	10.5	.2	22	89	1 HW	60.5	10.7	.3	24	80	3
1,000-bushel, no L-tube:													
3-10	2 HW	58.8	11.2	1.0	27	85	2 HW	58.3	11.1	1.0	29	78	1
3-11	2 HW	58.5	11.2	1.0	27	85	2 HW	58.5	11.2	1.0	30	78	1

[1] HW = Hard Winter.
[2] Storage was discontinued at time indicated because of insect infestation.
[3] Trace.

infestation, but this record of storage was no better than similar wheat stored in check bins without any type of treatment.

When the bins at Hutchinson were emptied, the commercial grade of the wheat was the same as when placed in storage.

No. 4. Periodic Fumigation

Treatment No. 4 was designed to prevent insect infestations in the stored wheat. The two fumigations in August and October at Hutchinson were intended to kill the insects in midsummer and again during late fall to clean the bins for the following winter, spring, and early summer. At first the two fumigations were set for June and September, but observations of insect flights showed that a fumigation in late summer (August) and in early fall (October) were better to hold the infestation to a minimum. Owing to the paucity of insects at Jamestown, the wheat was not fumigated in August for the purpose of controlling insects but rather to study the effects of a fumigant containing methyl bromide on the viability of the wheat.

At Hutchinson this treatment included 9 bins—seven 2,740-bushel bins and two 1,000-bushel bins. Four of the 2,740-bushel bins were equipped with L-tubes. The bins were filled during June 1941 with wheat of 11.1- to 11.9-percent moisture. Some of this wheat remained in storage for 5 years and none less than 3 years.

This treatment of two regular annual fumigations during August and October kept the wheat free of insects in all except one 2,740-bushel bin with L-tube. Rainwater leakage through the roof and wall on the south side in this bin caused an area of spoiled wheat that became infested with insects. They survived the fumigations in this wetted grain. At the end of 3 years' storage, rainwater leakage, insect damage, and heating in this bin caused 150 bushels of spoiled or partly damaged wheat. The final average probe sample of wheat from this bin was Sample grade because of objectionable odor. However, except for the spoiled portion that apparently imparted the objectionable odor in the final sample, the wheat in the bin was still in good condition.

Wheat in one other bin stored under this treatment graded Sample, owing to a bad odor at the end of 4 years of storage. This wheat was in one of the two 1-000-bushel bins included in this series. The sour odor of the final sample was caused by 50 bushels of spoiled wheat found on the bin floor where water had leaked through the wall and floor-wall joints. Except for this spoiled area, the rest of the wheat in the bin was in good condition. Insects did not cause any appreciable damage in this spoiled area.

Wheat in 2 other bins—one 1,000-bushel bin and one 2,740-bushel bin—dropped from grade 2 HW to 3 HW after 5 years of storage (table 22). Noticeable changes occurred in the germination of the wheat while stored under this treatment. The number of fumigations and the kind of fumigants used are given as the reasons for the low final germination percentages.

Periodic fumigation was found to be an effective method for protecting wheat against insect damage under climatic conditions such as at Hutchinson. Under this treatment wheat remained in storage for a long period with the minimum of insect damage. Damage that occurred was mostly from water leakage. Except for the 2,740-bushel bin that contained spoilage and insects, none of the bins in this treatment showed any signs of heating.

No. 5. Turning in Cold Weather

Treatment No. 5 was included in the tests, because turning grain at regular intervals is a practice followed quite generally by country and terminal elevators to maintain the good condition of grain. Under farm storage conditions, benefits might be derived if the wheat were turned during cold weather for the purpose of breaking up high-moisture areas in the bin, lowering the temperatures at the center of the bin, and breaking up any colonies of insects present. In addition, turning presents an opportunity to remove any spoiled portions that might have developed during the storage period and to repair any leaks in the bins.

To determine the merits of turning wheat during cold weather in farm-type storage, 10 bins of wheat at Hutchinson and 8 at Jamestown were assigned to this treatment. At Hutchinson seven 2,740-bushel bins, two 1,000-bushel bins, and one 4,100-bushel bin were used. Two of the 2,740-bushel bins contained a solid L-tube and two a perforated L-tube. At Jamestown six 2,740-bushel and two 1,000-bushel bins were used. These did not contain L-tubes.

These bins were filled during June and July 1941 with 1940 wheat that had been stored in terminal elevators. Because of the weevily condition of the Hutchinson wheat, it was fumigated immediately to have it insect-free at the beginning of the tests. The initial and final bin average wheat grade, fat acidity, and germination for each bin stored under this treatment are given in table 23.

Turning wheat in cold weather consisted merely of transferring the wheat from one bin to another (fig. 9), by means of a farm elevator equipped with an auger attachment for moving the grain from the center and far side of a bin to the elevator hopper.

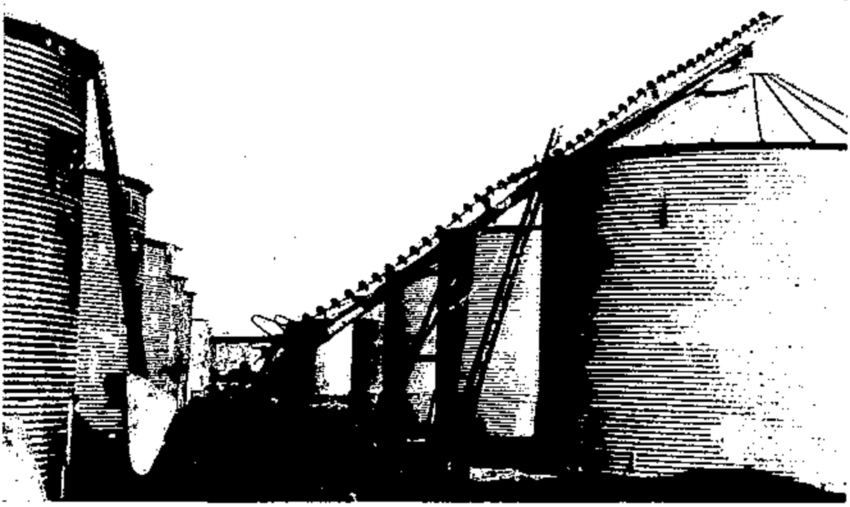

FIGURE 9.—Transferring grain from bin to bin.

TABLE 22.—*Average initial and final grade, fat acidity, and germination and length of storage for bins of wheat treated by "semiannual fumigation" at Hutchinson*

Size, description, and bin No.	Initial sample							Length of storage	Final sample						
	Grade [1]	Test weight	Moisture content	Dockage	Total damage	Fat acidity	Germination		Grade [1]	Test weight	Moisture content	Dockage	Total damage	Fat acidity	Germination
	No.	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*Years*	*No.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Units*	*Pct.*
2,740-bushel, no L-tube:															
9-1	1 HW	60.2	11.1	0.2	0.0	25	78	5	1 HW	60.3	11.1	0.3	0.6	43	0
10-1	2 HW	58.0	11.7	.3	.4	34	76	5	3 HW	57.4	11.8	.3	2.0	44	0
10-2	2 HW	58.2	11.6	.6	.5	21	86	5	2 HW	58.1	11.4	.3	.7	39	0
2,740-bushel, with solid L-tube:															
9-2	2 HW	59.7	11.3	.3	.5	25	80	4	2 HW	59.0	11.5	.2	.8	39	3
10-3	2 HW	58.3	11.5	.4	(2)	20	78	4	2 HW	58.3	11.5	1.6	.7	40	2
2,740-bushel, with perforated L-tube:															
9-3	2 HW	58.9	11.3	.7	1.0	23	72	4	2 HW	58.2	12.0	.1	.7	45	0
11-1	2 HW	58.6	11.3	.4	.2	22	89	3	S HW [3]	58.2	12.2	.2	.7	48	3
1,000-bushel, no L-tube:															
2-12	3 HW	57.2	11.9	.7	1.6	24	76	4	S HW [4]	57.2	11.8	.8	6.0	43	2
3-12	2 HW	58.4	11.5	.4	.7	25	84	5	3 HW	57.5	11.4	.6	.8	43	0

[1] HW=Hard Winter.
[2] Trace.
[3] Sample grade due to commercially objectionable foreign odor.
[4] Sample grade due to sour odor.

TABLE 23.—*Initial and final grade, fat acidity, and germination and length of storage of wheat stored in the "turning in cold weather" treatment at Hutchinson and Jamestown; turned in January 1942*

AT HUTCHINSON

Size, description, and bin No.	Initial sample							Length of storage	Final sample						
	Grade [1]	Test weight	Moisture content	Dockage	Total damage	Fat acidity	Germination		Grade [1]	Test weight	Moisture content	Dockage	Total damage	Fat acidity	Germination
	No.	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*Years*	*No.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Units*	*Pct.*
4,100-bushel, no L-tube, 5-11.	2 HW	58.5	12.6	0.5	0.7	23	82	2	S HW [2]	57.2	13.0	0.2	10.0	44	14
2,740-bushel, no L-tube:															
7-5	1 HW	60.1	11.2	.6	.5	29	79	3	2 HW	59.4	11.9	.4	1.6	37	27
8-4	2 HW	58.0	11.4	.9	1.0	28	86	3	3 HW	57.6	11.9	.3	.5	30	50
8-5	2 HW	58.2	11.3	1.0	1.0	26	80	3	2 HW	58.0	11.3	.2	.4	28	62
2,740-bushel, with solid L-tube:															
7-7	2 HW	58.1	11.4	.6	2.0	17	81	1½	2 HW	59.2	11.4	.6	.8	30	70
8-6	3 HW	57.4	11.3	.9	1.2	17	85	1½	2 HW	58.2	11.2	.8	.8	32	73
2,740-bushel, with perforated L-tube:															
7-8	2 HW	58.7	11.2	.6	1.8	17	86	1½	2 HW	58.2	11.1	.9	.4	37	69
8-8	2 HW	58.0	11.3	.9	.6	18	84	1½	3 HW	57.9	11.2	.9	.5	25	73
1,000-bushel, no L-tube:															
12-11	2 HW	58.8	11.3	.4	1.0	25	81	1½	2 HW	59.0	11.8	.2	.4	35	28
12-12	2 HW	58.3	11.2	.5	.6	25	80	1½	2 HW	58.0	12.0	.7	1.3	40	35

AT JAMESTOWN

Size, description, and bin No.	Grade [1]	Test weight	Moisture content	Dockage	Total damage	Fat acidity	Germination	Length of storage	Grade [1]	Test weight	Moisture content	Dockage	Total damage	Fat acidity	Germination
2,740-bushel, no L-tube:															
J-7	3 DNS	55.3	12.5	1.3	0.9	22	87	3	3 DNS	55.4	12.3	1.8	0.7	28	77
K-7	3 DNS	56.1	12.5	.3	.2	22	94	3	3 DNS	56.1	12.5	.4	1.2	27	80
K-8	3 DNS	56.3	12.5	.4	.4	19	93	3	3 DNS	56.3	12.5	.4	.5	23	89
L-8	3 HAD	60.0	12.2	.4	4.5	19	82	3	2 HAD	59.8	12.2	.7	4.0	27	81
M-7	2 HAD	59.8	12.5	.4	3.5	20	77	3	3 HAD	59.8	12.5	.8	5.2	27	74
M-8	2 HAD	60.1	12.8	.8	2.0	18	81	3	2 HAD	60.2	12.5	1.1	1.2	24	72
1,000-bushel, no L-tube:															
G-6	2 DNS	57.3	12.5	.6	.1	24	95	3	2 DNS	57.1	12.6	.8	.3	25	89
H-6	3 DNS	56.7	12.9	.6	.9	23	92	3	3 DNS	56.6	12.8	.7	.7	31	80

[1] HW=Hard Winter; DNS=Dark Northern Spring; and HAD=Hard Amber Durum wheat.
[2] S=Sample grade, because of sour odor.

The time required for 2 men to complete the turning of a bin of wheat depended upon the size of the bin and the ease in setting up and taking down the equipment. Ordinarily, 1,000-bushel bins were turned in 4 hours. A 2,740-bushel bin required about 7 hours and a 4,100-bushel bin about 10½ hours. In these tests the wheat was moved at the average rate of 470 bushels per hour. Tests with small pieces of wood indicated that the wheat was in the elevator approximately 14 seconds.

The original purposes of turning were accomplished, but their benefits to longtime storage of low-moisture content wheat are of questionable value.

Turning the wheat did lower the wheat temperatures in the center of the bin (table 24). The center temperature in the 4,100-bushel bin was lowered 17° F., in the 2,740-bushel bins without L-tubes 10° to 22°, and in the 1,000-bushel bins 7° to 15°. The effect of turning on the temperatures of wheat in the center of bins with L-tubes was slight. Lowering the center temperatures was the result of mixing the wheat while turning and exposing it to cold air. However, within a few months the center wheat temperatures in the turned bins were equal to the center wheat temperatures in the unturned bins (fig. 10).

The effect of turning on the average wheat temperatures in the bins depended considerably upon the conditions under which the wheat was turned (table 24). Under the turning conditions at Hutchinson and Jamestown the average wheat temperatures were lowered from 1° to 10° F. in 13 bins, but wheat temperatures rose from 1° to 10° during turning in 5 bins, because the turning was done while the air temperature was higher than the average wheat temperature.

Turning wheat was an effective means of breaking up the moisture accumulation in the surface grain. Turning was also effective in mixing small amounts of damp wheat with the drier portion if, originally, the bin was not filled throughout with wheat of uniform moisture content. This might happen if a bin were filled directly from the combine.

One turning, however, did not mix the wheat uniformly throughout the bin. Complete uniform mixture was not accomplished, as indicated by differences in moisture content of the wheat in different parts of the grain mass (table 24). Turning had little effect on the average moisture content. Of the 18 bins turned, the average moisture content in only 3 was changed by 0.5 percent or more.

Turning wheat was an effective means of breaking up insect colonies, but the net result was detrimental because the infestation was scattered throughout the grain. This became evident after the first turning at Hutchinson. For that reason, the two 1,000-bushel bins without L-tubes and the four 2,740-bushel bins with L-tubes were dropped from this treatment after the first turning and were assigned to other treatments. The three 2,740-bushel and the one 4,100-bushel bins without L-tubes at Hutchinson and all the bins at Jamestown were turned again the following year. Wheat temperatures and moistures in bins before and after the second turning were similar to those already reported for the first turning. The insect populations in the 2,740-bushel bins at Hutchinson were about equal to those in check bins receiving no treatment.

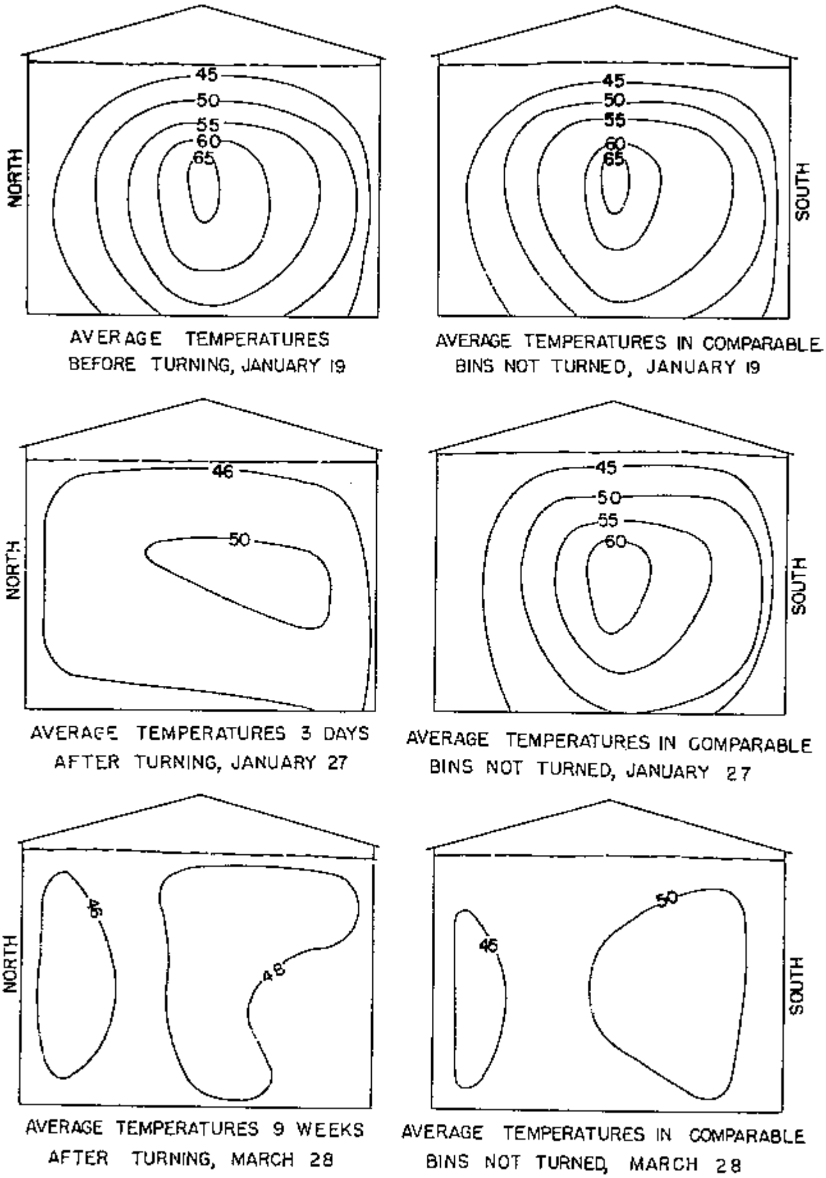

FIGURE 10.—Wheat temperature in 2,740-bushel bins without L-tubes before and after turning in January 1942, in comparison with those not turned, Hutchinson.

TABLE 24.—*Summary of wheat moisture content and temperature conditions in wheat bins before and after turning in January 1942 and air temperature during turning at Hutchinson and Jamestown*

Size, description, and bin No.	Moisture content						Wheat temperature				Change in average wheat temperature	Air temperature during turning		
	Before turning			After turning			Before turning		After turning					
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Center of bin	Average	Center of bin		Average	Maximum	Minimum
AT HUTCHINSON														
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
4,100-bushel, no L-tube, 5-11	12.5	14.0	11.9	11.9	12.8	11.4	60	74	50	57	−10	55	65	50
2,740-bushel, no L-tube:														
7-5	10.9	11.7	10.6	10.5	10.7	10.1	43	62	50	52	+7	40	55	40
8-4	11.1	11.5	10.8	11.1	11.4	11.1	50	60	46	50	−4	41	55	35
8-5	11.1	12.1	10.7	11.1	11.4	10.8	55	70	45	48	−10	40	60	30
2,740-bushel, with solid L-tube:														
7-7	11.0	11.7	10.6	11.1	11.6	10.7	40	[1] 53	47	[1] 40	−2	34	36	32
8-6	11.1	11.9	10.8	11.1	11.4	11.0	51	[1] 38	46	[1] 40	−5	35	38	32
2,740-bushel, with perforated L-tube:														
7-8	10.9	12.0	10.4	11.3	11.8	10.8	46	[1] 50	48	[1] 50	+2	45	55	35
8-8	11.0	12.0	10.4	11.1	11.8	10.4	40	[1] 53	44	[1] 47	−5	45	55	35
1,000-bushel, no L-tube:														
12-11				11.1	11.4	10.0	39	48	31	34	−8	6	12	0
12-12	11.2	12.3	10.6	11.4	12.2	11.0	37	50	33	35	−4	10	15	4
Average	11.2	12.1	10.8	11.2	11.6	10.8								
AT JAMESTOWN														
2,740-bushel, no L-tube:														
J-7	12.1	13.[illegible]	11.4	12.0	12.8	11.7	30	55	36	38	−3	29	30	22
K-7	12.6	13.[illegible]	11.7	12.4	13.4	12.2	38	64	37	38	−1	36	43	25
K-8	12.7	13.9	11.6	12.7	13.1	12.3	40	56	36	38	−4	38	48	27
L-8	12.0	13.5	11.4	12.1	12.4	11.8	39	54	37	39	−2	37	42	33
M-7	12.8	15.0	11.6	12.4	13.0	12.3	41	55	37	39	−4	42	47	34
M-8	13.0	15.6	12.0	12.4	14.3	12.1	34	52	35	36	+1	37	44	33
1,000-bushel, no L-tube:														
G-6	12.1	13.1	11.6	12.3	12.5	12.1	23	40	33	31	+10	35	38	33
H-6	13.2	13.0	12.2	12.7	13.2	12.4	25	39	32	32	+7	32	39	20
Average	12.6	14.0	11.7	12.4	13.1	12.1								

[1] Half the distance between L-tube and side walls.

Insect infestation in the 4,100-bushel bin at Hutchinson, however, was somewhat more severe. An average insect sample from this bin in October, 9 months after the first turning, contained 1 weevil and 5 bran beetles per 1,000 grams. By January the number of bran beetles had increased to 10. The average wheat temperature at this time was about 3° F. higher than normal. The maximum temperature on the south side was 85°, or about 21° above normal. One month later, immediately before turning, the average wheat temperature was 10° above normal and the maximum on the south side was 96°, or 42° above normal. The average grade and moisture content of the wheat was the same as the year before. Probing for samples before the second turning was difficult, indicating that some caking had occurred. The second turning of this bin of wheat was done on February 5, 1943, and the outcome revealed the detrimental effect of turning grain that is heating because of heavy insect infestation. Approximately 800 bushels of grain were slightly caked in this bin. The condition of the wheat before and after turning is given in table 25.

