DRYING CORN

AT THE COUNTRY ELEVATOR

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The change from ear corn to shelled corn harvesting in Illinois has created a large volume of high-moisture corn in the marketing channels. The practice of marketing corn directly from the field has placed much of the burden for conditioning this high-moisture corn on the country grain elevator. The volume of corn dried at Illinois elevators increased from approximately 121 million bushels in 1963 to approximately 228 million bushels in 1969. During this same period, the volume of corn marketed directly from the field increased by 65 percent and intensified the seasonal pressure on drying capacity.

Some elevators have willingly accepted and encouraged this added responsibility as an opportunity to increase profits through expanded services to farmers. Other elevators have been forced to accept the added burden of drying as the only means of maintaining their competitive position. Nearly every elevator operator in the state has had to face the decision of adding drying capacity to existing facilities; to decide wisely, he needs information on management techniques and on costs and returns associated with conditioning high-moisture corn. This report should help both elevator managers and farmers select conditioning systems and improve the efficiency of their grain conditioning equipment.

DRYING COSTS

Whichever method is used to reduce the moisture level of corn — heated air, unheated air, or natural drying in the field — the basic principles involved remain the same. The energy that must be applied to the kernel is determined by basic physiological relationships in all three cases, but the relative efficiency of a specific technique and the cost of the energy may vary widely.

Energy Requirements

The energy required to vaporize free water at 212° F. (the latent heat of vaporization) is 970 Btu's per pound of water. Vaporization at lower temperatures requires more energy; at 150° F., for example, 1,008 Btu's per pound are required. Vaporization of grain moisture requires even more energy since the moisture in grain is not as readily available as free water. Drying shelled corn that contains 22 percent or more moisture at 150° F. requires about 1,100 Btu's per pound of water removed. As corn moisture is reduced below 22 percent, the latent heat of vaporization increases: at 14-percent moisture content the latent heat of vaporization is about 1,170 Btu's.

These latent heat of vaporization values can be approached in slow drying systems characterized by low airflow rates; in heated air drying, however, where airflow may be as high as 100 cfm per bushel or more, efficiency is sacrificed for speed in drying. Heated air drying of shelled corn in the fall, when outdoor temperatures are in the 50's and 60's, will typically require about 2,000 Btu's of fuel per pound of moisture removed. In the winter, when temperatures are lower, more heat will be required.

Costs of Drying

The choice among alternative systems for drying grain should be based upon the costs of drying and the quality of the dried corn. Costs of drying can be classified as either direct or indirect; depending upon the individual elevator, the specific cost items in each category may differ. Direct costs include fuel and power used as energy in removing moisture, labor required to service and operate the dryer, taxes, insurance, and repairs associated with the dryer. Indirect costs include depreciation, interest on investment, administrative salaries, and a prorated share of associated services such as handling, weighing, sampling, etc. Direct costs per bushel are relatively constant for any volume. Indirect costs per bushel decline rapidly as volume increases.

Energy requirements and the price of fuel provide an estimate of the minimum cost for removing water from corn. Assuming that an energy input of about 2,000 Btu's is required to remove one pound of water from shelled corn and that the price of natural gas is seven cents per therm,[1] the fuel cost would be 0.14 cent per pound of water removed. To dry a bushel ten percentage points requires the removal of approximately nine pounds of water at a fuel cost of about 1¼ cents. Since no commercial dryers use energy 100 percent efficiently, this figure indicates a lower limit on fuel costs rather than the average fuel cost for commercial installations.

Survey of Drying Costs

Besides variations in ambient air conditions, gas rates, and the moisture content of the corn, other factors, less well-defined, affect the degree to which any individual elevator can approach a minimum cost level. To obtain estimates of costs under actual operating conditions, 30 elevators in central Illinois were asked to provide data on their drying operations for the four crop years 1967-68 through 1970-71.

The four-year average of selected cost items for each elevator is shown in Table 1. Averages for gas costs, dryer size, hours of operation, total bushels dried, and beginning and ending moisture levels were all calculated directly from data provided by elevator managers. Most

[1] 1 therm = 100,000 Btu's.

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Table 1. Four-year average costs of drying at selected country elevators in Illinois, 1967-70

Elevator code	Capacity (bu. per hr. per 5 points)	Annual hours of drying	Actual bushels dried	Equivalent bushels dried	Initial moisture	Ending moisture	Points removed	Cost in cents per bushel per point: Gas	Electricity	Labor	Deprec. and repairs	Taxes	Interest	Insurance	Total
1	2,000	350	278,512	406,868	22.1	15.0	7.1	.1028	.0380	.0469	.1941	.0331	.1029	.0203	.5381
2[a]	2,000	643	775,147	1,375,996	23.0	14.2	8.9	.1030	.0291	.0272	.1123	.0117	.0368	.0042	.3243
3	760	975	407,733	473,605	22.1	13.8	8.4	.2825	.0397	.0921	.0860	.0147	.0460	.0055	.5665
4[a]	1,400	784	245,413	484,350	23.4	14.0	9.4	.1487	.0408	.0943	.0740	.0107	.0368	.0073	.4126
5	2,200	1,221	857,674	1,644,275	23.5	13.8	9.8	.1230	.0669	.0447	.0551	.0045	.0157	.0021	.3120
6[a]	1,800	1,213	1,025,000	1,859,050	24.0	15.0	9.0	.0715	.0496	.0388	.0795	.0080	.0236	.0029	.2739
7[a]	2,800	1,572	804,903	1,395,075	23.2	14.4	8.9	.1305	.0516	.0573	.0795	.0117	.0405	.0087	.3798
8	1,400	228	127,896	216,070	22.7	13.8	8.8	.1220	.0315	.0568	.2650	.0466	.1339	.0317	.6875
9	450	791	140,098	178,945	21.5	15.0	6.5	.2205	.0323	.2375	.1279	.0163	.0547	.0251	.7113
10[a]	1,000	680	155,500	291,434	22.0	14.0	8.0	.6431	.0640	.2927	.6861	.1139	.3369	.0418	2.1785
11	1,500	792	480,000	760,545	22.2	14.2	8.0	.0849	.0480	.0681	.0862	.0126	.0432	.0086	.3516
12[a]	2,500	489	1,050,375	1,361,750	21.5	15.0	6.5	.0788	.0277	.0201	.1139	.0182	.0660	.0075	.3322
13	1,550	1,063	675,000	1,158,177	23.3	15.0	8.3	.0736	.0354	.0505	.1016	.0606	.0519	.0064	.3800
14	1,300	332	128,994	203,252	21.0	14.5	6.5	.1237	.0609	.0992	.2139	.0387	.1251	.0216	.6831
15	1,400	572	248,750	388,892	22.0	15.0	7.5	.0831	.0335	.0826	.2244	.0340	.1160	.0231	.5167
16	500	328	78,250	145,232	23.4	15.1	8.3	.1360	.0569	.1221	.3661	.0474	.1631	.0185	.9101
17[a]	2,500	837	1,707,250	1,508,865	18.8	15.0	3.8	.1429	.0835	.0345	.4149	.0782	.2312	.0264	1.0116
18	1,000	430	364,750	359,865	19.3	14.3	5.0	.0771	.0377	.0744	.1112	.0168	.0576	.0069	.3817
19	3,350	695	712,500	856,590	20.6	14.9	6.0	.1423	.0950	.0566	.2720	.0344	.1181	.0144	.7328
20	1,600	825	427,500	710,010	22.0	14.5	7.5	.1335	.0692	.0857	.2105	.0317	.1089	.0124	.6519
21	750	531	246,250	396,473	22.5	14.0	8.5	.1590	.0209	.0796	.2165	.0345	.1185	.0146	.6436
22	2,000	746	1,030,000	1,674,022	23.4	15.8	7.7	.2713	.1628	.0242	.0523	.0080	.0275	.0054	.5515
23[a]	1,000	395	280,046	309,010	19.6	14.0	5.7	.3852	.0352	.0712	.3287	.0595	.2039	.0210	1.1047
24	1,200	221	155,465	224,320	19.9	13.0	6.8	.1647	.0142	.0555	.0675	.0047	.0162	.0020	.3248
25	1,500	200	202,323	239,283	19.5	13.6	5.9	.2424	.0084	.0475	.1626	.0272	.0930	.0116	.5927
26	1,000	454	453,807	444,933	19.2	14.1	5.1	.3036	.0287	.0581	.2005	.0336	.1164	.0118	.7527
27	1,400	695	369,680	405,910	19.4	13.5	5.9	.1809	.0386	.0909	.1746	.0289	.0990	.0102	.6231
28	1,000	584	404,400	429,293	19.5	14.1	5.4	.1784	.0384	.0776	.2111	.0358	.1226	.0126	.6765
29[a]	1,000	390	526,681	524,347	19.3	14.3	5.0	.1626	.0208	.0421	.1891	.0338	.1159	.0119	.5762
30	4,500	900	1,552,521	3,222,025	25.5	15.0	10.5	.1229	.0266	.0158	.0805	.0114	.0390	.0049	.3011

[a] Only three years of data were available.

electricity costs were estimated on the basis of motor size and hours of operation. To maintain comparability among elevators, labor costs were calculated by assuming that all elevators operated 24 hours per day, using ¼ of a man's time during the 8-hour working day and all of a man's time at time and one-half for the remaining 16 hours.To avoid variability due to accounting procedures, the reported data on depreciation, repairs, taxes, interest, and insurance costs were replaced with a calculated value based on a percentage of the original investments. The taxes and insurance rates in effect in each geographical area were obtained from county tax offices and insurance agents. The volume of grain dried was converted to the number of equivalent bushels of 20.5-percent moisture corn dried to 15.5 percent, on the basis of actual pounds of water removed. As shown in Table 1, gas costs per bushel per point ranged from a low of .071 cents to a high of .643 cents. Total costs varied from .274 cents to 2.18 cents. Explaining these differences could provide guidelines for increasing drying efficiency at the country elevator.

