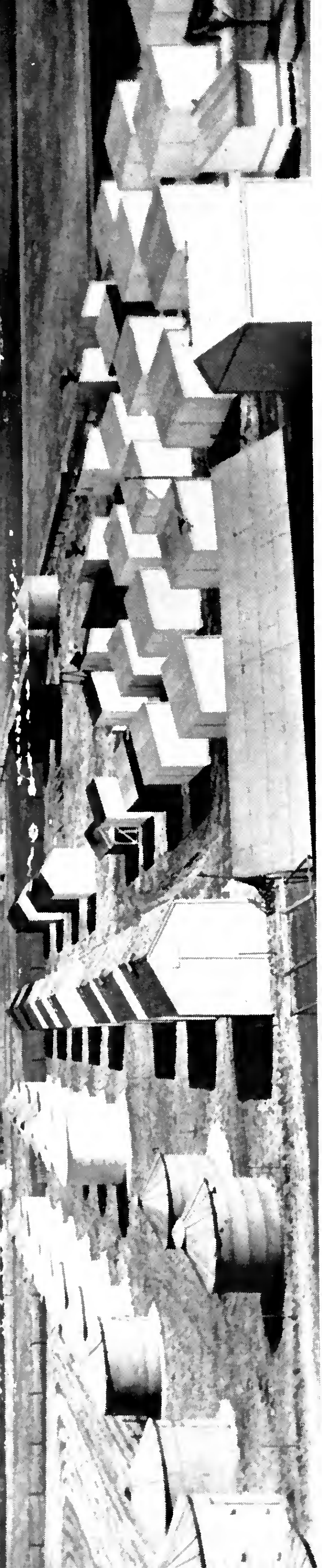

SOYBEAN STORAGE in Farm-Type Bins

A Research Report

By LEO E. HOLMAN and DEANE G. CARTER

Bulletin 553

UNIVERSITY OF ILLINOIS
AGRICULTURAL EXPERIMENT STATION
in cooperation with
U. S. Department of Agriculture

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Cover photograph shows most of the seventy farm-type bins used in the storage study at Urbana.

Urbana, Illinois — March, 1952

Publications in the Bulletin series report the results of investigations made or sponsored by the Experiment Station

A Research Report of
SOYBEAN STORAGE IN FARM-TYPE BINS

By Leo E. Holman and Deane G. Carter[1]

SOYBEANS HAVE BECOME a major crop in the United States only within the past twenty-five years, although they have been grown in various parts of the world for centuries. In 1924 the U. S. production of soybeans was less than 5 million bushels, but by 1944 production was up to nearly 200 million bushels, and in 1950 amounted to 287 million bushels. Production is centered largely in Illinois, Iowa, Indiana, Missouri, Ohio, and Minnesota, these states accounting for about 90 percent of the U. S. production during the ten years 1939-1948. Seven other states each produced more than a million bushels annually.

Soybeans are harvested over a short period, and more than half the crop is marketed direct from the field. During the fall of 1946, for example, about 120 million bushels, or 60 percent of the total, was marketed in 6 to 8 weeks' time. Such a marketing pattern puts a heavy strain on country elevators, other commercial storages, and transportation facilities. But even with this marketing pattern, a considerable amount is stored on the farm for several months. From 1943 through 1951, an average of 29.2 percent of the previous year's crop was still on farms on January 1, and 18.9 percent on April 1.

Storage capacity on the farm has not kept pace with the increasing production. Additional farm storage is needed to enable farmers to hold the crop and provide more uniform marketing throughout the year. Farmers generally will benefit by holding their soybeans for a month or longer. The farm price in Illinois rose substantially from October to May every year for twenty-five years, except in 1948-49 and during the war years, when price ceilings were in effect.[2] Total cost of farm storage for six months has been estimated at 10 to 20 cents a bushel.[3] This includes depreciation and upkeep of storage, insurance,

[1] Leo E. Holman, Senior Agricultural Engineer, Division of Farm Buildings and Rural Housing, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture; Deane G. Carter, Professor of Farm Structures, Department of Agricultural Engineering, Illinois Agricultural Experiment Station. Cooperators included M. D. Farrar, formerly of the Illinois State Natural History Survey, and R. F. Fuelleman and F. H. Crane, Department of Agronomy, who made germination, oil content, and fat acidity tests.

[2] Illinois Farm Economics, October, 1949, pp. 910-915.

[3] Soybean Digest, August, 1949, pp. 6-7.

taxes, interest on investment, labor of handling, shrinkage,[1] and minor deterioration.

Soybean-storage research in cooperation with the U. S. Department of Agriculture and other agencies was established at the Illinois Station in 1943.[2] The objectives of the study were: (1) to find the types of buildings best suited to preserve the quality of soybeans stored on the farm; (2) to determine the effect of the initial soybean-moisture content on grade and other quality changes while stored on farms; (3) to determine quality changes during storage and develop methods for preventing deterioration; (4) to learn the effect of soybean condition on insect activity and the control of insects infesting the crop; and (5) to find practical methods for drying or conditioning.

SCOPE OF THE STUDY

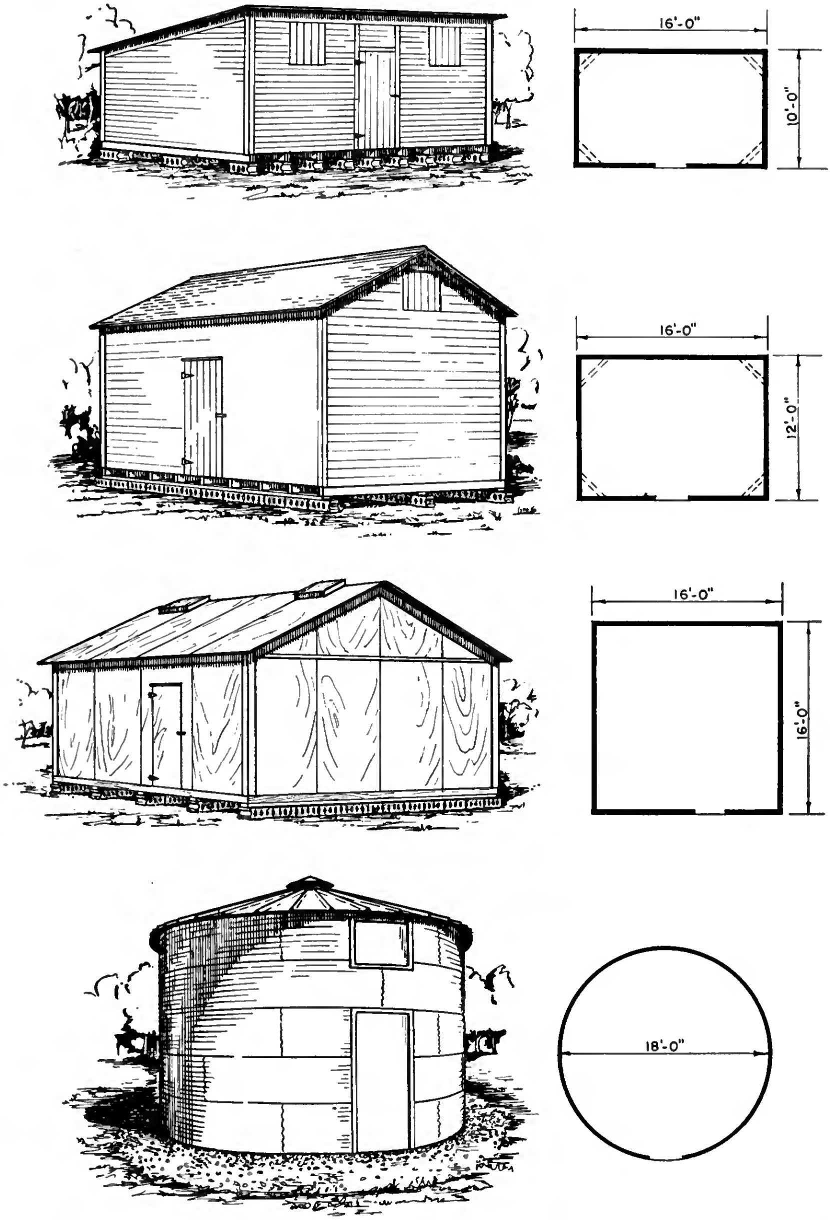
Bins. Seventy full-sized farm-type bins of various sizes and designs were used in these investigations.[3] Bin capacities varied from 600 to 2,800 bushels. Surface colors of white, black, and red were included, and some bins were left as unpainted galvanized steel. Shapes were round, rectangular, and twelve-sided. Depths ranged from 6 feet to 13½ feet. Siding materials were sheet steel, matched lumber, gypsum board, and painted and asphalt-covered plywood. Foundations were of crushed rock, concrete block, monolithic concrete, and earth fill. Four types of bins characteristic of those used in the study are shown in Fig. 1. Some of the variations among the bins are brought out in Table 1.

Soybeans. Various lots of soybeans having different moisture contents were sampled and tested periodically to determine the optimum moisture for storage under a variety of conditions and in bins of

[1] In weathertight storage the only "shrinkage" should be the weight lost by moisture evaporating from soybeans. Dry soybeans may absorb water and gain weight.

[2] The soybean study was part of a larger storage-research program conducted cooperatively by the U. S. Department of Agriculture, state agricultural experiment stations, and sometimes other agencies. The investigations also included storage projects on corn in Illinois, Iowa, and Indiana; wheat in Illinois, Kansas, Maryland, and North Dakota; and grain sorghum in Kansas.

[3] Most of the bins were provided by the Commodity Credit Corporation, others by the Douglas Fir Plywood Association, the Gypsum Board Institute, the Butler Manufacturing Company, and the Illinois Station. Other Commodity Credit Corporation bins were used for inspection and observation, especially as to insect infestation, moisture movement, anchors, foundations, and construction practices.



These bins are characteristic of those used in the study: 28 shed-roof types in two sizes (top), 14 gable-roof bins in several variations, one plywood sectional bin, and 20 circular bins in various types and sizes, mostly steel. (Fig. 1)

Table 1. — Characteristics of Bins Used in Soybean Storage Study at Urbana[a]

Wall material	Shape	Roof type	Size			Capacity
			Width	Length	Height	
			ft.	*ft.*	*ft.*	*bu.*
Wood	Rectangular	Shed	8	14	9	760
	Rectangular	Shed	10	16	7	830
	Rectangular	Gable	12	16	10	1 590
	Rectangular	Gable	14	24	10	2 820
	12-sided	Conical	14	(diameter)	8	1 100
Gypsum board	Rectangular	Gable	10	16	8	1 000
Plywood	Rectangular	Gable	16	16	8	1 600
	Circular	Conical	19	(diameter)	10	2 250
Steel	Circular	Conical	13½	(diameter)	8	944
	Circular	Conical	18	(diameter)	11	2 100
	Circular	Conical	18	(diameter)	13½	2 740

[a] Other variations were made in surface color, foundations, floors, linings, kinds of openings, anchors, perforations, duct systems, and provision for ventilation.

different types and sizes. Quantities were adequate for duplication to verify results. The soybeans were loaned to the project by the Commodity Credit Corporation. This arrangement proved to be mutually beneficial because it provided for convenient storage facilities, maintenance or improvement of quality, and adequate stocks for testing. The increase in price during the storage period offset much of the expense incurred.

During the four years of intensive investigation, 79,000 bushels of soybeans were used. Approximately 63,400 bushels were from the 1943 crop, 12,600 from the 1944 crop, and 3,000 from the 1946 crop. Initial moistures varied with different lots from 8 percent to 19.3 percent, wet basis.

The estimated market value of soybeans used in the experiments was $144,000 at the time of storage and about $170,500 when sold, a gain of about $25,000 during storage. This gain was due primarily to higher prices, although some improvement was made in grade, especially where artificial drying was done. Losses during storage were negligible, amounting to 0.3 of 1 percent of the amount stored.

Instruments. Copper-constantan thermocouple systems were inserted in the stored soybeans and a portable potentiometer was used to read grain temperatures. Official grain probes with extension handles were used to obtain samples from all bin levels for quality, moisture, chemical, and insect-count determinations. Tag-Heppenstall grain moisture meters were used to determine moistures. Germination, fat acidity, and acid number were determined with standard laboratory equipment. Air temperatures and relative humidities were recorded on hygrothermographs. Manometers, or draft gages, were used to measure air pressures during drying tests. Ames dial gages measured pressures exerted on bin walls.

Cooperation. Helpful assistance and cooperation were provided by the Illinois state office and the Champaign county office of the Production and Marketing Administration and by the Illinois State Natural History Survey. Official grade factors were supplied by the General Field Headquarters, Grain Branch, PMA, Chicago, Illinois. The Animal Science Department of the Illinois Agricultural Experiment Station provided facilities for weighing and carlot storage, and the Agronomy Department conducted tests for germination, fat acidity, oil content, and acid value of the oil.

Since this bulletin is limited to the storage phases of the research, data pertaining to insects, germination, fat acidities, and acid values are noted here only as criteria for evaluating storage. Detailed data were recorded by the Entomology Section, Illinois State Natural History Survey, and the Department of Agronomy, Illinois Agricultural Experiment Station.

Data to measure soybean quality. The records that were taken into account in determining changes in soybean quality during storage were: (1) official grade factors of moisture content, test weight, damaged kernels, foreign material, odor, and splits, (2) germination, (3) fat acidity and acid number of the oil,[1] (4) oil content, (5) respiration, (6) insect infestation, and (7) grain temperatures. Some 1,450 samples were taken during four years of investigation. Of these, 430 were composite samples representing average conditions in each bin and were submitted for official grade analysis. Grain temperatures were read at regular intervals.

