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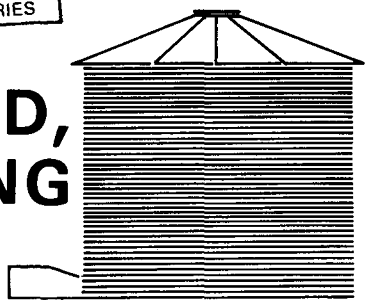

COMBINATION HIGH-SPEED, NATURAL-AIR CORN DRYING

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ADVANTAGES OF COMBINATION DRYING

Combination drying is any system in which high-speed drying is followed by in-storage cooling and natural-air drying as shown in figure 1. The high-speed phase can be a continuous flow or automatic batch dryer, or a bin dryer using elevated air temperatures (continuous flow; unstirred, stirred or recirculated batch) as illustrated in figure 2. Potential advantages of the combination approach include:

- reduced energy requirements,
- increased drying capacity, and
- improved grain quality.

The purpose of the high-speed dryer is to reduce the corn moisture content to a level where drying can be safely completed by moving natural (unheated) air through the grain mass. The natural-air process may take 4 to 8 weeks, or longer, to complete. In fact, drying may be halted in late fall and completed during the following spring.

Propane or natural gas requirements for high-speed drying are reduced since less moisture is removed compared to conventional high-speed drying with in-dryer cooling. The amount of savings depends on the moisture content at which grain is discharged from the high-speed dryer. Electrical energy requirements, however, are increased since fans are used for natural-air drying. Overall, energy requirements are reduced. The additional electrical energy will be used during October and November and possibly in March, April, and early May—months that fall between the seasonal air conditioning and heating peaks for the utility system.

Combination drying allows grain to move through the high-speed dryer 2 to 3 times more quickly than the conventional process allows. Removing less moisture in the first phase and cooling in the storage bin adds to high-speed dryer capacity.

If the high-speed dryer is a batch process, the cooling cycle can be eliminated. If the dryer is a continuous-flow process, its cooling section can be equipped with a propane burner to provide additional drying capacity.

Combination drying leads to improved grain quality since grain is discharged at higher moisture contents from the high-speed dryer and cooling is often delayed. This reduces susceptibility to breakage during handling. Test weight could also increase.

All of these advantages could be obtained with a strictly natural-air system. However, for corn above 25 percent moisture content, the shallower grain depths and/or larger fans needed to finish drying ahead of spoilage are often impractical. It is usually more practical to use high-speed drying to reduce moisture to 21 to 22 percent and then use natural air.

Energy Savings

Energy savings with combination drying vary with the type of high-speed dryer used. The efficiency of heated air dryers depends on the cubic feet of air per minute per bushel of grain (cfm/bu), drying air temperature, and corn moisture content. Table 1 presents comparisons of propane and electrical energy requirements for conventional and combination systems based on research at the Rosemount Agricultural Experiment Station. The high-speed dryer used in these field experiments was typical of many farm-type automatic batch or continuous-flow dryers.

Table 1. Estimated propane and electricity requirements to dry 100 bu for conventional and combination drying[1/2]

	Initial moisture content					
	24%		26%		28%	
Drying method	Propane gal	Elect. kWh	Propane gal	Elect. kWh	Propane gal	Elect. kWh
Conventional (high-speed to 16% with in-dryer cooling)	15.6	7.8	20.0	10.0	24.6	12.4
Combination (discharge hot, 21% in the bin after cooling, dry to 16% with natural air)	4.6	69.6	8.0	70.9	11.4	72.2

[1]Based on data from the tests at the University of Minnesota Rosemount Agricultural Experiment Station 1975-1978
[2]1 bu equals 56 lb of corn at 15.5%

ECONOMICS

A complete economic comparison is complex. Energy costs for drying are only a part of the total cost for the drying and storage operation. Investment

Table 2. Comparison of energy costs for conventional and combination drying in cents/bu[1]