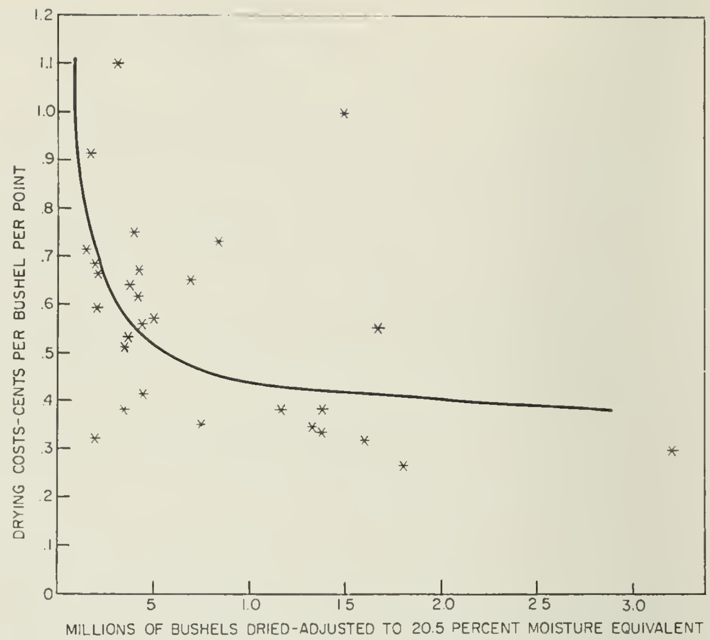
Yearly variations in average costs and volumes for all elevators (Table 2) suggest an important relationship between total costs, initial moisture, and volume dried. The cost per bushel per point for 1967 is the lowest for the 4-year period, primarily because of the large volume of extremely wet corn. The highest cost per bushel per point occurs in 1970 when, because of corn blight, volume and moisture levels were unusually low. This indicates that many of the differences in the average costs of drying are outside the control of the elevator industry and are dependent upon the vagaries of nature.

Table 2. Average values of selected drying data for 30 Illinois elevators for each of four years

	1967	1968	1969	1970
Average bushels dried	1,296,025	398,353	493,316	385,765
Average initial moisture	23.7	20.4	21.5	20.9
Average ending moisture	14.5	14.4	14.4	14.0
Average number of points removed	9.2	6.0	7.1	6.9
Average gas cost (cents per bushel per point)	.1443	.1878	.1578	.1844
Average total cost (cents per bushel per point)	.4095	.6196	.4886	.6559

Factors Affecting Cost Differences

The relationship between drying costs and volume dried is illustrated in Figure 1. Not all the variation in costs can be explained by differences in volume, and two elevators with identical volume often have widely divergent costs per bushel, as the figure shows. Identification of the other factors that help explain these variations requires statistical techniques capable of separating the effects of several variables acting simultaneously on drying costs.



Average drying costs at Illinois elevators, 1967-1970. Asterisks show costs and volume data for elevators reporting. (Fig. 1)

A regression equation in which total cost per equivalent bushel was a function of the variables of volume, capacity, points removed, type of dryer, and type of fuel accounted for 64 percent of the variation in total costs. Capacity and volume were assumed to have a nonlinear relationship to cost rather than a straight line relationship (see Fig. 1), so these two variables were entered in reciprocal form — 1/capacity and 1/volume. The results of model 1 in Table 3 show that volume, points removed, type of fuel, and type of dryer are all significant in explaining variations in total cost per bushel. Costs decline as volume increases — that is, as 1/volume decreases — and as the number of points removed increases. Dryers operating on natural gas have lower costs than those on propane. A batch-type dryer has lower total costs than a continuous flow dryer; this is not a result of greater operating efficiency, however, but reflects the lower depreciation costs due to the greater age of and lower initial investment in those batch dryers in the sample. Capacity was not a significant variable in explaining total costs.

The results of model 2 show the effect of these same variables on gas cost per bushel. Only the variables of type of fuel used and volume dried are significant. Since natural gas prices per therm are usually less than prices of propane, gas costs per bushel were significantly lower at elevators with natural gas. The addition of gas prices (cents per therm) to this model lowered the level of significance and did not increase the percent of explained variation; given the type of gas, little variation in prices was found.

An increase in volume dried was associated with a decrease in gas costs per bushel. One explanation is that larger volumes allow more continuous dryer operation.

Table 3. Regression coefficients relating selected independent variables to the cost of drying grain at Illinois elevators

Independent variable description	Regression coefficients from		
	Model 1	Model 2	Model 3
Type of dryer[a]	−1.31 (−3.33)[b]	−.122 (−.80)	−.191 (−1.24)
Initial moisture			−.094 (−2.08)
Points removed	−.16 (−2.88)	−.195 (−.88)	.071 (1.46)
Type of fuel[c]	−.88 (−3.08)	−.537 (−4.81)	−.543 (−4.95)
1/capacity[d]	.258 (1.31)	.024 (.31)	.044 (.58)
1/volume[e]	.376 (10.48)	.077 (5.50)	.073 (5.31)
Dependent variable[f]	1	2	2
Sample size	107	107	107
R^2	64	38	41

[a] Continuous flow = 1, batch = 0.
[b] Numbers in parentheses are t-values. Values greater than ±1.98 identify coefficients that are significantly different from zero at the 5 percent level.
[c] Propane gas = 0, natural gas = 1.
[d] The rated capacity is measured for 5 points removal from 10 bushels per hour.
[e] Volume is measured as the equivalent bushels of 20.5 percent corn.
[f] Only two dependent variables were used: 1 is the total cost of drying the equivalent of 20.5-percent corn to 15.5 percent (removing 5 points of moisture); 2 is the gas cost of drying.

Restarting the dryer every day during cold weather results in more lost heat than does the continuous operation frequently associated with large volumes.

It is evident from Table 3 that a batch dryer is neither more nor less efficient than a continuous flow dryer. Fuel requirements for moisture reduction vary with airflow and drying temperatures, factors that differ more from dryer to dryer than between batch and continuous flow dryers.

As discussed on page 2, the theoretical latent heat of vaporization decreases as the moisture level is increased. The results of model 3 substantiate this conclusion with a significant coefficient for initial moisture. The coefficient shows that the higher the initial moisture, the lower the cost of evaporating water. An increase of one percentage point in the initial moisture level decreases gas cost by .094 cents per bushel per 5 points. It must be recognized, however, that capacity is reduced as moisture level is increased and, in periods of pressure on elevator capacity, the lower costs of drying may be more than offset by the loss of volume and the risk of quality loss. Including initial moisture as a variable increases the level of significance for the other variables over that in model 2; the sole exception is 1/volume, which changes negligibly. The sign of the coefficient for points of moisture removed is reversed from that shown in model 2, although the coefficient is not statistically significant in either case.

Presumably, ending moisture would have an effect similar to initial moisture — the lower the ending moisture, the higher the cost. When this variable was included, however, the coefficient was not significant, because nearly all elevators dried to 14.0 or 14.5 percent and insufficient variation existed to measure its effect.

This analysis implies three important conclusions for country elevators. (1) The ratio of volume to capacity is the most important factor in explaining variations in the total cost of drying. Any action the elevator can take to increase the volume of corn dried with a given size of dryer will lower costs. Few elevators are currently using the dryer at more than 25 percent of its total annual capacity. (2) Economies of size in drying as measured by capacity are relatively unimportant in either gas cost or total cost per bushel. Maximum volume for a given capacity is a more relevant consideration. (3) Drying higher moisture corn will reduce the total capacity of a given size of dryer but it does not increase the drying cost per bushel per point.