CONDITIONS AFFECTING QUALITY OF SOYBEANS IN STORAGE

Moisture content is a primary element in safe storage. High moistures are generally responsible for most storage troubles, whether the soybeans are wet when stored or become damp in bins that are not weathertight. Their high oil content requires that soybeans be drier than corn or wheat to store safely under similar conditions. High

[1] Chemical tests for determining changes in quality. See page 494 for definition.

moistures also increase the respiration rate of stored soybeans. The number of insects found is also likely to be greater with high moisture content.

Moisture Content

Maximum moisture for safe storage varies with the length of the storage period and the purpose for which soybeans are to be used. The market discounts for moisture determine which moisture contents result in the highest returns. Such moistures may not be low enough for safe storage for the desired length of time. Seed stocks held for planting must have moistures low enough to assure high germination.

A close relationship was found between moisture and both market grade and chemical and germination changes (Fig. 2). The higher the moisture at the time of storage, the greater the deterioration.

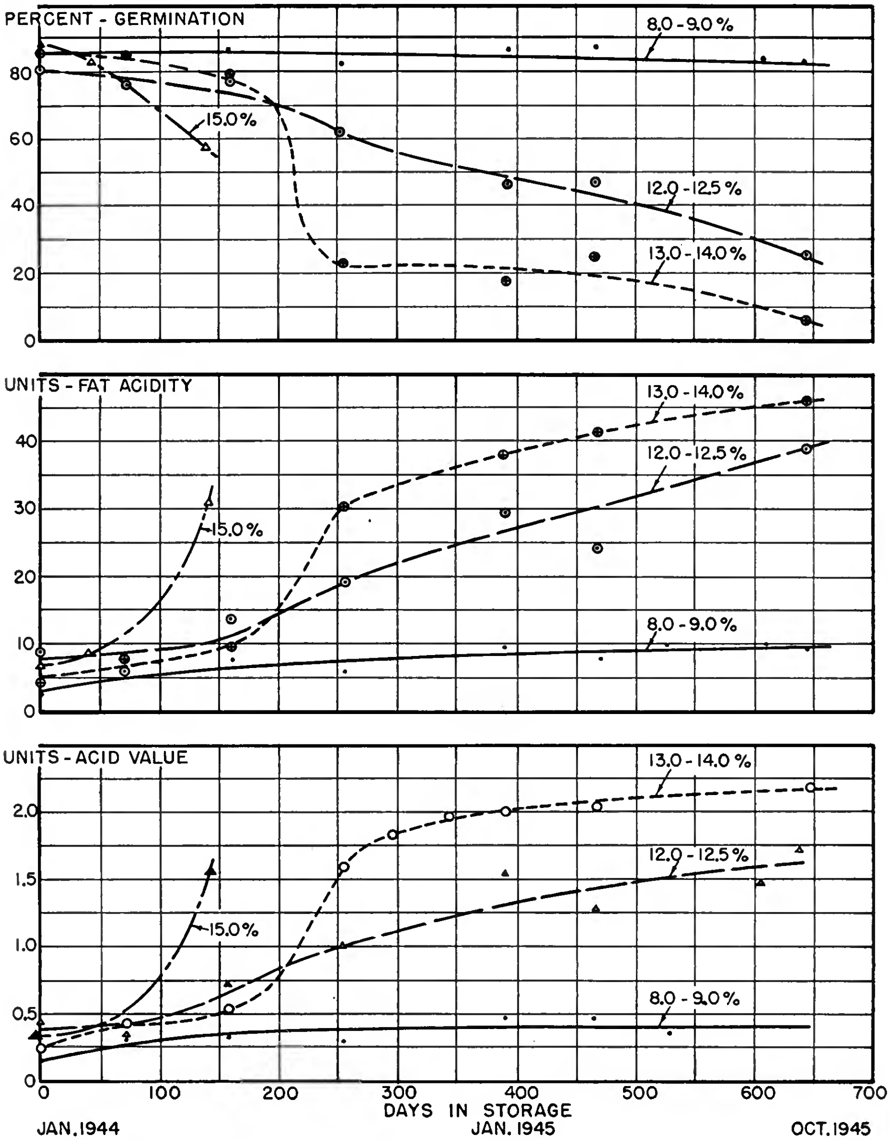
Moisture limits for safe storage. When all the records are considered together, they provide a guide to the length of the safe storage periods for soybeans of different moistures at Urbana or similar areas (see page 494 for climatic data for Urbana). In warmer areas the moisture content has to be lower for comparable storage, and in colder areas the moisture can be higher.

The bulk of the mature dry lots had a moisture content of 10 percent or less, although some had 11 percent. Other lots were stored with moistures of 12 to 12.5 percent, 13 to 14 percent, and 14 to 15 percent.

Moistures of 10 percent or less (also some at 11 percent). At initial moistures of 10 percent or lower, 1943 soybeans did not change in grade after nearly four years in farm-type bins. Average moisture increased by ½ to 1 percent in the period. The percent of damaged kernels increased slightly; germination decreased moderately after two and three years and more rapidly in the fourth year. Fat acidity, or acid number of the oil, did not increase significantly during the four-year storage period. Some loss in nutritive value undoubtedly occurred during long-time storage.[1] Similar conditions prevailed in the 1944 crop stored for two years with moisture contents of 11 percent or less. "Splits" ranged up to 27 percent, probably because of the low moisture content.

At these relatively low moistures, it was indicated that seed stock could be stored safely for one year with only slight decrease in viability

[1] In a study reported in the Journal of Nutrition **39**, 463-484 (1950), dry soybeans stored for nearly three years deteriorated definitely in the nutritive value of the proteins. This deterioration was attributed to intense embryonic respiration of the soybeans.



Deterioration of soybeans in bins is related to moisture content at the time of storage. Tests with eleven identical bins showed: little or no change at 8- to 9-percent moisture; gradual but not serious change at 12.0- to 12.5-percent moisture; rapid deterioration within 250 days at 13- to 14-percent moisture and within 150 days at 15-percent moisture. Three of the 13-14 percent bins with considerable spoilage were emptied after 250 days; the fourth bin was in better condition, and the record after 250 days is for that bin alone. (Fig. 2) and market stock might remain in good condition up to four years with little or no change in grade.

Moistures of 12 to 12.5 percent. Soybeans stored with moistures between 12 and 12.5 percent did not change in grade for nearly three years but became musty and graded "sample" during the third year. Average moisture increased about 1 percent during the period, partly because the bin walls were not completely tight. There was no significant increase in percentage of damaged kernels. Germination decreased considerably in the first year and was down to nearly zero after three years. Fat acidity units and acid numbers increased gradually during the first two years and in the third year went above the maximum allowed by the trade without discounts.

Under these conditions seed can be stored through the fall and winter for next season's planting with little decrease in germination. Commercial stocks can be kept for a year or more; except for a higher fat acidity, they can be stored up to about three years without significant loss.

Moistures of 13 to 14 percent. Soybeans stored at these moistures in January changed rapidly during the summer months, with a severe drop in germination and a gain in fat acidity. In two bins the contents were "sample" grade because of musty odors after 10 months, January to October.

Three of the four bins tested in this moisture range were emptied in November and 100 bushels were removed from the surface of the fourth bin because of deterioration. After 21 months of storage, the market grade of the soybeans remaining in the fourth bin was still No. 2, although germination had gone down to nearly zero and fat acidity had increased greatly.

At moistures of 13 to 14 percent, soybeans used for seed should be tested for germination just before planting. Crop for marketing can be stored until the following summer with little loss in quality. Serious deterioration is likely if the soybeans are carried into the second year.

Moistures of 14 to 15 percent. In all tests, soybeans stored from January through July with moistures of 14 percent and above graded "sample." The average moisture content decreased somewhat; percentage of damaged kernel increased slightly; germination decreased markedly; and fat acidity increased 25 to 35 units. At 15-percent moisture, soybeans stored in January dropped more than 30 percent in germination and increased to above 30 units in fat acidity after five months. Fifteen-percent soybeans can be stored through late fall and winter with little loss of quality, but serious deterioration begins with the arrival of warm weather. If intended for seed, they should be tested for germination before planting.

Respiration. Ramstad and Geddes reported that respiration increased with increases in moisture content and that mold growth was related to gains in respiratory activity.[1] Respiration rate remained low and relatively constant with low moisture content. At moistures above 14.5 percent, the daily rate increased steadily for several days and then tended to level off. Respiration increased sharply at moisture contents of 18 percent.

Common molds are generally responsible for abnormal heating when relative humidities are above 75 percent. Such heating usually stops at 122° to 131° F. Bacterial spoilage may cause temperatures up to 158° F., but since humidities above 95 percent are required for bacterial growth, the danger of such spoilage is slight. These high humidities are rarely encountered in soybean storage bins.

Moisture at harvest time. Moisture content at harvest usually ranges from 10 to 13 percent. It fluctuates considerably throughout

Table 2. — Daily Fluctuation of Soybean Moisture in the Field

Location	Date	Time of day	Relative humidity of air	Moisture content
			perct.	*perct.*
Ames, Iowa...........	10–14–1942	8:30 a.m.	82	15.3
		1:30 p.m.	42	9.9
		4:30 p.m.	48	9.1
Urbana, Illinois........	10–19–1944	11:10 a.m.[a]	58	11.2
		2:30 p.m.	50	10.4
		6:00 p.m.	60	9.2
Urbana, Illinois........	10–19–1944	11:30 a.m.[a]	58	11.6
		3:00 p.m.	50	9.9
		6:15 p.m.	60	9.6

[a] Time combine started.

the day, as shown by observations at Ames, Iowa, and Urbana, Illinois (Table 2).

Check was made of the moisture contents of 392 truck loads of soybeans at a local elevator in east-central Illinois between September 25 and October 16, 1944. Of these, 11 loads had moisture contents of 11 percent or less, 45 loads ranged between 11 and 12 percent, and 336 loads tested higher than 12 percent. Thus more than 85 percent of the

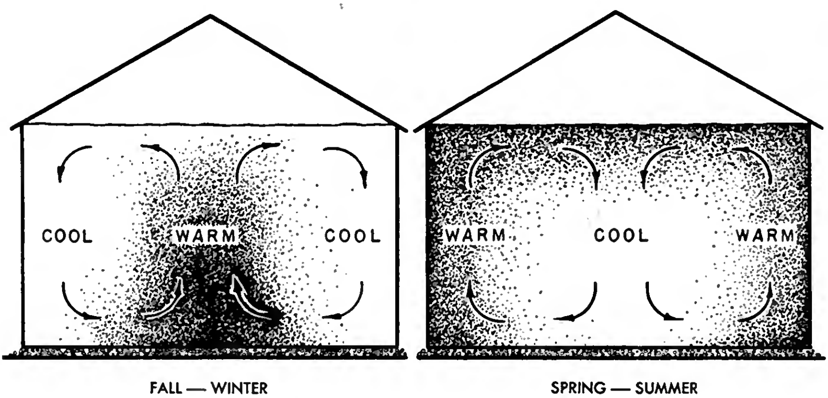
[1] Minn. Agr. Exp. Sta. Tech. Bul. 156. 1942.

deliveries contained more moisture than would be safe in long-time farm storage.

If moistures are uneven in various lots or loads going into a bin, the highest moisture, rather than the average, should be at the safe limit.

Moisture Movement and Accumulation[1]

Moisture migration or movement within the bin has been noted during the storage period, even when initial moistures are low enough for safe storage. Movement occurs to some extent in all types and sizes of bins. During the fall and early winter, the soybeans near the walls and upper surfaces cool faster than those at the center of the bin.



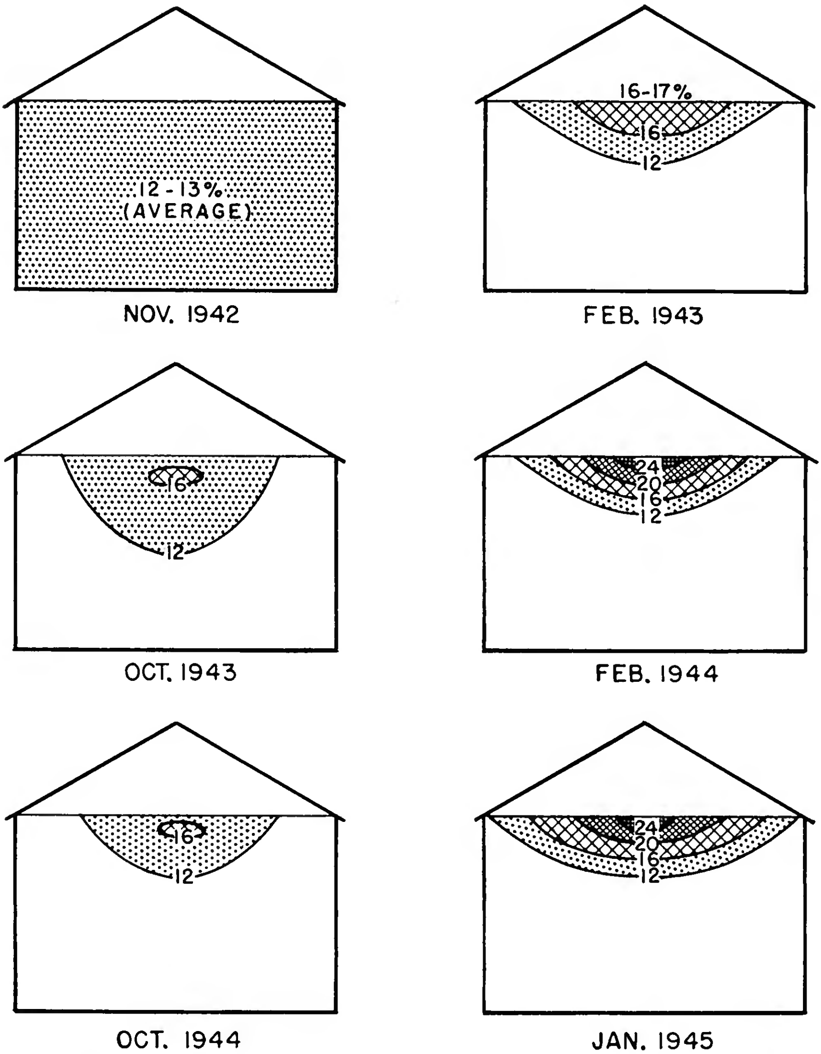
Air movement in soybean bins changes with the season. During the fall and winter, air moves down along the walls and up through the middle. This movement carries moisture to the top layers. In spring and summer the movement is reversed. (Fig. 3)

Temperatures at the center may be as much as 30 degrees F. higher than near the walls and top surface. This differential creates convection currents, causing cool air to move downward near the outside walls, then across toward the center where the air is warmed and rises toward the surface (Fig. 3). This slowly rising air carries moisture vapor from the warm portion into the cooler area near the surface, where some condensation occurs. Thus the moisture content is increased in the surface layers in a bowl-shaped mass which is 12 to 24 inches

[1] See also "Redistribution of Moisture in Soybean Bins" by Deane G. Carter and M. D. Farrar in Agricultural Engineering **24**, p. 296 (1943).

deep at the center and becomes thin or disappears entirely within 2 to 3 feet of the sidewalls.