Initial moisture content	Electricity cents/kWh	Propane, $/gal (Natural gas, $/thousand cubic feet) 0.50 (5.46) cv	0.50 (5.46) cb[2]	0.65 (7.10) cv	0.65 (7.10) cb	0.80 (8.73) cv	0.80 (8.73) cb	0.95 (10.37) cv	0.95 (10.37) cb	1.10 (12.01) cv	1.10 (12.01) cb
	3	12.7	7.9	16.4	9.6	20.1	11.3	23.7	13.0	27.4	14.7
	5	12.9	9.3	16.6	11.0	20.3	12.7	24.0	14.4	27.7	16.2
28%	7	13.2	10.8	16.9	12.5	20.5	14.2	24.2	15.9	27.9	17.6
	9	13.4	12.2	17.1	13.9	20.8	15.6	24.5	17.3	28.2	19.0
	11	13.7	13.6	17.4	15.4	21.0	17.1	24.7	18.8	28.4	20.5
	3	10.3	6.1	13.3	7.3	16.3	8.5	19.3	9.7	22.3	10.9
	5	10.5	7.5	13.5	8.7	16.5	9.9	19.5	11.1	22.5	12.3
26%	7	10.7	9.0	13.7	10.2	16.7	11.4	19.7	12.6	22.7	13.8
	9	10.9	10.4	13.9	11.6	16.9	12.8	19.9	14.0	22.9	15.2
	11	11.1	11.8	14.1	13.0	17.1	14.2	20.1	15.4	23.1	16.6
	3	8.0	4.4	10.4	5.1	12.7	5.8	15.1	6.5	17.4	7.1
	5	8.2	5.8	10.5	6.5	12.9	7.2	15.2	7.9	17.6	8.5
24%	7	8.3	7.2	10.7	7.9	13.0	8.6	15.4	9.2	17.7	9.9
	9	8.5	8.6	10.8	9.3	13.2	9.9	15.5	10.6	17.9	11.3
	11	8.7	10.0	11.0	10.6	13.3	11.3	15.7	12.0	18.0	12.7

[1] Estimates based on energy use data from table 1—conventional drying to 16%, combination drying to 21%, then completed with natural air to 16%

[2] cv-conventional drying
cb-combination drying

costs for equipment must be considered in any complete analysis. Since each situation is different, it is difficult to generalize. We will indicate relative energy costs for combination drying compared to conventional drying and then indicate some of the other factors that should be considered.

Using the results of table 1, energy costs for conventional and combination drying can be calculated at various fuel and electricity prices as shown in table 2. There is a savings in cost of energy to dry in most situations. These savings may not be enough to justify conversion to a combination drying and storage system, however. The following are some costs and benefits to consider:

Potential additional costs

- Storage bins must be equipped with drying floors and fans.
- Shallower bin depths (16 to 20 ft maximum drying depth desirable) to facilitate natural-air drying may lead to a more expensive storage structure.
- Extra electrical service may be needed.
- Materials handling equipment between the high-speed dryer and drying bins may have to be modified to accommodate handling hot, wet grain.
- Storage capacity may be reduced in existing bins due to space lost for drying floor and plenum, lower filling level (not above the eaves), and space lost because 8 to 10 percent less wet corn can be stored in the same volume compared to dry corn. Another ring of side-wall height can be added when new bins are built at relatively low cost.
- It may be more difficult to reach the specific moisture content desired for marketing. The final moisture content with natural-air drying can be more variable than with conventional drying because of varying weather conditions. For example, if grain is dried to 13.5 percent, the approximate 2.3 percent loss in weight represents a cost of 4.6 cents/bu at $2-bu corn and 6.9 cents/bu at $3-bu corn. Good management should help to avoid such overdrying in the natural-air phase.

Potential additional benefits

- Increased drying capacity in the high-speed dryer may allow a smaller and less costly dryer or delay the need to expand high-speed capacity.
- Improved grain quality may result in improved grade and a better selling price.
- Since less propane is needed, less time may be lost waiting for the fuel during a shortage. Timely harvest reduces field losses.
- Higher airflows used in natural-air drying provide improved ability to handle storage problems.

The potential costs and benefits associated with combination drying and storage vary in each situation. They may not be significant in some operations, while in others they could be larger than the value of the energy saved.

NATURAL-AIR DRYING PRINCIPLES

The natural-air drying process is illustrated in figure 3. Air is forced upward through the bin. Water is evaporated and carried away by the air. Drying takes place in a drying zone which advances upward through the bin. Grain above this drying zone remains at the initial moisture content (20 to 22 percent in this example). Grain below the drying zone is at a moisture content which is in equilibrium with the drying air conditions. The moisture content of this

Table 3. Equilibrium moisture content of shelled corn[1]

Temperature	Relative humidity 50%	60%	70%	80%	90%
20° F	13.9%	15.8%	17.5%	19.7%	22.7%
30	13.1	14.8	16.6	18.7	21.5
40	12.4	14.0	15.8	17.8	20.6
50	11.9	13.4	15.1	17.0	19.7
60	11.4	12.9	14.5	16.4	19.0

[1]Moisture contents apply to the drying air. Fan heat reduces ambient relative humidity.

"dry" grain fluctuates with the temperature and humidity conditions of the outside air. Table 3 illustrates the relationship between temperature, relative humidity, and equilibrium moisture content for shelled corn.

