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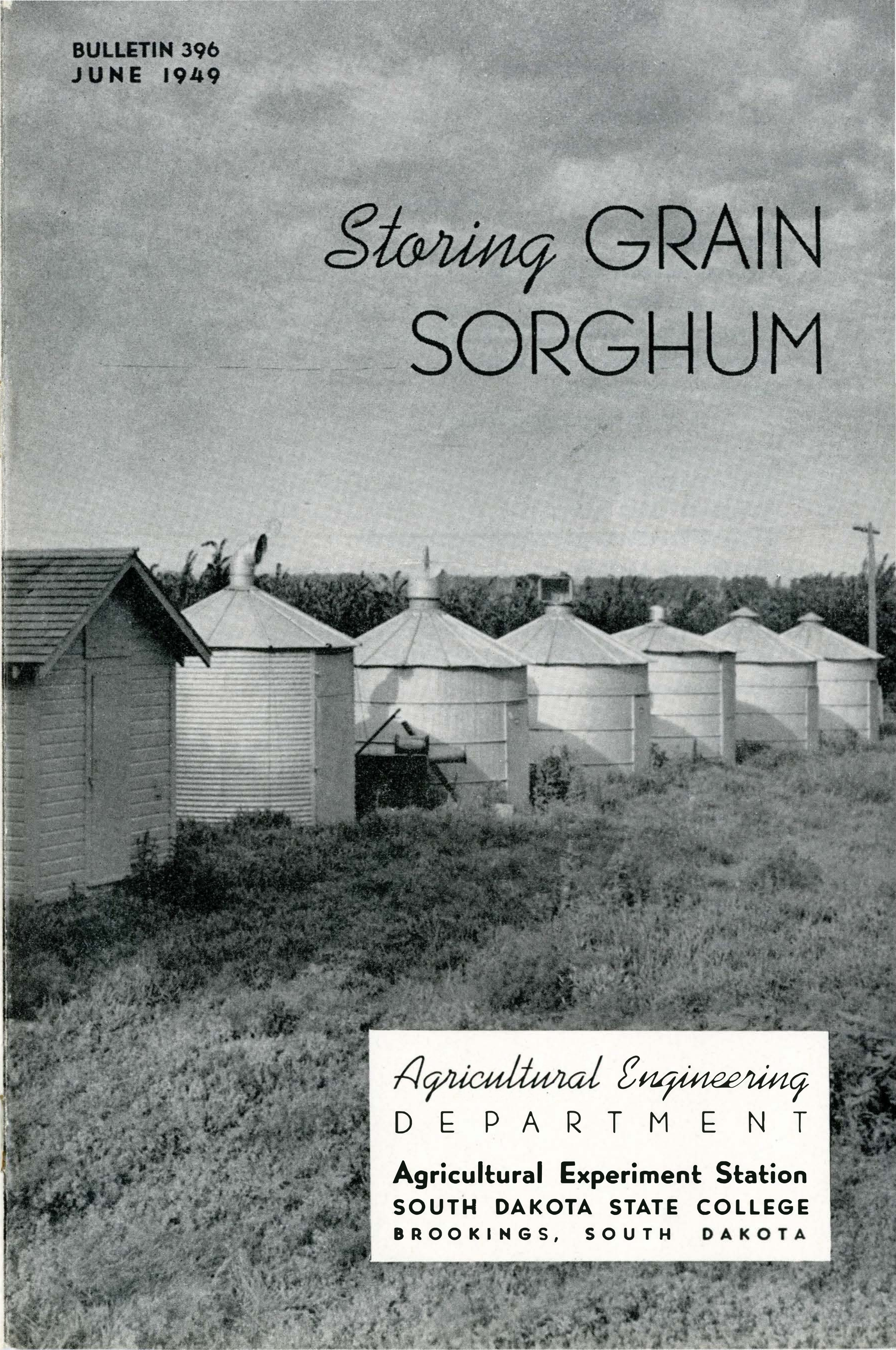

Agricultural Engineering
DEPARTMENT

Agricultural Experiment Station
SOUTH DAKOTA STATE COLLEGE
BROOKINGS, SOUTH DAKOTA

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Storing Grain Sorghum

By H. H. DeLong *and* E. I. Whitehead[1]

Introduction

Sorghum is an important grain and forage crop in South Dakota. Grain sorghum acreage increased from 16,000 acres in 1930 to 1,500,000 acres in 1939. Since then there has been a decline in acreage, due to the favorable seasons for production of corn. The use of unadapted varieties of southern grown sorghum seed was also a factor in the decline. However, sorghum is more resistant to grasshopper damage than is corn, and threat of grasshopper infestations may cause farmers to plant sorghum in preference. Also sorghum can stand periods of dry weather better than corn, making it an important crop to the farmer and rancher.

The varieties now grown in South Dakota are of the Martins Combine milo type and are suited to harvesting with a combine. Most of the seed, however, is produced in the south under a longer growing season. The grain often does not mature properly under South Dakota conditions. In years of early frost, followed by warm drying weather, the grain will dry. However, in years of late frost and cool damp weather the grain will have a high moisture content.

Sorghum planting should be after the date of the last probable frost, so planting is late, and South Dakota farmers have little chance to lengthen the growing season to fit the southern seed stock. New varieties are being developed for our state, but are not ready for release.

Grain sorghum can be harvested with grain harvest and threshing machinery, and the combine is the most popular method. In seasons with unfavorable drying weather the moisture content of the grain is apt to be above 13 percent and cause storage problems later on. Part of the moisture may come from bits of stalks, not separated from the grain, as the moisture content of the succulent stalk is usually higher than the grain itself.

Perhaps the easiest way of avoiding storage loss of sorghum grain from molding is to combine the grain late in the fall, place in bins in cold or freezing weather, and then feed the grain before spring. Most of the grain used in the tests at the South Dakota Agricultural Experiment Station was brought in, in December or January. No trouble in heating or spoiling occurred until spring.