The deterioration of the wheat stored in the 4,100-bushel bin after turning is additional evidence that turning wheat from one bin to another at a rather rapid rate in cold weather is not a satisfactory practice.

No. 6. Fumigating When Necessary

It is a common practice to protect stored wheat against insect damage by fumigation whenever considerable numbers of insects are found in the wheat. Hence, "fumigating when necessary" was included in the management studies at Hutchinson and Jamestown. In this treatment, the objective was to fumigate whenever dangerous insect populations developed. At Jamestown the absence of infestation made it unnecessary to apply the treatment.

At Hutchinson 24 bins of wheat were included in this treatment. Two of the bins had a capacity of 5,000 bushels each; 17 had a capacity of 2,740 bushels each; and 5 had a capacity of 1,000 bushels each. One of the 5,000-bushel bins and two of the 2,740-bushel bins were equipped with solid metal L-tubes; two 2,740-bushel bins were equipped with perforated metal L-tubes. Five bins were painted white.

Twenty of the bins were filled in the summer of 1941; four in January 1943. Most bins were filled with good quality wheat grading No. 2 HW and No. 3 HW. Three bins were filled with low test-weight wheat grading No. 4 HW and 3 others with wheat containing a high percentage (4.2) of dockage. Some of the wheat graded weevily when placed in storage (table 26).

Of the 24 bins of wheat assigned for storage under this treatment 5 were transferred at the end of 1½ years to treatment No. 9 for further study.

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TABLE 25.—*Changes in condition of wheat in the 4,100-bushel bin before and after turning at Hutchinson, February 5, 1943*

Date	Source of sample from bin	Sample: Grade [1]	Sample: Test weight	Sample: Moisture conditions	Sample: Dockage	Sample: Total damage	Sample: Sick wheat [2]	Sample: Odor	Sample: Fat acidity	Sample: Protein	Sample: Germination	Wheat temperature in bin: Maximum	Wheat temperature in bin: Average	Wheat temperature in bin: Above normal: Maximum	Wheat temperature in bin: Above normal: Average	Insects [3] per 1,000-gram sample of wheat
		No.	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*		*Units*	*Pct.*	*Pct.*	*° F.*	*° F.*	*° F.*	*° F.*	*Number*
Jan.[4]	Average	2 HW	58.2	12.0	0.6	1.3		O. K	36	12.5	29	85	64	21		10
Feb. 6	do	HW [5]	57.3	12.9	.5	3.5	1.5	Sour	42	12.6	16	64	96	14		161
13	Top half	HW [5]	57.4	12.9	.7	4.3	1.5	do			19	69		19		200
23	do	HW [5]	56.8	13.3	.6	2.5		do			11					210
Mar. 9 [6]	do	HW [5]	56.6	13.2	.6	5.2	2.0	do	49	12.9	3	75	107	25	55	140
13 [7]	do	HW	55.8	13.6	.7	8.0		do	62	12.8	1	70	103			18
20	do	HW	56.5	13.3	.4	7.4		do	56	12.6	2					
25	Average	3 HW [5]	57.5	12.9	.5	2.4		O. K	43	12.6	13					5
Apr. 26	do	HW	56.1	13.6	.6	12.0		Sour	59	12.7	4	65	83	10	22	8
May 15	do	HW [5]	57.2	13.0	.2	10.0	9.0	do	44	12.6	14					
27	Top 2,000 bushels were turned and cleaned into 2 smaller bins—130 gallons of screenings were removed, mostly insects and "flour." Wheat was fumigated and graded 3 HW "weevily" after fumigation.															
28	Remaining 2,000 bushels fumigated. Grade after fumigation was 3 HW.															
June 25	Wheat sold because of high moisture induced by insect infestation, which prevented successful fumigation.															

[1] HW=Hard Winter wheat.
[2] Individual kernels of wheat in which the germ is discolored, indicating a dead or deteriorated germ.
[3] Includes rice weevils, lesser grain borer, flat grain beetles, red flour beetles, long-headed flour beetles, and saw-toothed grain beetles.
[4] Sample of wheat before turning.
[5] Wheat was weevily.
[6] Top 8 inches caked. Cake broken and wheat fumigated with 12 gallons of carbon disulfide after sample was taken.
[7] Wheat fumigated with 8 gallons of carbon disulfide after sample was taken.

TABLE 26.—*Average initial and final grade, fat acidity, and germination and length of storage of wheat treated by "fumigating when necessary" at Hutchinson*

Size, description, and bin No.	Initial sample: Grade [1]	Initial sample: Test weight	Initial sample: Moisture content	Initial sample: Dockage	Initial sample: Total damage	Initial sample: Fat acidity	Initial sample: Germination	Length of storage	Fumigations	Final sample: Grade [1]	Final sample: Test weight	Final sample: Moisture content	Final sample: Dockage	Final sample: Total damage	Final sample: Fat acidity	Final sample: Germination	Final sample: Amount of insect damage
	No.	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*Years*	*Number*	*No.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*Bu.*
5,000-bushel:																	
No L-tube, 6-12	2	58.7	12.1	0.4	0.5	19	86	2½	5	2	58.0	11.6	0.4	1.7	39	25	[2] 50
With solid L-tube, 5-10	2	58.3	12.1	.5	.6	19	88	2½	3	2	58.3	12.3	.1	1.0	42	28	[2] 70
2,740-bushel, no L-tube:																	
9-4 [3]	2	59.7	10.9	.5	(4)	21	86	4½	0	[5] S	59.0	11.3	.6	2.0	39	20	25
9-5 [3]	2	59.9	11.5	.5	(4)	22	82	5	5	1	60.1	11.8	.2	(4)	39	27	0
10-4 [6]	2	58.5	11.6	.5	0	22	86	4½	7	2	59.0	11.4	.5	.3	37	24	10
9-6 [6]	3	57.7	11.6	.8	1.2	20	87	1½	3	3	57.0	12.0	.8	1.2	35	73	----------
10-5 [6]	3	57.7	11.8	.4	2.0	27	80	1½	2	2	58.2	11.2	.7	.8	38	62	----------
11-3 [7]	3	57.6	11.4	4.3	.5	29	81	2½	5	2	58.2	11.0	4.4	1.5	36	20	[8] 15
12-3 [7]	3	57.7	11.0	4.2	.6	26	78	2½	2	3	57.8	10.5	4.3	1.4	33	37	0
12-5 [7]	2	58.2	10.9	4.2	.2	28	81	2½	2	2	58.1	10.0	3.6	1.5	32	27	0
5-6 [6]	4	55.2	11.5	.9	1.7	27	76	1½	2	4	54.8	12.1	.9	1.0	40	88	----------
6-7 [6]	4	55.5	11.4	.7	.4	29	84	1½	2	4	54.8	11.8	.9	.9	39	65	----------
6-8 [6]	4	55.4	11.6	.8	.4	28	82	1½	2	4	55.0	11.5	1.2	.4	38	72	----------
2,740-bushel, no L-tube, painted white:																	
11-9	2	58.3	11.4	.6	3.5	22	82	3½	1	3	57.7	11.6	.3	2.6	32	60	0
12-8	2	58.2	11.6	.8	2.5	23	78	3½	0	2	58.5	11.9	.4	4.0	33	69	0
2,740-bushel, with solid L-tube:																	
11-4	2	58.2	11.5	.6	.9	27	81	2½	5	2	58.2	11.7	.1	1.5	33	4	15
11-5	2	58.3	11.7	.5	1.2	26	73	3	4	3	56.8	12.3	.3	1.5	45	2	[8] 25
2,740-bushel, with perforated L-tube:																	
9-7	2	58.2	11.4	.9	.4	20	89	3	3	[3] 3	57.6	12.0	1.0	1.0	42	5	0
10-6	3	57.9	11.8	.5	.2	26	78	3	3	3	57.6	12.2	.3	1.2	44	5	0
1,000-bushel, no L-tube:																	
3-13 [3]	2	58.5	11.3	.4	(4)	23	85	5	11	2	58.4	11.3	.6	.6	46	10	[8] 15
4-12 [3]	3	57.8	11.6	.6	1.5	25	76	5	5	[9] S	58.0	11.4	1.0	1.5	48	19	40
1,000-bushel, no L-tube, painted white:																	
½-2	2	58.4	11.6	.5	.2	20	89	5	0	2	58.3	11.9	.7	.8	39	57	[10] 4
1-2 [3]	2	58.7	11.7	.5	1.0	24	80	5	9	[9] S	58.2	11.6	.4	5.0	49	1	[8] 80
1-3	2	58.3	11.3	.5	1.4	22	85	5	5	2	58.6	11.7	.4	1.2	40	6	30

[1] All wheat is Hard Winter.
[2] Combined spoilage caused by moisture accumulation and insects.
[3] Weevily.
[4] Trace.
[5] Sample grade, owing to musty odor.
[6] Transferred to "one annual fumigation" treatment.
[7] Wheat of high dockage percentage.
[8] Combined spoilage caused by water leakage and insects.
[9] Sample grade owing to sour odor.
[10] Spoilage caused mostly by water leakage; only a trace of insect damage.

The remaining 19 bins were emptied after 2½ to 5 years of storage. The wheat in 9 bins showed changes in the final average grades; the wheat in 3 bins changed to Sample grade, because of musty or sour odors. Presumably these odors came from the portions of water-spoiled and insect-damaged wheat found in the bins when emptied, since the bulk of the wheat was still in good condition after 4½ to 5 years of storage. Six filled with wheat of borderline grade were changed in the numerical grade by one number—either up or down. However, the changes are easily attributed to probe sampling error. No great significance is attached to them.

Insect-damaged wheat was found in 11 of the 19 bins when emptied. Failure to prevent effectively insect damage in these 11 bins was caused by (1) the original 12.1-percent moisture content wheat in 2 bins; (2) rainwater leakage in 4 bins; (3) insufficient number of fumigations in 2 bins; and (4) improper timing of fumigation of 3 bins.

The 12.1-percent moisture content of wheat in bins 6–12 and 5–10 (table 26) was 0.8-percent higher than the average moisture of the wheat in the other bins. Insects thrived in this higher-than-average moisture content wheat. Failure to control effectively insects in these bins was owing to the combination of insect activity and moisture accumulation which formed areas of caked and rotted wheat within the bins that could not be penetrated by the fumigating gases.

Failure to prevent insect damage in bins 11–3, 11–5, 3–13, and 1–2 (table 26) was the result of spoilage caused by rainwater leakage through the walls and roofs of the bins. Insects became embedded in and under the spoiled areas and were safe from the lethal effects of the fumigants.

Failure to prevent insect damage in 5 of the 11 bins in this treatment, however, was not caused by either the moisture content of the wheat or by water leakage in the bins, but rather by the design of the treatment itself. Since this treatment was designed for the purpose of controlling a serious infestation rather than preventing one, fumigations were applied only when it was deemed necessary, as determined from insect counts on probe samplings. As it was difficult to establish the level of infestation from probe samples, fumigations were delayed too long in some cases. As a result much insect damage usually occurred in the wheat before the application of the fumigants.

An insufficient number of fumigant applications to the wheat in bins 4–12 and 1–3 enabled insects to do considerable damage. These bins of wheat were in storage 5 years. Each received 5 fumigations. The insects eventually became firmly established in a crusted area of wheat below the surface on the south side in each of these bins.

Improper timing of the fumigations in bins 9–4, 10–4, and 11–4 also enabled insects to do considerable damage. Wheat in these bins was in storage from 2½ to 4½ years. The bins were fumigated at the average rate of twice a year, but, the fumigants were applied mostly during the months of November, December, and January, following the period of heavy insect infestation that occurs during the increased late summer and early fall.

An average of 1.5 fumigations per year of storage was given the wheat, compared to the 2 fumigations per year under treatment No. 4. Any savings gained from fewer fumigations were lost by increased insect damage.

At Jamestown, however, only infrequent fumigations are required for insect control. In such climates a management practice of fumigating when necessary would appear to be practical and advisable.

Storage in white painted bins.—Bins painted white required fewer fumigations to protect wheat against insect damage, presumably because of lower grain temperatures. Two of the 5 steel bins painted white and used for storing wheat under the treatment of "fumigating when necessary" at Hutchinson were 2,740-bushel bins and 3 were 1,000-bushel bins. None had L-tubes. These bins were filled with wheat comparable to that in the other bins in this treatment. The wheat in the two 2,740-bushel bins was in storage 3½ years. In one of these bins wheat was not fumigated during this period; in the other it was fumigated once. No heating or insect trouble occurred in the wheat in these bins. For a similar period of storage, from 3 to 7 fumigations were given the wheat stored in unpainted bins in this series.

In one 1,000-bushel bin painted white, the wheat was stored for 5 years without any fumigation and when emptied, only 4 bushels of water-spoiled and insect-damaged wheat were found.

Storage of high-dockage wheat.—Much dockage in wheat makes insect control by fumigation difficult and expensive. Three bins were filled with wheat having a high percentage of dockage (4.2 percent). It was in storage 2½ years before it was sold. Insects were kept under control, but the presence of so much dockage made fumigation difficult as well as expensive, owing to the greatly increased dosages required. The dockage absorbs large quantities of the fumigant and prevents its proper distribution through the wheat.

Storage of low-grade wheat.—The grade of wheat as designated by test weight was not an influencing factor. Three bins in this treatment were filled with a low-test-weight wheat grading No. 4. No unusual difficulties were experienced in storing this wheat as compared to wheats of higher grades.

To summarize, the practice of "fumigating when necessary" was not so effective in controlling insects in the wheat at Hutchinson as was fumigating regularly during August and October, as in treatment No. 4. However, this treatment was satisfactory in the white painted bins.

No. 7 and No. 8. Turning, Cleaning, and Fumigating When Necessary

Ten bins of wheat at Hutchinson only were used for the experiments in which the turning and cleaning of grain, with and without subsequent fumigation, were tested as to effectiveness and practicability for the control of insect infestation and for prolonging the safe storage period. The objective of these treatments was to rid the wheat of foreign material, dockage, and insects by running it over a low-cost gravity-type screen (figs. 11, 12, and 13) at a rather rapid rate whenever the insect population was considered dangerous to safe storage. Five bins were to be treated for insect infestation by merely turning and cleaning the wheat, and five by turning and cleaning followed by fumigation. Each group of five bins included three 2,740-bushel bins and two 1,000-bushel bins; none had L-tubes.

FIGURE 13.—Portable gravity-type cleaning screen in position on bin. Note pipe for carrying screenings to sack on ground.

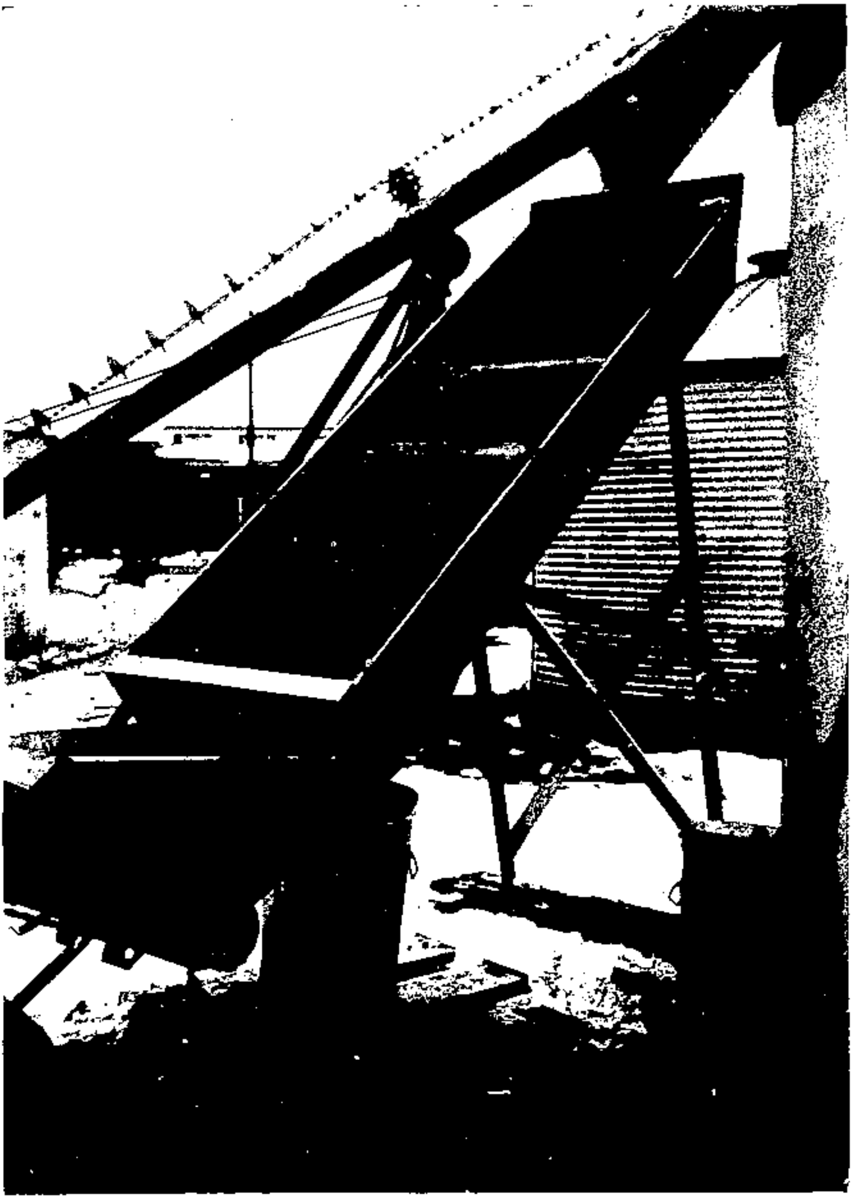

FIGURE 12. Wheat cleaning screen.

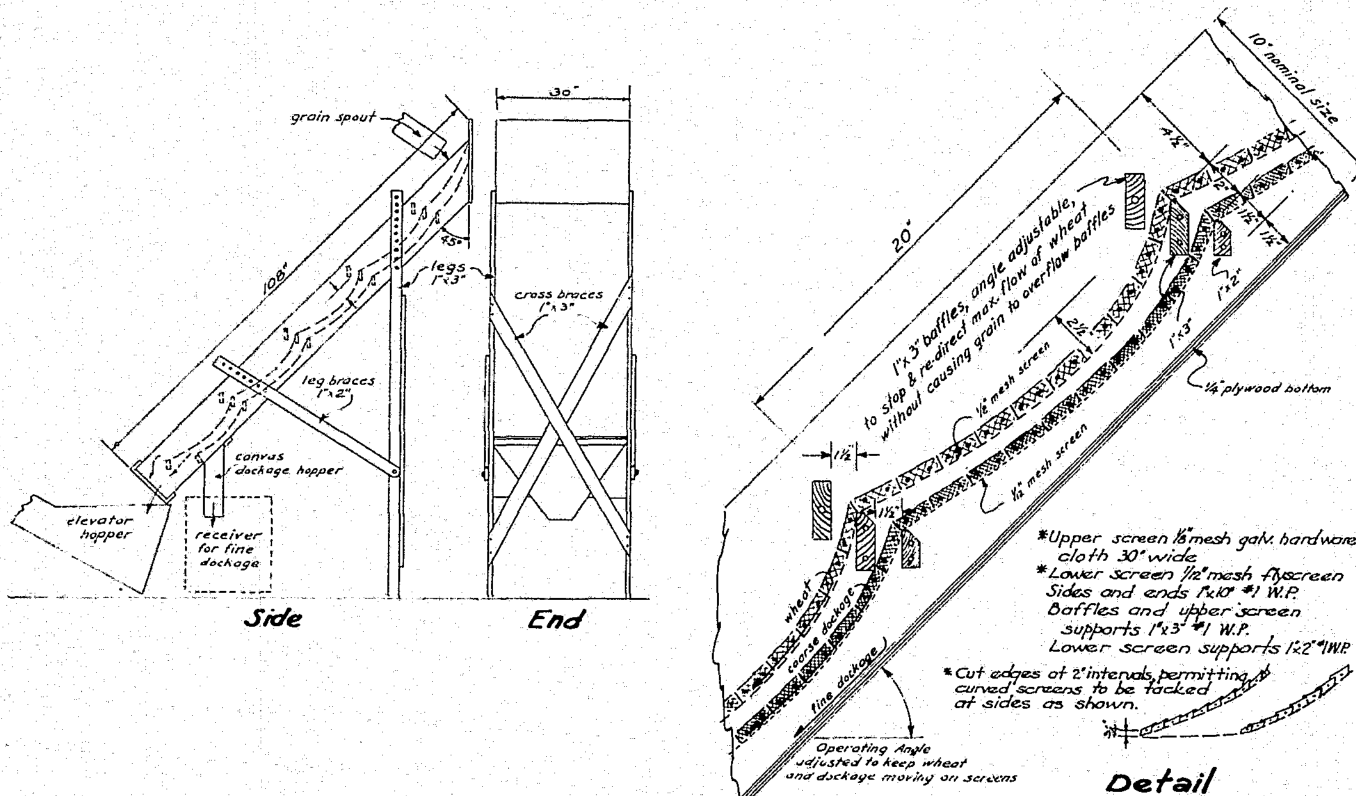

Figure 13.—Construction details of wheat cleaning screen.