Changes in equilibrium moisture content in October and November based on 23 years of weather data for St. Cloud, Minn., are shown in figure 4. Equilibrium moisture content generally increases as the fall season progresses because of decreasing temperatures. The wide variability in climatic conditions results in a range of equilibrium moisture contents that varies from year to year.

The key to natural-air drying is to move the drying zone through the top of the bin within the allowable storage time. The allowable drying and storage time for shelled corn is illustrated in table 4 for different temperature and moisture conditions. These data show that as moisture content of the corn increases, the allowable time for drying and storage decreases. This means that wetter grain requires higher airflow rates in order to accomplish drying within the allowable time. As the temperature increases, the allowable drying time decreases faster than the drying capacity of the air increases. This also means higher airflow rates are required to complete drying within the allowable time.

Table 4. Allowable storage time in days for shelled corn[1]

Corn temperature	Moisture content 15%	18%	20%	22%	24%	26%	28%
35° F	1174	242	120	71	48	35	28
40	879	181	90	53	36	26	21
50	492	101	50	30	20	15	12
60	275	57	28	17	11	8	6

[1]Based on USDA research at Iowa State University—0.5% dry matter decomposition

Since the grain at the top of the bin is the last to dry, it is the most critical. The more air that is delivered, the faster the drying zone moves through the bin and the more reliable the drying system. The fan is operated continuously until the drying zone moves through the top of the bin. The bottom layer of corn in the bin will overdry in good weather and re-wet during poor weather. The re-wetting allows the drying zone to continue to move upward.

Once the drying zone has moved through the bin, continued operation under typical weather conditions in late November and early December only leads to re-wetting of the grain at the bottom of the bin with little or no useful drying at the top of the bin. At this time, grain can be cooled to 25 to 30° F and the fan shut off. At these low temperatures corn stores well over winter at the 16 to 18 percent level. In many cases additional drying may not be necessary. For example, if the grain is to be fed to livestock throughout the winter months it can be used at 16 to 18 percent. If the grain is to be marketed throughout the winter it can be sold with little or no penalty. The penalty for marketing grain at 1 to 1.5 percent moisture content above the 15.5 percent level in winter and early spring should be small in most cases and would not justify the cost of additional drying.

The electrical energy supplied to the fan is converted to heat and is available for drying in natural-air systems. The heat added due to the electrical energy input to the fan results in a 1.5 to 3° F temperature rise in the drying air. An analysis of natural-air drying performance indicates that additional heat from electric, propane, or solar sources is not needed. Rather than using supplemental heat to reach the lower moisture contents that are often desired for full-year storage, natural-air systems should be designed and managed to complete drying in the spring. Such timing makes the most effective use of the electrical energy supplied to the system. A more detailed discussion of the effects of supplemental heat is provided in "Natural-Air Corn Drying," M-164.

Airflow Rates

As indicated, airflow is the key to natural-air drying. Airflow rates are specified in cubic feet of air per minute per bushel of grain (cfm/bu). If a fan is capable of moving 10,000 cfm through a 10,000 bu bin of shelled corn the airflow rate is 1 cfm/bu. This airflow rate results in a certain drying rate. If the airflow rate is doubled to 2 cfm/bu, the drying rate is doubled for the same conditions.

Since the allowable drying time decreases and the amount of water to be removed increases with moisture content, the required airflow rate increases rather rapidly with moisture. Also, since earlier harvest means warmer temperatures, the required airflow rate for a given moisture content is higher earlier in the season.

Table 5 shows the moisture contents that can be safely dried with different airflow rates for 3 harvest

Table 5. Maximum initial moisture contents for a fast-fill procedure[1]

Airflow rate (cfm/bu)	Harvest date Oct. 1	Oct. 16	Nov. 1
0.75	20.0%	20.5%	20.0%
1.0	21.0	21.5	21.5
1.25	21.5	22.0	22.0
1.5	22.0	22.5	22.5
2.0	23.0	23.5	24.0
3.0	24.0	25.0	26.0

[1]Fast-fill: filling the bin over a period of at most several days

Table 6. Brake horsepower per 10,000 bu corn for several airflow and depth combinations[1]

Airflow rate (cfm/bu)	Depth of corn 8 ft	10 ft	12 ft	14 ft	16 ft	18 ft	20 ft	22 ft	24 ft
0.75	0.8	1.3	1.9	2.8	3.7	5.0	6.3	7.6	9.5
1.0	1.5	2.5	3.8	5.4	7.4	9.9	12.6	16.1	19.3
1.25	2.4	4.1	6.3	9.3	12.6	16.5	21.7	28.0	33.1
1.5	3.7	6.1	9.5	14.2	18.9	25.8	33.1	41.6	-----
2.0	7.5	12.9	19.8	29.0	39.7	53.6	-----	-----	-----
3.0	19.8	30.3	52.0	75.6	-----	-----	-----	-----	-----

[1] Calculated horsepower per 10,000 bu of corn based on static pressure from M-166 and a fan efficiency of 50%

dates in Minnesota. If natural-air drying bins are filled rapidly (over several days) the fans must be capable of delivering the airflow given in table 5.