This method, however, offers no solution to the following people: (1) the farmer who wants to carry over wet grain for summer feeding, (2) the farmer who must carry over quantities for a stabilized feeding program, (3) the producer who wants to market the grain, (4) the shipper, or (5) the elevator operator. Spoilage by mold growth reduces feeding value and lowers the quality for commercial purposes.

For safe long-time storage, the moisture content of sorghum grain should be 13 percent or lower for South Dakota climate. In states with higher temperatures and humidities the maximum safe moisture percentage has been found to be 11 percent or 12 percent.

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The authors acknowledge the assistance given by C. J. Franzke, Assistant Agronomist, Turner Wright, Associate Animal Husbandman, and C. M. Nagel, Plant Pathologist.

General Safeguards in Storage

While a moisture content of 13 per cent or less is the first consideration of safe storage, many other factors are important. The first safeguard might be stated thus: "Dry first, then store in well-sealed bins." Once dry, the sealed bin will not allow moisture to be carried to the grain by any medium. Grain has a hygroscopic moisture balance[2] which enables it to absorb moisture from the air when the air contains more than the usual amount of moisture. In some localities the sealing of joints in steel storage bins is recommended, so that the grain that was dry when stored will stay dry.

In South Dakota, protection of the grain from snow or driving rain is important. Snow which sifts into a bin, then melts when warm weather comes, can raise the moisture content of part of the bin so that spoilage from mold growth can start. Once molding is started, and the grain temperature is raised, the mold may travel farther. Floors, doors, windows, roof, and side walls should all be inspected to see that no snow, driving rains, or ground water can enter.

Bins of grain carried through a summer season should be inspected for weevil and other insect infestation in July. Grain that has 12 percent moisture, or more, will allow rapid reproduction of the grain insects. Heavy infestation of insects also causes a rise in temperature of the grain. Chemicals such as ethylene-dichloride, carbon tetrachloride, carbon bisulfide, or ethylene dibromide are used in varying proportions. Directions for applying such fumigants can be found in Circular 760, "Grain Sorghum Storage," printed by the U. S. Department of Agriculture.

Careful threshing and cleaning of the grain will contribute to safe storage. Freedom from wet stalk particles is important. The tailings extension on the combine cleaning shoe should be closed

[2]See page 15.

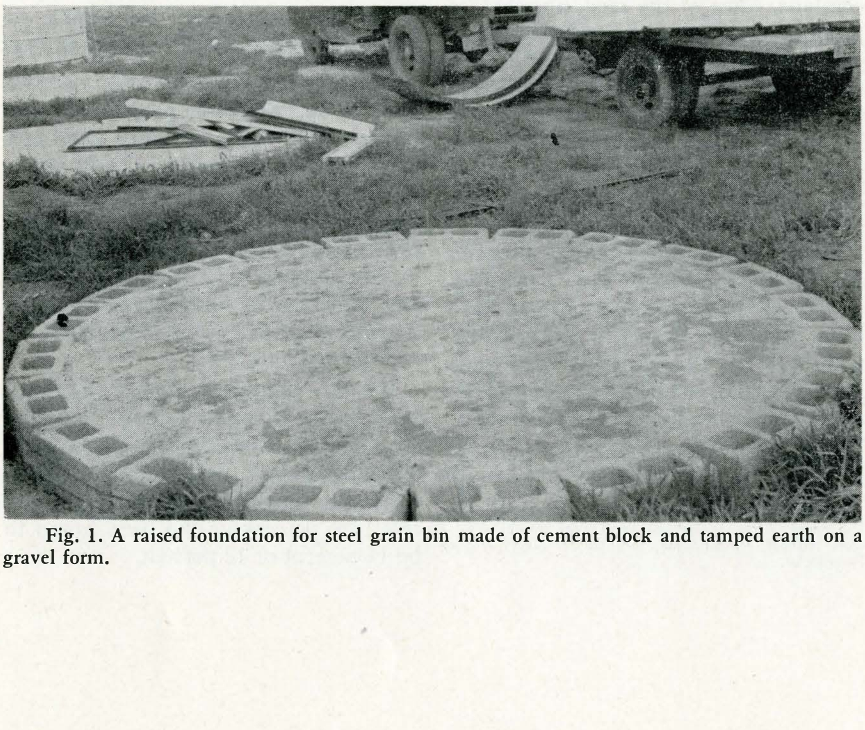

Fig. 1. A raised foundation for steel grain bin made of cement block and tamped earth on a gravel form.

enough to prevent stalk parts from returning and being broken up to seed size and thus entering the grain. Cylinder speed and concave setting should be made to get the least possible cracking of the grain. Cracked grains, with starchy surfaces exposed, are aids in the rapid growth of molds, if other conditions are favorable.

The Grain Molds[3]

Deterioration of grain sorghum (having more than 13 percent moisture) is frequently caused by fungi (molds). Mold growth may be barely visible, yet damage is done to the grain. In other instances mold growth is so abundant that "caking" occurs. While certain molds may start growth at slightly above freezing, others are capable of producing heat which may range up to 130° F.

A great variety of mold spores are present on any sample of grain. Sometimes there will be stratification (different layers of the moldy grain showing different colors). The molds digest parts of the sorghum seed, causing grain deterioration, accompanied by loss in bushel weight.

Some of the actively growing molds found in bins undergoing spoilage and heating have been isolated and are listed as follows: *Aspergillus flavus, A. Candidus, A. niger, Mucor sp.* and *Penicillium sp.* These organisms live on the starch and germ present in the grains of sorghum. It has been found that certain molds attack the starchy portions of the seed while others destroy the germ. Either of these types of deterioration will affect the feed value of the sorghum and reduce the bushel weight and quality.

When bins of grain sorghum had gone through a period of molding a great deal of dust was present. On several occasions, men shoveling the grain or working where they had to breathe the dust, appeared to suffer considerable discomfort. Effects of inhaling the dust (headache, nausea and fever) took place in from one to three hours. Those who have been thus affected by the mold dust are reluctant to repeat the experience.