The bins were filled with wheat in June 1941 and fumigated with 3 gallons of carbon disulfide per 1,000 bushels of grain directly after filling to have all the wheat insect-free at the beginning of the test. Eight of the bins contained No. 2 and two No. 3 wheat with the moisture contents ranging from 11.0 to 11.6 percent. There were no exceptional differences in the grade factors, fat acidities, or viabilities in any of the bins of wheat.

All the wheat in these treatments was turned and cleaned one or more times during the storage period of 2 to 4 years (table 27).

In the cleaning operations from 36 to 96 percent of the free-living insects were removed from wheat that was cleaned at a rate of approximately 500 bushels an hour. In 18 trials of cleaning wheat that graded "weevily," the screen was successful in reducing the insect population sufficiently in 11 trials to eliminate the word "weevily" from the grade.

A larger percentage of the free-living insects (bran beetles) was removed by screening than of the internal feeders (weevils). None of the immature stages of the weevils can be removed by mechanical means, since they feed within the wheat kernel, and the adult weevils are much more difficult to remove with a gravity screen than are bran beetles. For this reason, turning and screening frequently results in a redistribution of the insect population and, if done when the grain is warm, may cause a general increase in infestation throughout the bin.

The screen was also successful in removing fine dockage. In the first cleaning operation it removed approximately 60 percent of the total dockage in the wheat.

TABLE 27.—*Amount of dockage and percentage of insects removed from bins of wheat turned and cleaned (screened) at Hutchinson*

Treatment and bin No.[1]	Bin capacity	Treatment date	Dockage removed per 1,000 bushels of wheat	Insects per 1,000-gram sample		
				Before cleaning	After cleaning	Amount removed
First turning and cleaning:	*Bushels*		*Bushels*	*Number*	*Number*	*Percent*
5-9	2,740	12-23-42	7.3	7	2	71.5
7-11	2,740	1- 2-43		11	4	63.7
7-12	2,740	2- 1-43	2.1	13	2	84.7
1-14	1,000	12-29-42	5.2	65	5	92.4
1-15	1,000	12-30-42	4.1	18	3	83.4
5-7	2,740	9-10-43	6.1	27	2	92.6
5-8	2,740	9- 7-43	6.7	6	1	83.4
11-8	2,740	9-15-43	8.0	27	1	96.2
3-14	1,000	9-20-43	5.8	4	1	75.0
3-15	1,000	9- 2-43	4.2	25	5	80.0
Second turning and cleaning:						
5-9	2,740	9- 9-43	1.5	16	1	93.8
7-11	2,740	9- 6-43		30	11	63.4
7-12	2,740	9-13-43	3.4	12	2	83.4
1-14	1,000	8-30-43	1.5	31	20	35.5
1-15	1,000	8-30-43	1.0	28	3	89.3
5-7	2,740	(2)				
5-8	2,740	9-13-44	2.2	113	16	85.9
11-8	2,740	(2)				
3-14	1,000	(2)				
3-15	1,000	9- 7-44	2.0	17	3	82.4
Third turning and cleaning:						
5-9	2,740	(2)				
7-11	2,740	(2)				
7-12	2,740	(2)				
1-14	1,000	(2)				
1-15	1,000	(2)				
5-8	2,740	9-15-45	1.1	32	14	56.3
3-15	1,000	9-15-45	1.5		14	

[1] The first 5 bins were in the turning and cleaning series. The last 5 in the turning, cleaning, and fumigating series. Insect counts after cleaning given for the second series of bins is before the application of the fumigant.

[2] Transferred to other studies.

Within a month or two after screening, the wheat in the 5 bins in the turning and cleaning treatment was infested with an insect population too high for safe storage, while the 5 bins that were treated by turning and cleaning and fumigating were still free of insects.

For turning and cleaning to be effective in controlling insects in stored wheat for a long period of time, it would require several cleanings each year, especially in climatic areas favorable to insect development. Such practice would be prohibitive in cost.

When turning and cleaning is followed by fumigating, the insect population can be nearly eliminated, and it is an effective means of protection against insects over a long storage period. However, it is no more effective than fumigation alone unless the wheat is "dirty" or caked. The five bins assigned to the treatment of turning, cleaning, and fumigating had to be treated regularly each year to prevent the buildup of insect infestation.

No. 9. Regular Annual Fumigation in October

After 1½ years of observations on insect infestation in bins of wheat at Hutchinson, it was thought that wheat could be stored in that area without serious insect damage if the bins were fumigated once a year during the month of October. Since October is about the time of the year when insect populations reach their highest levels, it was expected that an adequate fumigation at this time would kill the insects in the bins and that the subsequent cool and cold weather would keep the bins free of insects until the next summer.

This practice of insect control by a regular annual fumigation in October was tried on 14 bins (table 28). These bins had been handled previously under other treatments and the wheat had been in them at least 1½ years before the regular annual fumigation in October was begun. They had already been fumigated at least once, and the wheat either had been or was weevily by the time the treatment was started in January 1943. Therefore, the test was not the same as if uninfested wheat had been used, and rather erratic results were obtained.

Most bins remained under this treatment for 1½ years, 4 for as long as 2½ years. During this period the insect infestations were no greater than in similar bins under treatment "fumigating when necessary." However, as shown in table 28, the "one-annual-fumigation" practice was not rigorously adhered to. Many of these bins received as many fumigations during their period of storage as some of those in the "fumigating-when-necessary" treatment. Those bins of wheat in storage for 1½ years should have received only 1 fumigation and those in storage for 2½ years should have received 2.

TEMPERATURE STUDIES

Temperature of the low-moisture wheat stored in the bins at Hutchinson and Jamestown was taken periodically in order to study the influence on wheat temperatures of different climates, of different bin sizes, of L-tubes, of bins painted white, of bins painted white and partially shaded through close grouping, of turning wheat in cold weather, and of insects.

TABLE 28.—*Average initial and final grade, fat acidity, and germination for bins of wheat treated with "regular annual fumigation in October" at Hutchinson*

Size, description, and bin No.	Initial sample: Grade	Initial sample: Test weight	Initial sample: Moisture content	Initial sample: Dockage	Initial sample: Total damage	Initial sample: Fat acidity	Initial sample: Germination	Length of storage	Fumigations	Final sample: Grade	Final sample: Test weight	Final sample: Moisture content	Final sample: Dockage	Final sample: Total damage	Final sample: Fat acidity	Final sample: Germination
2,740-bushel, no L-tube:	*No.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Units*	*Pct.*	*Years*	*Number*	*No.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Units*	*Pct.*
6-3 [1]	2	59.6	10.7	0.8	0.5	32	66	2½	2	[2] 2	59.1	11.9	0.4	0.6	35	30
6-4 [1]	1	60.0	11.3	.6	.2	30	71	1½	3	2	59.5	11.9	.3	.8	36	33
5-6 [3]	4	54.8	12.1	.9	1.0	40	88	1½	3	5	53.8	12.1	.8	1.0	44	14
6-7 [3]	4	54.8	11.8	.9	.9	39	65	1½	2	4	55.8	12.1	.6	1.5	37	30
6-8 [3]	4	55.0	11.5	1.2	.4	38	72	1½	2	4	55.5	11.7	.2	.8	30	47
9-6 [4]	3	57.0	12.0	.8	1.2	35	73	1½	2	[2] 3	57.0	12.3	.5	1.5	36	42
10-5 [4]	2	58.2	11.2	.7	.8	38	62	1	1	[2] 2	58.1	12.1	.3	1.0	38	13
11-2 [5]	[2] 2	58.4	11.3	.4	.4	38	70	2½	2	2	58.6	11.8	.5	1.0	40	40
12-1 [5]	[2] 2	58.8	11.0	.6	.6	37	34	2½	1	[2] 3	57.7	12.1	.3	1.5	39	24
12-2 [5]	2	58.2	11.4	.6	.8	39	56	2½	2	3	57.7	12.3	.3	1.0	48	14
2,740-bushel, with solid L-tube, 5-4	2	59.4	11.6	.6	.5	35	68	1½	2	2	59.2	12.0	.5	.5	34	53
2,740-bushel, with perforated L-tube, 5-5	2	59.0	11.5	.5	.5	28	76	1½	2	[2] 2	58.4	12.0	.8	.8	37	54
1,000 bushel, no L-tube:																
12-11	2	58.3	11.4	.4	1.2	30	62	1½	2	3	57.9	12.0	.2	------	36	21
12-12	[2] 2	58.0	11.5	.3	.8	40	32	1½	2	3	57.8	11.3	.2	1.0	43	15

[1] Changed to October fumigation from "no treatment after initial fumigation."
[2] Weevily.
[3] Wheat of low test weight. Bins changed to October fumigation from "fumigating when necessary."
[4] Only bin floor calked when erected. Changed to October fumigation from "fumigating when necessary."
[5] Floor, walls, and roof calked when erected. Bins changed to October fumigation from "no treatment after initial fumigation."

L-tubes were 18-inch tubing made of either solid or perforated metal running down the center of the wheat to the floor and across the floor to an opening in the emptying door. The opening at the top of the tube was only a few inches above the surface of the wheat.

The purpose of these tubes was to cool the center of the wheat mass and thus lower the average wheat temperature considerably,[14] especially during the winter.

There were two reasons for painting bins white: White paint reflects a higher proportion of the solar radiation than a galvanized metal surface and it also has a higher emissivity for long-wave radiation than a metal surface and cools more rapidly during the night or other time when not exposed to sunshine.

Wheat temperatures were taken by means of a portable potentiometer and thermocouples. The bins without L-tubes contained 20 thermocouples and the bins with L-tubes contained 32. In general, the thermocouples were arranged in the steel bins to obtain a north-and-south and an east-and-west cross section of the wheat temperatures. Ordinarily this arrangement consisted of placing thermocouples on floor, at regular intervals above the floor at the center of the bin, and at distances of 2 to 4 feet, depending upon the size of the bin, from the north, south, east, and west walls. The interval spaces above the floor ranged from 2½ to 5 feet, also depending upon the size of the bin. This general arrangement of thermocouples was modified in cases where special temperature readings were desired.

As originally planned, wheat temperatures were to be taken at regular 2-week intervals at Hutchinson and monthly at Jamestown. This plan was adhered to fairly well during 1942, the first year of storage. Later, however, the amount of work and shortage of labor during the war made it necessary to abandon the original plan and to take temperature readings less often.

In the analysis to follow, a reference to bin average refers to the arithmetical average of all the temperature readings in a bin. The maximum temperature refers to the highest individual reading in the bin and the minimum temperature to the lowest reading.

SOURCE OF HEAT

The temperature of wheat stored in common farm-storage structures is influenced by two sources of heat—external and internal. The external source is the heat of the atmosphere and solar radiation of the region where the bin is located. The internal source is the heat developed from respiration of the wheat, insect activity, mold growth, or other biological activity. If the wheat has a moisture content below 12 percent when stored in Kansas and below 14 percent in North Dakota, little internal heat is developed from respiration and mold growth, and the only serious internal source of heat is that produced by insect activity. Heat produced from insect activity, however, is usually localized and seldom affects the entire bin of wheat unless stored for a long period or disturbed and mechanically mixed.

[14] After this study was completed, methods were developed for cooling wheat, shelled corn, and other grains by slow ventilation when atmospheric temperature is lower than the grain temperature. This method is much more effective in preventing deterioration than the use of the L-tube described here.

Wheat is a poor conductor of heat and consequently there is a wide range of temperatures within a bin and a definite lag between the average wheat temperature and average air temperature (figs. 14 and 15). Wheat temperature variations within bins are illustrated in figures 16, 17, and 18 by a series of isothermal curves. Only the north and south cross-section temperature patterns are given for the 2,740-bushel bins.

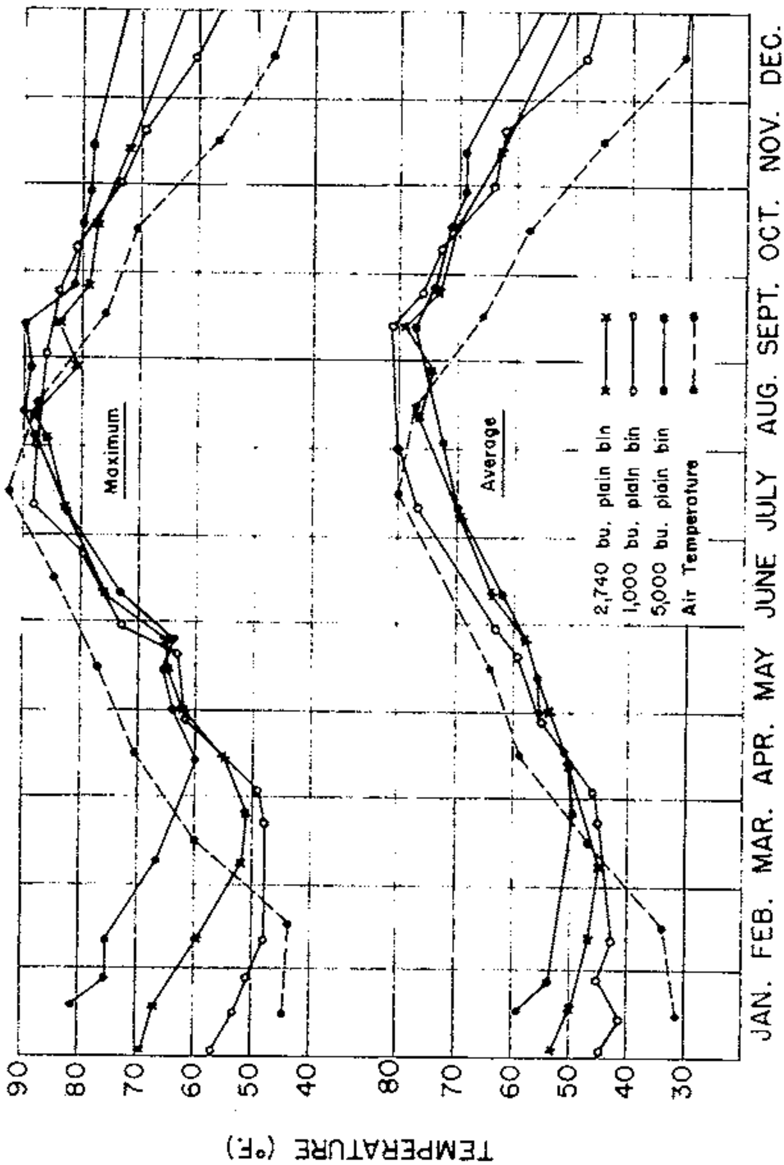

FIGURE 14.—Wheat temperatures in steel bins and air temperature at Hutchinson, 1942.

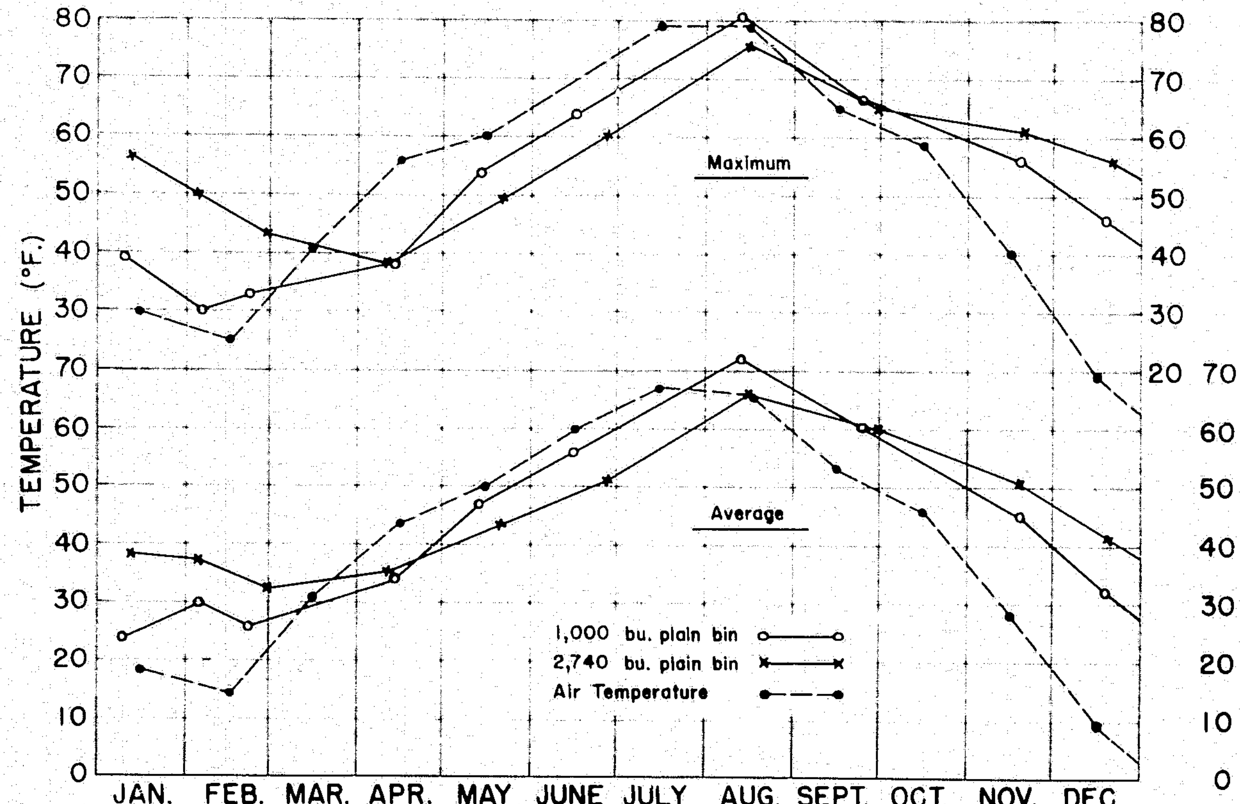

FIGURE 15.—Wheat temperatures in steel bins and air temperature at Jamestown, 1942.

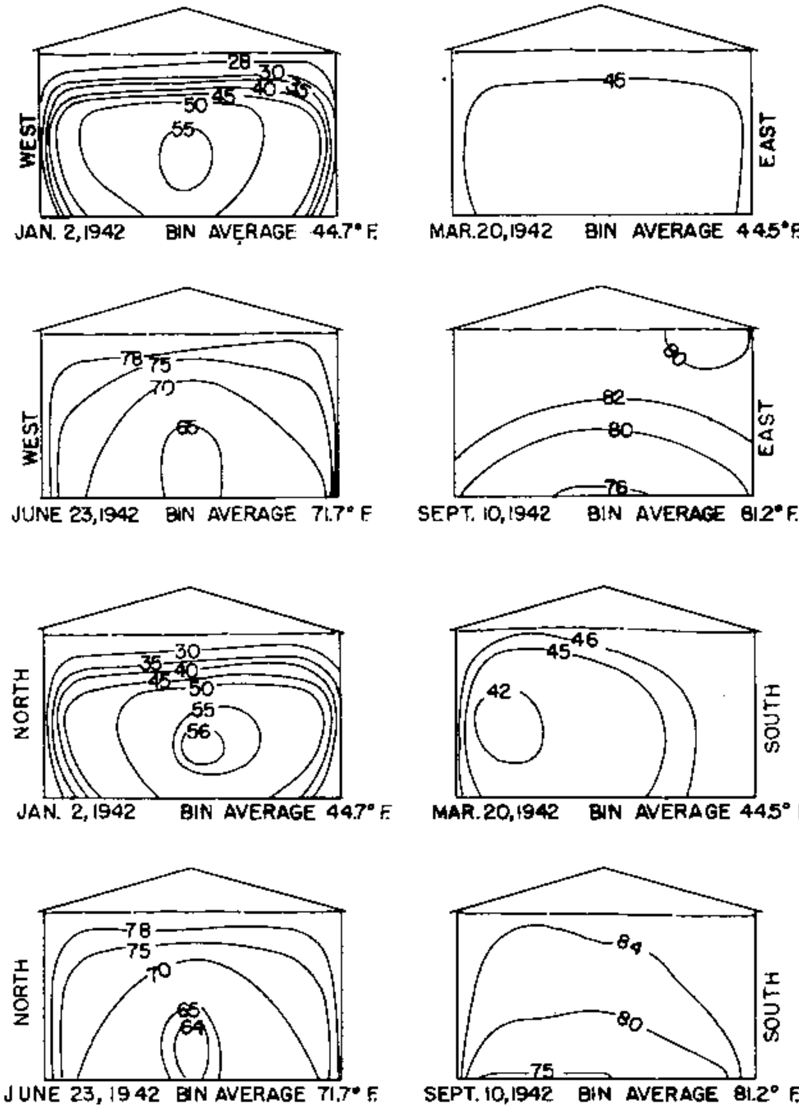

FIGURE 16.—Wheat temperatures in 1,000-bushel steel bins at Hutchinson, 1942.