Table 6 shows that the horsepower required increases rapidly with depth and airflow. Since the high-speed dryer is used to reduce the harvest moisture contents, full bin airflow rates of 0.75 to 1.25 are suggested for the natural-air drying phase.

Filling Schedules

There are two types of filling schedules that can be used for the natural-air drying phase of combination drying: fast-fill and delay-fill.

Fast-Fill Schedule

With the fast-fill schedule, the bin is filled to its maximum depth in a short period of time (1 to 3 days). The moisture contents that can be safely dried under a fast-fill schedule are listed by airflow rate and date in table 5. Moisture contents are somewhat lower on earlier dates because warmer temperatures lead to faster spoilage rates.

Example: A bin is equipped with a fan which delivers 1 cfm/bu when the bin is full. If a fast-fill schedule for mid-October is used, corn up to 21.5 percent moisture content can be added. If grain has dried to the appropriate level in the field it can be delivered directly to the bin without high-speed drying. At higher moisture contents, the high-speed dryer can be used to dry to this level. Grain can be delivered hot from the dryer and cooled in the bin. Normally 0.5 to 1 percentage point of moisture will be removed during cooling; therefore, natural-air drying starts at 20.5 to 21 percent moisture content.

The fast-fill schedule works well with combination drying since the high-speed dryer can produce the moisture contents needed for safe natural-air drying.

Delay-Fill Schedule

Since harvesting is often spread over a period of 2 to 4 weeks, filling the bins can also be delayed or spread over the same period. In this case somewhat higher moisture contents can be handled in the natural-air drying phase because the delay in adding the grain to the top of the bin reduces deterioration. Table 7 shows the moisture contents that can be safely handled at 3 full-bin airflow rates if filling is spread uniformly over 2 to 4 weeks.

Table 7. Maximum initial moisture contents for a delay-fill procedure[1]

Full bin airflow rate (cfm/bu)	Filling period (weeks)	Date filling starts: Oct. 1	Oct. 16	Nov. 1
0.75	2	21%	21.5%	21%
	3	22	22	21
	4	22.5	22.5	21
1.0	2	22	23	22.5
	3	23	23.5	22.5
	4	24	24	22.5
1.25	2	23	24	23.5
	3	24	25	23.5
	4	25	25	23.5

[1] Delay-fill: uniform filling over a 2 to 4 week period

This procedure works well with combination drying since the high-speed dryer can be used to insure the required moisture contents for the entire harvesting period. If field moisture contents drop below these levels during the period, corn can go directly to the bin without high-speed drying.

Example: A bin is equipped with a fan which delivers 1 cfm/bu when the bin is full. Harvesting starts in early October and it is estimated to extend over 3 weeks. Based on table 7, grain moisture content should be reduced to 23 percent or less in the high-speed dryer and then delivered to the bin. Grain coming in from the field at 23 percent or less can be delivered directly to the bin without high-speed drying.

Since it is often difficult at the beginning of the season to estimate how fast harvesting will proceed, a schedule should be developed that allows for the maximum filling rate. It is important to keep track of moisture contents and filling rates as the season progresses to assure the schedule is not exceeded.

If several bins are used for combination drying, partially fill each by rotating from bin to bin rather than completely filling a bin before moving to the next one. The delay in adding the corn at the tops of bins provides additional safety during natural-air drying.

MANAGEMENT OF THE SYSTEM

Harvest Time

Be careful not to exceed suggested moisture content levels for discharge from the high-speed dryer to the bin for cooling and drying. During the first year, reduce the moisture content a little more in the high-speed dryer than recommended. This allows you to become experienced in measuring the moisture content of warm, moist grain.

Since the moisture content of warm grain is difficult to measure accurately, grain samples for controlling the dryer should be taken from the cooled grain in the bin for best results. At these airflows, grain will normally be cooled within one hour after it reaches the bin.

CAUTION should be exercised when inspecting bins during cooling of hot corn. The hot, moist air coming off the grain can be hazardous to breathe and can potentially cause excessive dehydration leading to heat stress problems. No one should climb into the bin under these conditions. Care should be exercised even when looking through the door into the bin since metal surfaces may be slippery and eyeglasses may fog.