Much of the sorghum grain used in these storage trials was fed later to livestock. Molding does not necessarily mean a total loss of the grain as feed. No detailed feeding trials were conducted to determine the exact percent of feed value lost on a given sample. The following observations have been made, however, in the process of feeding moldy sorghum grain to lambs and hogs.

Some types of mold impart a bad taste to the grain and animals do not eat it readily, except as it is ground and mixed with other grain. No attempt was made to feed grain that was caked or discolored from mold. During several years of trials, nearly 2000 bushels were fed without loss of livestock or noticeable ill health. While those in charge of the feeding work have no reason to recommend such feed, they have found that some moldy grain is not a total loss for livestock feed. Most of such grain was used after the heating and molding period was over and the grain had "cooled down" to air temperature. In some cases the grain was run through a fanning mill to remove some of the dust resulting from molding. Hogs ate this grain more readily than the uncleaned grain, but they still did not seem to relish it.

[3]This part of the manuscript was prepared with the assistance of C. M. Nagel, Plant Pathologist.

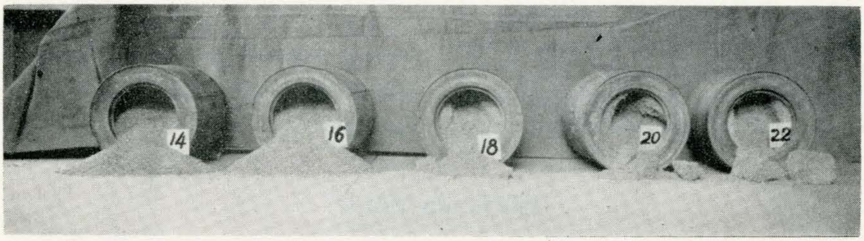

Fig. 2. Small samples which show mold development in relation to initial moisture content. (Moisture content indicated by numbers.)

Mixing Wet Sorghum With Dry Grain

Good results have been obtained in storing grain sorghum by mixing with dry oats. Tests were run on four bins during the first half of 1942. Sorghum and oats were secured for four 70-bushel bins. The milo had a 17½ percent moisture content. One 70-bushel bin was filled with this sorghum grain (Bin A) for a check bin. Bin B was filled with a mixture of 46 bushels of milo and 23 bushels of oats, mixed as the grain was put in the bin. Bin C had 35 bushels of milo and 35 bushels of oats. Bin D had 23 bushels of milo and 46 bushels of oats. Weekly records of bin temperatures and moisture tests were kept from February 7 to July 25.

Bottom-of-bin temperatures, and grain-surface temperatures followed the average weather temperatures rather closely. The center-of-bin temperatures were most indicative of what was happening. On Bin A there was a definite heating period starting in May, and reaching a peak of 130° in mid-June. By July 25 the heating was over and temperature back to normal.

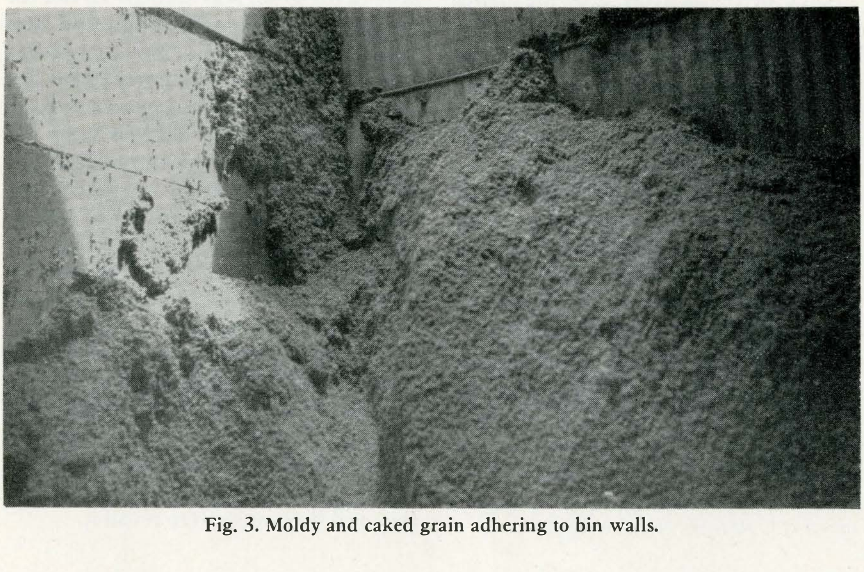

Fig. 3. Moldy and caked grain adhering to bin walls.

Moisture Changes in the Grain

In all four bins the milo seed started with 17½ percent moisture and came down to 15 percent. Bin A was seriously damaged and Bin B was mildly damaged while bins C and D kept perfectly. Perhaps the added lightness and porosity which the oats created helped in the mixed bins.

The moisture drop in the milo and the moisture increase in the oats were very noticeable during the first few days. After that the moisture of the oats did not increase materially nor did the moisture of the milo decrease. Details of this test are shown in Table 2.

Mixture Tests Repeated

Two experimental lots of oats and sorghum mixtures were observed between March 16 and August 23, in the 1945 season. The moisture content of the sorghum used was 18 percent and of the oats 12½ percent. Preliminary calculations were made to balance the amounts of grain so as to give a theoretical moisture balance of 14 percent for Bin 7. This called for a drop of 4 percent moisture in the sorghum and a rise of 1½ percent in the oats. An equation was set up to find the quantity of sorghum grain to be added to one bushel of oats in order to get this moisture adjustment.

(X bu. sorghum) (50#/bu.) (.04 moisture drop) = (1 bu. oats) (32# /bu.) (.015 moisture gain)

(X) (2.00) = .48

$X = \frac{.48}{2.00}$ or nearly .25

Bin 7 was, therefore, mixed with one-quarter bushel of sorghum to one bushel of oats. The bin kept well, had no high temperatures and finished the test with the oats at 12 percent moisture and the sorghum at 14 percent.