Shrink During Drying

A cost often overlooked in drying corn is the shrink that occurs during drying. The decrease in the total weight of corn as moisture is removed should be included as part of the cost of drying. The loss of water and the loss of dry matter during the drying process can be estimated by use of any of several shrink factors. The shrink resulting from the loss of water only is easily computed since removal of one pound of water from 100 pounds of corn reduces its total weight to 99 pounds (see Appendix A). There is evidence, however, that besides water loss there is also a loss of dry matter during drying. This latter loss (often called invisible shrink) may vary from nearly zero to several percent, depending upon handling procedures. This loss of weight becomes a part of the cost of drying at the elevator that must be covered by drying charges or by a shrink factor applied when wet grain is delivered by farmers.

Alternative methods of including invisible shrink are shown in Table 4. The first line in the table shows the bushels remaining after drying when only loss of water is assumed. The Minary Chart values given on the second

Table 4. Bushels of 15.5-percent moisture corn remaining from 1,000 bushels with shrink computed by use of four alternative adjustment factors

Adjustment factor	Beginning moisture (percent)							
	16	18	20	22	24	26	28	30
Dry matter basis[a]	994	970	947	923	899	876	852	828
Minary chart	989	965	942	918	894	871	847	823
Factor of 1.2[b]	994	970	946	922	898	874	850	826
Factor of 1.25[c]	994	969	944	919	894	869	844	819

[a] These values were obtained by dividing the percentage of dry matter in the corn at the beginning moisture level by the percentage of dry matter remaining at 15.5 percent moisture and multiplying this ratio by 1,000 bushels. No invisible shrink was included in the computation.
[b] These values were calculated by multiplying .012 × points of moisture removed × 1,000 bushels and subtracting from 1,000 bushels. The factor 1.2 × moisture removed gives the shrink per 100 bushels.
[c] These values were calculated by multiplying .0125 × points of moisture removed × 1,000 bushels and subtracting from 1,000 bushels.

line include an invisible shrink of ½ percent of the wet weight. (A more complete table of the Minary Charts is given in Appendix B, Table 4.) The last two shrink factors shown in Table 4 give a convenient estimate of shrink as a percent of the total bushels times points removed. Thus the shrink on 100 bushels with a reduction of 5 points of moisture is calculated, according to line 3, as 1.2 times 5 = 6 bushels. At moisture levels below 18 percent, it is evident that a factor of 1.25 provides no allowance for invisible shrink; at 24 percent, the factor of 1.25 is equivalent to the Minary Charts (that is, it is equivalent to ½-percent invisible shrink); above 24 percent, the 1.25 factor allows more invisible shrink than the Minary Charts.

MANAGEMENT TECHNIQUES FOR CONDITIONING CORN

Most elevator managers will find it profitable to provide drying services for farmers, if only to increase their volume of business. Once the decision has been made to install drying equipment or to expand existing capacity, several other management decisions must be made that will determine the profitability of the enterprise. The kind and size of dryer to use, the amount to charge for drying, and whether alternatives to drying can reduce drying costs are among the most important.

Selecting the Kind of Dryer

The size and kind of dryer that will best meet the needs of any particular elevator depend on the maximum volume of grain to be dried in any one year, the pattern of deliveries, and the resulting quality of the dried grain. Four basic types of dryers are currently on the market, with each type available from a number of reputable companies.

The relative cost of the alternative dryers described below depends primarily on the volume of corn dried. Investment costs per bushel of capacity are generally less for bin-type dryers, but labor costs are higher and physical space requirements make these dryers generally impractical for elevator use. Operating costs are quite similar for all dryers. As discussed on page 4, batch dryers tend to have lower investment costs per bushel dried but there is no significant difference in gas or operating costs.

In-storage layer drying is a method of filling and drying a bin of grain a layer at a time with each layer partially or completely dried before the next layer is added. The grain is dried by forcing air through a perforated floor or through an air duct system in the bottom of the bin. Although problems of overdrying the lower layers are occasionally encountered, the use of small quantities of heat — controlled by a humidistat or thermostat — will minimize this problem. For small volumes, layer dryers are a relatively low-cost way to provide good quality dry corn.

Batch-in-bin dryers increase the speed of in-bin drying by spreading a shallow layer of grain 2 to 4 feet deep over the perforated floor. This type of dryer uses drying air temperatures of up to 140° F. and airflow sufficient to dry the batch overnight. The dried batch is cooled, then removed from the bin with a sweep auger; the grain mixing that takes place during the unloading is sufficient to equalize any differences in moisture content that may have been created in the batch.

Greater drying bed depths are possible when stirring mechanisms such as suspended augers or recirculating conveyers are used to stir and mix the batch during the drying process.

Batch-in-bin dryers have an advantage of greater capacity per dollar of investment, but they require considerable space relative to capacity and are not well-adapted to large-volume commercial operations.

Batch dryers are designed with columns of grain, usually 12 to 24 inches thick, wrapped around a central air plenum. Airflow may approach 100 cubic feet per minute (cfm) per bushel and drying air temperatures of 180° F. may be used. The dryers are designed to remove 10 points of moisture in 2 to 3 hours; the grain cools for an additional 20 to 30 minutes after the heat is shut off. The installation of automatic controls to load and unload batch dryers has increased the popularity of these dryers for commercial elevators that have sufficient wet corn holding capacity.

Continuous flow dryers are better adapted to the commercial elevator's requirements of large volume, high capacity, and minimum labor than the preceding three types. The continuous flow of grain through the dryer can be adjusted according to the amount of moisture removal required. The relationship of airflow to grain flow is either cross, counter, or concurrent, or a combination of concurrent- and counterflow.

In a crossflow dryer, the flow of drying air is perpendicular to the flow of grain; in a concurrent-flow dryer, the air flows in the same direction as the grain; and in a counterflow drier, the airflow is opposite to the movement of the grain. Continuous flow dryers are generally operated with drying air temperatures in the 160° to 200° F. range, although some concurrent-flow dryers employ temperatures of 300° F. and higher. Thompson *et al.*[1] reported that acceptable corn quality was obtained with drying air temperatures up to 300° F., using airflow rates of 50 to 90 cfm per square foot of drying-bed area in grain depths of 2 to 4 feet. According to the report, crossflow dryers overdried the grain where the air entered and underdried it on the exhaust side. With the concurrent-

[1] Thompson, T. L., G. H. Foster, and R. M. Peart, April, 1969. *Comparison of Concurrent-Flow, Crossflow, and Counterflow Grain Drying Methods,* Marketing Research Report No. 841, U. S. Department of Agriculture, Washington, D. C.

flow and counterflow methods, however, each kernel of grain was subjected to the same drying conditions and the entire lot was dried to a uniform moisture content. Counterflow dryers removed more moisture per foot of drying bed than either of the other two dryers. The concurrent-flow process removed most of the moisture during the initial stages of drying and relieved some of the kernel drying stress with a built-in tempering period.

Drying capacities of continuous flow dryers range from approximately 100 bushels per hour to 2,000 bushels per hour or more, on the basis of 5 points of moisture removal. If a moisture reduction of 10 or more points is required, the grain is sometimes passed through the dryer more than once. Usually, wet grain enters at the top of the dryer, flows through a heated air section, then passes through an unheated air section from which it is discharged dry and cool. Some dryers have no cooling section; on others, the cooling section can be converted to a heat section when heated air drying is combined with aeration in the dryeration process.

Dryeration is a process in which hot grain is removed from a heated air dryer and placed in a separate bin before drying is complete. The hot grain is held without cooling for a few hours of tempering. Excess moisture is then removed by slow cooling. Typically, corn discharged from the dryer at temperatures in the range of 120° to 140° F. and then cooled to 50° F. or below with an airflow of one-half cfm per bushel will lose 1 to 3 additional percentage points of moisture. Cooling corn from a dryer temperature of 160° to 180° F. will reduce the moisture content by 4 to 6 percent. Dryeration, which was developed as a method of improving corn quality by reducing stress cracks and kernel brittleness,[1] thus increases the capacity of heated air dryers by eliminating the cooling period and by removing the grain from the dryer before drying is completed.

Selecting the Size of Dryer

Because of the uncertainties of weather, delivery pattern, corn production, and moisture content of the corn, the total drying capacity that would generate the greatest net return for any particular elevator cannot be accurately determined; some guidelines, however, are available. It is obvious, for example, that having a drying capacity equal to the maximum volume of corn delivered in any one day would result in underutilization of the dryer except for the day on which this maximum was received. It is also obvious that a drying capacity equal to the average daily receipts of corn over the total season would be inadequate during much of the harvest peak. While this would permit maximum use of the dryer and minimum cost per bushel dried, the business lost during the rush season and the risk of damaged corn would offset the lower drying costs.