Start in-storage drying fans as soon as you start delivering hot corn to the bin. This will avoid undesirable condensation buildup along the walls. During in-bin cooling, the hot moist air being discharged will form condensation on the roof and eaves. Condensation should not pose a problem unless water happens to collect and run along roof supports where it is deposited in one place. The downspout to the bin may be a potential source for problems since moist air rising in the downspout will cool with the water condensing and running back into the bin. One solution is to close off the entrance to the downspout at the bin so that air does not travel up the spout. Spring-loaded covers are available which automatically close when corn is not flowing.

Natural-Air Drying

Experience has shown that the best procedure is to operate the fan continuously until the drying front has moved through the top of the bin. *Do not* shut the fan off in the fall in periods of rainy weather or high humidity. Fan operation during these periods will continue to move the drying front through the bin and air movement will control grain heating. In late fall or early winter, the fan can be shut off according to the guidelines in table 8. After turning the fan off, a cover should be placed over the drying fan to prevent natural air currents from flowing through the bin.

Table 8 provides general guidelines for shutting off the fan in the winter and re-starting in the spring. Weather conditions influence the recommendations. In general, keep the fan running as long as average temperatures are above 25° F. When the temperature drops below this level for significant periods of time, the fan can be shut off before the indicated dates. Drying proceeds slowly below 25° F. More importantly, as long as the *grain* is below 25° F, deterioration rates will be low even at higher moisture contents.

During the winter check the top 2 or 3 feet of the bin periodically for moisture buildup (particularly near the center) or an increase in grain temperature. Run the fan for a total of 6 to 8 hours every several weeks if the ambient temperature is between 20° and 30° F. This is particularly important following an extended period below 0° to 10° F.

If it is necessary to continue drying in the spring, start the fan and run continuously according to the schedule indicated in table 8. If drying in the spring is not necessary, warm up the grain according to normal storage management procedures. (See "Management of Stored Grain with Aeration," M-165.) At 1 cfm/bu, a warming (or cooling) front can be moved through the bin in 12 to 24 hours; at 0.5 cfm/bu, in 24 to 48 hours. Check the grain temperature at the top of the bin to determine when warm-up has been completed.

Table 8. Recommendations for shutting off the fan in the fall and starting in the spring[1]

Fall Shut-Off (sample grain periodically)[2]

a) Turn off fan when grain in the top of the bin drops below 15.5% and temperature of the grain in the top drops below 35° F.

b) After Nov. 1, if the grain in the top of the bin drops below 17%, turn off the fan as soon as the temperature of the grain in the top of the bin drops below 30° F.

c) After Nov. 15, if the grain in the top of the bin drops below 18%, turn off the fan when the temperature of the grain in the top of the bin drops below 30° F.

d) After Dec. 1, if the grain in the top of the bin drops below 19%, turn off the fan when the temperature of the grain in the top of the bin drops below 25° F.

e) After Dec. 15, shut off the fan when the temperature of the grain in the top of the bin drops below 25° F regardless of moisture content.[3]

Spring Start-Up

a) Start up and run continuously after March 15 if the moisture content of grain remaining in the top of the bin is greater than 19%.

b) Start up and run continuously after April 1 if the grain remaining in the top of the bin is between 17% and 19%.

c) Start up and run continuously after April 15 if the grain remaining in the top of the bin is below 17% and you want to dry down to the 14% range for full summer storage. If you are going to market at 15.5%, you may only want to run the fan periodically since the average bin moisture content will probably be at or below 15.5% when the top reaches 17%.

[1]These are general guidelines for running the fan. Specific weather conditions may influence these dates. In general, keep the fan running as long as average temperatures are above 25° F. When temperatures drop below these levels for significant periods of time, the fan can be shut off before the dates mentioned above. Drying proceeds slowly below 25° F. More importantly, as long as *the grain* is below 25° F, deterioration rates will be low even at higher moisture content.

[2]During the winter check the top of the bin periodically for moisture buildup (particularly near the center) or an increase in grain temperature. Run the fan for a total of 6 to 8 hours every several weeks if the ambient temperature is between 20 and 30° F. This is particularly important following an extended period below 0 to 10° F.

[3]If one of the filling schedules discussed earlier is followed, corn moisture contents at the top of the bin will normally be 21% or below and drying can normally be safely completed in the spring. In rare circumstances corn *above* 21% may remain in the bin after the Dec. 15 shutoff. This wet corn can be held through the winter at temperatures below 25° F. However, the risk of spoilage during spring drying at the high moisture contents is greatly increased; thus, this corn should be fed, sold, or dried in some other manner before spring.

