University of Nebraska Lincoln EXTENSION
Know how. Know **now**.

EC710

Management of In-Bin Natural Air Grain Drying Systems to Minimize Energy Cost

Thomas W. Dorn, Extension Educator

With prices for all energy sources rising dramatically in recent years, grain producers are looking for ways to reduce the cost of drying grain on the farm. This publication will discuss in-bin natural air grain drying systems and will present management practices that reduce energy consumption while maintaining grain quality.

Field Dry Down

The least costly method of drying field corn is to let it dry naturally in the field. Assuming favorable drying weather conditions in early October (50°F and 50 percent relative humidity, wind, and sunshine), physiologically mature corn in the field can lose a point of moisture every three to five days. If corn is harvested at 18 percent moisture in early October and placed in on-farm drying bins equipped with fans producing 1 cubic foot per minute per bushel of corn in the bin (1 cfm/bu) and assuming natural (unheated) air, the time required to dry the corn to 15 percent moisture is about the same in the bin as in the field, about 15 to 18 days, depending on actual air temperatures and relative humidity.

Mechanical Grain Drying as "Insurance"

Drying cost is obviously not the only consideration in the decision whether to invest in on-farm grain drying facilities. Having the capability to mechanically dry grain is seen as "insurance" against years like the fall of 2009 when corn and soybeans matured very late due to lower than normal accumulation of heat units (growing degree days) in summer and fall.

Having the ability to harvest grain and finish drying it mechanically gives producers peace of mind. Producers know the grain in the bin will be protected from high winds or a heavy snow, which could result in field losses if the crop is still standing in the field.

The vast majority of grain bins are set up to push the air through the grain from the bottom of the bin. The air passes through the grain mass and exits at the top surface of the grain. For consistency, bottom-up airflow is assumed in this publication.

Table I. Equilibrium moisture content for various air temperatures and relative humidity values.

	Air Relative Humidity					
Temperature Degrees F	*40*	*50*	*60*	*70*	*80*	*90*
	Grain Moisture Content					
30	12.7	13.9	15.2	16.7	18.6	21.1
40	11.9	13.1	14.5	16.0	17.9	20.5
50	11.2	12.5	13.8	15.4	17.3	20.2
60	10.6	11.9	13.3	14.8	16.8	19.7
70	10.0	11.4	12.7	14.3	16.3	19.3

Source: *Grain Storage Tips,* **University of Minnesota Extension, William Wilke and Gary Wyatt.**

Grain Drying 101

In deep-bed, in-bin drying systems that don't employ a stirring device, a drying zone becomes established in the grain mass whenever the fan(s) are pushing air through the grain. The drying zone moves through the grain over time in the direction of airflow.

For illustration purposes, assume some drying has already been accomplished in the bottom 7 feet of grain in the bin. The grain in the bottom 3 feet has reached a state of equilibrium with the air so, by definition, the air is holding all the water vapor it can, given the current air temperature and relative humidity. See *Table I*. Therefore, no additional drying can occur in that 3-foot zone unless more favorable drying conditions occur.

The grain in the drying zone (assumed to be the grain from 3 feet to 7 feet above the drying floor in this illustration) is in the process of drying. Grain drying

Table II. Days required to dry corn to 15 percent moisture with 1.0 cfm/bu.

	Initial corn moisture content (%)					
	16	*17*	*18*	*19*	*20*	*21*
Air Properties	**Drying Time (days)**					
60°F						
60%	4.3	8.8	13.3	18.0	22.7	27.6
50%	3.2	6.5	9.9	13.4	17.0	20.6
40%	2.5	5.2	7.8	10.6	13.4	16.3
30%	2.1	4.2	6.4	8.6	10.9	13.3
Air Properties	**Drying Time (days)**					
50°F	16	17	18	19	20	21
60%	5.7	11.5	17.4	23.5	29.8	36.2
50%	4.1	8.3	12.5	16.9	21.4	26.0
40%	3.2	6.5	9.8	13.2	16.8	20.4
30%	2.6	5.3	8.0	1.8	13.7	16.6
Air Properties	**Drying Time (days)**					
40°F	16	17	18	19	20	21
60%	6.3	12.8	19.5	26.3	33.3	40.5
50%	4.7	9.5	14.4	19.4	24.6	29.9
40%	3.7	7.6	11.5	15.5	19.7	23.9
30%	3.1	6.3	9.5	12.8	16.3	19.8
Air Properties	**Drying Time (days)**					
30°F	16	17	18	19	20	21
60%	8.2	16.5	25.1	33.8	42.8	52.0
50%	6.2	12.6	19.2	25.9	32.7	39.8
40%	5.0	10.1	15.4	20.8	26.3	32.0
30%	4.1	8.4	12.7	17.2	21.7	26.4