[1] McKenzie, B. A., *et al. Dryeration — Better Corn Quality with High-Speed Drying,* AE-72, Agriculture College Cooperative Extension Service, Purdue University, Lafayette, Indiana.

The optimum drying capacity is therefore less than the maximum daily receipts of wet corn and greater than the average daily receipts during the year. This range may be narrowed further by noting that most wet corn may be held as long as three days before drying. Thus, maximum drying capacity should be less than the average receipts for the three largest consecutive days. Minimum drying capacity should be at least equal to the average daily receipts during the harvest season. The exact interval between these two extremes depends upon the pattern of delivery, the costs and returns of drying and merchandising, and the expected moisture levels of the corn.

Determining optimum capacity. In order to simultaneously consider all of these restrictions, a linear programming model was constructed to represent the decision alternatives available to the elevator manager. Sensitivity analysis was then used to determine the effect of various delivery patterns and profit levels on the optimum size of dryer.

For purposes of analysis the drying season was divided into three periods: a 3-month harvesting period, a 7-day peak during harvest, and the remainder of the wet corn season. It was assumed that the dryer could be operated 24 hours per day during the 7-day peak, 500 hours during the entire 3-month harvest period, and a total of 1,168 hours during the entire drying season. Rated capacity for removal of 5 points of moisture was used in determining volume dried per hour.

For purposes of the model it was assumed that the annual fixed costs of the dryer were $7.58 per bushel of capacity purchased regardless of the size of the dryer or the volume of corn dried. Variable costs of 1.25 cents per bushel for removal of 5 points were used during most of the year but were increased to 1.35 cents per bushel during the harvest season because of the possible need for overtime labor. It was assumed that an average of 5 points of moisture was removed from all corn received.

An elevator's return on drying is the custom drying charge paid by farmers; in the case of elevator-owned corn, returns may be calculated from the moisture discount as illustrated in Appendix B. Both of these methods, however, fail to recognize the influence of drying capacity on the total volume of corn and its effect on merchandising and storage income. An elevator capable of receiving and drying corn as rapidly as farmers wish to deliver it frequently attracts additional volume from competitors unable to provide this service. It is often difficult to place a specific monetary value on this effect but for purposes of illustration an arbitrary 1 cent per bushel dried was used in this model. In the following discussion and tables, returns to drying plus the income-creating value of a dryer are referred to as gross returns to drying. For example, a gross return of 6 cents per bushel consists of a 5-cent farmer payment for drying and a 1 cent per bushel allowance for the value of the service in attracting additional merchandising and storage income.

Calculations. The first example used was an elevator with a potential annual volume of 150,000 bushels of wet corn — 112,500 bushels of which are delivered during harvest and 37,500 of that 112,500 bushels delivered during a 7-day peak during harvest. The results are shown in Table 5. The effect of different levels of gross returns on dryer size and on the volume of corn dried was determined by parametric programming.

Table 5. Optimum dryer size for different levels of returns when potential annual volume is 150,000 bushels[a]

Gross returns to drying (cents per bushel)	Bushels dried during: 7-day peak	3-month harvest	Total season	Dryer size (bu./hr.)
2.00	4,200	16,700	54,200	25
2.48	25,200	100,200	137,500	150
5.86	35,000	110,000	147,500	208
7.67	36,875	111,875	149,375	224
8.00	37,500	112,500	150,000	458

[a] The seasonal delivery pattern was 25 percent (37,500 bushels) of the total volume available during the 7-day peak and 75 percent (112,500 bushels) of the total during the 3-month harvest.

At gross returns of 2 cents, much of the harvest rush is turned away because annual profits are too low to justify idle dryer capacity during a large portion of the year. At returns of 2.48 cents, dryer size is sufficient to permit drying all but 12,300 bushels of corn delivered during the 7-day peak. At higher levels of returns, a larger dryer is purchased even though there is excess capacity during most of the drying season. At gross returns of 5.86 cents per bushel, all but 2,500 bushels of the peak deliveries are dried. At gross returns of 8 cents, drying capacity is increased to 458 bushels per hour, and it becomes profitable to dry all the corn available. The same relationship holds true at larger volumes, as illustrated for 1,000,000 bushels in Table 6.

The effect of different delivery patterns is shown in Table 7. As the percent of volume delivered during the 7-day peak increases (potential annual volume and harvest deliveries remaining the same), dryer size increases but not enough to handle the entire volume of corn. Less grain is dried in pattern 7 than in pattern 2, since 10,000 bushels of grain delivered during the 7-day peak are turned away. Similarly, an increase in dryer sizes is evident in delivery patterns 4 through 6 as the 3-month harvest deliveries increase, all else remaining constant. Total volume dried, however, increases with the larger dryer because of the opportunity to dry more of the 7-day peak deliveries.

A comparison of Table 5 with pattern 5 of Table 7 reveals that, for a given pattern of deliveries and gross returns to drying, volume and capacity are directly related: if volume is increased by some multiple, dryer size is increased by the same multiple. Thus the entries in Table 7 can be converted to their equivalent for any other annual volume; for example, dryer sizes for a volume of 500,000 bushels would be one-half the recommended sizes in Table 7.

Table 6. Optimum dryer size for different levels of returns when potential annual volume is 1,000,000 bushels[a]

Gross returns to drying (cents per bushel)	Bushels dried during: 7-day peak	3-month harvest	Total season	Dryer size (bu./hr.)
2.00	84,000	334,000	584,000	500
2.41	168,000	418,000	918,000	1,000
5.86	175,000	425,000	925,000	1,042
6.61	205,000	455,000	955,000	1,250
9.25	250,000	500,000	1,000,000	1,615

[a] The seasonal delivery pattern was 25 percent (250,000 bushels) of the total volume available during the 7-day peak and 50 percent (500,000 bushels) of the total during the 3-month harvest.

Because of the many variables involved, no simple rule of thumb for selecting a dryer size can provide accurate results. Some examples, however, may be useful when combined with the pattern of relationships shown in Tables 5 through 7. Assume that a gross return to drying of 6 cents per bushel is anticipated. This could be 1 cent per bushel per point for 5 points of moisture removed plus 1 cent per bushel for the value of customer service. If receipts are highly concentrated with 75 percent of the wet corn coming during the 3-month harvest and 50 percent of annual volume received during the 7-day peak, dryer size may be estimated as 292 bushels of capacity for each 100,000 bushels of annual volume.

Not all of the peak receipts can be economically dried unless drying charges are increased — see pattern 7 of Table 7. If the receipts can be distributed over a longer period — through early season specials or by higher charges during the heaviest delivery period — a smaller dryer is sufficient. With a delivery pattern of 50 percent at harvest and 25 percent during the 7-day peak, each 100,000 bushels of volume require only 104 bushels per hour of drying capacity. Only when the 7-day peak drops

Table 7. Optimum dryer size for varying delivery patterns when gross returns are 6 cents per bushel and annual volume is 1,000,000 bushels

Pattern number	Percent of annual volume delivered in: 7-day peak	3-month harvest	Dryer size (bu./hr.)	Annual volume dried
1	10	50	1,000	1,000,000
2	10	75	1,300	1,000,000
3	10	100	1,800	1,000,000
4	25	50	1,042	925,000
5	25	75	1,250	960,000
6	25	100	1,500	985,000
7	50	75	2,917	990,000
8	50	100	2,500	920,000
9	75	100	3,333	810,000

below 25 percent of annual volume is it profitable to purchase drying capacity adequate to dry all the wet corn available at charges of 1 cent per bushel per point. For a pattern of 50 percent at harvest and 10 percent during the peak, dryer size may be estimated as 100 bushels per hour capacity for each 100,000 bushels of potential volume. The ratio for other patterns can be easily calculated from Table 7.

In selecting the optimum dryer size, the manager should not only examine past records but also consider potential changes in volume handled and in the pattern of receipts in future years. He should also evaluate the elevator's policies on charges and delivery schedules and should weigh alternative methods of handling high moisture corn.