An alternate method of calculation was used on Bin 8. By taking arbitrary mixtures one can calculate the theoretical final moisture content. It was decided to have the grain in Bin 8 at slightly higher moisture content than Bin 7, in fact, to go slightly beyond the critical point. The equation is shown below:

"y" represents the final moisture content of both grains.

(.18—y) represents the moisture drop of the sorghum, and (y—.125) the moisture gain of the oats.

(.75 bu. sorghum) (50#/bu.) (.18—y) = (1 bu. oats) (36#/bu.) (y—.125)

73.5y = 11.25

y = .153 or 15.3 percent moisture.

Bin 8 kept fairly well, but showed high temperatures of 90° in August. Molding was not noticeable, and the sorghum was at 15 percent moisture content at the end of the season with the oats at 13 percent.

Practicability of Drying by Mixing

The above mentioned trials together with other small sample trials, indicate that it is possible to dry sorghum grain by this method. There are two practical difficulties, the first of which is for the grower to have on hand, dry grain equal to several times the quantity of the sorghum to be dried. The work of re-elevating and mixing the entire quantity is laborious, but probably not more costly than several other methods. No special equipment is necessary, except for elevators and adequate bin space.

The second difficulty, that of separat-

ing the two mixed grains, need not follow if the mixed grain is fed that way. On most farms it probably could be fed as a mixed grain.

Several farm-type cleaning machines were tried for separating oats and sorghum. A standard fanning mill with four round hole scalping sieves and one wire weed screen gave the following results:

1. Whole milo at rear of mill 90-93 percent clean.
2. At front, oats of 100 percent cleanness.
3. Under mill, a mixture of very small oats, small milo, and cracked milo.
4. Light chaff and dust were blown out over the oats.

The rate of this mill in a short test was about 32 bushels per hour.

The Colfax Wild Oat Separator and Barley cleaner gave these results:

1. Going through the mill, whole milo of about 90 percent purity and 10 percent oats.
2. At side of mill, most of the oats with all chaff, dirt, small milo kernels and all finely broken milo kernel particles.
3. The capacity found on a short test was 15½ bushels per hour.

The Carter Disc Machine was used to separate bins B, C, and D.

1. The milo was cleaned perfectly. A 100 percent rating on the material coming through the mill can be expected.
2. Going out the discard side of the mill were all of the oats and a very small amount of milo.
3. Most of the cracked milo and dirt was sent through with the whole milo.
4. The capacity of the mill was 30 bushels per hour. It was run by a ⅓ HP electric motor. The discs were those used for cleaning seed wheat.

A "wild oat kicker" machine or small angle-sieve dockage machine gave 100 percent cleaning for oats going over the sieves. A larger sized machine would be needed for processing large amounts.

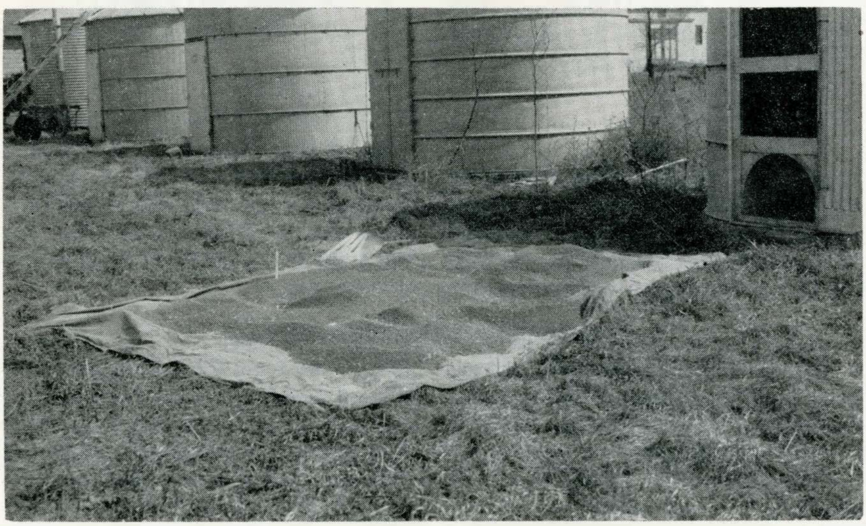

Fig. 4. Drying sorghum grain by spreading it in thin layers in the sun.

Sun Drying of Grain

Drying sorghum grain by spreading it in thin layers in the sun, proved successful and also was one of the most rapid ways of reducing moisture. The system involved much labor and is not recommended for large amounts of grain. The grain was spread on canvas or sisalkraft paper in a layer 3 inches deep. Moisture reductions of 2 percent in one day have been noted. The results are given in detail in Table 3.

The ideal drying day is one of high temperature, wind and low humidity. The operator must be alert to weather changes and get the grain under cover before rain comes. Also one must remember that this grain would absorb moisture from the air when the humidity was high. Under favorable conditions such a process, though not very practical, has three very basic conditions for effective drying: (1) an abundance of air with low relative humidity, (2) heat applied to the grain to aid in evaporation, and (3) the grain in thin layers.

Bin Drying in Thin Layers

Tests were run to determine the greatest possible depth at which a layer of high moisture sorghum could be safely stored. Sorghum grain of 18.6 percent moisture was placed on a bin floor and given a uniform slope from 4 inches to 24 inches in depth. This test began March 23, 1945, before heating or molding began. Slight molding was found at the 18 inch depth and all places of greater depth. Detailed results of the tests are given in Table 5.

Such a method does not make efficient use of bin space, but is effective. On some occasions the sorghum grain might be spread in feed alleys, driveways or above other grain in partly filled bins. Grain with a large amount of exposed surface will also absorb moisture, during humid periods, as is shown by the test.