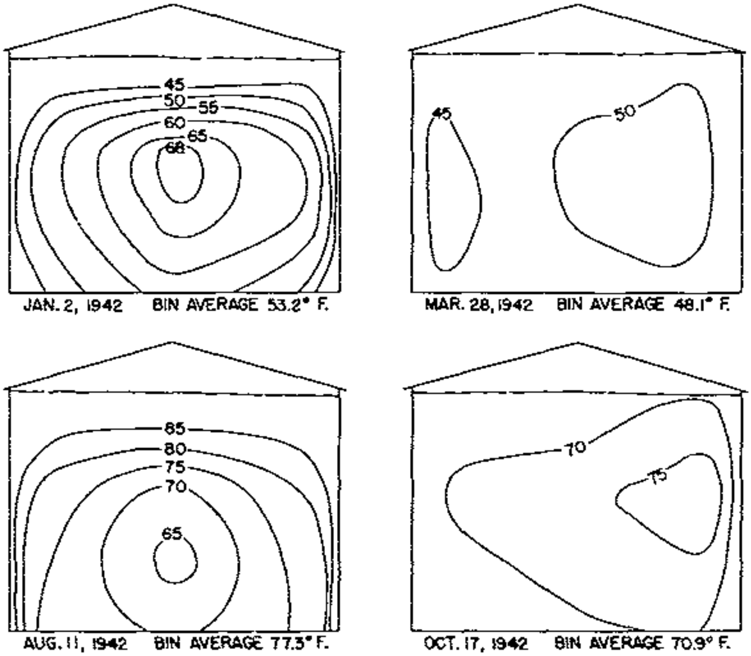

FIGURE 17.—Wheat temperatures in 2,740-bushel steel bins at Hutchinson, 1942.

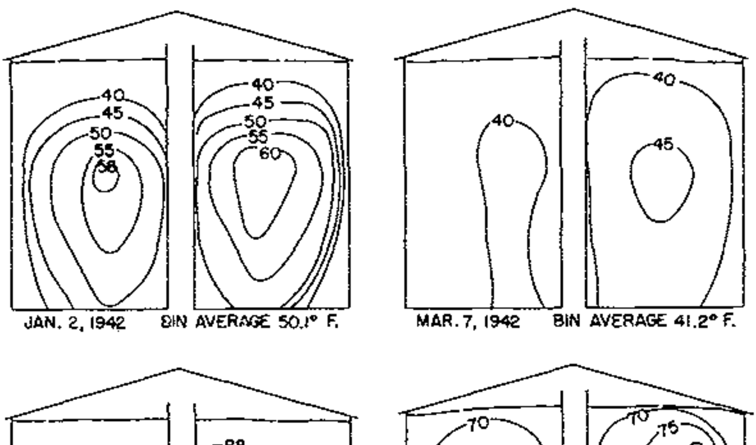

FIGURE 18.—Wheat temperatures in 2,740-bushel steel bins with solid metal L-tubes at Hutchinson, 1942.

ANALYSIS OF WHEAT TEMPERATURE VARIATION

The temperature of grain in a bin varies in different parts of the bin and at different periods during the year (figs. 14 to 16). These differences have an important relation to the condition of the grain in different parts of the bin because (1) abnormal temperatures are an indication of insect activity and of mold growth; (2) insect activity, mold growth, increase in fat acidity, decrease in germination, respiration rate, and other changes are each stimulated by higher temperatures up to a certain point; and (3) the movement of moisture from place to place within a bin of grain is largely the result of convection currents that are governed as to force and direction by temperature differences.

It was common practice to obtain frequent temperature readings at 20 fixed points in bins used for research studies at Hutchinson. This large number of readings makes an analysis of areas of temperature similarity possible.

A statistical study of temperature differences in 3 typical 2,740-bushel bins of wheat at Hutchinson was made, using 10 different readings taken during the year 1942 at each of the 20 locations in the bins. The analysis of variance method was used and the variances of bin, date, and thermocouple means for locations were isolated and tested for significant differences. Significant differences were found between bins, between dates, and between thermocouple locations as a whole, but individual thermocouples were found and grouped, including 2 to 5 locations, which had mean annual temperatures that did not differ significantly. It was possible to place the original thermocouples into 6 such groups, each representing an area in the bin with a different average annual temperature. Moreover, by selecting 1 location from each group, the average bin temperature at any time could be determined by readings at 6 points instead of 20. The areas represented by the groups are shown in figure 19. The

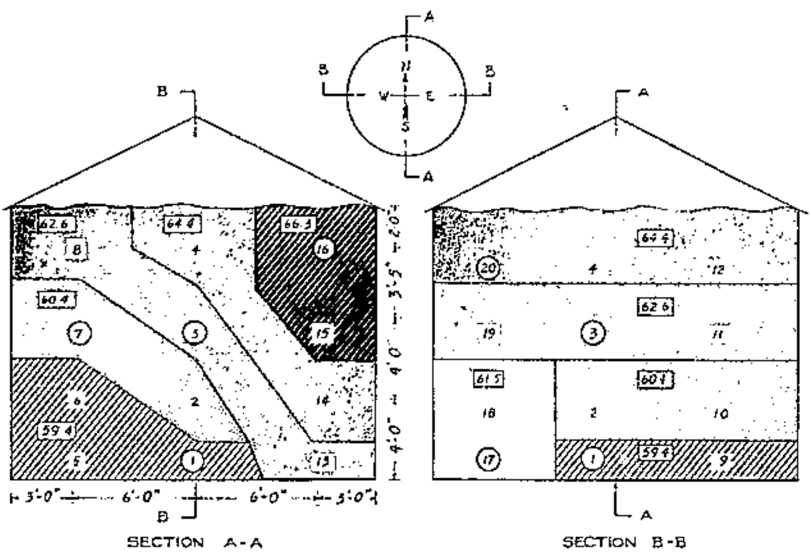

FIGURE 19.—Areas of equal average wheat temperature within bins, Hutchinson, 1942.

numbers 1 to 20 represent the locations of the 20 thermocouple junctions and those encircled are the junctions which can be read to give the temperature for a specific area. The boxed numbers are average annual temperatures during 1942.

In experimental work, measurements of temperatures at the 6 indicated points give substantially as good records of average temperatures as measurements at all 20 points.

EFFECT OF BIN SIZE

Wheat temperatures between small and large bins vary, but the difference is relatively small and has no particular advantage for maintaining the quality of stored wheat. The average wheat temperatures in 1,000-bushel bins at Hutchinson were 5° to 7° F. higher during the critical insect period of July, August, and September than those in 2,740-bushel and 5,000-bushel bins (fig. 14). Average wheat temperatures in the 2,740-bushel and 5,000-bushel bins for this period were almost identical. About the same difference occurred between the wheat temperatures in the 1,000-bushel and 2,740-bushel bins at Jamestown (fig. 15) as at Hutchinson.

The slightly lower wheat temperatures in large bins favor larger storage units when the object is to keep the bulk of the grain as cool as possible during the warmest period of the season. However, the disadvantage of larger bins is the higher wheat temperature maintained during the coldest season of the year when low temperatures are desired for killing insects. Wheat in the smaller 1,000-bushel bins had an average temperature 2° to 8° F. lower during the winter months than the 2,740-bushel bins at Hutchinson and as much as 14° lower at Jamestown (figs. 14 and 15). At Hutchinson the average winter wheat temperature in the 2,740-bushel bins was 5° to 10° lower than in the 5,000-bushel bins.

All the bins of wheat stored at Hutchinson and the 1,000-bushel bins at Jamestown had summer average wheat temperatures above 70° F. during 1942 (figs. 14 and 15). At Hutchinson average wheat temperatures were as high as 78° in the larger 2,740- and 5,000-bushel bins and as high as 82° in the 1,000-bushel bins. Average wheat temperatures in the 1,000-bushel bins at Jamestown reached 72°, but stayed above 70° less than a month.

Average wheat temperatures in the 1,000-bushel bins at Hutchinson reached 70° F. by the middle of June, fully 1 month earlier than the average wheat temperatures in the larger 2,740- and 5,000-bushel bins, and did not cool below 70° earlier in the fall. Consequently, the average wheat temperature in the 1,000-bushel bins was above 70° 1 month longer than the average wheat temperature in the larger bins. This additional month above 70° is ample time for most insects to produce another brood, and as a result, all other factors being equal, wheat stored in 1,000-bushel bins is usually more heavily infested with insects by late fall and early winter than wheat stored in larger units. This tendency to have heavier insect infestations in the 1,000-bushel bins offsets the bin-size advantage for maintaining lower winter temperatures.

Local spots in the bins, however, have temperatures high enough to encourage insect life, especially in the larger size bins. This is the result of the large variation in wheat temperatures within the bins. The differences between the maximum and minimum wheat temperatures in a 1,000-bushel bin is from 6° to 29° F. In the 2,740-bushel bins the difference is from 7° to 27°, and in the 5,000-bushel bins, from 11° to 30°. The smaller difference usually occurs during March and September when the wheat in the bin begins to warm or to cool because of outside air-temperature changes. The larger difference usually occurs during December and January and July and August. Maximum wheat temperature in a bin may be from 3° to 15° above the average wheat temperature.

The average maximum wheat temperatures occurring in the 1,000-, 2,740-, and 5,000-bushel bins at Hutchinson during 1942 were observed in the center of the wheat bulk about two-thirds of the distance from the floor through the winter months. The lowest maximum temperature observed in the 1,000-bushel bins was 48° F.; the maximum temperature was below 55° for 3 months. The lowest maximum temperature recorded for the 2,740-bushel bins was 51°; the maximum temperature was below 60° for 2 months. In the 5,000-bushel bins, the maximum wheat temperature was never less than 60°, but it was below 65° for 2 months.

In wheat with 9-percent moisture content these temperatures are not conducive to insect life. When the moisture content is between 10 and 11 percent, some of the more hardy insect species can survive in the maximum temperature areas found in the 5,000-bushel bins. When the wheat moisture content is between 11 and 12 percent, almost all types of insects can survive in the maximum temperature area in the 5,000-bushel bins and a relatively large percentage can survive in the 2,740-bushel bins. In wheat with moisture content above 12 percent, many insects can survive in the 1,000-bushel bins. However, if there is a heavy infestation, many of the insects can live through the winter in these 1,000-bushel and larger bins even in lower moisture content wheat. It is not unusual for insects to concentrate into local areas and raise the temperature by as much as 55° F. above the lowest average wheat temperature and survive the winter.

EFFECT OF L-TUBES [15]

Twelve 2,740-bushel bins at Hutchinson and 20 at Jamestown were equipped with L-tubes. One-half of the bins had L-tubes constructed of perforated metal pipe and the rest of solid metal pipe. (See p. 57.)

The bins with tubes maintained an average wheat temperature during the winter only slightly lower than that in the bins without tubes. The largest difference recorded between the average wheat temperatures in bins with and without tubes was 1° F. at Hutchinson, and 7° at Jamestown. This difference is less than the difference between average wheat temperatures observed in 2,740-bushel and 1,000-bushel bins with no tubes. At Hutchinson 1,000-bushel bins with no tubes recorded average wheat temperatures as much as 8° lower than 2,740-bushel bins with no tubes. At Jamestown the difference was 14°.

During the summer average wheat temperatures in the bins with tubes ranged from 2° F. lower to 2° higher than in the bins without

[15] See footnote 11, p. 57.

tubes at Hutchinson, but they were almost identical at Jamestown. During the fall, only a slight difference was noted between average wheat temperatures in bins with and without tubes.

Maximum wheat temperatures in the bins with tubes were as much as 10° F. lower during January than those in the bins without tubes. This resulted from the lowering of the center wheat temperature around the tubes. On the other hand, minimum wheat temperatures in bins with tubes were as much as 8° higher during August than those in the plain bins. This was caused by the additional heating of the wheat from the center of the bin through the tubes, which offset the cooling effect the tubes had on the center wheat temperature during the winter months.

At Hutchinson those bins equipped with perforated metal L-tubes lowered the center wheat temperatures faster and by approximately 1° F. more than those equipped with solid metal L-tubes. At Jamestown both types of L-tubes lowered the center temperatures at about the same rate, but the perforated L-tubes lowered them about 1° more. Typical wheat temperature patterns for winter, spring, summer, and fall in 2,740-bushel bins with L-tubes are shown by the isothermal charts in figure 18.

Though the effect of L-tubes on wheat temperature was not far-reaching, some benefit was presumably derived from the rapid cooling of the wheat in the center of the bin. As shown under the discussion of treatment No. 1 in the management studies at Jamestown (p. 33), many bins contained spoilage in the upper 20 inches of grain after 3½ years of storage. However, none of the 2,740-bushel bins equipped with perforated L-tubes or the 1,000-bushel bins contained such spoilage. Presumably the rapid cooling of the center wheat in these bins reduced the moisture accumulation at the surface of the wheat described on page 14.

EFFECT OF WHITE PAINT AND OF PARTIAL SHADING

Included in the studies at Hutchinson were tests of methods to keep the temperature of the grain as low as possible during the summer. Painting the bin walls and roof white to reflect the sun's heat was one such method studied at Hutchinson.

In the fall of 1941 one 1,000-bushel steel bin was painted white to observe the effect of this practice on wheat temperatures. A considerable reduction in temperature was effected, and early in 1943 the studies were extended. Two additional 1,000-bushel bins and seven 2,740-bushel bins were painted white. Four of the seven larger bins were grouped closely together to shade the walls partially. The results confirmed those of the year before: wheat temperatures were lower in painted than in unpainted galvanized bins.

Painted bins maintained a lower average and lower maximum wheat temperature throughout the season (fig. 20). The 1,000-bushel painted bins had wheat temperatures that averaged 7° F. lower than those in unpainted 1,000-bushel bins during August and September when wheat temperatures are the highest. Painted 2,740-bushel bins had wheat temperatures that averaged about 5° lower than those in unpainted bins. About the same difference was observed for the maximum wheat temperatures in the painted and unpainted bins

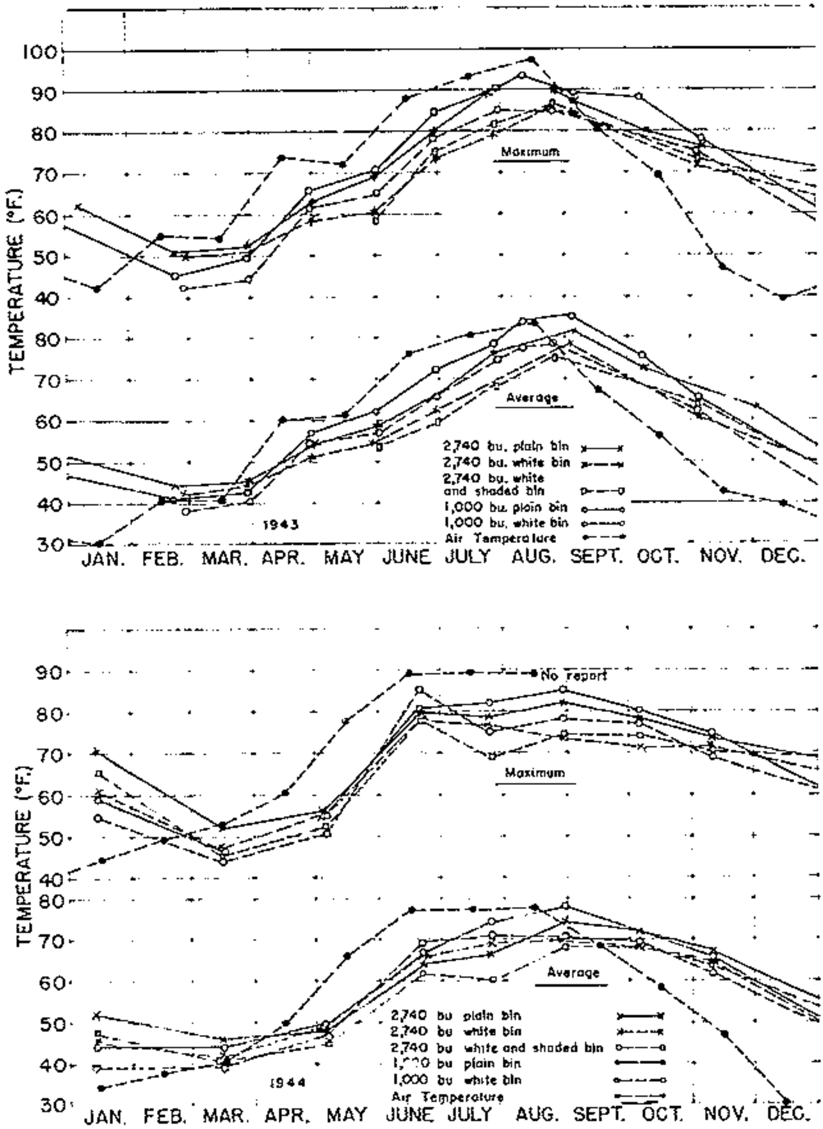

FIGURE 20.—Wheat temperatures in steel bins and air temperatures at Hutchinson, 1943 and 1944.

Partial shading the bin walls had little or no effect on the average and maximum wheat temperatures. Wheat temperatures in the partially shaded 2,740-bushel painted bins were about the same as the temperatures in the other unshaded 2,740-bushel painted bins.

Wheat temperatures in white painted bins were still high enough to support insect life and development, but the lower temperatures maintained in these bins helped to control insect infestations. The number of days that the wheat was above 70° F. in the white bins was considerably less than in the unpainted bins (table 29).

TABLE 29.—*Number of days wheat temperatures in steel bins and outside air temperatures were above 70° F. at Hutchinson, 1943 and 1944*

Bin size and description	Days when temperatures of wheat were above 70° F. in—					
	1943 [1]			1944 [2]		
	Maximum	Minimum	Average [3]	Maximum	Minimum	Average [3]
2,740-bushel:						
Unpainted	222	0	101	196	0	59
Painted white	147	0	59	167	0	0
Painted white and partially shaded	161	0	56	145	0	0
1,000-bushel:						
Unpainted	190	47	120	182	0	101
Painted white	160	[4] 35	78	158	0	60

[1] Atmospheric temperature was above 70° F. for 186 days; it averaged 70° or above during 24-hour period for 99 days.
[2] Atmospheric temperature averaged 70° or above during 24-hour period for 105 days.
[3] Based on all thermocouples.
[4] Estimated.

The number of days when the maximum wheat temperatures were above 70° F. in each group of bins indicates the period when insects could propagate in some part of grain of 11-percent moisture content. In the 2,740-bushel bins during 1943, the number of days that the maximum wheat temperatures were above 70° was reduced 75 days by painting the bins white; in 1944, by 29 days. In the 1,000-bushel bins the number of days that the maximum temperatures were above 70° was reduced 30 days by painting in 1943, and 24 days in 1944. For some species of insects, the additional days that the maximum temperature is above 70° in the unpainted bins is ample time to produce and develop an additional brood.

It is questionable whether any reduction in the number of days that the maximum temperature was above 70° F. can be attributed to the partial shading of the bin walls. Any reduction could easily be attributed to sources other than that effected by partial shading of the bin walls, such as too few temperature readings taken while wheat temperatures were increasing in the spring and decreasing in the fall, or the fact that a concentration of insects may have increased the temperature in a small portion of the grain. Any of these factors may affect the maximum temperatures recorded for a bin of grain. Maximum temperatures during the summer are usually found near the grain surface and are easily influenced and somewhat erratic. Since summer maximum grain temperatures are usually the direct result of the sun's heat on the roof, no difference could be expected in the number of days that the maximum temperatures would remain above 70° F. between unshaded white and the partially shaded white bins, because none of the roofs of these bins were shaded.

When the minimum temperature in a bin of wheat is above 70° F. it indicates the entire bulk of grain is subject to increased insect infestation. During the summer months the minimum temperature is found at the center and the lower center of the mass. The minimum temperatures in the 2,740-bushel bins were above 70° during September in 1942, but in 1943 and 1944 these temperatures did not go above 70° in either the painted or unpainted bins.

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Minimum temperatures in the smaller 1,000-bushel bins, however, usually go above 70° F. for a short time during August and September, depending upon the outside air temperature. In 1943 the average maximum air temperature reached 97° in August and the minimum wheat temperatures in the unpainted 1,000-bushel bins were above 70° for 47 days and approximately 35 days in the painted bins, a reduction of 12 days. In 1944 the average maximum air temperature in August reached 89° and the minimum wheat temperatures in both painted and unpainted 1,000-bushel bins remained below 70°. The highest average minimum wheat temperatures recorded for 1,000-bushel bins in 1944 were 66° for painted and 68° for unpainted bins.

Since the maximum and minimum wheat temperatures may occur in only a relatively small volume of grain, the reductions in average wheat temperatures are of the greatest interest. Approximately one-half the volume of grain has temperatures above the average wheat temperature. Consequently, if the average temperature is above 70° F., a large part of the entire bin of wheat is suitable for insect life and reproduction. During 1943 the average wheat temperatures were above 70° for 101 days in the 2,740-bushel unpainted bins, 59 days in the painted bins, and 56 days in the painted and partially shaded bins. A reduction of 42 days resulted from painting and an additional 3 days from partial shading.

Average wheat temperatures did not exceed 70° F. during 1944 in either the 2,740-bushel painted bins or in the painted and partially shaded bins. In the unpainted bins, however, there were 59 days during which average temperature was above 70°, thus providing ample time for many insect species to produce an additional brood. This indicates that wheat stored in painted steel bins is less likely to become infested than when stored in unpainted bins. Average wheat temperatures in 1,000-bushel painted bins were above 70° 42 days less during 1943 and 41 days less during 1944 than in unpainted bins.