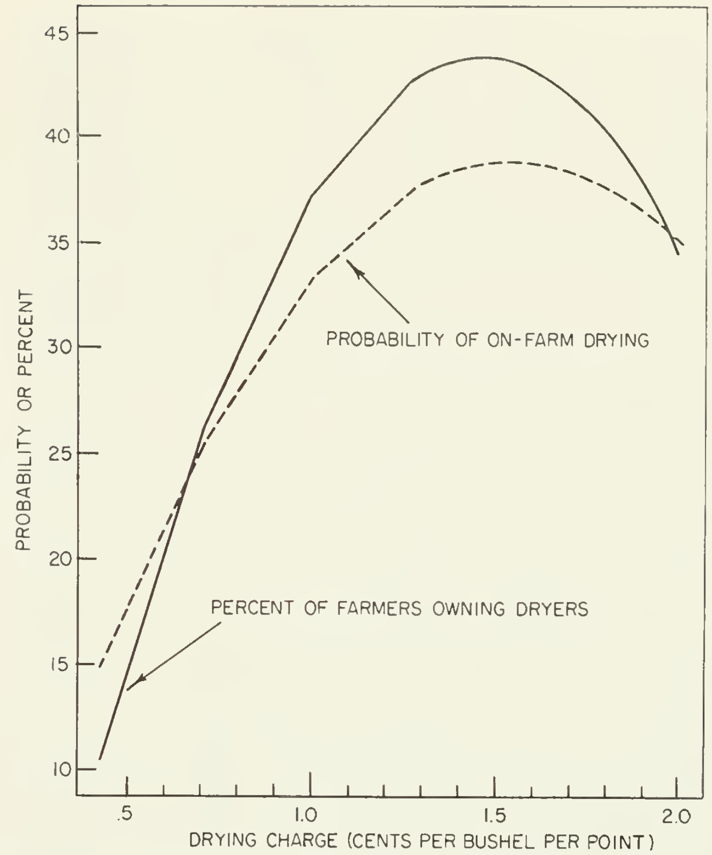
One of the implications of this analysis is that in order for an elevator to provide the seasonal services demanded by farmers, drying charges must be higher than actual costs of operation at full capacity. The greater the seasonal fluctuations in deliveries, the higher the drying charges will have to be for the elevator to profitably dry all the corn the farmers deliver.

Elevator Charges for Custom Drying

Elevators' charges for drying corn have two functions: to cover fixed and variable costs of drying and to adjust the demand for drying services to the capacity available for hire. The costs of drying have already been discussed.

Viewed in the long run, drying capacity can be expanded at a nearly constant cost per bushel, and the equilibrium between demand and supply will occur at the average cost of drying. Shortrun fluctuations in the demand for drying, however, and inherent seasonal patterns of demand result in a shortrun imbalance between the supply of drying capacity and the demand for drying services. Flexible drying charges help allocate the available capacity in such a way that the elevator can dry the maximum volume of grain. During periods of low demand, volume may be increased by setting charges near the cost of operating the dryer. During periods when demand exceeds the capacity of the dryer, higher charges may be necessary to slow the delivery rate of wet corn and avoid a backlog of grain that can go out of condition.

Desirable though it may be to regulate the shortrun demand for drying services, charges much above cost will encourage farmers to seek alternatives to drying at the elevator. Farmer responsiveness to changes in the drying charge is illustrated in Figure 2. Data collected from 436 farmers and 250 elevators regarding the 1967 harvest season indicated that the percent of farmers owning dryers was much higher in areas that reported drying charges of 1 cent per bushel per point than in areas that reported ½ cent per bushel per point. Moreover, because dryers are seldom left idle once they are purchased, this reaction is not readily reversible, and decreasing the drying charge will seldom decrease the number of farmer-owned dryers.



Effect of elevator charges on farm drying. (Fig. 2)

The factors which must be considered by the elevator manager in setting a schedule of drying charges are, therefore, his direct costs of drying, the total cost of drying, the fluctuations in the demand for drying services, and the charges in effect at other elevators in the same market area. If the charges for drying are varied over time, the average charge must be at least equal to the total cost of drying plus reasonable returns to capital and management. Charges below direct costs of drying may increase volume handled but are generally not in the best interests of the industry or the firm. The manager with flexibility to change the level of charges can increase volume handled and hence profits because he can respond to seasonal variations in demand and to the pressures of competition.

Cost Reduction Techniques

Shortrun profits from drying may be increased with charges kept constant either by lowering costs or by increasing volume. As indicated previously, one of the primary determinants of the cost per bushel for drying corn is the total volume dried, and the effect of volume on labor, depreciation, and interest expense per bushel has already been demonstrated. Managerial decisions that can encourage farmers to deliver a larger volume of grain to the elevator for drying include lower charges, special early-season rates, advertising, and general public relations.

There are also several operational techniques a manager can use to lengthen his drying season and thus increase his annual volume. During periods when corn with very high moisture content is being delivered, for example, he may remove 5 to 8 points of moisture, *holding the partially dried corn under aeration* for further drying when deliveries have dropped off. This effectively increases drying capacity, but the additional handling cost may be prohibitive in plants where aerated storage is not coordinated with the drying operation. The limits to storage of partially dried corn are shown in Figure 3 and discussed in the next section, "Alternatives to Drying."

Drying capacity may also be increased by *raising the drying air temperature, increasing the airflow in the dryer, or both.* Higher air temperatures should be used cautiously, however, to avoid excessive kernel temperatures and possible problems with quality (page 13).

During the peak of harvest, *scheduling deliveries* from producers will increase utilization of available capacity. Advance scheduling can also improve customer relations, since producers can plan their harvesting and delivery rates and avoid waiting lines and delays at the elevator. The elevator manager benefits from a more even flow of wet grain to the dryer and an extended drying season.

Blending different moisture levels of grain is a common technique for lowering the average moisture content of the wet grain without drying. This practice currently meets grading standards but does not, however, increase the storage life of the wet corn. The rate of deterioration in a blend of moisture levels is the same as that of the wettest corn in the mixture. A moisture range of 2 or 3 points will seldom create any problems in a blend and in fact is probably unavoidable, given the facilities and practices found at most elevators. But blends of corn where the range of moisture is as great as 8 or 10 points should be avoided unless the blend is to be dried or consumed within the storage limits of the wettest grain in the mixture.

Dryeration (see page 7) increases dryer capacity but has little effect on the total cost of conditioning the corn. Reduced fuel costs and increased capacity per dollar of investment in drying equipment are offset by increased power requirements for aeration, investments in holding bins and associated equipment, and handling costs. The quality of the dried grain is the most important advantage of this technique.

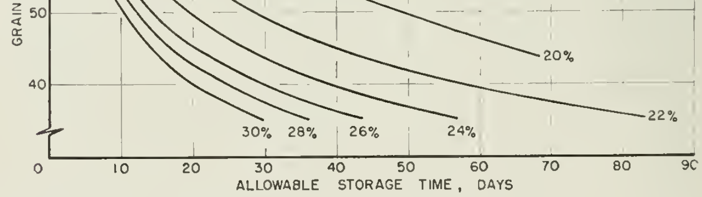
While different kinds and models of dryers differ slightly in their efficiency in removing moisture, drying costs per bushel are more affected by differences in the adjustment and operation of the equipment. Because of this, at any given installation there may be greater variations between dryers of the same brand and model than between the equivalent dryers of different brands. It is important to properly adjust and operate every dryer according to the manufacturer's instructions.

ALTERNATIVES TO DRYING

High-moisture corn may be stored and conditioned without using a heated-air grain dryer. The alternatives to this at present offer few or no cost advantages over traditional drying techniques but they are appropriate in particular situations. Cooling high-moisture corn extends its allowable storage time (Fig. 3), which can relieve some of the pressure on drying facilities at the peak of harvest. This method of managing corn works best if the moisture content at harvest is no greater than 22 or 23 percent and if the average daily air temperature is about 40° F. or below; otherwise, the corn is likely to deteriorate before it can be cooled and dried.

How Aeration Cools Grain

As cool air is passed through grain, heat is removed and grain temperature is lowered. In addition, unsaturated air releases heat to evaporate moisture from wet grain, cooling both the air and the grain in the process. As the temperature of the air drops, however, its ability to evaporate water decreases. This ability is measured by the difference between the dry bulb temperature and the wet bulb temperature.[1] When the dry bulb and wet bulb temperatures are equal, the air is 100 percent saturated and no additional evaporation of moisture or cooling of the air will take place. At relative humidities of less than 100 percent, however, the wet bulb temperature will be lower than the dry bulb temperature



Allowable storage time for shelled corn at various temperatures and moisture contents. During these times the grain will lose .5 percent in dry matter but will still be acceptable. Data are from the U. S. Department of Agriculture Grain Storage Research Laboratory at Ames, Iowa. (Fig. 3)

[1] "Wet bulb" refers to the temperature indicated by a thermometer that has its bulb encased in a wet cloth. The difference between the dry bulb and wet bulb temperatures (the wet bulb depression) is an indication of the relative humidity.

Table 8. Wet bulb temperatures at various relative humidities

Relative humidity	Dry bulb temperature, °F.			
	30	40	50	60
100 percent	30.0	40.0	50.0	60.0
90	29.0	39.0	48.5	58.5
80	28.0	37.5	47.0	56.5
70	27.0	36.0	45.5	54.5
60	26.0	35.0	43.5	52.5
50	25.0	33.5	42.0	50.0

(Table 8). This means that the wet corn will become several degrees cooler than the dry bulb temperature of the entering air as the unsaturated air evaporates moisture from the corn and cools to the wet bulb temperature.