If grain appears to be heating or going out of condition, move enough of it to stabilize the situation. This grain can be run through the high-speed dryer to quickly reduce the moisture content to a safe level.

If a portion of the grain is above 15.5 percent when you are ready to market (17 to 18 percent at the top of the bin), it may be feasible to remove several percentage points in the high-speed dryer before selling. The moisture discount schedule will determine whether this is necessary or economically desirable. Blending of wetter grain with drier grain at the time of sale is another method of reaching the 15.5 percent level.

Grain Handling, Cleaning, and Leveling

If a conventional drying system is converted to combination drying, make sure that materials handling between the high-speed dryer and the drying-storage bin does not create a bottleneck. Capacities of augers handling hot, 20 to 22 percent corn will be reduced compared to dry, cooled corn. Downspout angle for this corn should be at least 45° to insure gravity flow.

Fine material and broken corn reduce total airflow; therefore, performance is better with cleaner corn and screening is highly desirable for natural-air drying. The screenings can be fed or put into a silo with other material. (Remember the fines are wet and will spoil without drying.) If the corn is not screened, reduce the rate of filling to compensate for reduced airflows. Since the fines tend to accumulate in the center, unloading some corn from the center when the bin is full will be beneficial.

It is important to keep grain level to promote uniform airflow. Grain spreading devices can help to distribute the grain. In many cases, some additional hand leveling will significantly improve uniformity in airflow. Hand leveling should be considered in all cases when you are done adding corn to the bin. In fact, because resistance to airflow is typically greater in the center of the bin than at the outer edges, "dishing out" the center of the bin is usually beneficial. Where possible, drawing grain out of the center unloading hopper of the bin helps to reduce the amount of grain to be moved when leveling or dishing out the center. It also removes some of the fine material in the center of the bin.

This is one publication in a series that evaluates alternatives for saving energy, improving grain quality, and increasing capacity in corn drying. The series provides information on how to incorporate these alternatives in drying systems. The publications include:

- M-161 Saving Energy in Corn Drying
- M-162 Dryeration and In-Storage Cooling for Corn Drying
- M-163 Combination High-Speed, Natural-Air Corn Drying
- M-164 Natural-Air Corn Drying
- M-165 Management of Stored Grain with Aeration
- M-166 Fan and Equipment Selection for Natural-Air Drying, Dryeration, In-Storage Cooling, and Aeration Systems

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Figure 1. Schematic of combination high-speed, natural-air drying system