EFFECT OF INSECTS ON WHEAT TEMPERATURES, MOISTURE CONTENT, AND GRADE

Anyone working with stored wheat has noticed that whenever there is an accumulation of insects in any spot in the grain mass, the temperature at this spot is higher than that in the rest of the grain. This ability of insects, when in abundance, to produce considerable heat presents one of the difficulties of storing grain for long periods without some means of artificial control in climates favorable to insect life. Ordinarily, winter atmospheric conditions in Kansas lower the temperature of dry wheat stored in 1,000-bushel bins sufficiently to eliminate most insect life, but this natural means of insect control is effective for holding down insect population for a short time only.

When insects are allowed to reproduce and develop in stored grain without any artificial control, they soon become so numerous that they can live undisturbed throughout the winter by congregating in pockets and producing their own heat and moisture. This accumulation and activity results in severe damage to the wheat, not only from "flour" and other damage caused by insects, but also indirectly from self-generated heat from respiration of the dampened wheat. Eventually there will develop an area of rotted, caked, and moldy grain in the bin, which, if severe enough, will cause the entire lot to grade Sample because of odor.

From January 1943 to May 1946 two 1,000-bushel bins (Nos. 3–10 and 3–11) at Hutchinson were used to study the effect of uncontrolled insect activity in the stored wheat. These bins were filled in 1941 with No. 2 Hard Winter wheat of 11.2- and 11.5-percent moisture. Prior to January 1943 they had received applications of fumigants to control the insects. The wheat was actually in storage for 5 years and for the last 3½ years the insects were allowed to develop at will.

For comparative purposes an additional set of temperature readings and insect counts were made (table 30). These readings and counts are averages from other 1,000-bushel bins at Hutchinson receiving various treatments of insect control consisting mainly of applications of fumigants during the late summer and early fall. These temperatures are taken as normals.

The insect population counts were made on average wheat samples taken from the bins and represent the average number of insects in the bins and not the number present in any localized concentration. The number present in any concentrated infestation would be many times greater than any of those shown (table 30).

Most of the effect of insects on wheat temperatures is localized, unless the infestation becomes extremely intense. For the first 1½ years, the average wheat temperatures and also the minimum wheat temperatures in the 2 bins in which insects were uncontrolled were approximately the same as the temperatures in other 1,000-bushel bins where the insects were controlled. The only exception was in the maximum wheat temperature in bin No. 3–10. This bin had a maximum temperature as much as 14° F. above the maximum wheat temperatures for other 1,000-bushel bins where insects were controlled. The number of insects per 1,000 grams of wheat in this bin reached 102 in September 1943. This was approximately 80 insects more per 1,000 grams than were found in its companion bin No. 3–11 and in other 1,000-bushel bins on the site, which had about the same number of insects and approximately the same maximum temperatures during 1943 and part of 1944.

Uncontrolled insect activity in bins not only increased the wheat temperature but also increased the moisture content, especially in sections above the heaviest insect concentration on the upper south side. A moisture traverse, determined from a series of probe samples at 1-foot intervals above the floor from the center and 2 feet from the walls on all 4 sides, was made on bin No. 3–11 on December 5, 1944 (table 31).

Bins No. 3–10 and No. 3–11 were fumigated and emptied in May 1946. After 5 years of storage, with the last 3½ years without insect control, the damage caused by insects was relatively heavy. Approximately 18 bushels of caked, moldy, and rotten grain was found in each bin. The major spoiled sections measured from 4 to 5 feet horizontally and from 2 to 2½ feet vertically. They were next to the south wall and centered 5 feet above the floor.

These spoiled sections were the direct result of insect activity. The indirect result, and one of considerable importance, was the effect the insects had on the average grade of the wheat. The wheat in these bins eventually graded Sample because of a sour odor developed by the insects.

TABLE 30.—*Insects per 1,000 grams of wheat and the average, maximum, and minimum wheat temperatures in bins Nos. 3-10 and 3-11 and the average in other 1,000-bushel bins at Hutchinson from January 1943 to May 1946*

Date temperature was taken	Bin No. 3-10				Bin No. 3-11				Average of other 1,000-bushel bins			
	Insects per 1,000 grams [1]	Wheat temperatures			Insects per 1,000 grams [1]	Wheat temperatures			Insects per 1,000 grams [1]	Wheat temperatures		
		Average	Maximum	Minimum		Average	Maximum	Minimum		Average	Maximum	Minimum
1943	*Number*	° *F.*	° *F.*	° *F.*	*Number*	° *F.*	° *F.*	° *F.*	*Number*	° *F.*	° *F.*	° *F.*
Feb 26	8	40	43	37	1	41	44	38	5	40	45	37
May 31	2	62	70	54	1	61	70	54	1	62	71	55
July 23	37	79	91	67	21	77	90	65	16	78	90	65
Sept. 3	102	87	99	77	18	81	90	77	23	85	89	78
Oct. 7	30	74	96	60	11	73	85	63	25	75	88	60
Nov. 3	22	66	92	48	13	61	74	48	1	65	78	51
1944												
Jan. 5	15	46	63	34	6	44	57	34	1	44	56	34
Mar. 9	10	44	49	38	1	43	47	39	0	44	47	40
May 2	11	50	58	44	1	48	54	42	0	49	55	43
June 21	27	71	82	59	2	67	79	56	0	66	81	53
Aug. 30	120	82	97	75	9	76	86	67	14	78	85	68
Sept.	150				31				28			
Oct. 5	130	77	99	56	55	75	96	65	1	72	80	63
Nov. 8	64	74	95	61	45	71	97	62	2	66	75	59
Dec. 16	42	55	80	39	40	54	82	38	1			
1945												
Feb. 6	14	41	50	34	13	43	52	36	0	45	52	40
May 30		58	78	48		58	70	49	0	59	70	50
July 31	6	82	91	72	9	79	90	67	1			
Sept. 5	120	86	98	74	50	84	96	71	10	81	91	72
Nov. 30	59	62	84	55	254	73	98	52	7			
1946												
Jan. 4	52	46	63	38	661	67	105	49	0			
Mar. 5	14	50	55	45	1,068	65	95	48	0	49	55	44
May 1	1	59	65	52	555	76	101	56	0	61	68	53

[1] Insect species included flour beetles, flat grain beetles, long-headed flour beetles, saw-toothed grain beetles, lesser grain borer, rice weevils, and granary weevils. The insect counts were seldom made the same day as temperature readings.

TABLE 31.—*Moisture content*[1] *of wheat in bin No. 3–11 at Hutchinson, December 5, 1944*

Distances above floor (feet)	Location in bin				
	North	West	Center	East	South
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*
[2] 7.5	11.9	12.2	12.5	12.6	13.8
6.5	12.1	12.4	12.9	12.6	13.1
5.5	12.0	12.2	12.0	12.1	12.8
4.5	11.7	12.1	11.8	11.8	12.2
3.5	11.5	11.8	11.7	11.7	11.7
2.5	11.6	11.5	11.5	11.4	11.5
1.5	11.3	11.5	11.7	11.6	11.6
.5	11.7	11.7	11.9	12.0	11.5

[1] Average wheat moisture content at filling time was 11.5 percent.
[2] Surface of grain.

The first average wheat sample to be designated as Sample grade in bin No. 3–10 occurred in November 1944 after almost 2 years of storage without fumigation (table 32). Not all the wheat in the bin at this time, however, was Sample grade wheat. Spot wheat samples taken halfway down in the bins at the center and near the 4 walls during November 1944 showed the wheat located at the center, south, and east sides in bin No. 3–10 to be Sample grade. Wheat from the west side graded No. 3 and from the north No. 2.

The average sample from bin No. 3–11, which had a smaller insect count than bin No. 3–10 until November 1945 (table 30), did not grade Sample until December 1945 (table 33). This was 1 year later than the grading of bin No. 3–10 and followed fully 3 years of storage without fumigation.

TABLE 32.—*Wheat grade and other determinations on spot samples halfway down in bins Nos. 3–10 and 3–11 at Hutchinson, November 18, 1944*

Bin No.[1] and sample location	Grade[2]	Test weight	Moisture content	Dockage	Odor	Damage		Fat acidity	Protein	Germination
						Insect	Total			
3–10:	*No.*	*Lb.*	*Pct.*	*Pct.*		*Pct.*	*Pct.*	*Units*	*Pct.*	*Pct.*
North	2 HW	58.0	11.4	0.5	O. K.	0.5	1.0	32	12.2	51
West	3 HW	57.7	11.4	.5	O. K.	1.2	2.4	35	12.3	24
Center	S HW	57.4	12.0	.8	Sour	1.3	2.0	36	12.1	30
East	S HW	57.8	10.9	.8	do	1.7	2.4	38	11.9	21
South	S HW	56.5	12.4	.6	do	2.0	3.0	50	12.0	2
3–11:										
North	S HW	58.1	11.4	.5	Sour	.3	1.5	34	11.8	42
West	2 HW	58.0	11.5	.4	O. K.	.6	1.6	34	12.0	41
Center	3 HW	57.5	11.5	.6	O. K.	.5	1.5	33	11.7	45
East	S HW	58.0	11.5	1.1	Sour	.3	1.6	36	12.0	46
South	3 HW	57.8	11.8	.3	O. K.	.3	1.6	38	12.0	24

[1] Average sample from bin No. 3-10 graded Sample Hard Winter "Weevily" and from bin No. 3-11, No. 3 Hard Winter "Weevily."
[2] HW=Hard Winter; S=Sample; all samples graded "Weevily."

TABLE 33.—*Wheat grade and other determinations on average samples[1] from bins Nos. 3–10 and 3–11 at Hutchinson, 1941–46*

Date sampled	Bin No.	Grade[2]	Test weight	Moisture content	Dockage	Odor	Damage: Insect	Damage: Total	Fat acidity	Protein	Germination
		No.	*Lb.*	*Pct.*	*Pct.*		*Pct.*	*Pct.*	*Units*	*Pct.*	*Pct.*
June 20, 1941	3-10	2 HW	58.8	11.2	0.8	O. K.		1.0	27	11.9	85
	3-11	2 HW	58.5	11.5	.3	O. K.		.5	21	11.7	86
Dec. 31, 1941	3-10	2 HW	58.4	11.4	1.0	O. K.		.4	25	12.0	
	3-11	2 HW	58.4	11.4	1.0	O. K.		.9	25	11.8	
June 29, 1942	3-10	2 HW	58.3	11.1	.8	O. K.		.6	26	12.0	74
	3-11	2 HW	58.5	11.2	1.1	O. K.		1.0	32	11.6	73
Dec. 1, 1942	3-10	2 HW	58.0	11.5	1.3	O. K.		1.2	33	12.0	79
	3-11	2 HW	58.5	11.4	1.1	O. K.		.8	37	11.7	82
May 21, 1943	3-10	2 HW	58.3	11.3	.3	O. K.		1.1	31	11.8	76
	3-11	2 HW	58.7	11.3	.2	O. K.		.6	34	11.5	75
Jan. 13, 1944	3-10	3 HW	57.0	11.7	.3	O. K.		.7	32	12.1	53
	3-11	2 HW	58.2	11.4	.3	O. K.		.5	31	12.5	60
Nov. 18, 1944	3-10	S HW[4]	56.0	11.4	.7	Sour	1.2	2.2	39	12.5	34
	3-11	3 HW[4]	57.6	11.7	.6	O. K.	.6	2.4	34	12.2	41
Dec. 3, 1945	3-10	S HW[4]	57.1	11.5	.8	Sour	1.5	5.0	42	12.0	12
	3-11	S HW[4]	57.5	12.0	.4	do	.9	3.0			15
May 15, 1946[3]	3-10	S HW	58.0	12.1	1.4	do	1.3	4.8	51	11.8	22
	3-11	S HW	57.1		1.6	do	4.5	6.0	51	11.6	

[1] The wheat was not fumigated during the last 3½ years of storage.
[2] HW=Hard Winter wheat; S=Sample.
[3] Taken after fumigation.
[4] Weevily.

STORAGE IN OTHER THAN STANDARD STEEL BINS

BOLTED STEEL OIL TANK

One special steel structure used to store wheat at Hutchinson was an oil tank that represented the extreme in tightness insofar as bolted steel structures are concerned (fig. 21). This tank was 21.5 feet in

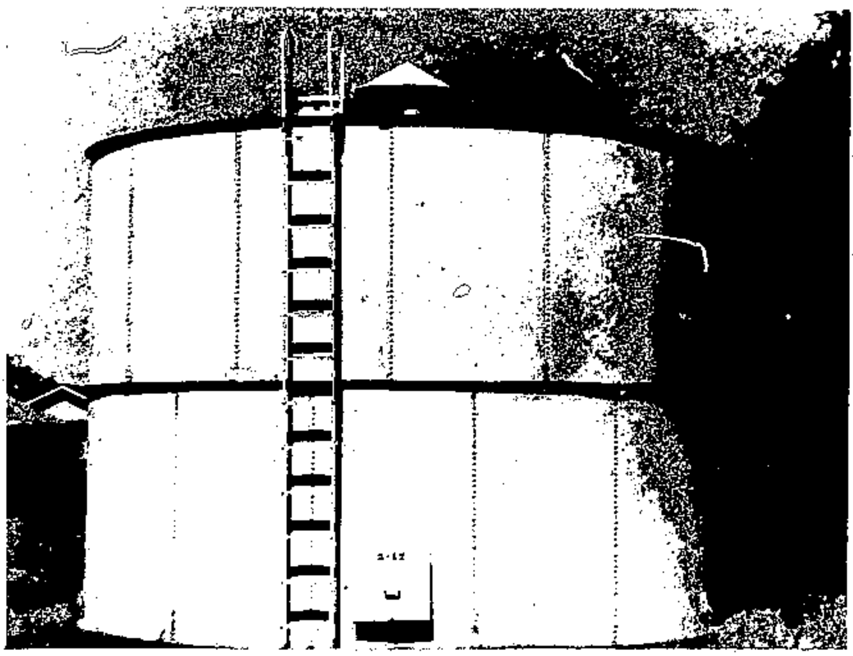


FIGURE 21.—Bolted steel oil tank with rubber gaskets between joints.

diameter and 6 feet high, having a total capacity of about 4,600 bushels. It was constructed of metal sheets bolted together at the joints. For tightness, all of the joints, including those in the flat roof, were lined with rubber gaskets. For ventilation the tank was equipped with a hooded ventilator in the center of the roof. Wheat was put in through a porthole in the roof and taken out through a small door in the wall next to the floor. Four 5-inch portholes were built into the roof for probing purposes.

The tank was first filled on July 30, 1941, with No. 2 Hard Winter wheat with a moisture content of 12.9 percent. It remained in storage until November 10, 1941. In the 3½ months of storage the wheat developed an insect infestation and had begun to heat as a result of high moisture and insects. It was sold because it was difficult to fumigate. The wheat, when removed graded No. 2 Hard Winter "Weevily." Approximately 4 quarts of caked grain were found along 2 feet of one vertical wall seam on the southeast side of the tank. The bolts of this joint were tightened before refilling the tank.

When the tank was filled the second time, it was also sealed for the purpose of keeping out insects and to observe the effect of sealing, if any, on the quality of the grain. A special sheet metal hood was constructed to cover the central ventilator, and all other roof openings were calked. This tank with its tight fit between the roof and wall joint was ideal for this study. The tank was painted white because of its rusty condition.

The tank was filled in November 1941 with No. 2 Hard Winter "Weevily" wheat having 11.3 percent moisture. In order to have the wheat free of insects, it was fumigated before sealing. A sample of grain taken after fumigation contained no live insects.

The wheat remained in storage 11 months before it was removed for inspection. The commercial grade of the wheat in the bottom half of the tank was still No. 2 Hard Winter and the moisture content 11.3 percent, but the top half graded Sample because of a sour odor of unknown cause. It was thought to be caused by the odor of small spoiled spots permeating a large portion of the wheat, made possible by the unusual tightness of the bin. The final insect sample contained only 2 insects per 1,000 grams of wheat.

Spoilage was confined to 12 small spots, owing to water leaks through the joints. The largest spot consisted of approximately one-half bushel of grain. It was in the same location as observed in the original unloading. The other small amounts of spoiled wheat in the bin were confined to a few quarts of caked grain located usually where 3 bin sheets were joined together at one point. In addition, small quantities of spoiled grain were found along the junction of the floor and wall sheets. Total spoilage amounted to approximately 5 bushels. All bolts at these places were tightened and the seams calked on the inside and outside of the tank before refilling the third time.

This tank was filled for the third time during November 1942, with wheat grading No. 2 Hard Winter having a moisture content of 11.4 percent. It remained in storage for 3½ years. The bin was not sealed.

During the 3½ years of storage the condition of the wheat never reached a critical stage in moisture accumulation at the surface of the wheat, in grain temperatures, or in insect infestations. The highest moisture ever recorded was 12.7 percent found in the center top 6 inches during March 1945. The highest average temperature recorded was 71° F. in September 1945, and this was approximately 3° lower than the average temperature of the wheat in 2,740-bushel steel bins at that time. No insect life was found in the wheat until the fall of 1944, 2 years after storage. This consisted of a few bran beetles that died during the winter. However, by the following fall 3 years after storage, insect activity had increased to 18 bran beetles per 1,000 grams of grain. These, too, died during the following winter. All insects present in this bin were the bran beetle type. None of the destructive weevil type was found.

When this wheat was removed from storage it still graded No. 2 Hard Winter. Approximately 2 bushels of spoiled grain was found, owing to a few major and several minor wall-seam leaks. No structural defects were noted in the tank.

Storing wheat in this bolted oil steel tank has shown that:

1. The strength of the structure is suitable for wheat storage.

2. Storing wheat in an airtight bin may seriously affect the odor of a large quantity of the wheat if small spoiled spots develop.

3. Larger farm storage units can store wheat as safely as smaller units insofar as the quality of the grain is concerned.

4. It is difficult to eliminate water leaks through bolted joints. This was a structure having joints designed to hold liquids, but it leaked water and caused spoilage to the wheat even after additional attempts had been made to see that the bolts were tight and extra precaution had been taken by calking seams. Though extreme caution is taken in assembling the steel tank, wheat pressures or a sagging foundation may cause a bolted joint to open enough to allow water to enter.

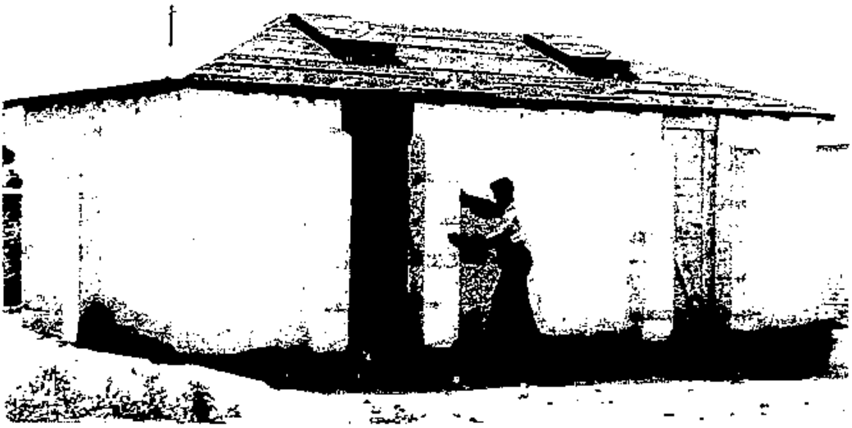
5. Owing to the flat roof, some storage space must be sacrificed or the wheat is difficult to fumigate.

EXPERIMENTAL CONCRETE BLOCK BIN

In June 1942 the Portland Cement Association erected a concrete block bin 12 feet by 24 feet by 8 feet for test purposes at Hutchinson. No reinforcing steel was used; the walls were reinforced by outside concrete block pilasters (fig. 22).

This bin was divided into north and south halves by a concrete block partition. Each half had a capacity of 1,000 bushels. A double layer of reinforced kraft paper was placed over the 3-inch sand fill in the north compartment before the 3-inch concrete floor was poured, and the inside walls were brushed with 2 coats of an emulsified-asphalt material. The floor of the south compartment consisted of a 3-inch concrete slab laid over a 3-inch sand fill with no paper below the concrete. The inside walls were also moistureproofed with 2 coats of emulsified asphalt as was one-half of the floor. Half of the floor was untreated. The entire outside of the structure, except for the north wall was given a sand-cement wash, and, when dry, 2 coats of white cement-base paint.