Temperature conditions are reversed during the spring and summer, when grain is cooler at the center of the bin. Convection currents carry



In a 2,000-bushel steel bin in central Illinois, moisture varied by seasons, building up to about 24 percent in the second winter. Moisture went down each summer, and the bin average stayed about the same. (Fig. 4)

moisture from the surface toward the center. Moisture movement during the summer is not as pronounced as in winter, so surface moistures are not reduced to the original condition.

A rather extreme case of the seasonal movement of moisture and its accumulation is shown in Fig. 4. Soybeans stored at 12- to 13-percent moisture increased to 24 percent in the surface layers after two winters, while moisture was less than 11.5 percent in the lower central two-thirds of the bin.

Moisture migration was noted in soybeans stored in 830-bushel wood bins having wood floors set above the ground. Even with 8- to 9-percent soybeans, moisture fluctuated between 8.7 percent and 11.1 percent in the surface layers, and some variation occurred near the bottom. Similar conditions were found in identical bins where moistures were 12 to 12.5 percent and 13.5 to 14.0 percent.

In general, accumulations of moisture due to movement do not affect a large volume unless the bin average is 13 percent or higher. Stirring the surface during late fall and winter helps to break up crusting and to prevent spoilage. Limited tests using air ducts and motor-driven fans to draw cold air downward through the central part of the bin were effective in equalizing temperatures and stopping convection. Air ducts must be installed before the bins are filled, however.

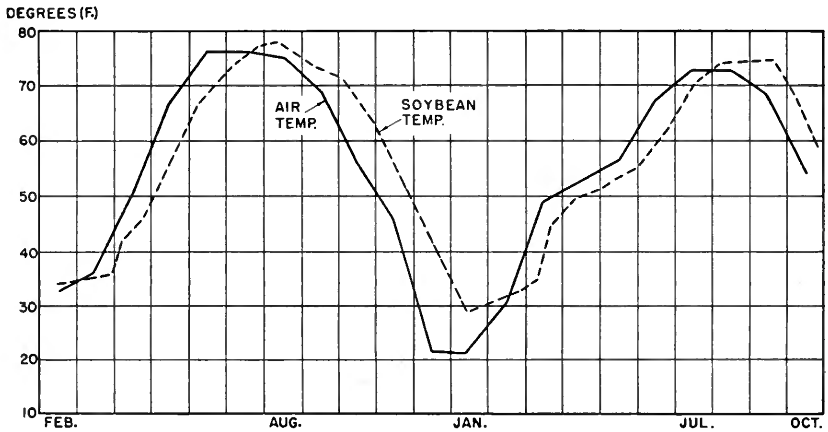
In moderately dry soybeans, the movement of moisture is not a serious problem. No trouble was encountered in the Illinois studies with samples stored at 12-percent moisture or less.

Temperature

Little or no heating occurred in soybeans stored with moistures below 14 percent. Germination and fat acidity were affected, however, even at normal air temperatures, when the grain moistures were above 12 percent. In the Ramstad and Geddes study (page 459), soybeans remained sound and kept their viability well at a moisture content of 15.8 percent for a year and a half when stored at 39° F. On the other hand, germination was seriously reduced by storage at room temperature, even with a moisture content of less than 10 percent. Rapid loss resulted under conditions which favored the growth of microorganisms.

Relatively low temperatures are desirable for all grain storage. Mechanical ventilation can be used to cool the grain during winter, but it is not practical to attempt to maintain low temperatures during the summer in farm storages.

Seasonal variations. The temperature in stored soybeans changes slowly except for the layers next to the bin wall and at or near the surface. Even with a considerable change in outside temperature, changes can scarcely be detected within a day at a distance of 2 to 3 feet from the wall or below the surface. However, the average bin temperature varies widely throughout a season. The average for dry



Soybean temperature lagged almost a month behind average monthly air temperature at Urbana in 830-bushel bins during 1944 and 1945. (Fig. 5)

soybeans stored in ten 830-bushel wooden bins from February, 1944, to October, 1945, reached a high of 78° F. in August and a low of about 30° F. in January (Fig. 5). Grain temperatures averaged less than 70° F. for about nine months of the year.

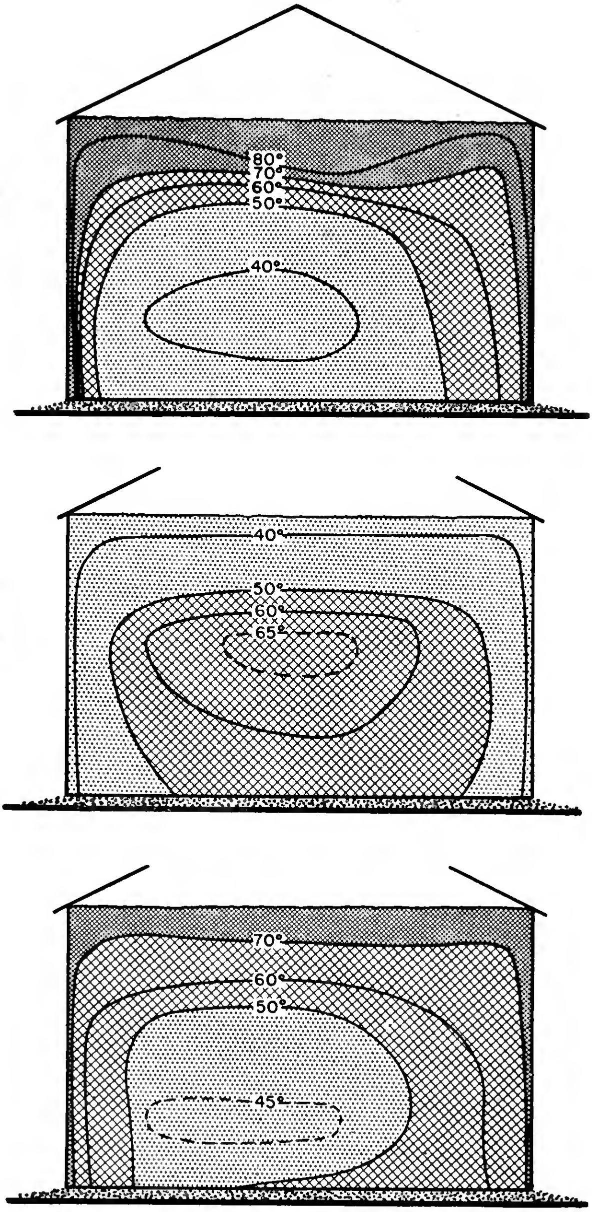
Temperature lag. The lag between air and grain temperatures was considerable. The extremes in the bins lagged about thirty days behind the outside maximums and minimums (Fig. 5). Temperature lag varies somewhat in bins of different sizes and types. Small wooden bins with wood floors placed well above the ground had a shorter time lag than larger bins set on earth or crushed-rock fills.

Variations within bins. Average bin temperatures do not present a complete picture since temperatures differ in various parts of a bin. In a 2,000-bushel steel bin, the May, 1944, temperature was 40 degrees lower at the center than in the upper surface (Fig. 6). In November, 1944, the pattern was reversed with 65° F. at the center and 40° F. near the surface. In May, 1945, temperatures were similar to those of

MAY 18, 1944
Warm weather raises temperatures near walls and surfaces

NOV. 29, 1944
Center stays warm until late in season

MAY 30, 1945
Temperature lags in center section



Temperature patterns in north-south cross-section through the center of a 2,000-bushel steel bin on crushed-rock base at Urbana. Temperatures lag and change slowly near the center, but respond quickly near walls and surface. (Fig. 6)

May, 1944, although the differential was not as great. The same general pattern applies to most bins, as noted in Fig. 7.

Effect of bin size, color, and material. Temperature conditions did not vary greatly in bins of different sizes, colors, and materials, and temperature differences were not great enough to have any important effect on storage (Fig. 7). Season of the year and weather at the time of sampling were the primary influences. Bins with floors in contact with the ground varied least in the center and near the floor, while in wood-floored bins temperatures followed the seasonal air temperatures more closely. The smaller the bin, the greater the total fluctuation over the year.

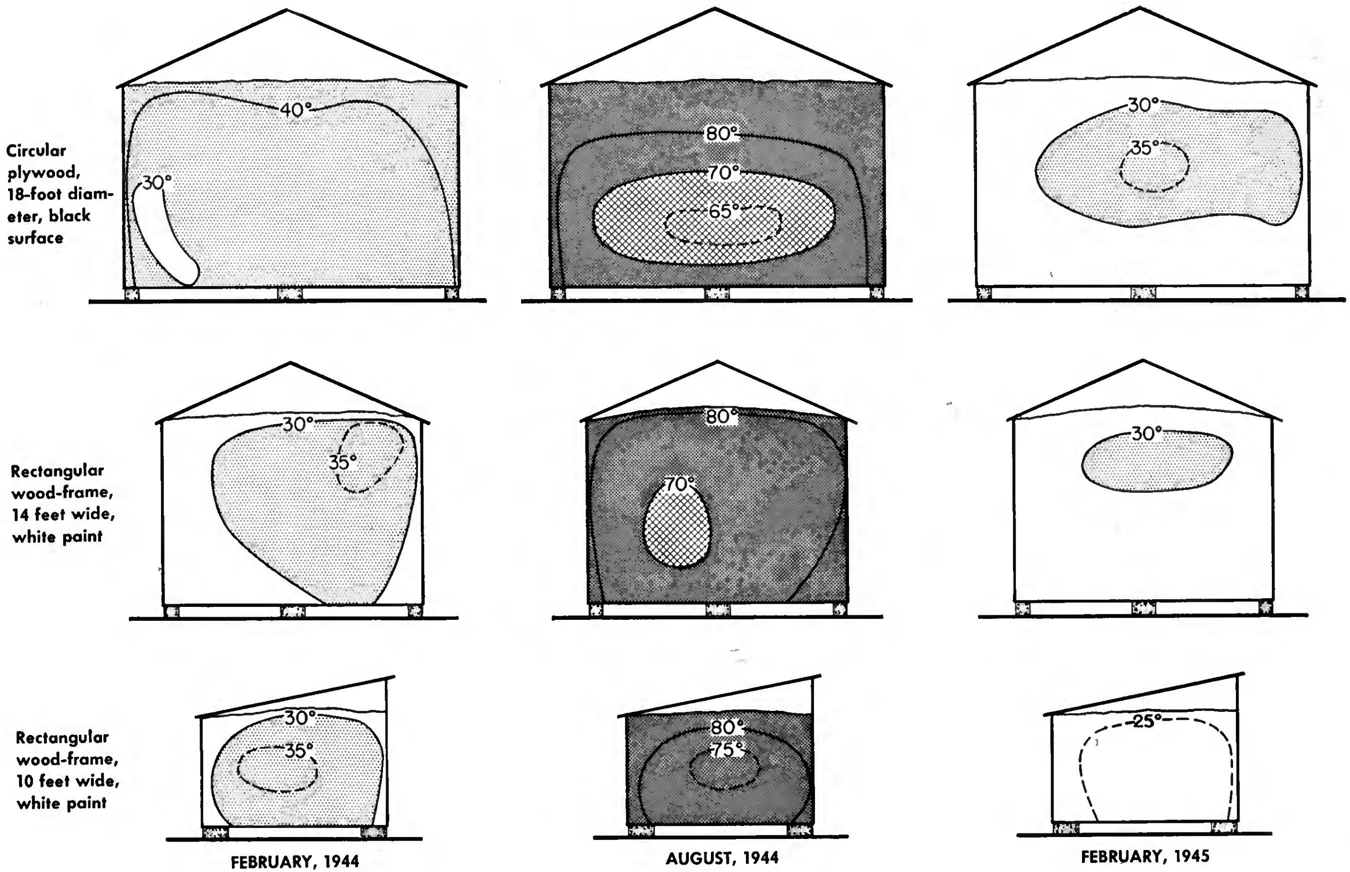
The least fluctuation in temperatures was near the center of the bins. Usually the exposure to the sun produced higher temperatures in the south portion of the bins.

Surface color and material had only slight effect on temperature variation (Fig. 8). Temperatures in an unpainted circular steel bin, a black-surfaced circular plywood bin, and an aluminum-painted circular plywood bin were measured just inside the south wall, 6 inches inside the wall, and 18 inches from the wall (Table 3). Air temperatures ranged between 73° and 85° F. Temperatures were higher near the wall in the black bin than in the other two, but did not vary appreciably at the 6-inch and 18-inch distances. Differences would probably have been greater in hotter weather.