Storage in Grain Sacks

Three tests were run with sorghum grain stored in grain sacks: one group in an unheated granary, a second in a similar location but placed outdoors in the sun occasionally, and a third group in a steam-heated room. Even under the last named condition, drying was very slow. Grain near the outside of the sacks dried several percent lower than that at the center. A 69-day period was needed to dry the grain from 18.5 percent to an average of 13.1 percent. The grain at the sack centers was 14.3 percent at the end of the test. Table 6 gives data for all three of the tests.

Natural Ventilation for Bins Not Successful

Recognizing the desirability of storing and drying grain in the bin without rehandling or without machinery, two 500-bushel perforated steel bins were obtained. Four 500-bushel plain steel bins were also obtained so that check tests could be run. One of the perforated steel bins had a pressure cowl with central flue, and also had a perforated floor, with the bin placed on a grid of small boards to give air access to the small floor openings. In the 1943 season trials, the perforated bin described above did not prevent the grain from heating and molding seri-

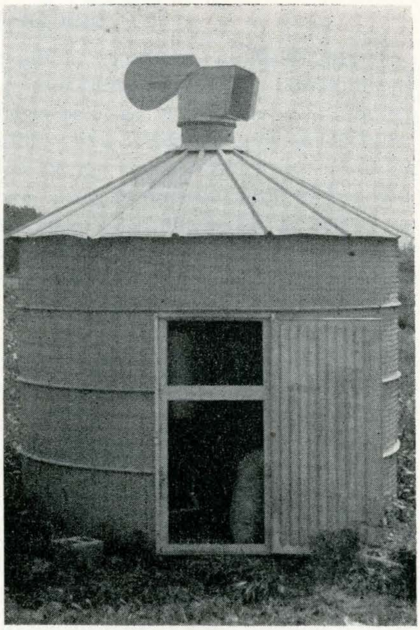

Fig. 5. Perforated steel bin with pressure-type cowl used on natural ventilation trials.

ously.

A second trial was given this same bin in the 1945 season. However, additional flues, made in various sizes and shapes, were placed vertically in the bin so that no portion of the grain was more than 18 inches from a side wall, center flue, or small flue. Heating was noticeable during the summer, although temperatures did not go as high as in the plain steel bin with no ventilators. The grain which started the summer season at 19 percent had dried down to 13 percent and 15 percent, with the lower moisture content grain being adjacent to side walls or flues. Drying was too slow however to prevent severe molding throughout the bin. Detailed records of temperature and moisture are given in Table 4.

Test Run on Cupolas

Several types of steel cupolas were tested during the 1942 season as to their effectiveness in moving air through a granary. With no back pressure, a considerable volume of air is moved through the steel bin when the wind velocities are medium to high. All cupolas and cowls have one fault in common, and that is their failure to work when the wind stops blowing. Calm days may occur when ventilation is most needed. Ventilation of this nature cannot be relied on to dry sorghum grain. Tests showed that grain next to the cupola flues may take on added moisture from the air during weather of high humidity.

Suction cowls, pressure cowls, and spinner cowls were tested. Table 7 gives the results of the tests.

Small Laboratory Heater-Drier

The outstanding results, as far as speed of drying was concerned, were obtained by a small laboratory-built heater-drier. This piece of equipment consisted, first, of a hopper to hold the grain, and directly below it a heating chamber with electrical heating units. Below that, the grain dropped into chutes built of screen, where cold air was forced through the grain. A loss of 1 to 1½ percent moisture in one handling was noted when the grain temperature was maintained at 100° F. When a temperature of 260° F. was maintained, a 3 percent drop was obtained in one operation. Such high tempatures are not recommended until further studies prove them to be safe and practical.

The heating of the grain greatly increased the vapor pressure within the kernels and caused the grain to sweat. The moisture could actually be felt on the seed coat of the grain, and when the cold air was blown through, this excess moisture was evaporated and carried away.

Although the machines used in these tests worked very slowly, the method has possibilities of being applied to machines big enough for commercial use. In fact, some very large units of grain driers installed in elevators are of this type.

Forced Air Used In Wagon-Sized Driers

Two different types of load-sized driers were used for drying sorghum. The first shown in Fig. 6 was a standard wagon box equipped with two large ventilator flues in the bottom of the box. A 1/4 HP electric motor and a furnace fan formed the blower mechanism. Moisture content of grain was reduced approximately 1 percent each 24-hour period. No further work was done with this type of drier as it was considered too slow. If a few loads of sorghum direct from the combine could be dried in specially equipped wagons during the night, then transferred to their permanent bins before the next days' combining, no bin-drying structures would need to be built.

A second wagon-type drier was built on a 7½ by 12 foot trailer bed. It had a false bottom with plenum chamber into which the fan ducts were attached. The depth of grain never exceeded 24 inches, thus making a short path of air travel. With the small furnace fan as a blower, corn was reduced 6 percent in moisture content in three days. Drying rates were considered too slow, and a larger fan with weed-burner heating unit was constructed.

This tractor-mounted blower was built from old corn shredder parts and the pressure oil burner was added for raising

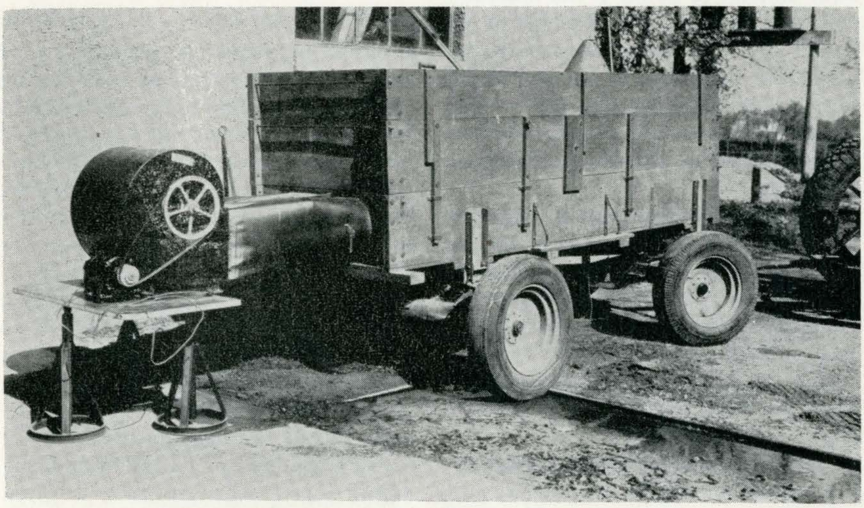

Fig. 6. Small detachable blower for use with wagon-load lots.