The north compartment was filled June 20, 1942. No structural failures or weakness of any type could be detected after the bin was full. Within 60 days, however, fine vertical cracks were observed in the east and west walls along the plane of the inside face of the north wall (fig. 22, *B*). All the mortar joints and blocks along



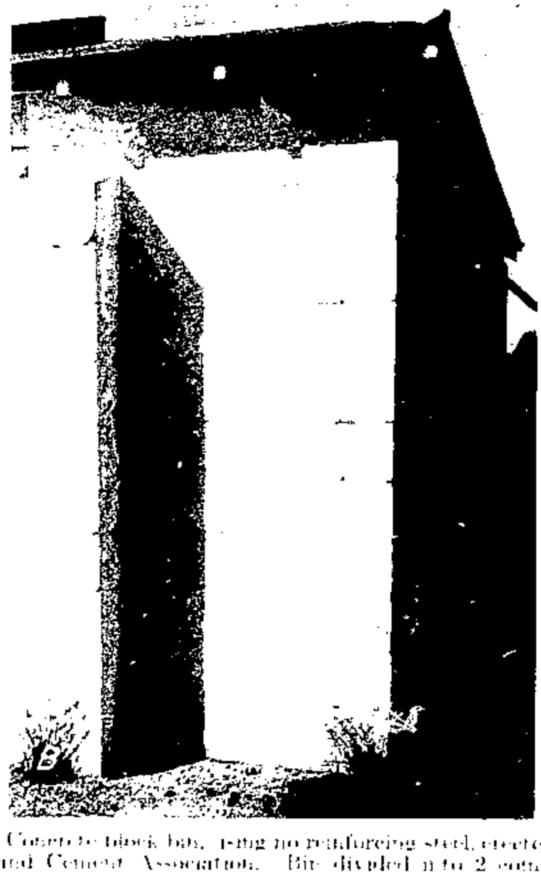


FIGURE 22.—A, Concrete-block bin, using no reinforcing steel, erected at Hutchinson by Portland Cement Association. Bin divided into 2 compartments by concrete block partition. Note pilasters for reinforcing walls. B, Crack in wall of bin [illegible] days after filling.

this plane were broken, except at the foundation. Eventually, these cracks opened to 0.08 of an inch on the west wall and 0.03 on the east. The north wall was completely free of cracks except at the foundation. The wheat was removed after 5 months' storage.

Approximately one-half bushel of grain was caked to the lower one-third of the north wall. The north wall was the only wall that was not treated with outside paint.

The south compartment was filled with wheat during July 1942 and emptied after 3 months of storage. This compartment gave satisfactory performance except for a small amount of spoilage occurring on the floor next to the door and caused by water leakage. Some wheat stuck to the asphalt coating but did not appear to be deteriorated and could easily be brushed off. In addition, about 1 bushel of caked grain stuck to the bottom fourth of the east and west walls behind the pilaster blocks. It was noticeably thicker at the mortar joints, indicating that the moisture causing the grain to cake probably had entered the bin chiefly through the mortar joints. There was no caking or other evidence of grain deterioration on either the treated or untreated half of the floor.

In a letter to H. J. Barre, W. R. Swanson [16] summarizes a discussion with Sanford Coats of the Portland Cement Association on the failure of the concrete block bin as follows:

> Because there was localized failure on the corners of the north wall and the corners of the south wall did not fail, although they were constructed in the same way, Mr. Coats felt that the design was evidently close to the necessary strength. There were also the following limitations to this first concrete block bin:
>
> 1. The concrete blocks used were made on a small hand-tamping machine and the blocks were "green" when they were incorporated into the structure.
> 2. The north compartment was filled and failed first whereas the south compartment which was filled somewhat later has shown no signs of failure.
> 3. The building was located next to the truck highway where the vibrations of the ground from the passing vehicles made a very severe test of the structure.
>
> The results of the tests on the first concrete block bin showed that some structural improvements could be made without materially increasing the cost of the building. Two important changes suggested were the use of steel reinforcements at the corners where the failures occurred and the use of longitudinal ties fastened to the plates of the end walls and dividing partitions.

Several different plans were discussed and some drawn to improve the structure, but no further work was done at Hutchinson.

PREFABRICATED AND PRECUT WOOD BINS

Early in 1942, before the supply of wheat became short during World War II, additional space was needed to store a large carryover of surplus wheat. Because a freeze-order on steel prevented the purchase of additional steel bins, wheat was stored in prefabricated and precut wood bins. Eleven of these wood bins, Nos. 13-1 to 13-11, were erected at Hutchinson in the fall of 1942 for the purpose of studying different methods of interior bracing, interior chemical wall treatment for insect control, exterior wall paints for temperature studies, watertightness of the bins, and performance of the bins for wheat storage (table 34). All these bins (fig. 23) were the same size and similar in design: 12 feet wide, 16 feet long, 10 feet high to eaves, gable roof, filling door in each gable end, emptying door in one side

[16] See footnote 3, p. 1.

wall, single walls of drop siding, and a shingle roof. Each bin held 1,500 bushels. Three bins were prefabricated (wall sections bolted together on the job); other bins were precut. The interior walls were treated immediately after erection, but the exterior walls were not treated until the summer of 1943.

Each bin was supported off the ground by 36 8- by 8- by 16-inch concrete building blocks equally spaced in 4 rows running lengthwise of the bin. The blocks were laid with the openings horizontal, to give greater bearing surface on the ground. Roughly, 1 block was used for every 50 bushels of grain. None of the foundation blocks under any of the 11 bins failed—this number of blocks was sufficient to withstand the weight of the full bin. Settlement of the blocks was not severe. When the bins were filled, the blocks settled from ½ inch on firm soil to 1½ inches on softer windblown soil.

The bins were filled in October and November 1942 with 1941 wheat containing between 11- and 12-percent moisture. The commercial grade was No. 3 Hard Winter in bins Nos. 13–6, 13–7, 13–8, and 13–10; No. 2 Hard Winter in the other 7 bins. There were no failures in the structures at the time of filling. Deflection of the walls was greatest (about ½ inch) at a point 3 feet from the floor and 3 feet from the corners of the end walls in the bins without corner braces. The maximum wall deflection was only one-half as great in the bins with corner braces.

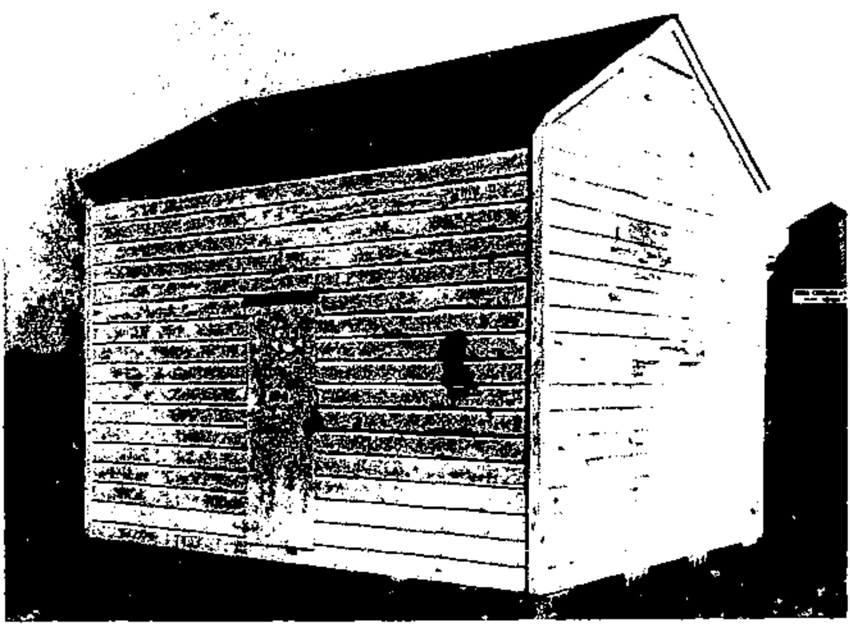


FIGURE 23. Wood bin used in wheat studies at Hutchinson, showing the arrangement of the concrete foundation blocks. The wires at the corners anchored bin to buried logs. Peeling paint was caused by green wood used in construction. The filling door in gable did not exclude water.

TABLE 34.—*Schedule for construction of wooden bins and treatment of exterior and interior at Hutchinson, 1942*

Bin No.[1]	Bin type	Exterior wall painted with	Interior coated with	Number of corner braces	Longitudinal braces: Number	Longitudinal braces: Size	Longitudinal braces: Distance from floor	Transverse braces: Number	Transverse braces: Size	Transverse braces: Distance from floor
						Inches	*Feet*		*Inches*	*Feet*
13-1	Precut	2 coats white	Insecticide;[2] walls and floor; 2 coats south side.	4	2	2 x 6	5½	4	2 x 6	6
					1	2 x 6	8½	2	2 x 4	9
13-2	Unlined, prefabricated	1 coat white	White paint; walls and floor; 2 coats south side.	4	2	2 x 6	5½	4	2 x 6	8½
					1	2 x 6	9	2	2 x 6	5½
13-3	Lined, prefabricated	2 coats white	No treatment	4	2	2 x 6	5½	4	2 x 6	8½
					1	2 x 6	9	2	2 x 6	5½
13-4	do	1 coat white	do	4	1	2 x 6	9	4	2 x 6	8½
					2	2 x 4	6	2	2 x 6	5½
13-5	Precut	do	do	4	1	2 x 6	8	4	2 x 6	6½
					2	2 x 4	5½	2	2 x 4	9½
13-6	do	2 coats white	do	0	1	2 x 6	8	2	2 x 4	9½
					2	2 x 4	5½	4	2 x 6	6½
13-7	do[4]	1 coat red	White lead paint, 2 coats south side	4	1	2 x 6	8	2	2 x 4	10
					2	2 x 4	5½	4	2 x 6	6½
13-8	do	2 coats white	Nicotine sulfate; south wall only	4	1	2 x 6	8	2	2 x 4	10
					2	2 x 4	5½	4	2 x 6	6½
13-9	do	do[3]	Insecticide;[5] south wall only. Another insecticide;[6] west wall only.	4	1	2 x 6	8	2	2 x 4	10
					1	2 x 6	5½	4	2 x 6	6½
13-10	do	1 coat red	Insecticide;[2] south wall only. Another insecticide;[5] all walls and floor.	4	1	2 x 6	5½	4	2 x 6	6½
					1	2 x 6	8			
13-11	do	2 coats white	Whitewash; walls and floor	0	1	2 x 6	5½	4	2 x 6	6½
					1	2 x 6	8			

[1] All bins 12 feet wide, 16 feet long, 10 feet high, and contained 1,500 bushels.
[2] Tetrachlorphenoxyethoxy ethyl chloride.
[3] Roof painted white also.
[4] Two nails per studding in siding.
[5] Phenothioxine.
[6] 4 and 6 chloro-2-phenylphenol (technical).

Wheat was held in storage in these bins from 24 to 30 months, and, except for spoiled grain which was kept separate from the rest of the wheat, the commercial grade of the wheat was the same as when placed in storage. Observations made on the bins when emptied were as follows:

No. 13-1.—About 120 bushels of wheat spoiled as the result of wall leaks and filling-door leak. Caked grain 6 to 10 inches thick clinging to end walls and floor.

No. 13-2.—About 2 bushels grain spoiled at junction of wall sections. Good quality lumber and workmanship in this bin.

No. 13-3.—About 1 bushel wheat spoiled at nail holes in wall. Two 2- by 6-inch crossties broken. Siding in good condition.

No. 13-4.—Slight spoilage of grain at wall section joints. Siding good.

No. 13-5.—60 bushels of wheat spoiled on north and south walls, especially under filling doors. Caked grain on side walls caused by cracks and sappy boards.

No. 13-6.—100 bushels of grain spoiled. North wall completely caked to 1½ feet thick at floor center, upper corners only were clean. South wall about half as bad. Siding in good mechanical condition.

No. 13-7.—60 bushels of grain spoiled as a result of leakage at filling doors and at wall from boards warping and cracks opening. Siding pulled away from studs and sills as much as 1 inch. One 2- by 4-inch transverse tie and one 2- by 6-inch longitudinal brace broken.

No. 13-8.—90 bushels of wheat spoiled as a result of wall leaks and poorly fitted gable doors.

No. 13-9.—75 bushels of wheat spoiled because of wall and door leaks; mostly the result of door leaks.

No. 13-10.—20 bushels of wheat spoiled mostly by door leaks. Some caked grain all around the sills.

No. 13-11.—75 bushels of grain spoiled by wall and door leaks.

Broken ties were found in two bins. In both bins these were the lower set of ties. In bin No. 13-3 it was the two 2- by 6-inch transverse ties 5½ feet above the floor. No reason could be given for this breakage, except for the poor quality of lumber used, for in another bin identically braced, the ties were sound.

Insufficient nailing and the pulling away of the sills from the floor are given as the cause for the broken and cracked ties in bin No. 13-7.

Of the 11 bins 2 contained no corner ties. None of the longitudinal or transverse ties were broken in these bins.

Bins Nos. 13-9, 13-10, and 13-11 had only 2 longitudinal ties, an upper and a lower through the center, and were sufficiently braced to hold the wheat pressures, with and without corner bracing. Two of these three bins (Nos. 13-10, 13-11) contained only a lower set of 4 transverse ties 6½ feet above the floor. All other bins in this study contained 3 longitudinal and 6 transverse ties. In the 2 bins having 2 longitudinal and 4 transverse ties, with and without corner bracing, no broken ties were found. Quality of lumber and workmanship were evidently as important as number of ties.

Leakage of water through poorly fitted filling doors in the gable ends was the chief cause of spoilage. Next in importance was spoilage caused by leakage through the siding (fig. 24). Minor spoilage was caused by leakage under sills in some of the bins and leakage through joints of the sectional bins.

Leakage of rainwater was the chief defect in these bins. The walls constructed of 1- by 8-inch novelty matched siding on 2- by 6-inch studs when adequately nailed (not less than 3 tenpenny nails per board per stud) were sufficiently strong to withstand the wheat pressures but were not tight enough to exclude rainwater. This situation was aggravated by the use of green lumber of poor quality when the bins were constructed. Shrinking boards allowed additional water to enter through the walls. Covering the outside of the bin walls with metal or asphalt roofing will eliminate most if not all of the leakage through the walls. Waterproof paper lining inside the walls also will eliminate most of the leakage through the walls, but care must be taken when working in paper-lined bins, since the paper is easily torn. The paper lining in 1 bin at Hutchinson was severely damaged by rodents, and extensive patching would have been required had the bin been refilled.

The total amount of spoiled grain found in these wood bins was 603 bushels, or an average of 55 bushels per bin as compared with an average of 4.5 bushels per steel bin.

Effect of White and Red Paint on Wheat Temperatures

During 1944 studies of the effect of painted walls on wheat temperatures (p. 65) were extended to include the 11 wood bins at Hutchinson. For this study the bins were divided into 4 groups and painted during the summer of 1943 as follows:

Group 1.—3 bins, walls painted with 1 coat of white paint.
Group 2.—4 bins, walls painted with 2 coats of white paint.
Group 3.—2 bins, walls and roofs painted with 2 coats of white paint.
Group 4.—2 bins, walls painted with 1 coat of red paint.

Eight wheat temperature readings were taken in each of these bins during 1944.

FIGURE 24.—Bin 13 S: Right, spoilage on walls caused by poorly fitted filling doors in gable ends; left, leakage through siding cracks. Wheat in storage 2½ years.

Statistically, significant differences occurred between the wheat temperatures in these bins, but the differences were more likely caused by insect infestation than by the different paint treatments on the outside walls (table 35). A difference in the annual average wheat temperatures between any 2 bins greater than 2.3° F. was considered significant. Accordingly, the wheat temperatures among the 3 bins in group 1 and the 2 bins in group 3 were not significantly different, but the wheat temperatures among the 4 bins in group 2 and between the 2 bins in group 4 were significantly different. The significant differences among the bins in group 2 were the result of the low temperatures recorded for bin No. 13-3 and the difference between the 2 bins in group 4 was caused by the high temperatures recorded for bin No. 13-7. This analysis shows that even bins that are similarly treated may have temperatures significantly different.

When comparing the group average temperatures, it was found that apparently the number of coats of white paint on the walls made no difference insofar as the wheat temperatures were concerned.

Comparing grain temperatures in group 3, which had 2 coats of white paint on walls and roofs, with those in groups 1 and 2, there was an average difference of 1.6° F. Group 3 had the higher temperature. The opposite would be expected to be true because of the painted roofs in group 3. Some discrepancies, however, are easily pointed out. For example, the average temperature in bin No. 13-6 in group 3 was not significantly different from the averages in bins Nos. 13-1, 13-8, or 13-11 in group 2. Apparently, the higher temperature from a heavy insect infestation in No. 13-9 (group 3) and the low temperature in No. 13-3 (group 2) caused the average difference between these groups to be significant.

Temperatures in the red-painted bins in group 4 were significantly different from those in groups 1 and 2 but not from group 3. Here again the high temperatures in one bin (No. 13-7) raised the group average enough to make the difference significant.

From a study of the number of insects present per 1,000 grams of wheat and the maximum temperatures found in the bins, the high wheat temperatures in most of these bins are related to the number of insects present and not so much to the type of treatment. The red bin (No. 13-7) had the highest temperature average. It also had the greatest insect infestation and the highest maximum grain temperature. The lowest insect populations were found in bins Nos. 13-4 and 13-3 from groups 1 and 2. These bins also had the lowest temperatures.

Effect of Inside Wall Treatment on Insects

The inside walls of 9 of the 11 wood bins were treated with chemicals, white paint, or lined with kraft paper. Except for the kraft-paper covering, the inside wall treatments were intended as insect controls. Two of the bins received no inside wall treatment. According to the insect counts in the 11 bins (table 35), mere painting or spraying of the inside walls and floors of wood bins did not control insects. There were as many and sometimes more insects in the treated bins than in the untreated bins. Most of these bins had to be fumigated one or more times to keep the insect population under control.

TABLE 35.—*Average and maximum wheat temperatures and number of insects per 1,000 grams of wheat in wood bins at Hutchinson, 1944*

Group [1] and bin No.	Average wheat temperatures					Maximum wheat temperatures						Insects per 1,000 grams				
	Feb. 2	May 10	Aug. 29	Nov. 24	Bin average [2]	Feb. 2	May 10	July 28	Aug. 29	Oct. 9	Nov. 24	Jan.	July	Sept.	Oct.	Nov.
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	*Number*	*Number*	*Number*	*Number*	*Number*
Group 1:																
13-2	44.1	48.9	75.2	58.5	59.5	47	60	79	78	78	70	2	----	----	8	7
13-4	43.5	50.1	73.1	56.5	58.7	46	60	79	76	77	66	2	----	[3] 3	0	[3] 1
13-5	43.6	49.6	75.8	60.1	59.8	46	60	87	85	81	72	1	----	----	67	29
Average	----	----	----	----	59.3	----	----	----	----	----	----	----	----	----	----	----
Group 2:																
13-1	45.0	47.9	78.4	58.7	60.7	47	60	84	92	86	71	1	----	----	[3] 69	21
13-3	43.7	49.5	73.5	56.5	57.6	47	59	77	78	75	66	1	----	1	1	[3] 0
13-8	42.9	50.6	75.2	60.5	60.3	47	62	85	82	81	70	3	4	51	48	25
13-11	42.9	48.1	74.7	59.3	59.4	46	59	87	89	80	71	2	2	20	15	9
Average	----	----	----	----	59.4	----	----	----	----	----	----	----	----	----	----	----
Group 3:																
13-6	44.1	50.2	77.4	58.9	60.4	48	62	80	87	84	68	0	1	15	12	[3] 15
13-9	41.4	52.6	79.5	60.0	61.6	44	63	83	90	89	70	2	3	36	40	34
Average	----	----	----	----	61.0	----	----	----	----	----	----	----	----	----	----	----
Group 4:																
13-7	43.4	48.3	81.2	73.8	64.0	47	59	102	100	104	95	2	15	103	[3] 103	12
13-10	43.9	49.2	76.5	58.6	60.7	49	64	86	89	81	71	6	4	25	24	----
Average	----	----	----	----	62.4	----	----	----	----	----	----	----	----	----	----	----

[1] See table 34 for exterior and interior treatment of bins.
[2] Average of 8 readings.
[3] Insects after bin fumigated during month.

Comparison of Wheat Temperatures in Wood and Steel Bins

Average wheat temperatures in the 1,500-bushel wood bins were about the same as the temperatures in the 1,000-bushel steel bins (table 36). Average temperatures for the 1,000-bushel steel bins were estimated from the temperature curve in figure 20. Wheat temperature variations within wood bins are similar to those in steel bins. North-south cross-section temperature variations in wood bins at Hutchinson are shown by isothermal curves in figure 25.

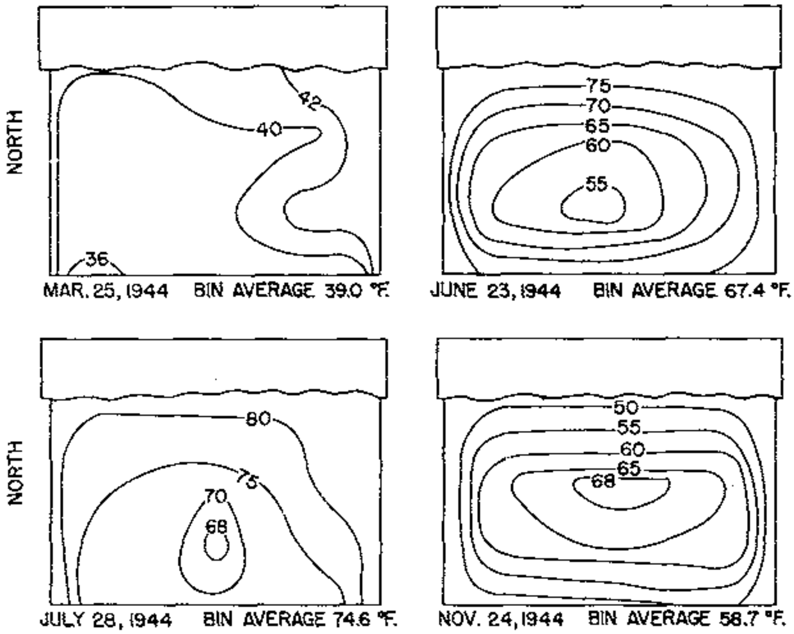


FIGURE 25.—Wheat temperatures in 1,500-bushel wood bins at Hutchinson, 1944.