The recommended airflow rate for cooling corn at harvest time is ½ cfm per bushel. At this rate, the corn will reach the wet bulb temperature after about 24 hours of fan operation. If the fan is operated only at night — to take advantage of lower nighttime air temperatures — it will take three or four days to complete the cooling.

Winter Aeration

Continuous aeration during late fall and through the winter will reduce corn moisture content. During periods of high humidity, damp air will lose some moisture to the corn through which it first passes, if the corn has less than about 22 percent moisture. The resulting drier air can then penetrate further into the moist corn before becoming saturated. This tends to equalize the moisture of all the grain, which helps prevent deterioration in the wettest grain. Continuous aeration utilizes heat energy from the air to remove additional moisture from the grain. During periods of warm weather during winter, grain temperatures increase. Then as outside temperatures fall, the relative humidity of the cool air is lowered as it strikes the warmer grain and more moisture is evaporated as the grain is recooled.

Experimental work with aeration indicates that it is best to operate the fan continuously when corn has an initial moisture content of 20 percent or more. With a lower initial moisture, however, the fan might well be controlled with a humidistat. From December through February, for example, the average relative humidity in the Corn Belt may approach 80 percent, and air this moist at temperatures below 50° F. will dry corn only to 17 to 19 percent (Table 9). Moisture content can be further reduced only by aerating when relative humidity is below about 80 percent — which can be controlled with a humidistat.

Table 9. Equilibrium percent moisture content of shelled corn at various air temperatures and relative humidities

Air temp. (°F.)	Relative humidity (percent)								
	50	55	60	65	70	75	80	85	90
30	13.0	13.5	14.5	15.5	16.5	17.4	18.7	20.3	22.5
40	12.5	13.0	13.8	14.7	15.5	16.5	17.6	19.4	21.5
50	12.0	12.5	13.3	14.0	14.8	15.8	16.9	18.6	20.5
60	11.4	12.0	12.6	13.4	14.0	15.0	16.0	17.7	19.5
80	10.4	11.0	11.6	12.2	13.0	14.0	15.0	16.2	17.9
100	9.3	10.2	11.0	11.8	12.3	13.2	14.2	15.3	16.7
140	7.9	8.4	8.8	9.6	10.3	11.1	12.1	13.3	14.6

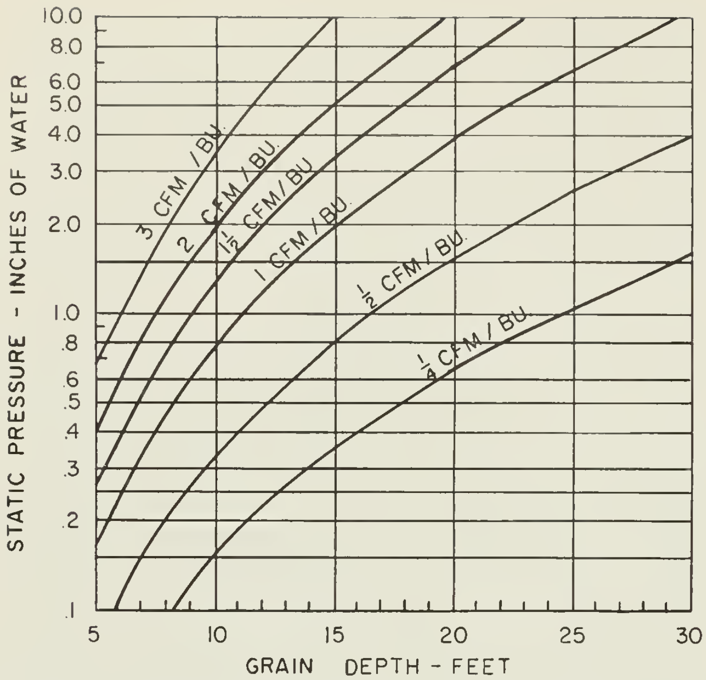
Aeration of dry grain with airflows of 0.1 cfm per bushel and less has usually been done by operating the fans to pull air downward through the grain. This downward movement of air partially offsets the moisture migration that results from the natural tendency for air to move upward from the warm grain toward the cool upper surface. The exhaust air, which is usually comparatively warm and moist, is expelled through warm grain in the lower part of the bin and not through the cold upper surface where some moisture might condense.

When greater airflows — ½ cfm or more per bushel — are used to hold or dry wet corn, *forcing* air through the grain is preferable. This takes advantage of the heat dissipated by the fan motor, which is often enough to raise the temperature of the air by 1 to 3 degrees. At air temperatures below 50° F., a 3-degree increase in dry bulb temperature should lower the relative humidity by about 10 percentage points; this is sufficient to change the equilibrium moisture content of corn by about 2 percentage points (Table 9).

When forced air is used, fines and trash are kept off the air ducts so that air movement is not restricted. Storage buildings cannot be collapsed with forced air as can happen if air pulled through the grain creates a strong vacuum. In storage facilities that use long ducts, placing a duct under pressure also gives a more uniform distribution of air than does exhausting air from the duct. Further, this method makes it easier for the operator to check the condition of the corn. If air is drawn down through the corn, the upper layers dry first and the operator might overlook the fact that the grain lower down is still wet; when the air is forced upward, however, the wettest corn is on top, where it can be easily inspected. Low-pressure, high-volume fans may be needed to move additional air over the surface of the grain to prevent condensation of moisture on the underside of the roof of the storage bin.

Power Requirements

Power requirements are an important consideration in aeration. The recommended minimum airflow is ½ cfm per bushel. Power requirements go up so rapidly with an increase in airflow that an airflow of much over 1 cfm per bushel is limited to shallow grain depths. Figure 4 indicates the size of aeration fan needed. For example,



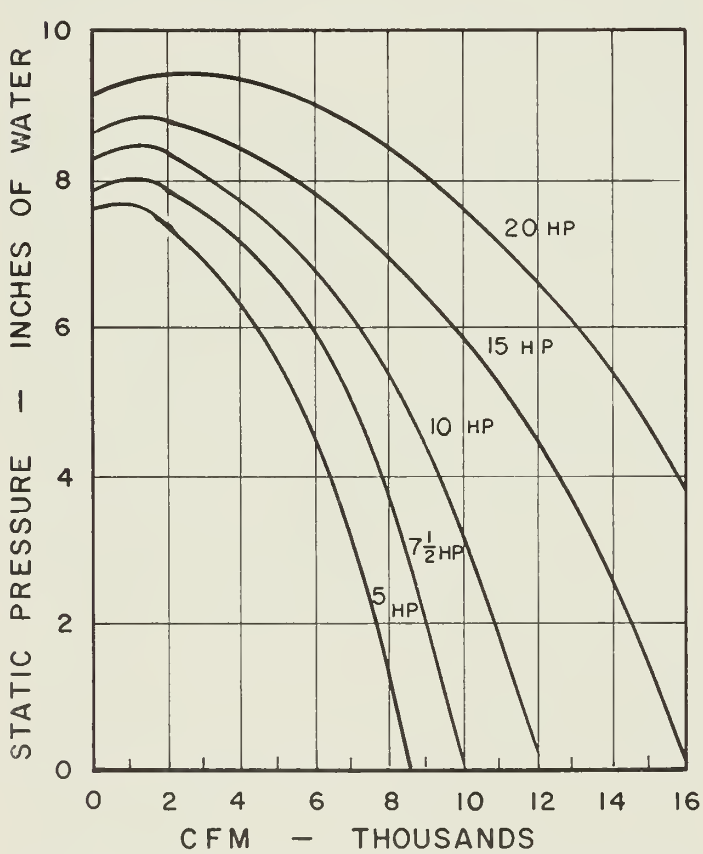
Static pressure requirements for airflow in shelled corn. Based on a multiplier of 1.5 applied to Shedd's data (*Agr. Eng. Jour.*, vol. 34, Sept., 1953). (Fig. 4)

if an airflow of ½ cfm per bushel is desired and the grain depth is 20 feet, a fan capable of delivering ½ cfm per bushel against a static pressure of 1½ inches of water is required. If there are 20,000 bushels of grain, the fan must deliver 10,000 cfm. The actual motor size can be estimated from Figures 5 and 6, which show typical air delivery rates for vane-axial and centrifugal fans. Actually, the fan selected should be big enough to deliver 10,000 cfm at a pressure slightly greater than 1½ inches to compensate for the ⅛- to ¼-inch pressure loss likely to occur in the transition from the fan to the plenum. In floor duct systems the pressure loss will be even greater. Screening corn and distributing it evenly into storage will help make aeration and drying more efficient.