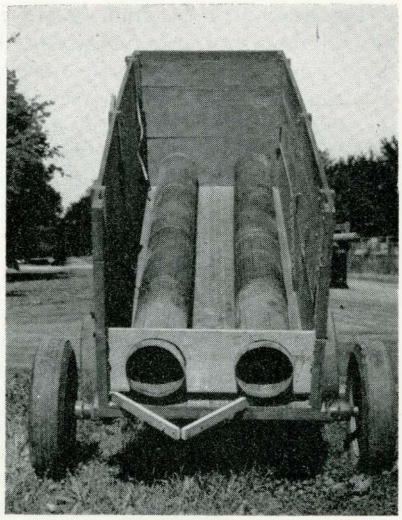

Fig. 7. Ventilator flues used in wagon drier.

the temperature. Exhaust fumes from the burner were allowed to go through the dryer system. Entering air temperatures of 180° F. were used and evaporation of the drying grain brought the outgoing air temperatures down to 95° F. The burner, which was not too reliable was run intermittently during two 6-hour daytime periods. The sorghum grain dried, but during the process mold development was noted on parts of the upper surface. The fact that the burner was not dependable prevented further tests.

Well Designed Grain-Drying Machinery

Well designed grain-drying machinery is hardly to be made on the farm. A carefully engineered balance between power used, heat generated, and amount of air delivered must be maintained. A large amount of power is not necessary and, therefore, it is not desirable to use tractor power for doing the grain drying work. The right type of fan is essential so that large amounts of power are not required to move the air. In addition large passageways for this air should be provided.

The source of heat may be coal, fuel oil, or liquified petroleum gas. Some machines may be of the heat-exchanger type, with no fumes from the burner entering the drying air. Others may let the exhaust from the burner enter with the drying air, and on these, added safety measures must be observed to prevent fires.

Fans should be designed to work properly against the desired air pressure and move the maximum amount of air with the least possible power invested. Heat should be regulated so that it will never go above a specified temperature.

With all of these requirements in mind, engineers from the Bureau of Plant Industry, Soils, and Agricultural Engineering, made up specifications for seven different heater-drier units during the 1947 season. Part of the specifications for one of the seven types is reprinted here to show some of the typical requirements of the best designs known to date. For large amounts of grain a heater-drier may be the only satisfactory answer for the safe storing of sorghum grain. However, the cost of a drier unit will be high, and it should be so designed and so mounted as to be also usable for grain from the combine, ear corn, hay drying, or perhaps other drying jobs that may develop in our farming practices. Part of the specifications for a 3 HP drier, using liquified petroleum gas fuel, is given here.

Specifications

Fan: The fan shall have capacity to deliver to the crib or bin at least 9,000 cubic feet per minute of drying air against a a static pressure of ½-inch water column. This means that the fan must deliver the specified volume against ½-inch pressure in addition to the pressure drop through the drier. The power requirement to drive the fan shall not exceed 3-brake horsepower at the above rate of air flow and static pressure.

Power Unit: The power unit shall operate on L-P gas and be capable of operating continuously at not less than 3-brake horsepower without over-heating It shall be a 4-stroke cycle automatic throttle governed with efficient oiling, cooling, carburetion, ignition and air cleaning systems. The engine shall have controls and accessories necessary for safe and satisfactory operation on L-P gas.

Heating Unit: The drier shall be provided with a heating unit designed to burn propane or butane and approved by the Underwriters Laboratories. The products of combustion are to be discharged into the air to be used for drying. The heating unit shall have a capacity sufficient to add 780,000 British thermal units per hour of sensible heat to the air passing through the drier. The capacity of the heating unit is to be adjustable to approximately 50 percent and 75 percent, as well as 100 percent of the above specified heating capacity. The percent of carbon monoxide by volume in the drying air shall not exceed one one-hundredth of one percent (0.01) and the drying air shall be free of objectionable odors.

Before the products of combustion are discharged into the main air stream, they shall pass through a spark arrester consisting of at least 1½ inches of loosely felted, uncoated, medium fibre glass. The temperature of the air passing through the filter shall not exceed 600° F, and the face velocity through the filter shall not exceed 300 feet per minute. This arrester shall be supported by metal suitable to withstand the temperatures to which it is exposed and shall be easily accessible for inspection, cleaning and replacement.

Safety: (1) An automatic control shall be provided which will stop the flow of fuel within 45 seconds in case of flame or ignition failure.

(2) An automatic control shall be provided which will not permit fuel to be supplied except when the drying air is moving normally. This control may be either a mechanical interlock or an electric circuit control which cuts off the fuel supply when the main air flow is stopped for any reason. The control shall be arranged so that the fan or blower unit may be operated without operating the heating unit.

(3) Operation of the above controls shall not be dependent upon connection to an electric power line. If electric current is required for the controls, a suitable generator driven by the main power unit and necessary accessories shall be furnished. The arrangement shall be such that in case of any failure in the electric circuit, the fuel will be shut off.

(4) All air intakes to this drier unit shall be screened with a material of not greater than ½-inch mesh.