TABLE 36.—*Average wheat temperatures in the 1,500-bushel wood bins and 1,000-bushel steel bins at Hutchinson, 1944*

Date	Average wheat temperatures	
	Wood bins	Steel bins
	° *F.*	° *F.*
Feb. 2	43.5	44.0
Mar. 25	38.7	45.0
May 10	40.5	40.0
June 23	67.4	66.5
July 28	74.6	74.5
Aug. 29	76.4	77.5
Oct. 9	71.6	71.5
Nov. 24	60.1	61.5

SPECIAL BINS

Not only was steel in short supply early in 1942, but the supply of seasoned lumber and nails was also short. Consequently, to help

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furnish the necessary space to store the surplus wheat, many manufacturers designed storage bins using any lumber available or other conventional building materials. Several of these units were erected at Jamestown and studied as to their general performance as storage bins. Dimensions and general construction features of some of these bins are given below.

Twelve-Sided Wood Bin

A 12-sided wood bin, 15.3 feet in diameter by 8 feet high, was made of 4- by 8-foot panels at Jamestown (fig. 26). The 1,150-bushel bin had no roof door and was filled through a removable ventilator.

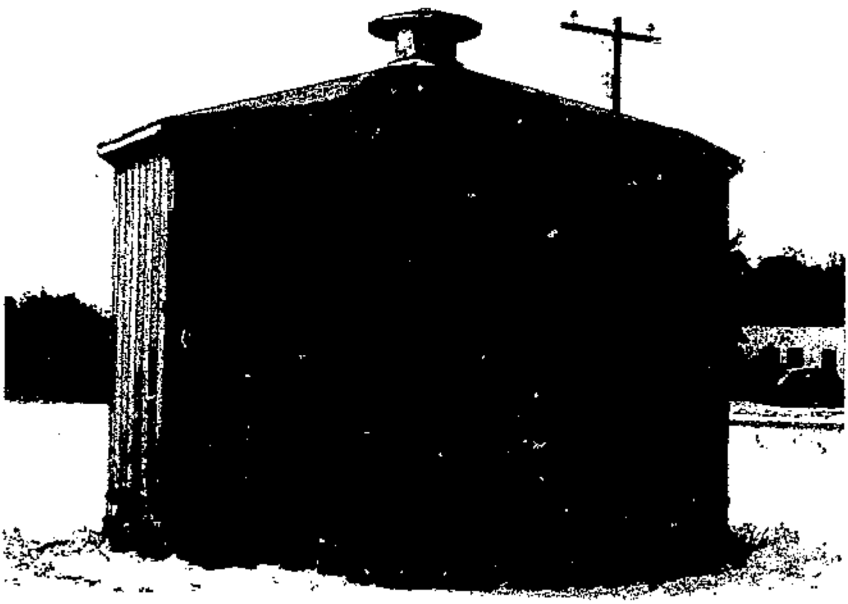


FIGURE 26.—Twelve-sided wood bin, at Jamestown.

The bin was filled with wheat in May 1942 and emptied May 1944. The grain was in good condition except for 2 bushels of spoilage around outside edge of floor caused by water leakage. The ventilator let in small amounts of snow during storms. There were no structural failures in the bin.

Tongue-and-Groove Wood Bin

At Jamestown other wood bins were built of tongue-and-groove 2- by 12-inch plank, with a fashioned corner lock and horizontal ties and uprights (fig. 27). This construction provided the necessary strength to resist the pressure of the grain. The bins were about 15.5 feet square and 10 or 18 feet high. The plank walls were easy to erect and required less labor and nails to build than the conventional wood bin. Wheat was stored in these bins from 1 to 2 years. Spoilage of

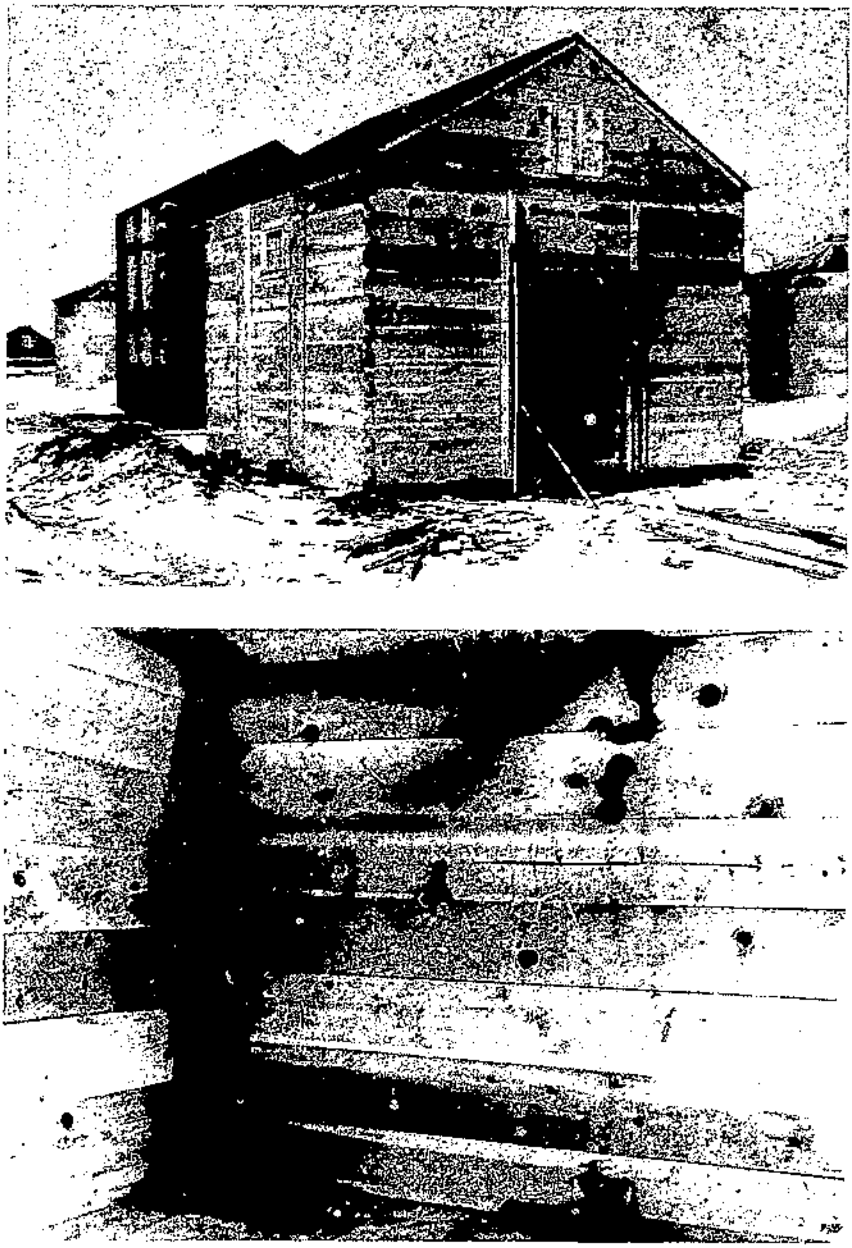


FIGURE 27.—*A*, Tongue-and-groove wood bin, with fashioned corner lock and horizontal ties and uprights; *B*, spoilage as the result of water leakage at corner locks and where internal braces protruded, at Jamestown.

varying amounts was found in the bin as a result of water leakage through the corner locks and on the walls where the internal braces protruded. Flashings over the protruding braces prevented leakage around these openings, but no completely satisfactory method was found for preventing leakage through the interlocking corner joints.

Roll-Roofing Bin

Figure 28 shows a 400-bushel roll-roofing bin built at Jamestown. Walls made of 2 layers of heavy roll roofing cemented together were supported externally by 2- by 4-inch studs, 16 inches on center. The floor was a wood platform, and the roof consisted of a single layer of roll roofing. After 22 months of storage about 3 bushels of spoiled wheat was found on the central part of the floor where water had accumulated after entering through leaks around the scoop door. Some spoilage was found around the outer edge of the floor at the floor-wall junction. Wheat sticking to the sides was not deteriorated and was easily brushed off. The final grade of the grain was still No. 2 DNS, as when placed in storage.

Rectangular Insulation-Board Bin

The walls of a 1,050-bushel rectangular bin, 11 by 15 by 8 feet were made of ¾-inch vaporsealed insulation board externally supported by wood framing. The outside of the walls was calked at the studs and sills. Roof was also of insulation board, but it was covered with roll roofing. A wood floor on skids was used under the bin. Wheat was stored in this bin for 21 months without failure from wheat pressures or storms. The initial grade of wheat was maintained and less than a bushel of spoilage was found, which was caused by the use of platform type of floor. This floor permitted water leakage at the floor-wall junction, where calking failed.

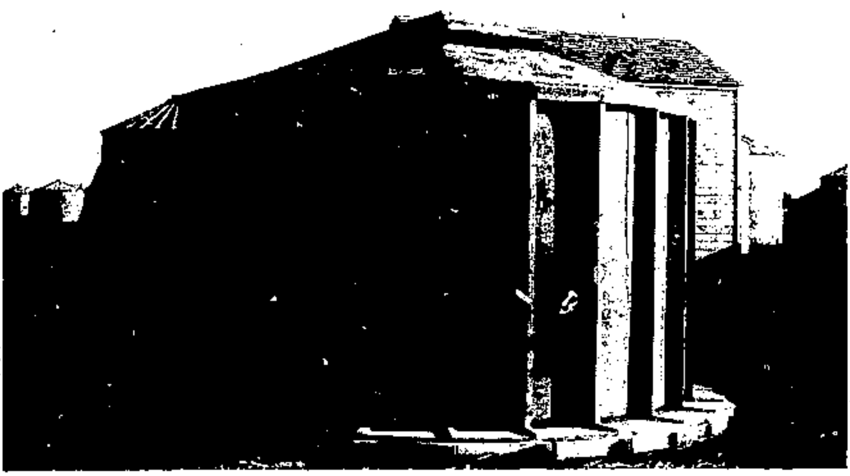


FIGURE 28.—Roll-roofing bin supported externally by 2- by 4-inch studs, at Jamestown.

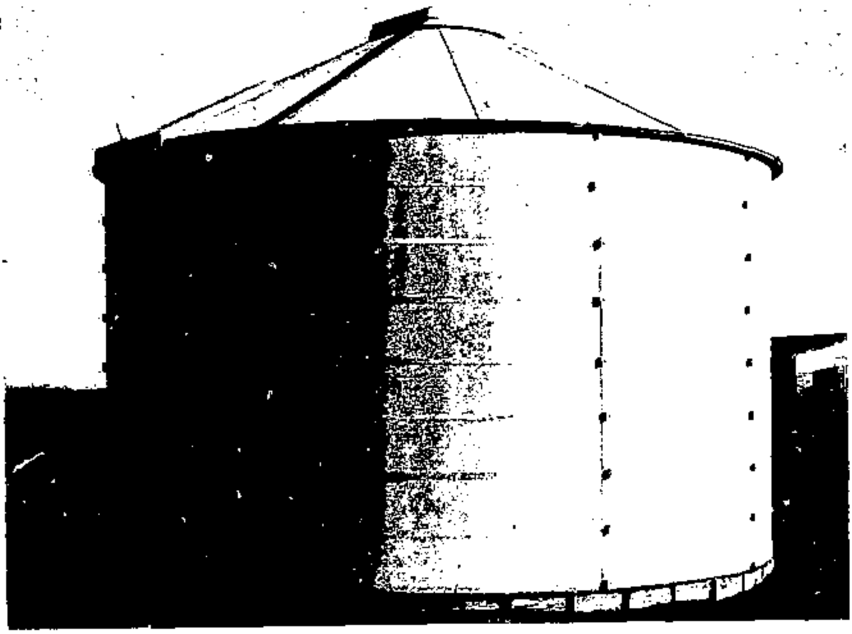


FIGURE 29.—Circular bin, using wallboard panels for walls and roof at Jamestown. This bin contained no spaces between the 2 sheets of wallboard.

Circular Wallboard Bin

Five circular bins 1,000- to 2,250-bushel capacity were erected at Jamestown (fig. 29). The walls were made of prefabricated panels consisting of 2 sheets of ⅜-inch wallboard glued together, either with or without spacers between them. The walls were supported with steel hoops and were from 8 to 10 feet high. Roofs were also of wallboard. Some of these bins had wood platforms for floors, and some had sheets of wallboard coated with asphalt that were laid on dirt fills. The principal fault of these bins was the failure to exclude water through the panel joints and at the floor-wall junction, which resulted in excessive spoilage, ranging from 3 to 18 bushels per bin.

Rectangular Wallboard Bin

The roof, walls, and floor of a 1,200-bushel rectangular bin (12 by 20 by 7 feet) were constructed of ²⁵⁄₃₂-inch asphalt-impregnated wallboard sheathing externally spaced 12 inches on center (fig. 30). Construction of this bin was similar to the 1,050-bushel insulation board bin, except for the elimination of the platform type of floor. As a result, the only spoilage found was about 1 pound of caked grain on the floor caused by a nail-hole leak in the roof.

TEMPORARY GRAIN BINS

At times a bumper crop of wheat is produced that chokes all marketing facilities, fills all available permanent storage, and still leaves an excess that has to be piled on the ground fully exposed to the weather.

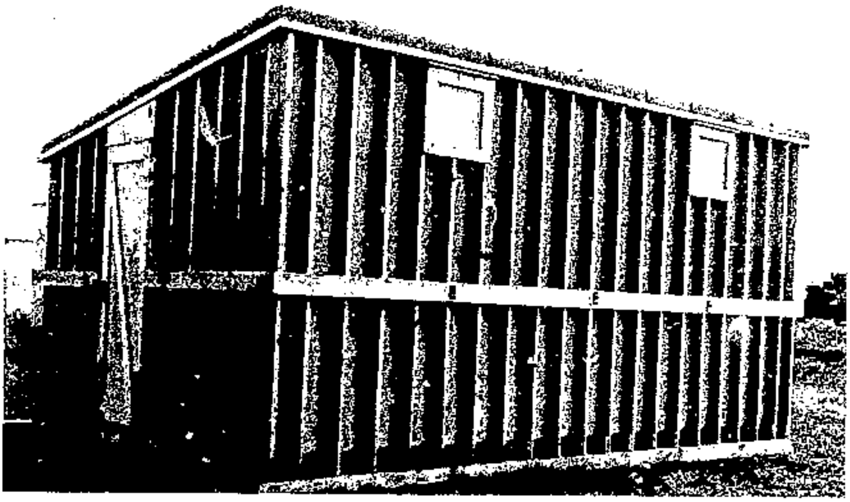


FIGURE 30.—Rectangular wallboard bin constructed at Jamestown.

These piles of wheat are subjected to tremendous amounts of spoilage unless moved in a short time. To help avoid much of this unnecessary spoilage of excess wheat, several types of temporary grain bins were built and studied at Hutchinson and Jamestown. The capacities of these bins ranged from 106 to 2,250 bushels. They were built of materials that are not commonly used for storage bins, such as wire mesh and waterproof paper. A description of these bins and their conditions and the condition of the wheat in them when emptied are given below.

A Covered Rick

As a temporary storage about 500 bushels of wheat were placed in a rick at Hutchinson and protected by roll roofing of various grades, and some other materials. The rick was about 16 feet wide, 38 feet long, and 3½ feet high at the peak of the ridge. In making the rick, roll roofing was laid out to form a floor upon which wheat was piled and shaped. The roll roofing was then carried over the grain to form a roof or cover (fig. 31). The various grades of material used included 15-lb. asphalt-saturated felt, 35-, 45-, 55-, and 65-pound mica-surfaced roll roofing, and 35-pound talc-surfaced roll roofing, all of which were used both as floor and roof. Also used in the roof were strips of 90-pound mineral-surfaced roll roofing, 2 sheets of corrugated fiberboard, and 3 sheets of matched vaporproofed insulating board. One-half of rick was enclosed by 2- by 12-inch boards set on edge and supported by stakes. The other half was enclosed only by the roofing.

Laps in the floor were not cemented. Roof laps were treated in 4 ways: (1) A 1- by 4-inch board was placed under the lap and cemented and nailed; (2) a similar treatment with a lath nailed over the lap; (3) laps cemented with the cold cement supplied with the rolls of roofing; and (4) laps cemented with hot asphalt. The joint in the corrugated fiberboard was lapped 2 corrugations, but no cement used. The tongue-and-groove joint in the insulating board was cemented with hot asphalt.

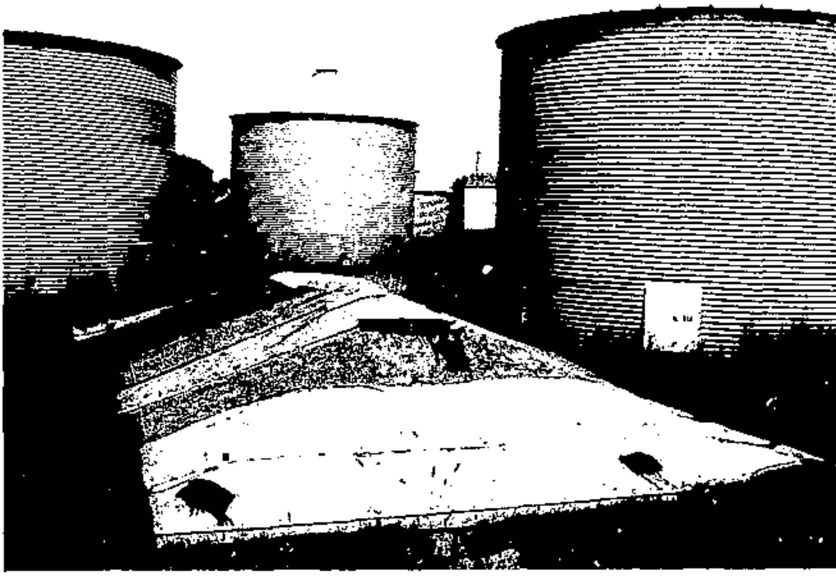


FIGURE 31. Temporary storage in rick of about 500-bushel capacity: Hutchinson, 1945.

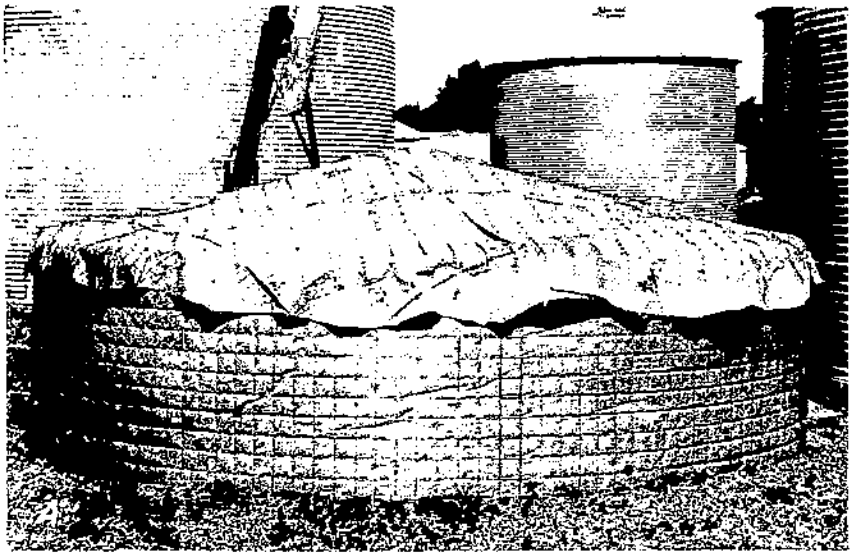
The portion of the rick not enclosed with boards was reinforced with stakes at the laps in the roofing and with a 1- by 4-inch board used as a nailing strip at the end.

The rick stood for 3 months, and when uncovered the bulk of the wheat was in good condition. There was no spoilage at the ridge, but about 20 bushels of spoiled grain was found on the floor caused by leaks through 8 or 10 punctures near the outer edge of the cover. The board enclosure of the rick seemed to be detrimental rather than helpful. There was a tendency to form a dip in the cover near the board. More spoilage occurred at the board edge than at the unprotected edges of the rick.

No difference could be observed from the various grades of roofing or other materials used or in the various methods of making the lap joints. The rick, however, was difficult to construct, and several accidental punctures were made in the materials during construction, which is a major disadvantage to this method of temporary storage. Though this rick was watertight to ordinary rains, it had not been subjected to any hailstorms. No unusual insect problems were encountered in this method of storage.