Table 3. — Temperature Variations in Bins of Different Types and Color at Locations Near the South Wall, Urbana, Illinois (1945)

Date, time, air temperature	Type of bin	Bin temperatures[a]		
		Inside south wall	6 inches from wall	18 inches from wall
		°F.	°F.	°F.
April 9, 3:45 p.m., 73° F.	Unpainted steel	78	53	48
	Black surfaced plywood	84	54	48
	Aluminum painted plywood	80	55	51
April 10, 3:45 p.m., 75° F.	Unpainted steel	84	55	47
	Black surfaced plywood	85	56	48
	Aluminum painted plywood	82	58	51
April 11, 4:00 p.m., 76° F.	Unpainted steel	81	58	49
	Black surfaced plywood	88	58	49
	Aluminum painted plywood	83	59	52
April 12, 3:30 p.m., 74° F.	Unpainted steel	82	59.5	49.5
	Black surfaced plywood	86	60	50
	Aluminum painted plywood	81	61	52
June 23, 2:45 p.m., 85° F.	Unpainted steel	..	..	..
	Black surfaced plywood	109	71	65
	Aluminum painted plywood	100	71.5	65

[a] Readings taken 4 feet below the surface.



Temperature patterns differed somewhat with type of bin, kind of foundation, size, shape, and color, but all bins varied with the season in a similar way. Records were taken in north-south (left to right) cross-section through the center. (Fig. 7)

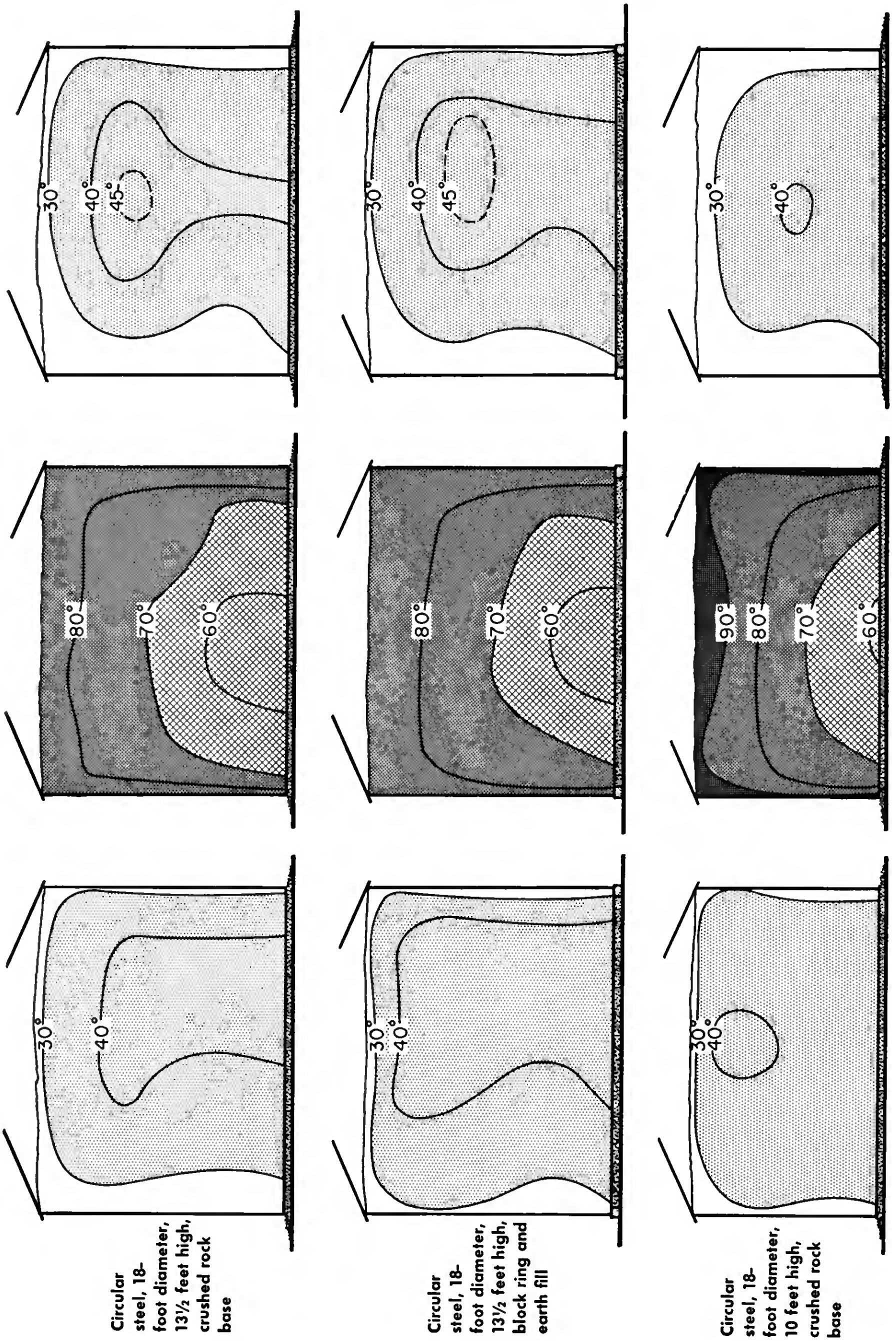
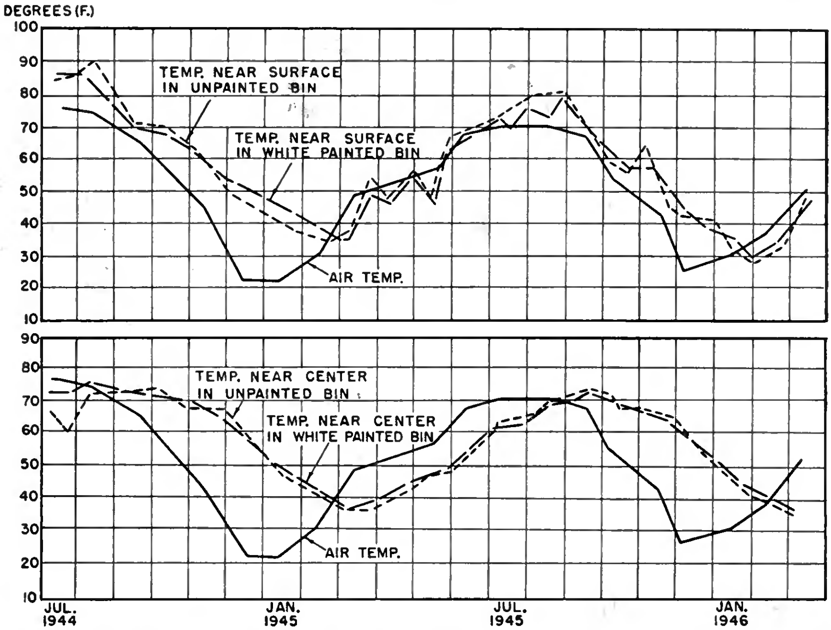


Fig. 7. — Concluded



Temperatures near the surface followed air temperatures rather closely, but changed slowly in the center (and near the bottom) of bins. The painted exterior had little effect on temperature. Record is from 2,000-bushel steel bins on crushed rock. (Fig. 8)

Insects[1]

Few insects were found in good-quality, low-moisture soybeans stored in weathertight bins in the Illinois studies. However, when insects infested spots of high-moisture grain, they produced additional moisture which was quickly absorbed by the grain. In this way, insects contributed to spoilage beyond the actual grain they consumed.

Insects found in stored soybeans were essentially the same as those found in stored corn, with the exception of the granary weevil (*Sitophilus granarius*) and the rice weevil (*Sitophilus oryza*). Neither of these was found in samples obtained over a two-year period. The larvae of Indian-meal moth (*Plodia interpunctella*) could be found in most bins at any time. In some bins the webs formed a layer over the entire surface. Feeding was largely confined to split beans in the upper layers. Bins containing high percentages of splits had the most Indian-meal moths.

[1] M. D. Farrar, formerly entomologist, Illinois State Natural History Survey, provided the information on insects.

Insects classified as "bran bugs" were attracted to bins where moistures were high in the surface layers. The most common was the flat grain beetle (*Laemophloeus pusillus*). The foreign grain beetle (*Ahasverus advenus*) became abundant in areas of moldy grain.

Other insects appeared in some or all bins during the first year of storage. They were never abundant enough to threaten direct damage but they did contribute to spoilage. Among these were the long-horned flour beetle (*Cynaeus angustus*), the cadelle beetle (*Tenebroides mauritanicus*), the saw-toothed grain beetle (*Oryzaephilus surinamensis*), the rust-red flour beetle (*Tribolium castaneum*), and the hairy fungus beetle (*Typhaea stercorea*). A black beetle (*Murmidius ovalis*) became abundant in many bins, always associated with moldy grain. Also psocids, or booklice, and grain mites were common in many bins. Dermestid beetles appeared in the second year of storage, probably as scavengers on dead insects. The most common were *Trogoderma versicolor,* and in fewer numbers, the black carpet beetle (*Attagenus piceus*).

It was concluded that under Illinois conditions insects are not a serious handicap in the storage of soybeans of 12-percent moisture or less for periods of two or more years. Experiments at other locations indicate that insects may become troublesome where higher moistures are encountered. The insect problem may be summarized as follows: At *less than 8 percent* moisture no insect damage is likely. At *8 to 10 percent,* there is relatively little damage. At *10 to 12 percent,* insects reproduce in 12-percent moisture areas of the bin. At *12 to 14 percent,* soybeans will be attacked by a variety of insects and some spoilage will result. *Above 14 percent,* heavy infestation may occur as the insects become active in warm weather.

In these experiments the soybeans were not disturbed or fumigated during storage because no serious infestation occurred.

Field and Bin Damage

Field damage. Soybeans damaged prior to harvest are more difficult to store without danger of loss than the normal mature crop. Damaged soybeans should be relatively dry when stored. Immature, sprouted, or otherwise damaged kernels respire more rapidly than sound plump kernels. Mature soybeans exposed to rainy damp weather develop field damage, turn brown, develop a mealy or chalky texture, and may sprout or rot. Frosting of immature soybeans results in green damage.

Damage within bins. Position in the bin influences changes that take place in soybeans. More rapid deterioration occurs near the surface, due in part if not entirely to moisture accumulation. The increase in fat acidity was much greater near the surface than near the floor, except in low-moisture bins. At moistures above 12 percent, germination was lowest in samples from near the surface. These variations emphasize the need for germination tests for soybeans to be used for planting.

DRYING HIGH-MOISTURE SOYBEANS

The losses resulting from the storage of high-moisture soybeans naturally raise the question of drying or conditioning to reduce moisture to a safe level for storage. For this reason the drying studies reported here were made a part of the storage investigations at Urbana. In general, the experiments proved that: (1) ordinary wind ventilation was not effective; (2) drying could be done with forced air in mild dry weather; and (3) effective drying was possible with forced warmed air. In these respects the problems of drying soybeans and shelled corn are similar.

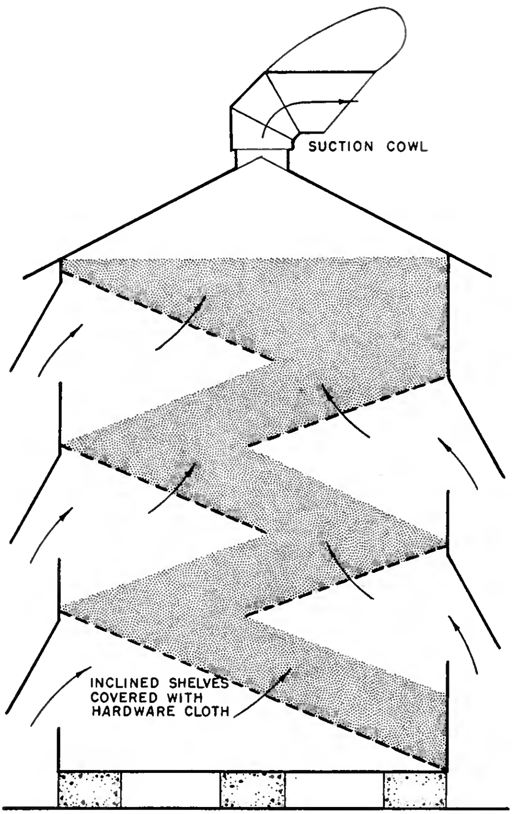
On the other hand, it is not practicable at the present time to dry soybeans on the farm unless equipment is used also for other crop drying. The investment in drier, duct system, and other equipment, plus the expense of operation, makes the cost too high for drying soybeans in the amounts most farmers have. It is more practical to limit farm storage to soybeans having less than 14-percent moisture and sell the rest, taking a discount if necessary.

Various methods of air circulation were used to remove excess moisture from grain to make it safe for storage. They included: (1) natural wind ventilation, (2) fan ventilation with unheated air, (3) fan ventilation with heated air, and (4) moving and blending. Air movement may be created by the wind or more quickly by forced circulation with fans. In either case, the air acts as carrier to heat the grain, vaporize water from the grain, and carry away water vapor.

Natural Wind Ventilation

The effectiveness of drying with natural air varies with outdoor temperature and humidity. The method is slow under the best conditions. Wind ventilation was studied in nine bins at Urbana, in which five different ventilating arrangements were used. With one exception, the use of tubes, ducts, perforated sidewalls, and roof ventilators failed to improve the condition of soybeans.