Aeration of Grain by Elevator

Two tests were run by this method, the first with a 50-bushel lot of sorghum arranged to be transferred from one bin to another by a small bucket elevator. On February 20, 1943, the grain containing 16 percent moisture, was placed in the bin. Temperature records were kept until July 10, together with moisture tests. The grain was changed from one bin to the other five times, from June 10 to July 10. The bin temperatures had reached 60° F. when elevating began. About one-third of the bin contents were elevated at a time, giving the newly elevated grain a chance to dry. Results were disappointing, as the grain dropped from 15 percent moisture, at the beginning of elevation, to 14 percent at the end of elevating, and to 13 percent by July 30. The amount of drying done did not warrant the time or effort invested.

In the 1945 season the method was repeated with larger bins and with the blower elevator. The grain from one 500-bushel bin was blown into an adjoining bin, and then on to a third. On April 18, the sorghum grain in steel Bin A averaged 18½ percent, but one place in the bin had developed temperatures up to 120° F. On April 19 and 20, most of this bin was put through the blower elevator into Bin B. Considerable cracking was done to the grain. The temperature was not lowered, except that some of the colder grain was mixed with the warmer. Moisture tests of 18½ percent showed no moisture drop. Heating continued and on May 4, most of the bin was near 100° F. Most of the grain was "blown over" to Bin C that day, and the average moisture samples was 18.3 percent. On the following day, an average of moisture samples from Bin C was 18 percent. The grain was cracked very badly after the second elevation. That grain which had been elevated twice had a very long and intense heating period. Temperatures up to 140° F. were recorded in this bin. The fine starch powder from the broken kernels no doubt aggravated the heating by promoting more rapid mold growth.

Summary

1. Combining high-moisture sorghum late in the fall, and feeding this wet grain before spring, is a way to avoid storage trouble, but offers no solution to the farm operator who wishes to carry over a supply of feed for more than one season.

2. For safe long-time storage, sorghum grain should have a moisture content of 13 percent or less when placed in the bin.

3. Sorghum grain in storage should be watched during spring and summer months for local areas of mold growth or insect infestation. Either condition may cause heating, increased respiration, and the beginning of spoilage for the entire bin.

4. Grain mold grows on the germ or the starchy part of the sorghum kernel, causing loss of bushel weight, caking, bad flavor of the grain, and at times a very dusty condition of the grain.

5. Mixing wet sorghum grain with dry oats has been a satisfactory way of storing sorghum where a later separation of the two grains was not necessary.

6. Sun drying is both rapid and effective, but involves much hand work and exposes the grain to many weather hazards.

7. Bin drying in thin layers is effective, but slow, and does not make efficient use of bin space.

8. Drying sorghum in grain sacks proved workable and effective for small amounts, such as seed stock, but the drying process is very slow.

9. Methods which did not prove effective or practical were: (1) storage in perforated steel bins with many flues, (2) mechanical handling with elevators or blowers, (3) or forced cold air through large bins during damp spring weather.

10. Drying grain by heater-drier machinery is effective, but should be done carefully, as the process calls for well designed equipment and careful bin management.

The Hygroscopic Properties of Sorghum

By "hygroscopic property" is meant the ability of a given substance to absorb and hold a given amount of water at given temperatures and relative humidities. In studies (at this station) on the hygroscopic moisture content of grain sorghums (milo type), relative humidities of 20, 40, 60, and 80 percent were maintained using sulfuric-acid solutions of desired strength. (1). Temperature effect was studied at 34° F. and 68° F. The hygroscopic moisture content of wheat (whole grain) in equilibrium with the above relative humidities and temperatures was also studied.

The hygroscopic moisture data obtained is presented in Table 1 for grain of the following moisture contents: (1) of the sorghum 13.3 percent, and (2) wheat samples of 10.67 percent.

Temperature affects the hygroscopic moisture content of sorghum or wheat inversely; that is, the higher the temperature at a given relative humidity, the lower will be the moisture content of the grain. This temperature effect has also been noted by Fenton (3) using Blackhull Kaffir. Temperature also affects the rate at which the moisture content of the grain equilibrates with moisture in the air, as it was observed that at 34° F. about 70 days were required for the grain to reach equilibrium, whereas at 68° F. only 15 days were required.

The moisture response of both sorghum and wheat grain to increasing relative humidities at either 34° F. or 68° F. is approximately a direct line relationship. The hygroscopic responses of the majority of the cereal grains is such that when percent moisture is plotted against relative humidity, the line graphs for all the grains are grouped close together (4).

Like other grains, grain sorghums have hygroscopic properties; that is, they tend to reach and maintain an equilibrium moisture content with the sur-

Table 1. Effect of Temperature on Moisture Content of Sorghum Grain and Wheat

	Relative Humidity	Temperature	
		34° F.	68° F.
Sorghum	20	10.49 percent	9.83 percent
	40	14.02 percent	12.40 percent
	60	17.22 percent	15.51 percent
	80	22.95 percent	20.08 percent
Wheat	20	9.46 percent	9.05 percent
	40	12.86 percent	11.97 percent
	60	15.62 percent	15.27 percent
	80	22.13 percent	20.49 percent

rounding air. When the vapor pressure of the air surrounding the grain is greater than the vapor pressure exerted by the moisture in the grain itself, the grain tends to gain moisture until the vapor pressure within the grain equals that of the surrounding air; conversely, when the vapor pressure within the grain exceeds that of the surrounding air, then moisture tends to leave the grain. The equilibrium moisture content at a given vapor pressure is determined to a large degree by the nature of the hydrophilic (water-loving) materials present in the grain itself.

The rate at which grain will gain or lose moisture is roughly proportional to the vapor pressure difference which prevails between the grain and the surrounding air space; the rate is affected, however, by the resistance to movement of moisture vapor set up by the surface layers of the grain, and in this respect, sorghum resists more than wheat.

In drying grains the temperature of the grain is the greatest single factor, for as the temperature rises the vapor pressure of the moisture held within the grain increases rapidly. The moisture content of the grain is also a factor affecting vapor pressure, but it is of less importance than temperature, inasmuch as the vapor pressure of seeds having moisture contents at about 20 percent approaches that of water, so that beyond 20 percent the moisture content of the seed has little effect.