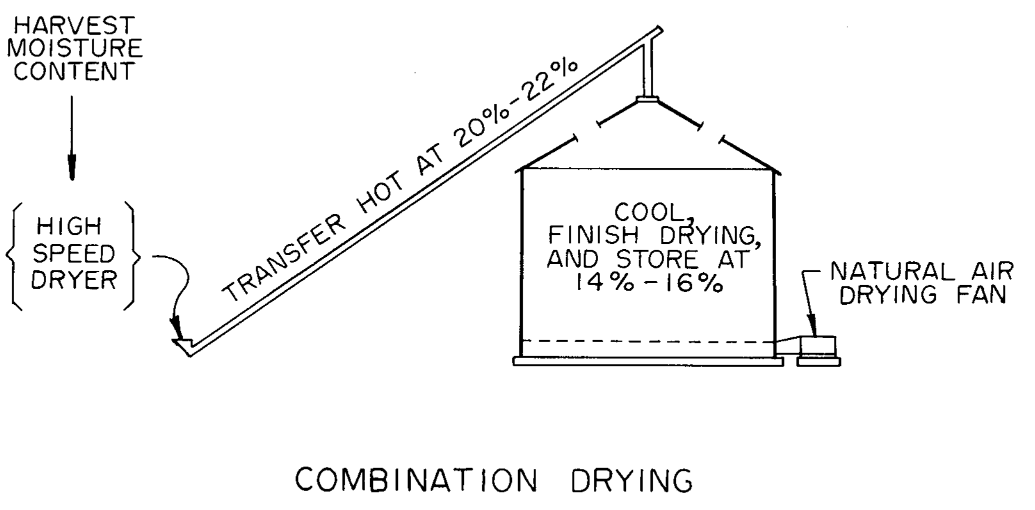


Figure 2. Schematic diagrams for five types of high-speed dryers

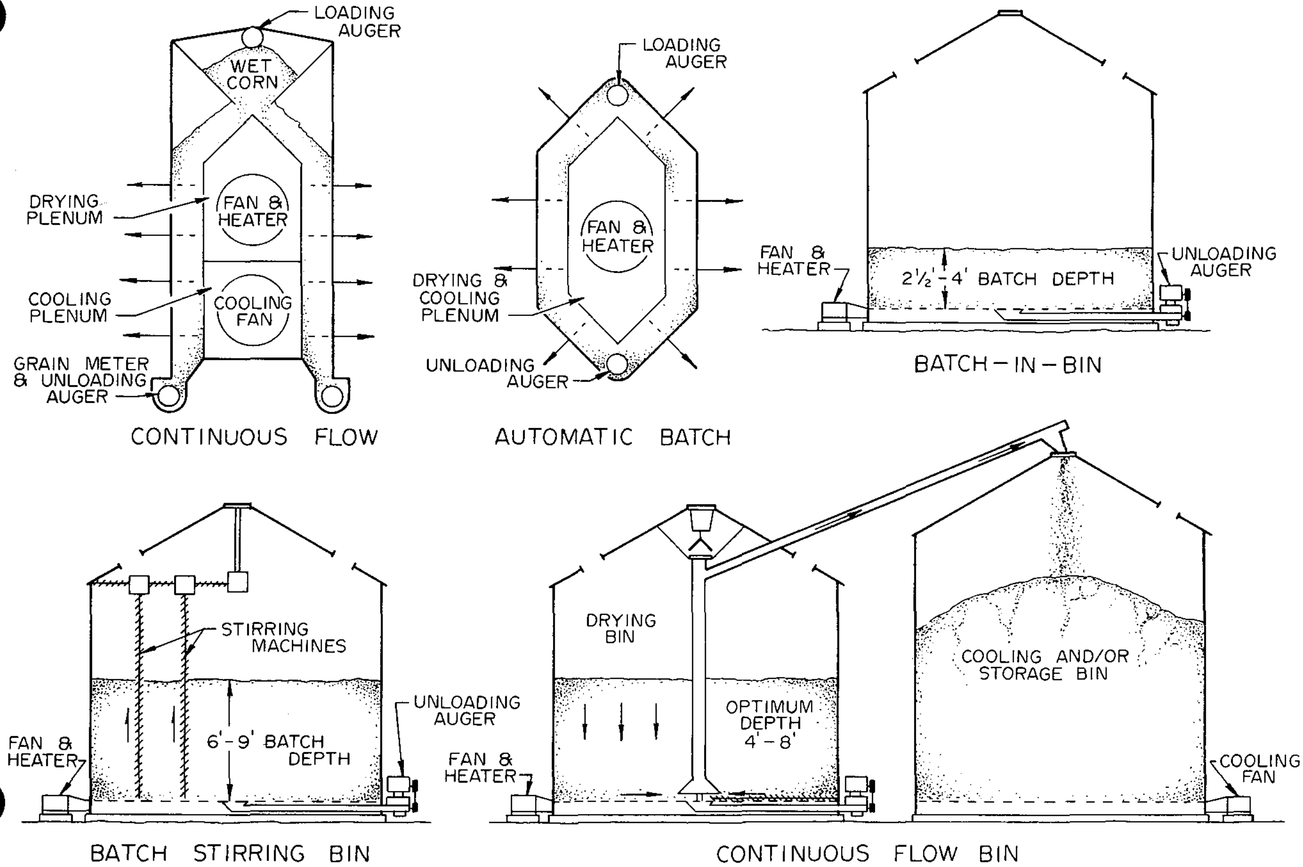


Figure 3. Illustration of in-storage drying

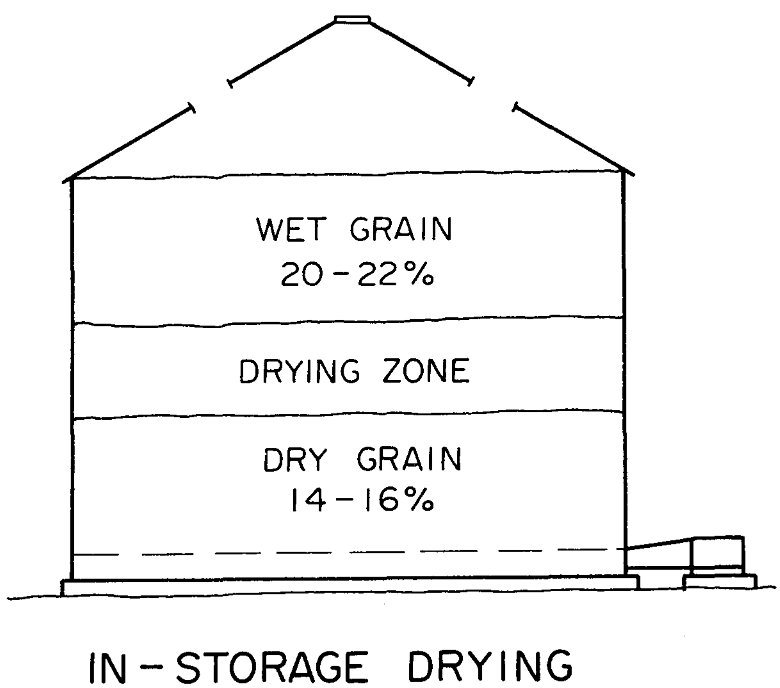
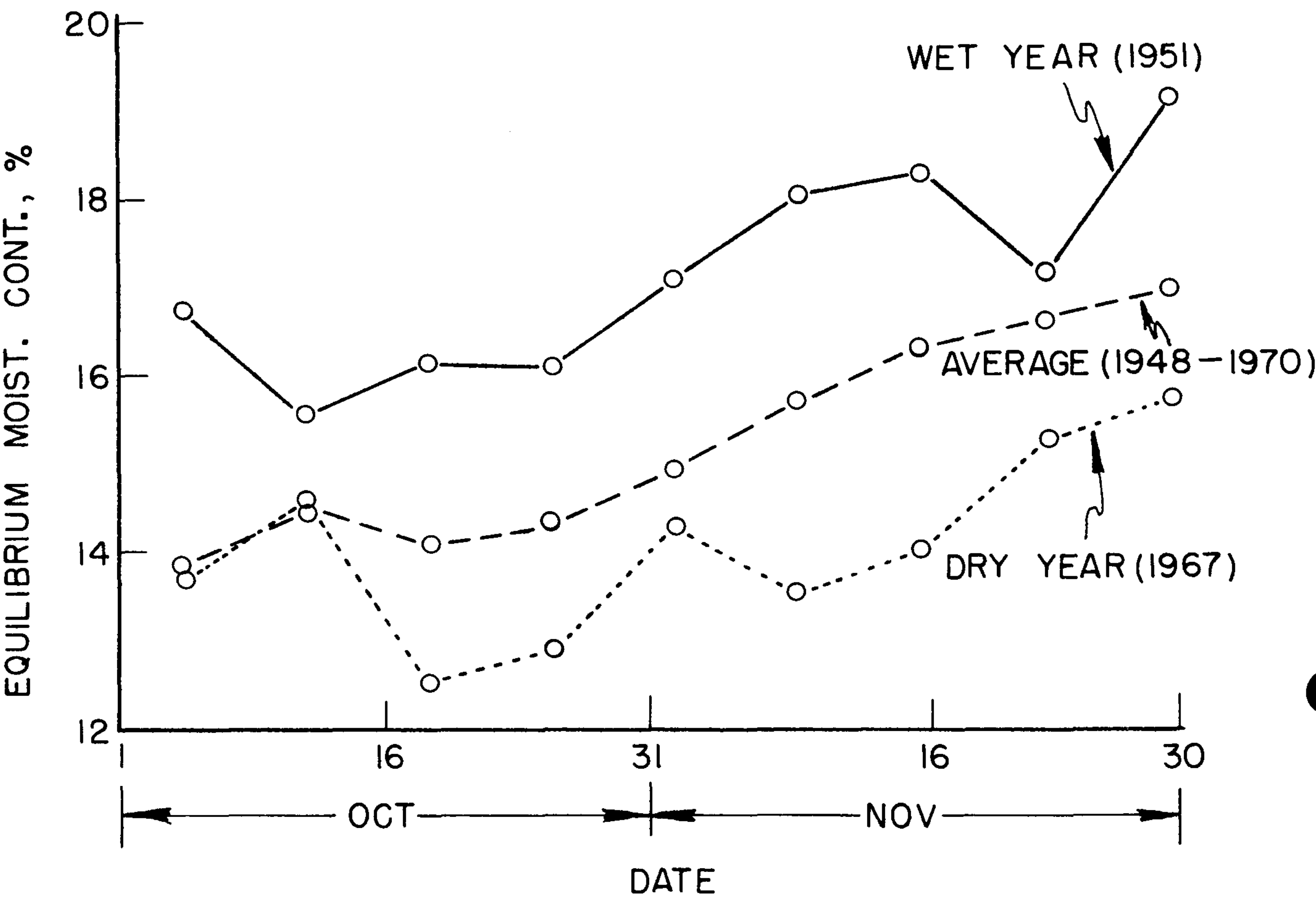


Figure 4. Equilibrium moisture content of shelled corn at St. Cloud, Minn.—23 years of weather data



WARNING: Flowing Grain Is Dangerous

Never enter a grain bin or other grain storage area while the grain is flowing. Flowing grain will exert forces against the body great enough to pull the average size person under the grain in only a few seconds leading to death by suffocation.

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