The only design that gave effective drying was a "shelf" type bin

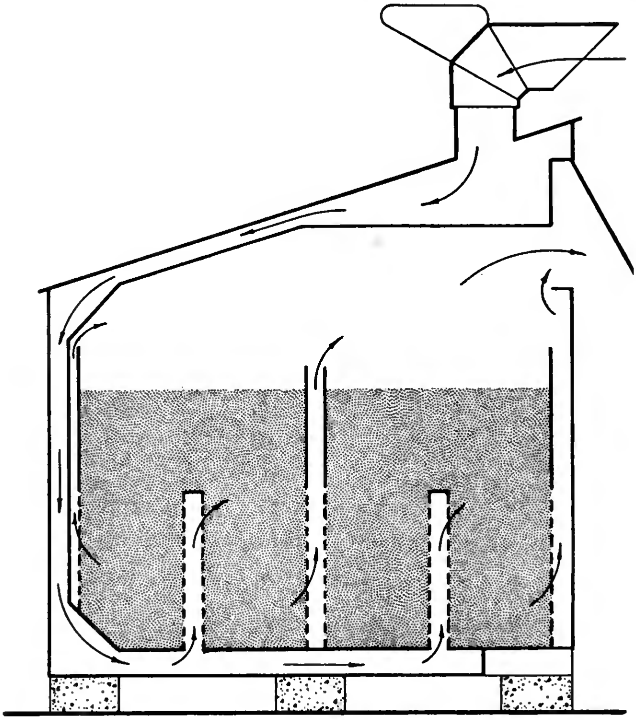


The relatively thin layers of soybeans in this inclined-shelf bin were dried effectively by natural air circulation during the summer. (Fig. 9)

(Fig. 9) in which grain was placed on sloping wire shelves in layers 12 to 18 inches thick. About 250 bushels of soybeans with an average moisture content of 15.3 percent were stored in January. By the following August the moisture was down to 12.1 percent. The shelf arrangement reduced the amount of storage space, however, so the cost for each bushel of storage was relatively high.

Four wooden bins were remodeled for a study of the effect of wind ventilation. Each was provided with a pressure-type cowl connected to ventilation ducts on the inside (Fig. 10). Ducts were so arranged that air entering through the roof cowls passed through a maximum of 2 feet of grain.

Even though temperatures during February, March, and April, 1945, were somewhat above normal at Urbana and relative humidities were lower than average, the moisture content increased by 1.1 to 1.4



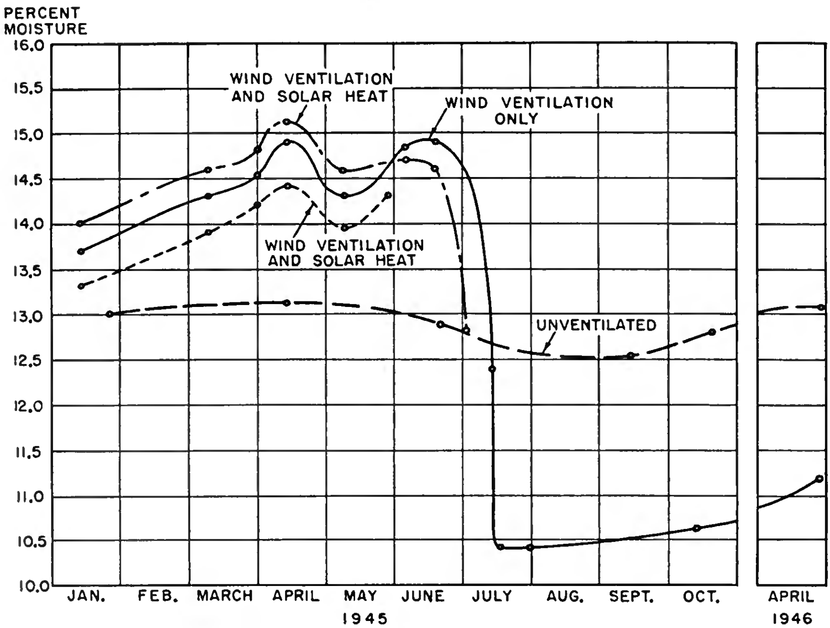
This bin with wind-pressure cowl, air ducts, and channels was not effective for drying by natural ventilation, except during the summer. (Fig. 10)

percent in the ventilated bins (Fig. 11) because of the usual poor drying conditions at this time of the year. One bin was emptied in May, 1945. Two that were carried through June and July dried satisfactorily. One that was held until April, 1946, tested 11.2-percent moisture and the soybeans graded No. 1. The moisture change was negligible in an unventilated check bin.

The south roof slope and the south wall of two of the bins were covered with black-painted sheet metal to take any possible advantage of heat absorbed from the sun. This, however, was not effective in warming the incoming air.

Wind ventilation through shallow depths of grain is helpful immediately after harvest and during late spring and summer. Considerable expense and labor are necessary to equip a bin as shown in Fig. 10.

Four circular steel bins were remodeled for wind-ventilation tests. They were equipped with roof cowls and perforated tubes, drums, and



In three bins ventilated as illustrated in Fig. 10, wind ventilation did not reduce moisture during winter and spring but rather tended to increase it. Moistures did not change in the unventilated check bin. (Fig. 11)

walls for the distribution of air throughout the bin. The decrease in moisture was insignificant between December and September, while germination and grade decreased and fat acidity increased (Table 4).

Table 4. — Soybean Drying Tests With Natural Wind Ventilation

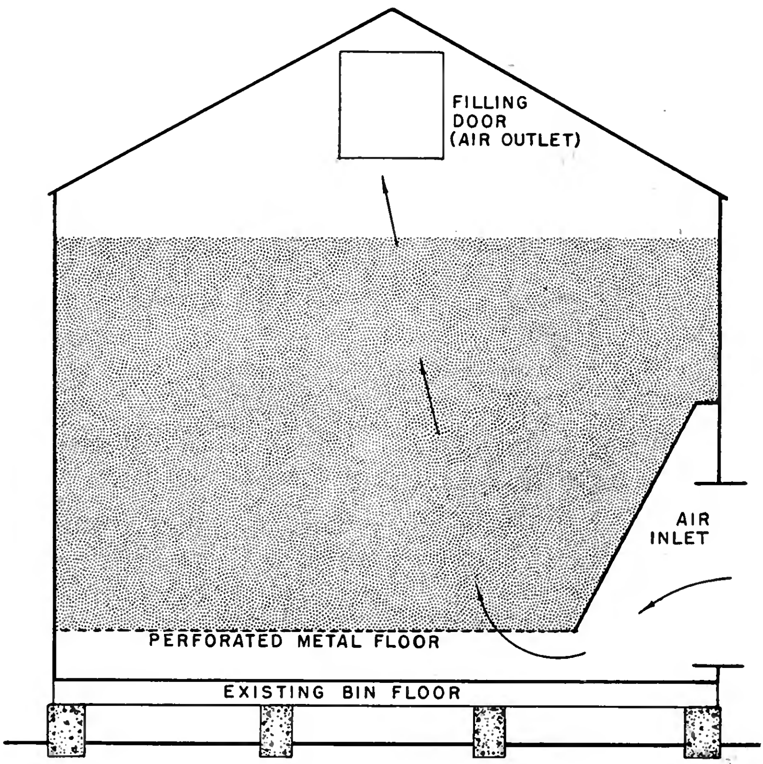
Bin	Sampling date	Grade	Moisture (wet basis)	Strong germination	Acid value of oil	Fat acidity
			perct.	*perct.*	*number*	*units*
I-1	1-15-44	3 Y.	15.5	81	.78	7.0
(Downdraft ventilator; perforated central and radial tubes)	9-4-44	Sample musty	13.7	19	2.36	41.1
U-53	12-16-43	3 Y.	15.0	84	.78	14.1
(Same as above)	9-1-44	Sample musty	14.2	18	2.64	45.2
U-50	12-17-43	3 Y.	14.4	84	.30	5.6
(Downdraft ventilator; perforated central tube; perforated inner wall sheets)	9-7-44	Sample musty	13.7	31	1.43	25.8
H-1	1-15-44	3 Y.	15.3	83	.48	8.5
(Same as above)	6-17-44	3 Y.	15.6	55	.93	16.1

Fan Ventilation With Unheated Air

Results of fan drying with unheated air depend primarily on air temperature and relative humidity, although there is a definite advantage in the forced-air flow obtained with a motor-driven fan.

Drying with unheated air is satisfactory only when drying is rapid enough to prevent molding. Airflow of 3 to 10 cubic feet per minute is needed and can be obtained without excessive use of power through 3- to 6-foot depths of soybeans. For effective drying, temperature should be above 60° F. and relative humidity below 75 percent, although with soybean moistures of 15 percent or higher, some drying can be done at a lower temperature and a higher humidity.

In the tests at Urbana, soybeans were placed in a wooden bin over a perforated false floor and air was forced upward (Fig. 12). The fan



Arrangement for drying with forced air through perforated floor. In this and other tests with natural air, satisfactory drying was accomplished only when air temperature was above 60° F. and relative humidity was below 75 percent. (Fig. 12)

Table 5. — Soybean Drying Tests With Forced Unheated Air[a]

	Test 1 (Aug.-Oct.)	Test 2 (Nov.-Apr.)	Test 3 (June)
Initial amount, bushels	585	550	535
Initial grain depth, feet	4.5	4.3	4.2
Moisture, wet basis, percent			
Before drying	14.7	13.8	14.2
After drying	10.7	10.5	11.7
Drying time, hours	308	494	180
Electricity used, kilowatt-hours	89	227	59
Water removed, pounds			
Total	1 570	1 220	910
Per hour	5.1	2.5	5.0
Per kilowatt-hour	17.7	5.4	15.4
Air temperature, °F.			
Range	33–89	11–78	50–88
Average	70	43.5	72.5
Relative humidity, percent			
Range	30–70	32–70	40–70
Average	60	60.7	60.8

[a] Air forced through perforated floor. Air volume, 5 cubic feet per minute per bushel. Static pressure = 0.5 inch water.

motor was controlled by a humidistat to permit operation only when the relative humidity of the atmosphere was 70 percent or less. Results are summarized in Table 5.

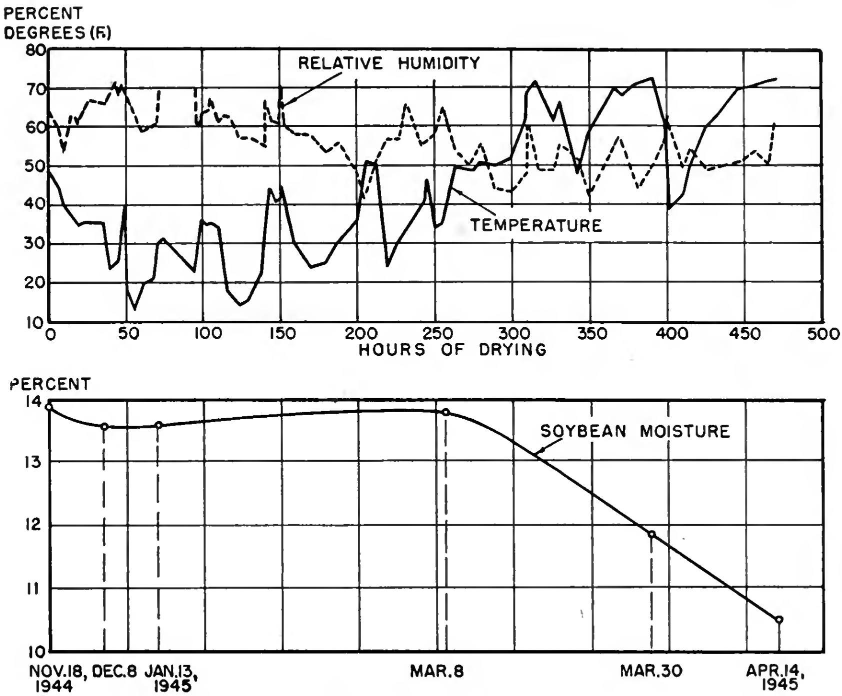
Tests 1 and 3 were made when conditions were favorable for drying; the air averaged about 70° F. and relative humidity about 60 percent. Test 2 was run under less favorable conditions with an average temperature of 43.5°. Depth of grain, volume of air, and static pressure were about the same in the tests.

Under the more favorable conditions (Tests 1 and 3) the hourly drying rate was nearly twice as high and about three times as much water was removed for each kilowatt hour of electricity used as in Test 2. During Test 2 no drying was obtained from November to March, when the air temperature averaged about 25° F., although the fan operated for 250 hours at times when the relative humidity was less than 70 percent (Fig. 13).

Fan Drying With Heated Air

Drying with heated air has the advantage of being independent of weather conditions. It is faster and can be controlled better than either natural air circulation or forced ventilation with unheated air. Portable driers designed especially for the farm are available for either bin-type or batch-type driers. Continuous-flow driers, similar to those used in commercial elevators, are available in farm-size units.

Maximum permissible temperatures depend on the depth of the



Soybean moisture was not reduced during the first 250 hours of forced-air drying during cold weather, even though a humidistat limited the operation of the fan to times when the relative humidity was below 70 percent. (Fig. 13)

soybeans, the amount of moisture to be removed, the rate of air flow, and the length of time grain is dried. Current recommended maximum temperature is between 130° and 140° F. for farm drying of soybeans intended for commercial sale. Soybeans for seed should not be subjected to more than 110° F., since viability is destroyed at about 113° F.

Bin driers. In a bin drier, the grain next to the incoming air will dry first and the outer or top layers last. The difference in rate of drying in different parts of the bin depends on the depth of grain, temperature, relative humidity, and volume of air per bushel of grain. At depths of more than 4 feet, drying is more uniform if the air is raised only 10 to 15 degrees above outside temperature. This results in a relatively slow drying rate, especially during cold weather. With air heated 50 to 100 degrees above outside temperature, depths of 1 to 3 feet give more uniform and faster drying.