The moisture content of sound grains determines to a considerable extent the rate of respiration. It has been shown for cereal grains, soybeans, and flaxseed (5, 6) that the respiratory rate accelerates sharply when the seed has a moisture content within or above a critical moisture level; for most cereals the critical moisture level lies within 14-15 percent. Heat production accompanies this accelerated respiration and means must be provided for its dissipation.

Basic Principles of Grain Drying

In all grain drying there are several basic principles to keep in mind. They are listed below in statement form, but more could be said about all of them if space permitted:

1. Air is the moisture carrying agent in all grain drying procedures.
2. The ability of air to hold moisture increases as its temperature increases.
3. The vapor pressure of air increases as the relative humidity increases. Table 8 gives the vapor pressure relation and the moisture holding ability of air at given temperatures and relative humidities.
4. When the air has a lower vapor pressure than the grain, drying will occur and vice versa.
5. Drying air is cooled down by the evaporation of moisture from the grain.
6. When air travels through a long path of grain, evaporation may cool the air stream down to where it will no longer absorb moisture from the grain but may release some back to the grain.
7. Grain next to the air entrance side may dry to several percent lower than grain near the air path outlet.
8. Air of 120° F. is the maximum allowable without damage to milling quality of sorghum.
9. Air of 150° F. is the maximum allowable without injuring germination.
10. Respiration rate of grain increases with temperature and moisture content, and one of the end products of respiration is water vapor.
11. Both insect growth and mold growth are accompanied by production of heat, and in the process of oxidation of carbohydrates, one end product is water vapor.

Table 2. Record of Moisture Change, Spoilage, and Germination of Mixture Tests*

Bin No.	A	B		C		D	
Mixture	All Milo	⅓ Oats	⅔ Milo	½ Oats	½ Milo	⅔ Oats	⅓ Milo
Moisture at Start—Feb.7	Milo–18%	Milo Oats	18% 11%	Milo Oats	18% 11%	Milo Oats	18% 11%
Moisture at End–July 25	Milo–15%	Milo Oats	15% 13%	Milo Oats	15% 13%	Milo Milo	15% 13%
Spoilage	Near 100%	20%		None		None	
Germination	11%	13%		52%		69%	

*Germination tests run by E. L. Erickson.

Table 3. Sun Drying Tests

	Temperature	Relative humidity	Time	Beginning Moisture	Ending Moisture	Loss Percent
Grain 1″ to 3″ deep on canvas —warm March 28	Tem. near 65°	Near 40%	1 day	18.6	16.5	2.1
Grain 1″ to 3″ deep on Sisalkraft paper	Varying 64° to 79°	Varying 75% to 40%	2 days	16.5	12.5	4.0

Table 4. Natural Ventilation in Perforated Steel Bins on Two Seasons, 1943 and 1945.

Description of Test	Time (Days)	First moisture (Percent)	Last moisture (Percent)	Drop in moisture (Percent)	Results
Natural Air Drying					
500 bu. perforated bin added flues—1943	144	19.0	14.5	4.5	Very moldy
500 bu. perforated bin added flues—1945	157	16.1	12.1	4.0	Moldy in spots

Table 5. Sorghum Grain, Varying Depths, on Wood Bin Floor.

Depth of layer	Days on test	Percent moisture at start	Percent moisture at end	percent loss	Condition of grain at end
4-inch layer	113	18.6	15.2	3.4	Good
12-inch layer	113	18.6	15.9	2.7	Trace mold
18-inch layer	113	18.6	16.3	2.3	Moldy

Table 6. Sorghum Grain, Stored in Grain Bags, Under Varying Conditions.

Location and condition	Days on test	Percent moisture Beginning	Percent moisture Ending	Loss	Condition of grain at end
In grain bags, 70° room*	71	16.5	13.4	3.1	Good
In grain bags 70° room*	69	18.5	13.1	5.4	Trace of mold
In grain bags, stored in granary	39	17.9	14.8	3.1	Trace of mold
In grain bags, stored in granary placed out on 3 different days	39	17.9	14.7	3.0	Trace of mold

*Relative humidity usually from 30% to 40%.

Table 7. Performance of Various Cupolas for Steel Grain Bins.

Cupola type	Wind velocity	Test conditions	Volume of air c.f.m.
Large pressure cowl, 1.75 sq. ft. area	7.8 m.p.h.	3/32″ water pressure 10″ gr.	11.0
	9.6 m.p.h.	⅛″ water pressure 10″ gr.	21.4
	11.0 m.p.h.	5/32″ water pressure 10″ gr.	27.2
	16.0 m.p.h.	5/32″ water pressure 10″ gr.	41.6
Large suction cowl, 1.76 sq. ft. area	8.4 m.p.h.	0″ water pressure 10″ gr.	0.0
	14.0 m.p.h.	1/16″ water pressure 10″ gr.	10.8
	18.05 m.p.h.	⅛″ water pressure 10″ gr.	26.4
	15.00 m.p.h.	No back pressure Bin door open	1,110.2
Small spinner type, .785 sq. ft. area	15.00 m.p.h.	No back pressure Bin door open	614.0

Table 8. Properties of Saturated Water Vapor With Air

	For Saturated Vapor For 1 Pound of Dry Air		For 60% Relative Humidity— For 1 Pound of Dry Air		For 30% Relative Humidity— Per 1 Pound of Dry Air	
Temperature Degrees F	Vapor Pressure lbs. per sq. in.	Grains Moisture	Vapor Pressure lbs. per sq. in.	Grains Moisture	Vapor Pressure lbs. per sq. in.	Grains Moisture
0	.01853	5.50	.01112	3.30	.0056	1.65
30	.08080	24.07	.04848	14.442	.02424	7.221
60	.2561	77.21	.15366	46.326	.07683	23.163
90	.6980	217.1	.41880	130.26	.2094	65.13
120	1.692	566.5	1.0152	339.90	.5076	169.95

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