A 750-Bushel Wire-Mesh and Kraft-Paper Bin

The wire wall of the kraft-paper bin at Hutchinson was made with a 50-foot length of 48-inch width 4- by 4-inch mesh, 12-gage welded wire fencing formed into a 16-foot diameter circle. The 2 ends of the fencing were joined by overlapping 2 vertical strands and tying each of the 26 crossings with 2 turns of wire (fig. 32). The wire wall was lined with a 60-inch width of 2-ply reinforced kraft paper. Thus, the paper extended a foot above the fencing to form a tuck-in under the



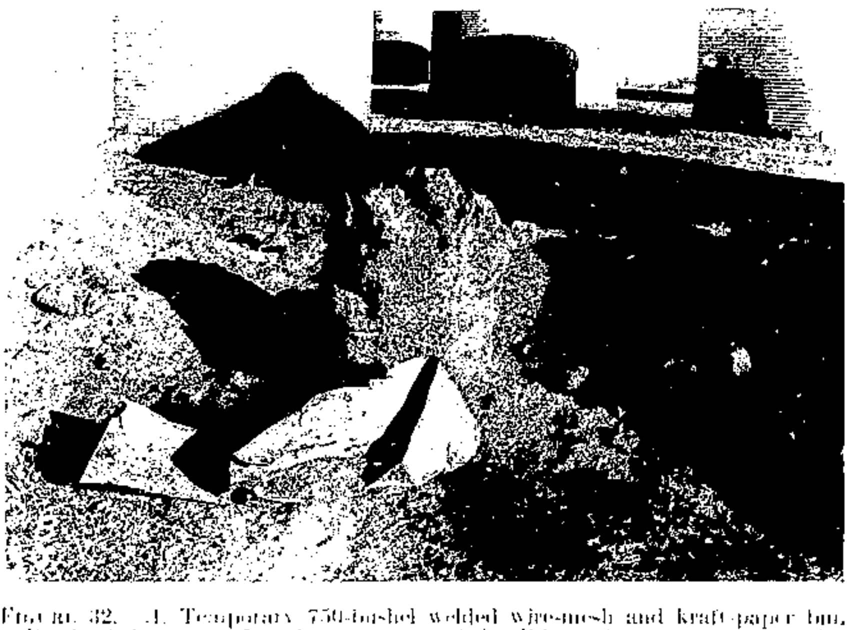


FIGURE 32. *A*, Temporary 750-bushel welded wire-mesh and kraft-paper bin. *B*, Spoiled grain after bin was emptied. Wheat in storage 7 months, Hutchinson, 1945.

cover. Similar kraft paper was then shaped to form a floor, placed inside the wall sheet but extending up the walls a foot, and pressed down at the floor-wall joint. Floor sections were lapped 4 to 6 inches. Actually, the bin was constructed while being filled. First the floor was laid inside the wire-wall ring and grain piled on it until it reached the edges. Next, the wall lining was put up between the fencing and upturn of the paper floor and grain was pushed against it to hold it in place. The bin was then filled until the level of the wheat was about 4 inches above the top of the fencing at edges and 2 feet above it at center. The remaining 8 inches of the wall lining was then turned in onto the grain to form the tuck-in under the cover. The cover consisted of 3 lengths of the kraft paper placed in parallel fashion across the cone-shaped top of the grain and lapped a minimum of 1 foot; it was held in place by a wire netting over the top and tied to the wall wire. None of the joints were cemented.

The bin stood full for 7 months. Interim attention consisted of tarring a few punctures or abrasions in the paper, chiefly in the walls, adjusting the anchoring of the wire netting over the cover, straightening the wire where punctures in the cover seemed imminent, and releveling the wheat under laps in the cover to improve top drainage. The bin was not subjected to hailstorms.

In 7 months weathering had eroded the upper ply of the kraft paper, exposing the tar cementing material and the reinforcing fiber, and punctures occurred in the cover in several places. Water leakage through these punctures in the cover formed columns of moldy and caked grain in the bin (fig. 32, *B*). Water from cover leaks also formed a layer of caked grain at the floor; however, some moisture came up from the soil beneath. The kraft paper of the floor was completely rotted, with little strength left even in the reinforcing fiber. There was less spoilage over the kraft-paper floor than over roll-roofing floors used in other temporary bins where leaks through the cover had resulted in water on the floor. In roll-roofing floors, the water cannot escape and the layer of spoiled grain becomes increasingly deeper.

About 130 bushels of spoiled grain was found in the bin. A rather heavy infestation of insects was found, and considerable heating was evident in connection with the large masses of damp grain.

The study in this bin showed that:

1. Reinforced waterproofed kraft paper can be used to protect grain in temporary structures for short periods.

2. One layer of the paper supported by 4- by 4-inch mesh welded wire is adequate for walls 4 feet high and for a period of 6 months.

3. One layer of the paper used as a cover was punctured in several places and weathered to the point of leaking by the end of 3 months. Other tests have shown that 2 layers of the paper when not punctured provided adequate protection for a year.

4. One layer of the paper used as a floor in contact with the soil has little protective value, except possibly in dry weather and for periods not exceeding a month.

5. Extending the paper lining 1 foot higher than the wire in the walls and filling to a point 4 inches above the wire are effective in forming a watertight, puncture-free junction between wall and cover.

6. A satisfactory bin of this type should consist of a ring of welded wire mesh (not over 4- by 4-inch mesh, 12-gage, 48-inch width)

supporting 1 layer of waterproofed, 2-ply, reinforced kraft paper (60-inch width), a floor of roll roofing (35-lb. or heavier, laps do not require cementing), and a double cover of the same paper as that used in the wall. Careful attention must be given to the junction of wall sheets and cover as well as the laps in the cover. The bin should be filled 4 inches above the fencing, crowning the center at least 2 feet.

A 1,500-Bushel Paneled Wire-Mesh and Paper-Lined Bin

The paneled wire-mesh and paper-lined bin was built at Hutchinson and measured 18 feet in diameter and 7 feet high. The wall consisted of 18 panels made by welding a section of standard 6- by 6-inch mesh concrete reinforcing wire between 2 angle iron bars that formed uprights or studdings and provided the flange for the joint (fig. 33). These panels were fastened together with 8 bolts at each joint. Stability of the wall was obtained by extending the angle bars 6 inches into the ground. Two layers of fiber-reinforced, waterproof kraft paper lined the inside of the wire wall. The floor consisted of 45-pound roll roofing laid directly on the ground, laps cemented, and edges at the wall turned up between the 2 layers of kraft paper. The cover or roof was a cone-shaped lightweight waterproof canvas resting on the grain except at the center, where a pole supported the canvas to form a peak and at the eaves where it rested upon the wall. A hole was cut in the side of the wall for emptying the bin at the end of the test.

This bin was filled with wheat on May 21. By July 9 leaks had occurred at the eaves through holes where the canvas cover crossed the walls and at the depression in the canvas cover just inside the walls after the grain had settled. Holes were rubbed in the canvas at the walls by winds activating the cover. Cover leaks caused discoloration on the paper wall lining at several points.

The bin was emptied in August after 3½ months of storage. Five columns of caked and moldy wheat were found (fig. 33) extending from top to floor, all caused by leaks through the canvas cover at the walls. The entire floor was coated with caked and moldy wheat to a depth of 1 to 5 inches where the water that entered through the canvas cover, settled at the bottom of the bin, and could not escape. The total spoilage amounted to about 100 bushels.

There were no failures in the bin caused by wheat pressures or rainstorms, and the bin maintained its shape well even when emptied. The bin, however, had not been subjected to any hailstorms. All the damaged wheat in this bin was caused by the cover. With an effective cover the bin would be a satisfactory temporary storage for periods up [illegible] months. Danger of puncturing the kraft-paper wall lining should not be overlooked. No unusual insect problems were found in this bin.

A 1,400-Bushel Welded-Wire Mesh and White-Surfaced Roll-Roofing Bin

The welded-wire mesh and roll-roofing bin at Hutchinson (fig. 34) was 16 feet in diameter and 8 feet high. Two rings of 4- by 2-inch mesh, 12-gage, 48-inch width, welded-wire fencing were used to make the 8-foot wall height. One 100-foot roll of fencing was cut into 2 parts, each 50 feet long. A 4-inch length of each horizontal strand was left extending beyond the end vertical strand on each end of the two pieces of fencing. Loops were then formed on these 4-inch

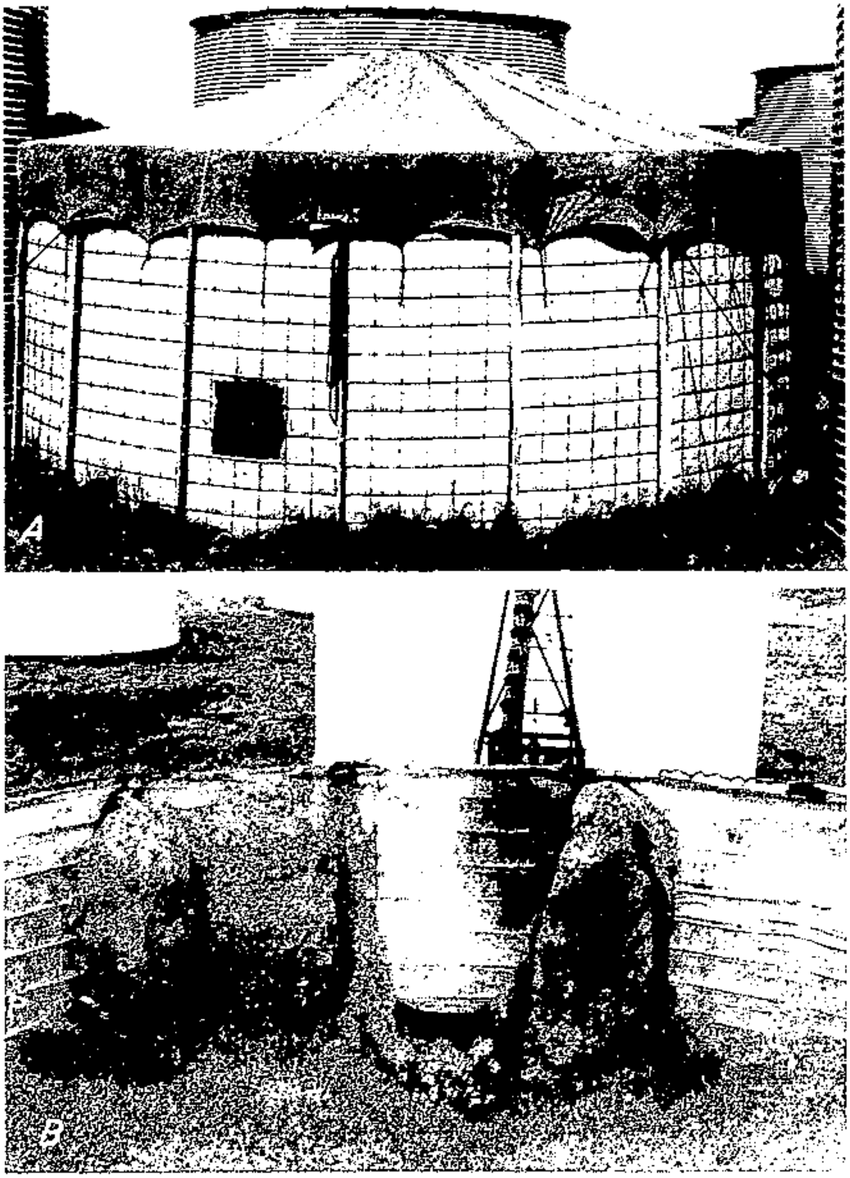


FIGURE 33. *A*, Temporary 1,500-bushel paneled wire-wall and paper-lined bin. *B*, Columns of caked and moldy grain adjacent to the east wall. One column had crumbled but left its mark on the wall. Wheat in storage 3½ months, Hutchinson, 1945.

extensions, and the joint completed by inserting a ⅜-inch iron rod through the loops (fig. 34).

The first ring was set in position and a 16-inch width of white asbestos-surfaced roll-roofing placed inside the fencing at the bottom to start the wall lining. The lower edge was notched 4 inches from the ground at intervals of 2 feet to provide for tucking under the floor.

Precut lengths of 45-pound black roll roofing were then placed on the ground to form the floor. The lengths had been cut to provide an 8-inch extension up the walls on the inside and were also notched at 2-foot intervals for easy fitting to the circular walls. Laps in the floor sheets were 2 to 4 inches but were not cemented. Filling the bin with wheat was then started, and additional wall lining rings of 32-inch width white roll roofing were added as the filling progressed. With laps of approximately 2 inches, the top ring extended about 8 inches above the proposed filling depth and allowed a tuck-in under the cover sections.

The cover, also made of white-surfaced roll roofing was fabricated in 4 sections, each consisting of 5 wedge-shaped triangular sheets of the white roll roofing cemented to a backing material. Backing materials used were (1) 35-pound roll roofing on the northeast quadrant, (2) tarpaulin on the southeast quadrant; (3) reinforced waterproofed kraft paper on the southwest quadrant; (4) asphalt felt and roofer's cotton gauze, each forming approximately one-half of the backing, on the northwest quadrant.

Four 1- by 8-inch boards were laid radially on the surface of the grain to form a foundation for the laps of the cover sections. A lath nailed over each lap secured the joint and formed an effective seal.

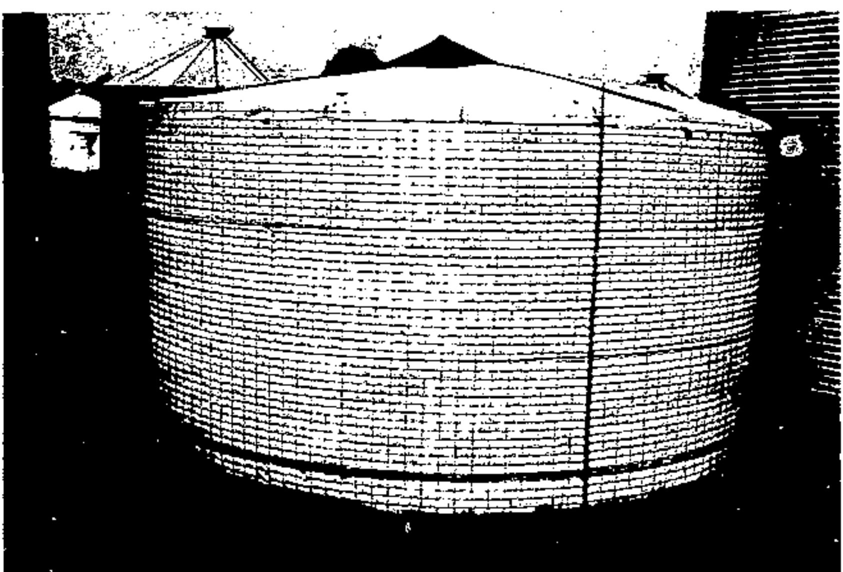


FIGURE 34.—Temporary 1,400-bushel bin of white asbestos-surfaced roll roofing and welded-wire fencing with roll-roofing flooring, Hutchinson, 1945.

A cone of roll roofing, fabricated on ½-inch mesh hardware cloth for completing the apex of the roof, was secured by a roofing nail driven into each lath. At the eaves the cover was tucked in between the fencing and wall lining. Before applying the cover, the apex of the cone of wheat received a pad of cotton about 4 feet in diameter and 8 inches thick at the center. It was thought that this cotton might absorb moisture accumulating at the surface of the grain.

A section of 45-pound black roll roofing was placed in the first ring of wall lining on the west side for a comparison with the white material. No difference was noted.

The structure remained in good condition for 10 months of storage. Interim attention given this bin consisted of patching with roofing cement 2 or 3 punctures of unknown origin in the cover and sealing with calking compound an abrasion in the wall lining. No hailstorms occurred during the test on this bin.

When the bin was emptied it was found that water leaks had occurred in two sections of the cover and at the roof apex. The apex leak resulted from too flat a slope. The cone of grain should be built higher at the center. Leaks in the sections occurred only at the crossing of laps in the white cover and the backing material. The southeast and southwest sections, lined respectively with tarpaulin and reinforced waterproofed kraft paper, were of a single piece each; hence, no leaks developed. One leak developed in each of the other two sections. It was quite apparent that the leaks were not large. The caked and rotten grain formed irregular saucer-shaped masses 10 inches and 18 inches deep, respectively, in the northwest and northeast sectors. Only a small quantity of water percolated to the bottom of the bin to form a small area of caked grain in the northeast sector. The grain adjacent to the wet spots was slightly musty and the odor permeated the entire mass through the mixing of the grain in emptying the bin, so that the lot graded Sample. Total spoilage amounted to about 35 bushels.

The study of this bin showed that:

1. This type of temporary bin can be made entirely waterproofed and therefore could be used to store grain for periods of a year or more.
2. Constructing the roof and making it watertight is the most difficult part of the structure.
3. Punctures required for fumigation or accidental breaks can be patched effectively with asphalt cement and roll-roofing or calking compound.
4. Neither the 4- by 2-inch mesh, 12-gage wire, nor the asbestos-surfaced roll roofing failed at any time during the 10-month storage period.
5. The roll roofing floor laid directly on the ground was effective in this bin as in previous trials. A fill of earth is desirable, however, to raise the floor about 3 inches above grade and provide drainage away from the floor-wall junction.
6. The test using cotton batting as an absorbent for the expected surface moisture accumulation did not receive a fair trial because of leaks in the roof.

Pressed-Wood Walls and Kraft-Paper Covered Bin

The 700- to 1,000-bushel bins of pressed wood and kraft paper are classed as temporary because of the roofs. One was tested at Hutchin-

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son, and three at Jamestown. They were 4 feet high and 15 to 18½ feet in diameter. The walls of these bins were made of pressed-wood panels bolted together and formed into a circle. (fig. 35).

In the bin at Hutchinson the lower edges of the wall sheets were buried 6 inches below ground level. The floor consisted of a 6-inch layer of sand above the ground level covered with composition roofing. This proved to be a good floor. At Jamestown the pressed wood walls of these bins rested on paper-covered wood floors laid over gravel or on concrete block piers. Some leakage occurred at the floor-wall junction in these bins where calking failed.

After filling the bins with wheat and heaping the center to form a cone, straw was laid around the upper edge of the wall and then the wheat was covered with 2 layers of waterproof reinforced kraft paper under wire mesh to form the roof.

Wheat was stored in these bins from 10 to 19 months without any wall failures. However, severe weathering and mouse damage to the kraft paper permitted considerable spoilage. Spoilage from leaks through the roofs ranged from 3 to 75 bushels per bin.

Discussion

Temporary grain storage structures must be as carefully planned, constructed, and filled as permanent bins, for there is less opportunity to examine the grain or modify conditions after filling. It is assumed that temporary bins will be used only as emergency storage to replace uncovered piles of wheat on the ground and that they will be watched closely and emptied as soon as feasible. Grain that is not in condition for permanent storage cannot be considered suitable for safe temporary storage. Some generalizations can be made from the types of temporary storage tried at Hutchinson and Jamestown.

To obtain a satisfactory cover is the most difficult part of constructing a temporary storage. It must resist deterioration by weathering, puncture by hail or other falling objects, and must be watertight. From the standpoint of ease in application and freedom from leaks, a double cover of reinforced waterproofed kraft paper is highly desirable. It may be anchored with a large-mesh, lightweight poultry netting tied to the walls. Roll roofing, because of its narrow width, must be lapped in many places and therefore requires cementing. It is, however, longer lasting, and if used as a top cover cemented to an undercover of kraft paper it makes a good cover. Canvas is likely to admit water wherever it comes in contact with the grain or the structure and must be watched carefully.

In the various covers studied for temporary storage, none of the tests showed evidence of moisture condensing on the underside of the cover directly on the grain. It must be remembered, however, that most of these bins stood less than a year.

Walls of wire mesh lined with reinforced waterproof paper or roofing are quite effective. With horizontal strands not more than 4 inches apart, 12-gage wire is ample for an 8-foot wall height. Mesh sizes of 6- by 6-inch, 4- by 4-inch and 4- by 2-inch were tried. None failed under the conditions used. The latter 2 mesh sizes are preferable, and when used with 1 ply of reinforced kraft paper are effective for a period of 6 months. For longer periods 2 plies should be used. Either white-surfaced or black roll roofing in 45-pound weight is

FIGURE 35.—*A*, Temporary 700-bushel bin with pressed-wood walls, double-thickness waterproof reinforced kraft-paper roof, and heavy roll-roofing flooring. *B*, Columns of spoiled grain and layer on floor caused by leaks through weathered and damaged roof. Wheat in storage 11 months, Hutchinson.

effective for a year or more with 4- by 2-inch mesh. For a shorter period 4- by 4-inch mesh is satisfactory.

Floors of 45-pound roll roofing laid directly on the ground, with strips lapped but not cemented, were used successfully. Laying it on a level with the surrounding grade permits water to accumulate at the base of the wall with some danger of grain spoilage. When placed on a slight fill providing definite drainage away from the bin on all sides, there is reasonable assurance of no spoilage from this cause. Wood floors are not necessary in temporary bins.

Some disadvantages of temporary storage bins are: (1) Difficulty of construction, requiring two or more men; (2) lightweight building materials are easily torn and are vulnerable to wind and hail damage; (3) grain is difficult to inspect; (4) fumigation is more difficult than in standard steel or wood bins; (5) temporary bins must be emptied—they are not satisfactory when only partially full; and (6) building paper materials can be used only once unless extreme care is taken in handling them.

The essential recommendations regarding piling grain on the ground for temporary storage are to choose a plot of slight slope; to smooth the ground; to pile the grain high in the form of a long rick, keeping the surfaces of slopes as steep and free from depressions as possible; and to provide a cutoff ditch for drainage water on the uphill side of the pile. The ditch should be kept very near the pile of grain and be given enough pitch to drain well. Water then flows over the surface of the wetted grain into the ditch and is carried away. Without the ditch, water accumulates at the base of the slope where most of the spoilage occurs. Hence, any enclosure or flooring material usually tends to increase spoilage by retaining the water and directing it under the pile.

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