It is not practical to force large volumes of air through deep layers of soybeans because of the power requirements. Airflow may range widely, from 5 cubic feet per minute per bushel through 6 to 8 feet of grain to 60 cubic feet per minute through 1 to 2 feet.

Four tests with heated air were made in two types of bin driers (Table 6). The soybeans ranged from 15 to 19 percent moisture before drying.

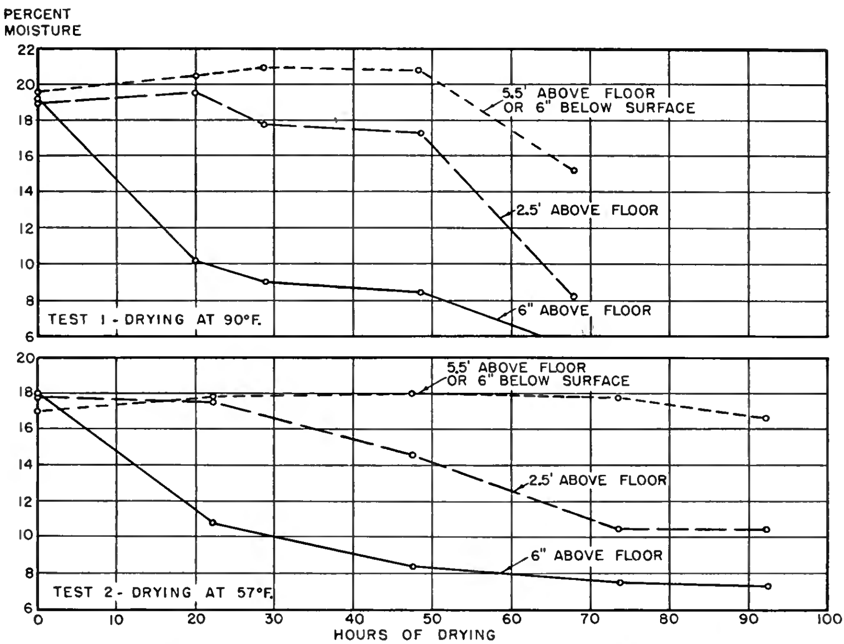
In Tests 1 and 2 an oil-burning heater and centrifugal fan were used and heated air was forced upward through a perforated floor. Depth of grain, air flow, air temperature, and quantities of grain were similar; the principal difference was the higher drying temperature in Test 1 (90° F. as compared with 57° in Test 2), which gave a shorter drying time (68 hours against 92). More fuel was used to complete the drying at the faster rate with a consequent reduction in thermal efficiency. In both tests the average moisture after drying was far lower than necessary either for safe storage or for the highest market returns.

Table 6. — Soybean Drying Tests With Forced Heated Air

	Air forced upward: oil-burning heater		Waste engine heat; air forced upward in Test 3; 2-way airflow from center in Test 4	
	Test 1	Test 2	Test 3	Test 4
Initial amount of grain				
Pounds	42 900.0	43 476.0	34 140	62 970
Bushels	715.0	724.6	569	1 049.5
Grain depth, feet	6	6	8	8
Moisture, wet basis, percent				
Average before drying	18.9	17.6	16.1	15.0
Average after drying	7.1	9.1	11.0	11.0
Range after drying	5.0 to 15.3	7.2 to 16.7	6.9 to 17.2	9.4 to 13.2
Drying time, hours	68	92	77	76
Fuel used, gallons	148.5	86	90.0	91
Calculated air volume, cubic feet per minute				
Total	5 000	5 500	5 000	10 000
Per square foot	30	35	50	25
Per bushel	7	7.5	9	10
Static pressure in plenum chamber, inches of water	2.0	2.0	2.7	1.8
Average air temperature, °F.				
Plenum chamber	90	57	57.5	48
Outside	35	38	37.0	37
Average relative humidity, percent				
Plenum chamber	14	28	30	42
Outside	81	56	65	65
Water removed, pounds				
Total	5 400	4 046	1 990	2 970
Per hour	79.5	44	26	39
Per gallon of fuel	36	47	22	32.5
Thermal efficiency, percent[a]	33	42.5	24	35

[a] Thermal efficiency (percent) = $\frac{\text{pounds of water evaporated} \times 1170 \text{ (BTU)}}{\text{gallons of fuel} \times \text{BTU per gallon } (130{,}000)} \times 100$

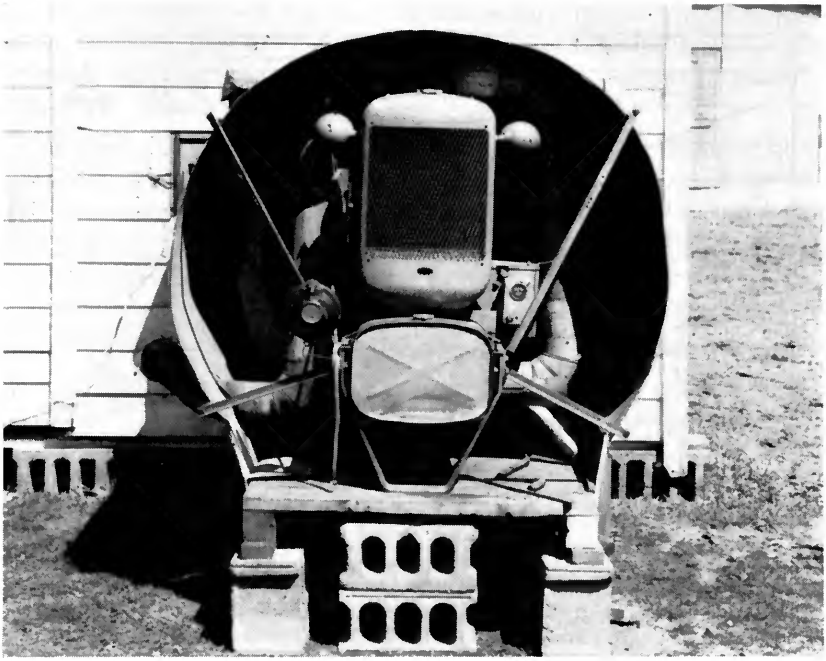
The 6-foot depth was too much for the airflow and temperature conditions of the tests. As a result, soybeans near the air inlets were overdried before surface moisture was reduced. It was necessary to move and mix the dried grain to equalize the excessive differences in moisture at different points in the bin which are illustrated in Fig. 14. Drying would have been more uniform if the rate of airflow per bushel had been increased. This could have been done either by increasing the total air volume or by reducing the grain depth.



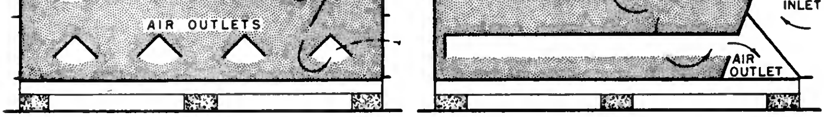
In bins with perforated floors, soybeans dried faster near the floor. In grain 6 feet deep, the variation between the bottom and top was excessive with the airflow per bushel used; a higher rate would have cut down this variation. Drying at 90° (upper) was faster but less efficient than at 57° (lower). See also Tests 1 and 2, Table 6. (Fig. 14)

In Tests 3 and 4 most conditions were similar for the two tests. Drying was done simultaneously with portable engine-driven fans (Fig. 15). The air temperature was raised 20.5 and 11.0 degrees respectively by the heat given off by the engines.

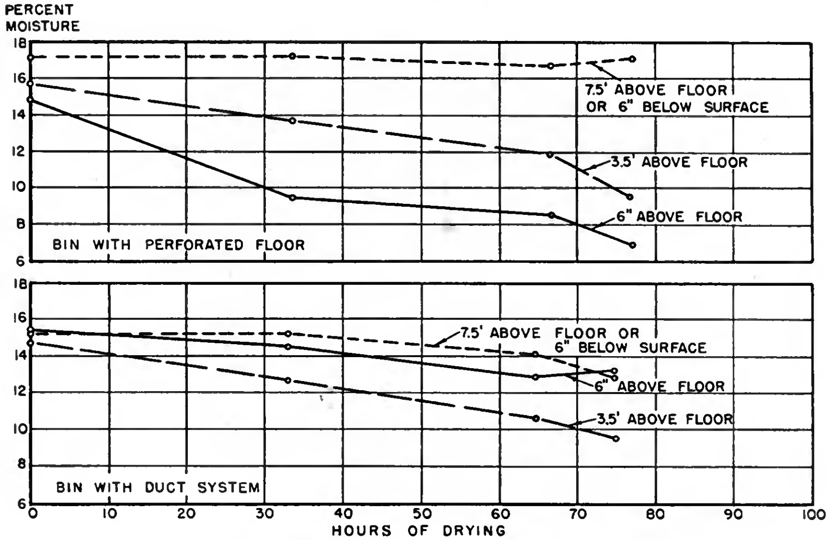
The main difference was that the bin for Test 4 was equipped with ducts as shown in Fig. 16. These reduced the distance through which



This portable drying unit consisted of a propeller-type fan connected to the drive shaft of a stationary engine. The shield directed inlet air past the engine so as to utilize the waste heat for drying. (See Tests 3 and 4, Table 6.) (Fig. 15)



A duct system with air inlets at center height and outlets near the floor and at the top reduced the distance the air moved through the grain in forced-air drying tests. (Fig. 16)



Drying with heat was more uniform and more effective in bins with duct systems than in bins with a perforated floor. With other conditions uniform, forcing the air through an 8-foot depth resulted in a greater moisture differential than through shallower depths. (Tests 3 and 4, Table 6.) (Fig. 17)

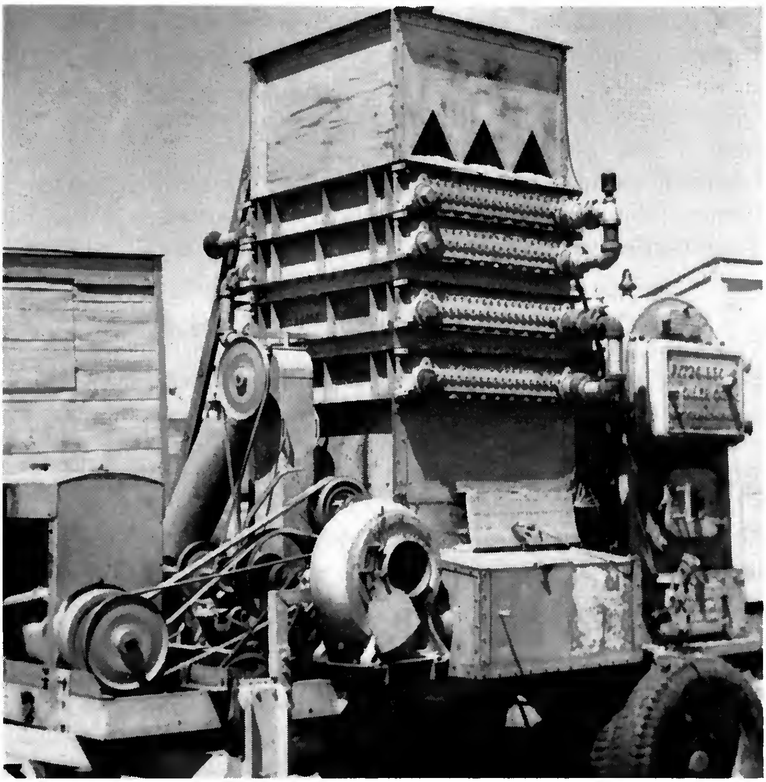
Table 7. — Soybean Drying Tests With Continuous-Type Drier

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Initial weight, pounds	4 700	5 130	5 910	5 180	9 870	4 600	5 640
Moisture, wet basis, percent							
Before drying	13.9	14.0	14.3	14.9	14.8	15.5	15.8
After drying	10.5	10.7	12.3	12.4	12.6	13.4	13.9
Average water temperature, °F.							
Into coils	216	219	182	180	219	180	180
Out of coils	205	203	174	170	209	170	169
Maximum grain temperature, °F.	167	162	143	142	165	138	141
Coal used per hour, pounds	48	52	40	47	43	42	40
Drier capacity per hour, bushels[a]	33	39	46	47	46	50	49
Water removed, pounds							
Total	150	180	130	130	220	90	120
Per hour	65	85	62	72	58.5	55	60
Per pound of fuel	1.4	1.6	1.5	1.5	1.5	1.4	1.6

[a] Bushels (60 pounds) of soybeans after drying.

the air moved to about 4 feet, compared with 8 feet for the bin with perforated floor in Test 3. The shallower depth reduced the moisture gradient, increased the drying rate, and gave a higher thermal efficiency (Fig. 17).

Continuous drier. A continuous drier was used in a number of tests (Table 7). The soybeans were heated as they moved downward, between and in contact with extended heating coils (Fig. 18). Unheated forced air cooled and dried the grain as it passed through a cooling area in the drier. The capacity of such a drier is affected by the amount of moisture removed, fuel used, atmospheric conditions, and the fan and discharge mechanism speed. Tests were made during June and



Experimental drier developed at the University of Maryland and used in the Urbana studies. It consisted of coal-fired boiler, extended heating surface coils, and engine-driven fan. Moisture was removed by allowing the grain to flow continuously past the heating coils while unheated air was blown through the grain. (Fig. 18)

July with air temperatures averaging about 75° F. and relative humidities about 60 percent. Two different heats and two fan speeds were used. The drier capacity ranged between 33 and 50 bushels an hour under the operating conditions and moisture reductions obtained. Thermal efficiencies were low.

Moving and Blending

Soybeans that start to heat can be moved from one bin to another to break up hot spots and to mix the hot and cool grain and get uniform moisture distribution. Soybeans with excess moisture cannot be safeguarded merely by moving them because only slight reduction in moisture can be expected. In bins where hot spots are caused by insects, moving will scatter the insects throughout the entire mass; then the soybeans should be fumigated immediately after turning. Most farm storages are not equipped to move grain from bin to bin economically.