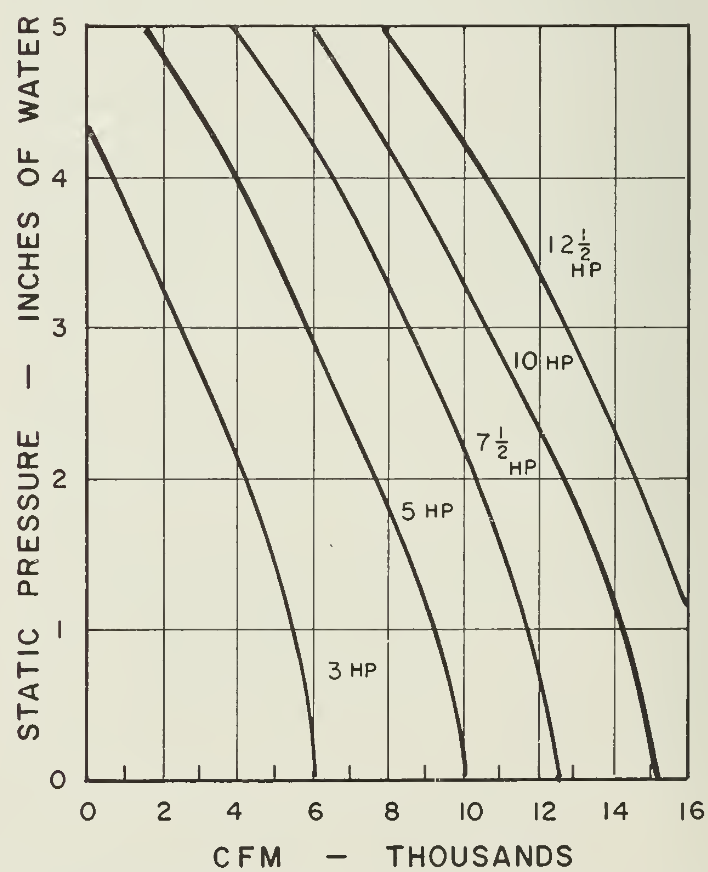
Low-Temperature Drying

Low-temperature drying is a method of reducing corn moisture over an extended period of several weeks, using a much lower air flow rate and temperature rise (usually 5 to 8° F.) than in traditional heated air dryers. The slower rate of drying results in fewer stress cracks and less mechanical damage than with continuous flow dryers.

Table 10 indicates how much the air temperature must be raised to dry corn satisfactorily in the cool weather that usually prevails in Illinois at harvest. For example,



Typical performance of centrifugal fans. Not to be used for power requirement selection. Refer to manufacturer's performance ratings. (Fig. 5)



Typical performance of vane-axial fans. Not to be used for power requirement selection. Refer to manufacturer's performance ratings. (Fig. 6) drying corn to 14 percent when the air temperature is 50° F. and relative humidity is 80 percent requires a temperature rise of 5 degrees. The amount of heat required to raise the temperature of the drying air can be calculated by the formula:

$$\text{Btu/hr.} = 1.1 \times \text{desired temperature rise} \times \text{cfm.}$$

If the air passes over the fan motor, heat from the motor will contribute 1 or 2 degrees of the required temperature rise shown in Table 10. In order to complete drying in a reasonable length of time (3 to 6 weeks), a minimum airflow rate of one cfm per bushel is required. Power requirements for a given airflow can be approximated by finding the static pressure for a given depth of corn from Figure 4 and referring to the fan manufacturer's ratings (air volumes at various static pressures). All-electric equipment, including electrical resistance heaters, is being installed in many low-temperature drying systems to provide the additional heat energy.[1]

Table 10. Temperature increase required for low-temperature drying of shelled corn (°F.)

Average daily air condition: Temperature	Relative humidity	Final moisture level desired (percent, wet basis): 16	15	14	13
50 °F.	90 percent	4	6	8	10
	80	1	3	5	7
	70	(*)[a]	(*)	2	4
	60	(*)	(*)	(*)	1
40	90	5	7	9	11
	80	3	4	7	9
	70	(*)	1	4	6
	60	(*)	(*)	(*)	3
30	90	6	8	10	12
	80	4	5	8	10
	70	1	2	5	7
	60	(*)	(*)	2	4

[a] The indicated moisture content (or lower) is achieved without increasing air temperature.

CORN QUALITY CONSIDERATIONS

Kernel temperature is an important determinant of corn quality. Apparently there is no significant change in the feeding value of corn dried at kernel temperatures as high as 180° F. Corn dried for the corn milling industry, however, is generally limited to 140° F. kernel temperature. Seed corn is dried with a maximum air temperature of 110° F. Except with seed corn, the drying air temperature may be considerably higher if the kernel is not exposed long enough to become overheated.

Thompson and Foster[2] demonstrated that many of the kernel stress cracks associated with heated air corn drying were formed during the final stages of drying and the fast cooling period. Stress cracks contribute to breakage during handling and mean smaller and lower-quality grits in the milling processes. Stress cracks in dried corn can be reduced by dryeration (see page 7).

Since the quality of corn is not decreased when it dries naturally in the field, it would appear that a similar quality could be achieved with artificial drying if drying air temperatures were kept sufficiently low. Because speed of drying is also a consideration, however, it may be necessary to sacrifice some quality in order to dry large volumes of wet corn.

[1] Additional information on low-temperature grain drying with electric heat is available from the Agricultural Engineering Department, University of Illinois, Urbana, Illinois 61801.

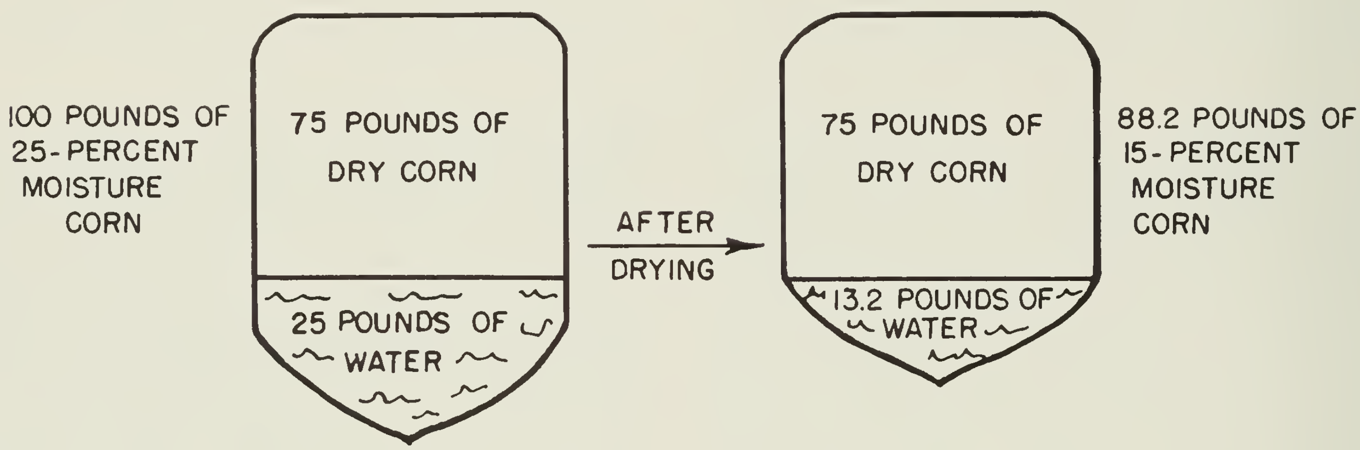
[2] Thompson, Ralph A., and George H. Foster, 1963. *Stress Cracks and Breakage in Artificially Dried Corn,* Marketing Research Report No. 631, U. S. Department of Agriculture, Washington, D. C.

APPENDIX A. Shrink During Drying

One hundred pounds of 25-percent moisture corn contains 75 pounds of dry matter and 25 pounds of water. During drying, water is evaporated, which reduces the amount of water and therefore the total weight of the original quantity of corn. Removing 10 pounds of water does not result in 15-percent moisture corn, however, but in 16⅔-percent moisture corn (15 pounds of water remaining ÷ 90 pounds of total weight remaining × 100 = 16⅔ percent). Because the total weight is changed during drying, 100 pounds of 25-percent moisture corn must have 11.76 pounds of water removed to become 15-percent corn. This is calculated by the formula: weight of water remaining ÷ (weight of dry matter remaining + weight of water remaining) = percent moisture. In this case, $x \div (75 + x) = 15$ percent, and $x = 13.24$ pounds of water remaining. The result is easily verified by dividing 13.24 pounds of water remaining by 88.24 pounds of total weight remaining and multiplying by 100 to get 15 percent.