Quantities of 15.2-percent and 10.3-percent soybeans were mixed in order to test the value of blending. The average after mixing was 11.9 percent, which from the standpoint of moisture improved the 15.2-percent lot by two market grades. Temperatures in the high-moisture portion were materially lowered.

REQUIREMENTS FOR SOYBEAN BINS

Some factors that affect storage are independent of the type of storage bin used. For example, moisture of the soybeans at the time of storage must be within the safe limits, or they will not store well regardless of how good the bin is. High temperatures increase the rate of deterioration in any bin. Insect damage varies with climatic conditions and increases as the temperature goes up.

The principal requirement for a bin to furnish satisfactory storage is that it exclude moisture. It should also be so designed that it is strong enough to withstand pressures, be safeguarded against wind damage when empty, and be convenient to fill and empty.

The following discussion is based upon the Illinois study and on experience in design and construction, observation, and results of similar studies. The findings are embodied in the bin designs included in the farm-building plan services of the state agricultural colleges and the U. S. Department of Agriculture. Information about these plans can be obtained from any state agricultural college.

A number of the bins used in the Illinois study were built for purposes other than study of the structural requirements, but they provided ample opportunity for comparisons and helped to establish the recommendations which follow. Information about the bins used in the Illinois study is given in Fig. 1 and Table 1.

Construction features necessary to meet the requirements for safe soybean storage include:

Foundations that provide necessary bearing on the ground and that raise the bins far enough off the ground to safeguard against damage by ground water.

Anchors that hold bins firmly in place and particularly protect against wind damage when the bins are empty.

Floors that are watertight, rodent-proof, strong enough to carry the loads, and with smooth hard surfaces for ease in shoveling.

Walls tight enough to hold fumigants, waterproof, and designed to carry lateral and vertical pressure.

Roofs framed, anchored, and covered to exclude moisture, resist wind damage, and furnish headroom to give clearance for inspecting and treating.

Openings for convenience in filling and emptying, to provide access, and as required for air circulation.

Foundations

Concrete foundations are commonly used for permanent storage buildings. Foundations for semipermanent or temporary storages vary according to the type of construction. Thus concrete blocks are used for wood-frame buildings while steel bins are placed on crushed rock or gravel, on concrete block rings with an earth or gravel fill, or on metal foundation rings. Each of these methods was used in the Illinois studies.

Permanent foundations. Concrete is the most satisfactory material for foundations for permanent buildings. Typical footings are 12 inches wide and 8 inches thick. Foundation walls should be at least 8 inches wide at the top and extend at least 12 inches below and above the ground level. It is advisable to reinforce footings with two half-inch steel rods.

Temporary foundations. Concrete blocks were used for temporary foundations under the wood-frame bins at the Illinois site. Two sizes of blocks, 8 by 8 by 16 inches and 8 by 12 by 16 inches, were used

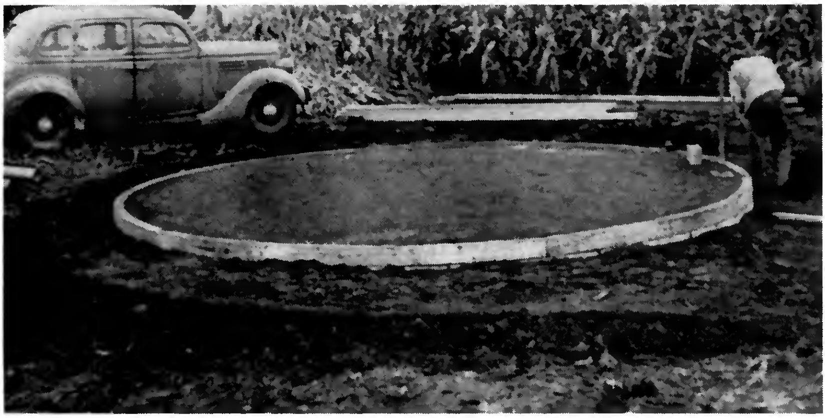
Concrete blocks with the cores horizontal were leveled to make temporary foundations for small bins. (Fig. 19)

to simplify erection on uneven ground (Fig. 19). Blocks were placed parallel with the floor joists for bins having a capacity of 1,000 bushels or less. Blocks for larger bins were set at right angles to the floor joists to prevent tipping. A 2-by-6 sill was placed over the blocks to equal-

Blocks were placed at right angles with the floor joists under large bins, and a 2-by-6-inch sill was laid across the blocks to keep both the blocks and the joists from tipping. (Fig. 20) ize the load (Fig. 20). Such an arrangement is recommended for all bins, regardless of size.

Blocks were spaced to provide approximately one bearing block for each 3,300 pounds of soybeans. This spacing provides a factor of safety against crushing, and is generally adequate for ordinary firm soil. Concrete blocks should be placed with the cores horizontal to gain full bearing.

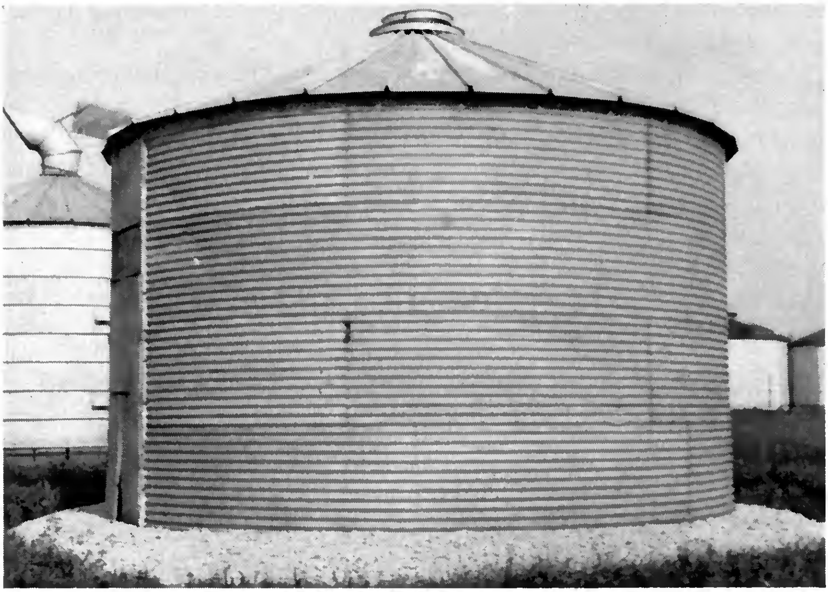
Masonry blocks laid in a ring slightly larger than the bins were used in foundations for a number of steel bins. The space inside the ring was filled with tamped earth (Fig. 21). The ring supported the



Typical concrete block-ring foundation with tamped earth fill used under steel bins with steel floor. (Fig. 21)

vertical load imposed by the walls while the fill carried the weight of the contents. Block cores should be vertical and the blocks set with edges extending only an inch or two beyond the bin walls. This keeps water from coming in at the junction of wall and foundation. Considerable spoilage resulted where this precaution was not taken.

Most of the steel bins were set on crushed rock (Fig. 22). About 12 cubic yards were found to give the most satisfactory base. The walls tend to settle into the rock while the sheet-metal floor does not, so the floor is an inch or more above the lower edge of the sidewalls. This prevents water from entering at the edge. Coarse gravel may be used instead of crushed rock, but sand is not satisfactory because it shifts and causes the floor to sag out of shape.



Crushed rock smoothed out, mounded slightly in the center, and extended about 2 feet beyond the wall proved to be a good base for steel-floored steel bins. About 12 cubic yards of rock are needed. (Fig. 22)

Anchors

Metal bins must be anchored when empty to prevent wind damage; many have been blown from their foundations and partly or totally wrecked for lack of anchors or because of poor anchoring. Whatever method is used, it should prevent both sliding and tipping. Anchor bolts are recommended for attachment to permanent concrete foundations.

One of the most effective anchors for circular metal bins is the metal foundation ring (Fig. 23). This ring is set in the ground and forms the base section of the wall. It replaces block rings, guy wires, posts, and "dead man" anchors. The foundation ring not only provides an effective anchor, but it also eliminates the floor-wall junction as a source of leaks. This method is recommended over the "dead man" and post-type anchors, described below.

Posts have been used effectively to anchor circular steel bins up to 18 feet in diameter and 13 feet high, but they are not recommended for aluminum bins or for taller steel bins. In the Illinois tests, wood posts 4 to 6 inches in diameter were set $2\frac{1}{2}$ to $3\frac{1}{2}$ feet in the ground. They extended about 4 feet above the ground and were bolted to the

A heavy asphalted metal ring forms the lower portion of the wall and provides a good foundation and excellent anchorage for a metal bin. (Fig. 23)

wall. Two strands of No. 9 galvanized wire, one near the top and one near the bottom of the posts, were used to keep the posts from spreading. Four posts were used to anchor steel bins 18 feet in diameter and 13 feet high.

One method of anchoring metal bins which was used in the study was to attach bars to the walls at four points and anchor each to a "dead man" set 2 to 3 feet in the ground and 3 to 4 feet from the wall. The method, however, is not recommended for aluminum bins or for the taller steel bins.

Floors

With concrete floors the surface should be at least 8 inches above the ground. A moisture barrier is desirable to safeguard against moisture coming up through the floor, such as a layer of asphalt-type roll roofing between the fill and floor. Since most bins are emptied but once a year, roll roofing or aluminum foil can be used on top of the floor. These materials, however, are easily damaged when shoveling grain from the bin. Painting with emulsified asphalt does not provide good protection.[1]

Sheet-metal floors are commonly used in circular metal bins that are not permanently placed. Sheets should be coated on the underside with asphalt paint to retard rusting.

[1] Agricultural Engineering **26**, 417-420 (1945) and **27**, 357-362 (1946).

For wood floors matched boards should be used to provide a grain-tight fumigant-tight floor. At least 12 inches of clearance above the ground is needed for air circulation, dryness, and to help protect against rodents. The size of floor joists is determined by the span and the load (soybean weight varies between 45 and 48 pounds a cubic foot). Table 8 lists joist sizes for lumber with a strength equal to that of No. 1 Douglas fir for typical spans and joist spacings.

Table 8. — Joist Sizes at Various Spacings and Spans Required to Support Soybeans at Different Depths

Depth of soybeans	Joist spacing	Size of joists[a] for—			
		4-foot span	6-foot span	8-foot span	10-foot span
	in.	*in.*	*in.*	*in.*	*in.*
6 feet	12	2 x 6	2 x 6	2 — 2 x 6	2 — 2 x 8
	16	2 x 6	2 x 8	2 x 10	2 x 12
	24	....	....	2 — 2 x 10	....
8 feet	12	2 x 6	2 x 8	2 x 10	2 x 12
	16	2 x 6	2 — 2 x 6	2 — 2 x 8	2 — 2 x 10
	24	....	2 — 2 x 8	2 — 2 x 10	3 — 2 x 10
10 feet	12	2 x 6	2 — 2 x 6	2 — 2 x 8	2 — 2 x 10
	16	....	....	....	2 — 2 x 12
	24	....	2 — 2 x 8	....	....
12 feet	12	....	2 — 2 x 8	2 — 2 x 10	....
	16	....	2 — 2 x 8	2 — 2 x 10	2 — 2 x 12
	24	....	....	3 — 2 x 10	3 — 2 x 12

[a] Joists supported at ends only. Sizes based on bending stress of 1,600 pounds per square inch and horizontal shear of 160 pounds per square inch (equivalent to or better than No. 1 Western Douglas Fir). The table is based on ordinary commercial sizes of lumber. Joist sizes are not given where common sizes are not applicable. Horizontal shear values limited the maximum width of joist to 6 inches in 4-foot span, 8 inches in 6-foot, 10 inches in 8-foot, and 12 inches in 10-foot.

Walls

Bin walls must be strong enough to withstand both lateral pressure and vertical loads (see page 495 for an analysis of loads and pressures). The safe depth for soybean storage for common sizes and spacing of studs is given in Table 9.

Studs should be securely fastened at the floor line. Crossties must be provided at the top of the studs. Additional crossties near mid-height will permit greater depths than are shown in the table. Bins should be braced against end- and side-sway by diagonal braces nailed to the studs at each inside corner.

The sectional-type wood bins used in the studies required crossties and also tieing and bracing to prevent bulging. Two-by-six crossties 6 feet above the floor were used in the larger bins, and 2-by-4 ties were used in bins of 1,000 bushels capacity or less.

Table 9. — Safe Depths of Storage for Soybeans in Bins With Studs of Common Sizes and Spacings[a]

Size of studs (inches)	Spacing, center to center	Length of stud	Depth of grain[b]	Size of studs (inches)	Spacing, center to center	Length of stud	Depth of grain[b]
	in.	*ft.*	*ft.*		*in.*	*ft.*	*ft.*
2 x 4............	24	8	5	2 x 6............	24	8	8
2 x 4............	16	8	6	2 x 6............	16	10	9
2 x 4............	12	8	7½	2 x 6............	24	10	8

[a] From Farmers' Bulletin 2009, "Storage of Small Grains and Shelled Corn on the Farm." This table is based on the ordinary commercial sizes of lumber. If the studs are full-size rather than nominal, the depth of grain can be increased ⅓. If large knots occur in any of the studs or if the lumber is soft and lightweight, ties should be used across the bin. Studs should be well fastened to the floor system and to crossties at the top of the studs.

[b] These figures apply also to wheat, rye, shelled corn, and grain sorghum. Depth of oats may be a half more and of barley a third more.