Invisible loss generally included in shrink tables refers to loss of dry matter. An invisible loss of ½ percent of the original weight of 100 pounds would be ½ pound, so the 15-percent corn would contain 74.5 pounds of dry matter and 13.15 pounds of water [$x \div (74.5 + x) = 15$ percent, so $x = 13.15$ pounds of water].

It is often more convenient to use standard tables, such as Table 4 in Appendix B, to determine the total weight and shrink.



APPENDIX B. Comparison of Returns from Selling Corn on the Moisture Discount with Returns from Selling 15.5-Percent Corn

Table 1. Moisture discounts, shrink and returns from 1,000 bushels of corn at various moisture levels, and prices of Number 2 corn: 2 cents discount per point[a]

Moisture level (percent)	Market discount (cents per bushel)	Total receipts if sold as wet corn	Bushels of 15.5-percent corn left after drying[b]	Total receipts if sold as 15.5-percent corn	Returns from drying: Total	Returns from drying: Cents per bushel
Number 2 corn priced at $1.00 per bushel						
30	29	$ 710.00	823.40	$ 823.40	$113.40	11.3
28	25	750.00	847.07	847.07	97.07	09.7
25.5	20	800.00	876.66	876.66	76.66	07.7
22.5	14	860.00	912.16	912.16	52.16	05.2
20.0	9	910.00	941.75	941.75	31.75	03.2
18.5	6	940.00	959.50	959.50	19.50	02.0
Number 2 corn priced at $1.20 per bushel						
30	29	$ 910.00	823.40	$ 988.08	$ 78.08	07.8
28	25	950.00	847.07	1,016.48	66.48	06.6
25.5	20	1,000.00	876.66	1,051.99	51.99	05.2
22.5	14	1,060.00	912.16	1,094.59	34.59	03.5
20.0	9	1,110.00	941.75	1,130.10	20.10	02.0
18.5	6	1,140.00	959.50	1,151.40	11.40	01.1
Number 2 corn priced at $1.40 per bushel						
30	29	$1,110.00	823.40	$1,152.76	$ 42.76	04.3
28	25	1,150.00	847.07	1,185.90	35.90	03.6
25.5	20	1,200.00	876.66	1,227.32	27.32	02.7
22.5	14	1,260.00	912.16	1,277.02	17.02	01.7
20.0	9	1,310.00	941.75	1,318.45	8.45	00.8
18.5	6	1,340.00	959.50	1,343.30	3.30	00.3

[a] Market discount is computed on the basis of 2 cents for each percent of moisture above 15.5 percent.
[b] The weight loss through drying includes ½-percent invisible shrink.

Table 2. Moisture discounts, shrink and returns from 1,000 bushels of corn at various moisture levels, and prices of Number 2 corn: 3 cents discount per point[a]

Moisture level (percent)	Market discount (cents per bushel)	Total receipts if sold as wet corn	Bushels of 15.5-percent corn left after drying[b]	Total receipts if sold as 15.5-percent corn	Returns from drying: Total	Returns from drying: Cents per bushel
Number 2 corn priced at $1.00 per bushel						
30	43.5	$ 565.00	823.40	$ 823.40	$258.40	25.8
28	37.5	625.00	847.07	847.07	222.07	22.2
25.5	30.0	700.00	876.66	876.66	176.66	17.7
22.5	21.0	790.00	912.16	912.16	122.16	12.2
20.0	13.5	865.00	941.75	941.75	76.75	07.7
18.5	9.0	910.00	959.50	959.50	49.50	05.0
Number 2 corn priced at $1.20 per bushel						
30	43.5	$ 765.00	823.40	$ 988.08	$223.08	22.3
28	37.5	825.00	847.07	1,016.48	191.48	19.1
25.5	30.0	900.00	876.66	1,051.99	151.99	15.2
22.5	21.0	990.00	912.16	1,094.59	104.59	10.5
20.0	13.5	1,065.00	941.75	1,130.10	65.10	06.5
18.5	9.0	1,110.00	959.50	1,151.40	41.40	04.1
Number 2 corn priced at $1.40 per bushel						
30	43.5	$ 965.00	823.40	$1,152.76	$187.76	18.8
28	37.5	1,025.00	847.07	1,185.90	160.90	16.1
25.5	30.0	1,100.00	876.66	1,227.32	127.32	12.7
22.5	21.0	1,190.00	912.16	1,277.02	87.02	08.7
20.0	13.5	1,265.00	941.75	1,318.45	53.45	05.3
18.5	9.0	1,310.00	959.50	1,343.30	33.30	03.3

[a] Market discount is computed on the basis of 3 cents for each percent of moisture above 15.5 percent.
[b] The weight loss through drying includes ½-percent invisible shrink.

Table 3. Returns from drying at various prices and moisture levels of corn (cents per bushel per point)[a]

Moisture level (percent)	Corn price						
	$.90	$1.00	$1.10	$1.20	$1.30	$1.40	$1.50
	Discount of 2 cents per point						
30	.903	.779	.662	.537	.414	.297	.172
28	.896	.776	.656	.528	.408	.288	.168
25.5	.890	.770	.640	.520	.400	.270	.150
22.5	.871	.743	.614	.500	.371	.243	.114
20.0	.844	.711	.578	.444	.311	.178	.067
18.5	.800	.667	.500	.367	.233	.100	−.033
	Discount of 3 cents per point						
30	1.903	1.779	1.662	1.538	1.414	1.297	1.172
28	1.896	1.776	1.656	1.528	1.408	1.288	1.168
25.5	1.890	1.770	1.640	1.520	1.400	1.270	1.150
22.5	1.871	1.743	1.614	1.500	1.371	1.243	1.114
20.0	1.844	1.711	1.578	1.444	1.311	1.178	1.067
18.5	1.800	1.667	1.500	1.367	1.233	1.100	0.967

[a] Computed from the same data as Tables 1 and 2.

Table 4. Bushels of corn remaining when 1,000 bushels of corn are dried to selected moisture levels with invisible shrink computed at ½ percent

Beginning moisture (percent)	Ending moisture levels (percent)							
	13.0	14.0	15.5	16.0	17.0	18.0	19.0	20.0
13.0	1000							
13.5	989.3							
14.0	983.5	1000						
14.5	977.8	989.2						
15.0	972.0	983.4						
15.5	966.3	977.6	1000					
16.0	960.5	971.7	989.1	1000				
16.5	954.8	965.9	983.2	989.0				
17.0	949.0	960.1	977.2	983.1	1000			
17.5	943.3	954.3	971.3	977.1	989.0			
18.0	937.5	948.5	965.4	971.2	983.0	1000		
18.5	931.8	942.7	959.5	965.2	976.9	988.9		
19.0	926.0	936.9	953.6	959.3	970.9	982.8	1000	
19.5	920.3	931.0	947.7	953.3	964.9	976.7	988.8	
20.0	914.5	925.2	941.7	947.4	958.9	970.6	982.6	1000
20.5	908.8	919.4	935.8	941.4	952.8	964.5	976.5	988.7
21.0	903.0	913.6	929.9	935.5	946.8	958.4	970.3	982.5
21.5	897.3	907.8	924.0	929.5	940.8	952.3	964.1	976.2
22.0	891.6	902.0	918.1	923.6	934.8	946.2	958.0	970.0
22.5	885.8	896.2	912.2	917.6	928.7	940.1	951.8	963.7
23.0	880.1	890.3	906.2	911.7	922.7	934.0	945.6	957.5
23.5	874.3	884.5	900.3	905.7	916.7	927.9	939.4	951.2
24.0	868.6	878.7	894.4	899.8	910.7	921.8	933.3	945.0
24.5	862.8	872.9	888.5	893.8	904.6	915.7	927.1	938.7
25.0	857.1	867.1	882.6	887.9	898.6	909.6	920.9	932.5
25.5	851.3	861.3	876.7	881.9	892.6	903.5	914.7	926.2
26.0	845.6	855.5	870.7	875.9	886.6	897.4	908.6	920.0
26.5	839.8	849.7	864.8	870.0	880.5	891.3	902.4	913.7
27.0	834.1	843.8	858.9	864.0	874.5	885.2	896.2	907.5
27.5	828.3	838.0	853.0	858.1	868.5	879.1	890.1	901.2
28.0	822.6	832.2	847.1	852.1	862.5	873.0	883.9	895.0
28.5	816.8	826.4	841.2	846.2	856.4	866.9	877.7	888.7
29.0	811.1	820.6	835.2	840.2	850.4	860.8	871.5	882.5
29.5	805.3	814.8	829.3	834.3	844.4	854.8	865.4	876.2
30.0	799.6	809.0	823.4	828.3	838.4	848.7	859.2	870.0
30.5	793.9	803.1	817.5	822.4	832.3	842.6	853.0	863.7

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