Roofs

Roofs may be covered with any standard type of roofing applied according to manufacturer's directions. Tarred felt or other lightweight materials are not generally recommended for durable, permanent structures. Light-colored reflective surfaces tend to hold summer temperatures slightly lower inside than dark surfaces. In developing plans, designers should use a calculated load of 300 pounds concentrated at the center of spans for roof areas that must be walked on or an estimated load of 30 pounds a square foot, whichever is greater.

Openings

A number of wooden bins had filling doors in end walls or side walls. These were not adequate for power elevating equipment, since only a portion of the bin could be filled without hand shoveling. Roof hatches were more satisfactory from the standpoint of labor saving. Bins with gable or conical roofs provided headroom for inspecting and sampling, and in general were more convenient than low-pitched shed-roof bins for filling, fumigating, and raking the surface. Most bins were built with full-height entrance doors, although some were fitted only with 2-by-2½-foot doors in the lower part. Both types were suitable for power equipment used in emptying bins.

Exclusion of Moisture

The degree of weathertightness of a bin was found to be more significant in safe storage than size, shape, or color. Soybeans absorb moisture readily and even small leaks in a bin may cause serious damage. Normally dry soybeans stored in tight bins kept well, regardless of the materials used in construction while significant spoilage occurred in bins that were not weathertight.

Wood-frame bins having a single layer of matched-board siding often fail to give satisfactory storage. The following defects were observed in the investigation:

Shrinkage cracks between boards, apparently due to the use of unseasoned lumber (Fig. 24).

Defects in the siding, such as splits or large loose knots.

Car-siding laid horizontally.

Seepage through end joints in siding (Fig. 25).

Panel joints between sectional panels not tight.

Reinforced waterproof paper applied on the inside walls did not prevent water damage. Moisture was trapped between the bin wall and the lining; the paper decayed, and moisture also seeped in at the edges of the lining. Better protection was obtained by applying matched boards, plywood, or other rigid wallboard as a lining on the inside of the studs. This reduced the capacity somewhat, and the space between the inner and outer wall coverings had the disadvantage

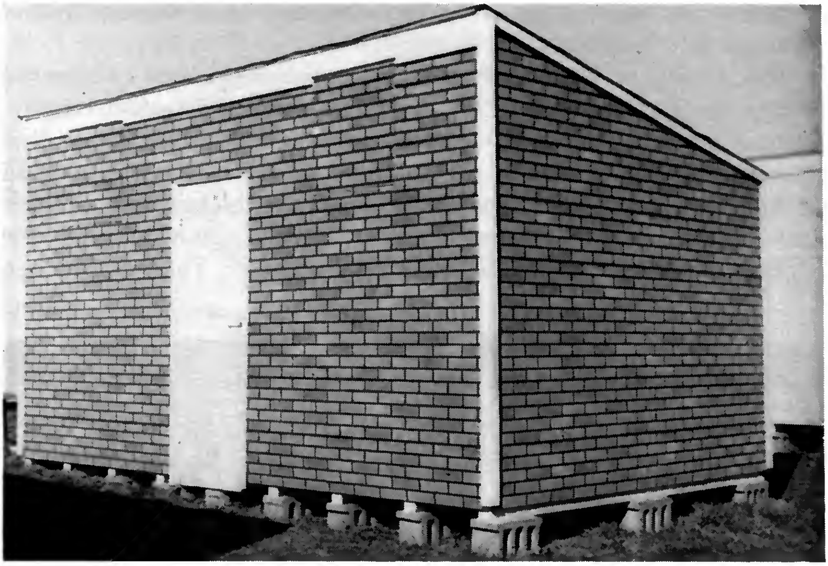
These horizontal cracks resulted from shrinkage of the siding boards. A double covering outside the studding would protect the soybeans. (Fig. 24)

of forming an inaccessible place where soybeans might accumulate and rodents and insects stay.

Single walls were made watertight by applying a layer of material over the siding. Included in the tests were exterior plywood, cement-asbestos board, and mineral-surfaced asphalt sheets (Fig. 26). Other exterior-type materials such as shingles or sheet metal might be used.

The main points of leakage in steel bins were the junctions between floor and wall and between door and wall, in vertical joints, in roof joints, and around loose bolts and faulty bolt holes. These defects can

Leaks resulted in damaged soybeans on the inside of bin walls. Reinforced paper lining was not enough to prevent such damage. (Fig. 25)



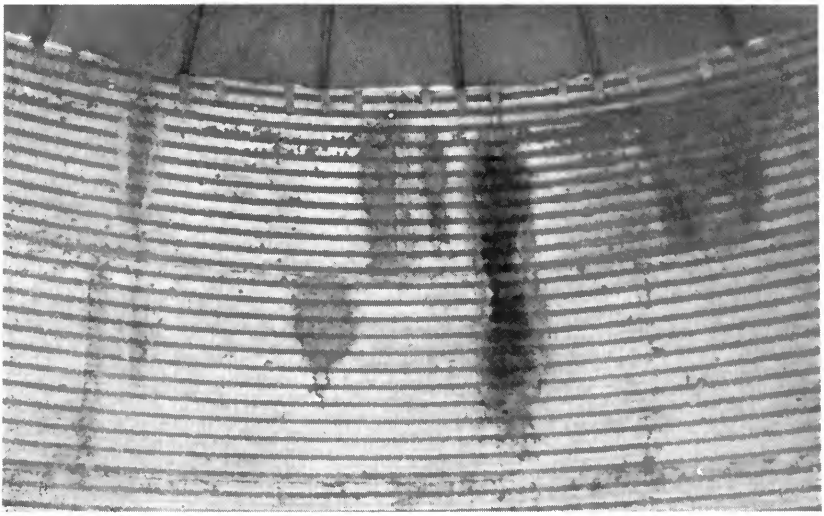
Single-walled wood bins can be made weathertight by an overlay of material such as cement-asbestos sheets, roofing, shingles, or sheet metal. An asphalt-type siding is illustrated. (Fig. 26)

be avoided by adequate design and care in erection. In one bin leaks occurred and damage resulted where the roof bolts were attached to connect the roof to the sidewall. Moisture entered around the clip bolts and leaked directly into the grain (Fig. 27). This fault was remedied in later designs.

Sealing all vertical joints with caulking compound or gasket materials and tightening bolts uniformly are important steps in making steel bins weathertight. At the junction between wall and floor it is important that the surface of the floor be higher than the base of the wall to keep water from draining in.

Insect and Rodent Control

Insects. Bins should be cleaned thoroughly and any accumulations of old grain or feed removed before they are filled. A contact spray is recommended for the walls of wooden bins. Bins that become infested usually should be fumigated. This requires tight walls and floors. Wide, shallow bins with a large surface area need heavier doses of fumigants than deep bins with a small surface area.



Stains show where damage occurred due to leaks around roof clip bolts before faults in design and erection were remedied. (Fig. 27)

Bins filled to the top are difficult to fumigate because the vapors applied to the surface tend to spill over the edges.

Fumigation requires special skills and practices. Most fumigants are dangerous and precautions must be taken to safeguard the operator. They should be applied only by persons who understand the materials, dosages, and methods of using. Information can be obtained from entomologists or others experienced in fumigation.

Rodents. Rats and mice are responsible for important losses in stored grain. A combination of structural measures and rat control is necessary. Concrete foundations and floors and wood floors a foot or more above the ground help to keep out rats.

A number of poisons or rodenticides are available for general use. Others can be obtained and used only by persons trained in handling them. Detailed information on rodent poisons and their use can be obtained from the U. S. Department of Agriculture or the U. S. Department of Interior, Washington 25, D. C., or from any state college of agriculture.

APPENDIX

Climatic Data for Urbana, Illinois

Crop-storage conditions vary with location and with temperature, humidity, and total sunshine. For example, reflective surfaces serve to maintain lower temperatures in bins in sunny locations than in bins where cloudy and partly cloudy weather prevails. Insect infestation and spontaneous heating are more likely to occur with high humidities and high temperatures. The following data are included for the purpose of comparison with other areas where storage investigations are conducted:

Month	*Mean monthly temperature (1943-1946)* *°F.*	*Mean monthly relative humidity (1943-1946)* *percent*	*Mean total sunshine per day (1930-1944)* *hours*
January	28.2	80.3	4.3
February	32.8	75.6	5.1
March	44.0	73.9	6.0
April	51.6	68.2	7.6
May	61.0	73.4	8.0
June	72.4	70.2	10.2
July	75.3	61.4	10.8
August	73.2	70.2	10.1
September	65.8	70.8	8.5
October	56.0	65.0	7.2
November	42.3	75.3	5.4
December	28.0	78.8	3.6

Temperature, Moisture, and Fat Acidity Measurements

Standard apparatus and established procedures were used throughout the storage studies, as described in the bulletin. Brief reference is made here to specific apparatus or method as a guide to comparison with other investigations.

Temperature measurements within masses of soybeans were made by means of copper-constantin thermocouples read by a portable potentiometer. In some bins 50 or more couples were used. Soybean samples from bins were obtained with grain probes with partitioned cells so that samples from individual cells might be taken at specified depths. The probes were inserted at predetermined positions on the surface. By these means samples could be examined separately, or composite samples made for bin averages.

Fat acidity was determined and stated in terms of the number of milligrams of potassium hydroxide required to neutralize the free fatty acids in 100 grams of water-free soybeans. Acid number or "acid value of the oil" is defined as the number of milligrams of potassium hydroxide required to neutralize the free fatty acids in 1 gram of soybean oil. This value is used to express the quantity of free fatty acids present in the oil. In commercial practice the free fatty acids are stated as percentages, calculated as oleic acid. This percentage is about one half the "acid value." The specifications of the National Soybean Processors Association allow a maximum of 1.5 percent of free fatty acids without discount for crude-domestic soybean oil.

Equilibrium Moisture Content

Only brief mention is made of equilibrium moisture content, but the term has significance in storage studies. Soybeans lose moisture to the air, or conversely they gain moisture from the air, except when the internal vapor pressure and the partial pressure of water vapor in the air are in equilibrium. The relative humidity of the air has a greater influence than temperature on the moisture content of soybeans. At any given relative humidity, each 10-degree rise in temperature tends to reduce soybean moisture content by about ¼ of 1 percent. The following tabulation shows the relation between relative humidity and equilibrium moisture content at various relative humidities for a given temperature of 77° F.[1]

Relative humidity percent	*Soybean moisture percent*	*Relative humidity percent*	*Soybean moisture percent*
31.0	6.1	62.0	10.4
35.0	6.5	70.0	12.4
43.0	7.4	71.2	12.4
50.0	8.0	81.1	16.4
51.0	8.3	85.0	18.4
60.0	9.6	93.0	25.1

Pressures and Loads

The angle of repose for dry soybeans is approximately 16 degrees when filling or piling and 29 degrees when emptying or funneling. Both lateral and vertical pressures are exerted on walls and vertical pressure on floors. Friction accounts for the vertical load on walls. Lateral pressure on walls varies up to a maximum of 30 to 60 percent of the pressure on the floor. It increases with depth of grain up to two and a half or three times the diameter or width of bin, after which it increases only slightly as the depth increases. In bins deeper than three diameters, a large proportion of the load is carried by the walls.

Pressure measurements were made in the Illinois experiments in two rectangular wooden bins 12 feet wide, 16 feet long, and 10 feet high. Lateral pressure increased 14 to 16 pounds a square foot and vertical pressure, 7½ to 8½ pounds a square foot for each foot of fill. These values check well with those calculated by Janssen's formula:[2]

$$L = \text{lateral pressure, lb./sq. ft.} = \frac{wR}{u'}\left(1 - e^{\frac{-ku'h}{R}}\right)$$

when the following coefficient values were used: w = 45 pounds per cubic foot; u′ = 0.312, the coefficient of friction of soybeans on bin walls;[3] k = 0.450, ratio of lateral to vertical pressures; R = 3.43, hydraulic radius of bin; and h = 10-foot depth of grain.

[1] Taken in part from Minn. Agr. Exp. Sta. Tech. Bul. 156 (1942) and in part from Can. Jour. Res. 22F, 1-8 (1944).

[2] Z. Ver. deut. Ing. 39, 1045-1049 (1895).

[3] 1950 Grain Bin Requirements. U. S. Dept. Agr. Cir. 835.

SUMMARY

Studies of soybean-storage requirements at Urbana, Illinois, involved the use of about 70 farm-type bins, 79,000 bushels of soybeans, and six and a half years of study.

Moisture was found to be responsible for most storage trouble. If moisture is held within safe limits, most other problems either disappear or are minimized.

Soybeans need to be drier than corn or wheat to store safely under similar conditions. Soybeans of 10-percent moisture or less remained in generally good condition up to four years. At about 12-percent moisture, market grades held up for nearly three years, but germination and other values declined gradually. At 13-percent moisture, safe storage was limited to one winter season, from harvest to late spring. At 14 percent, the safe period was limited to the winter months. Soybeans with moistures of 15 percent or more usually should not be stored in farm-type bins.

Best conditioning resulted from drying with forced heated air and from using forced unheated air when air temperatures were above 60° F. and relative humidity below 75 percent.

The kind of construction materials used and their thermal conductivity, reflectivity, or color had no significant effect on conditions within bins. Insects caused little or no trouble if moisture was low enough for satisfactory storage and bins were made weathertight.

Movement of air within the bin during the winter months may result in excessive accumulation of moisture in the surface layers of soybeans, and consequently in lower germination, molding, crusting, and insect damage in those layers.

Bins must be weathertight to prevent damage due to leakage. Particular care is necessary to exclude moisture from metal bins by following manufacturers' directions, joining metal sheets tightly, and caulking where necessary. Wood walls should usually be double, either lining or sheathing with siding, or a weathertight cover over the board siding. Foundations and floors should be built up enough to avoid damage from ground water.

Anchoring is necessary to prevent wind damage to bins while they are empty.

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