The relative humidity of the exhaust air was assumed to be 85 percent for natural air drying.

occurs when moisture at the surface of the kernels evaporates into the passing airstream. As the surface of the kernel dries, moisture in the interior of the kernel migrates to the surface. The drying process continues until fan operation is discontinued or the grain at a given location in the bin comes into equilibrium with the air properties. Moisture evaporating from the grain humidifies and cools the airstream. Both factors increase the relative humidity of the air.

The airstream passes through the grain mass gaining moisture from the grain until the air has picked up all of the water vapor it can hold, given the air temperature at that particular location in the bin. This defines the top of the drying zone. The grain's moisture content above the top of the drying zone remains unchanged or may be wetted somewhat by the nearly saturated air leaving the drying zone.

Since grain moisture is removed by the air moving through the grain, the time to dry grain is directly proportional to the rate of airflow, cubic feet per minute per bushel of grain in the bin (cfm/bu). Drying bins are equipped with high output fans usually capable of moving at least 1 cubic foot of air per minute per bushel (1 cfm/bu) when the bin is full of grain.

Table II shows the estimated days to dry corn from various initial moisture contents to 15 percent moisture content using natural (unheated) air and 1.0 cfm/bu airflow and stated air properties (dry bulb temperature and relative humidity).

Since drying time is directly proportional to the airflow, the producer can calculate the estimated drying times when using airflows other than 1.0 cfm/bu. For example: *Table II* shows when drying corn from 18 percent to 15 percent moisture with 50°F and 50 percent relative humidity air, the estimated drying time is 12.5 days using 1.0 cfm/bu airflow. If the airflow is 1.25 cfm/bu, the estimated drying time would be 12.5 days / 1.25 = 10 days. For 1.5 cfm/bu, the drying time would be 12.5 days / 1.5 = 8.3 days. For 0.8 cfm/bu, the drying time would be 12.5 days /0.8 = 15.6 days.

Storage bins are usually equipped with much smaller fans in relation to the bin capacity than drying bins. Usually, storage bins are equipped with aeration fans capable of pushing a fraction of a cfm/bu (0.2 to 0.3 cfm/bu is most common). The lower airflow rates in the storage bins are adequate for pushing incoming air through grain to regulate grain temperature but are considered inadequate for drying grain.

An estimate of the time (hours) to push a temperature front through a bin of corn is 15 divided by the airflow, cfm/bu. For convenience, refer to *Table III* to look up the estimated hours to push a warming or cooling front through corn, given a range of airflows.

Table III. Estimated hours to push a temperature front through shelled corn.

Airflow, cfm/bu	*Time, hours*
0.1	150
0.2	75.0
0.3	50.0
0.4	37.5
0.5	30.0
0.6	25.0
0.7	21.4
0.8	18.8
0.9	16.7
1.0	15.0
1.1	13.6
1.2	12.5
1.3	11.5
1.4	10.7
1.5	10.0

Since drying bins are equipped with larger, more expensive aeration fans and other equipment, producers attempt to optimize the mix of drying bins versus storage bins they own. In this system, multiple batches of grain are usually dried in the drying bin(s). When the grain is sufficiently dried, it is transferred to the storage bins and another batch of grain is placed in the drying bin. One advantage of owning drying bins — besides the ability to dry grain on the farm, which provides more flexibility when selling — is that drying bins can double as storage bins when grain drying is completed for the year.

Select the Right Fan

All fans operate on a static pressure versus airflow curve, unique to the particular fan model.

Figure 1 shows a typical fan curve. The higher the static pressure the fan must overcome, the less airflow, cubic feet per minute, the fan can produce.

The effort required to move air through a grain mass can be compared to walking through water on the shallow end of a swimming pool. The deeper the water you are trying to walk through, the greater the effort necessary to achieve and sustain a given travel speed. Likewise, the faster you try to walk, the greater the effort required to move through a given depth of water.

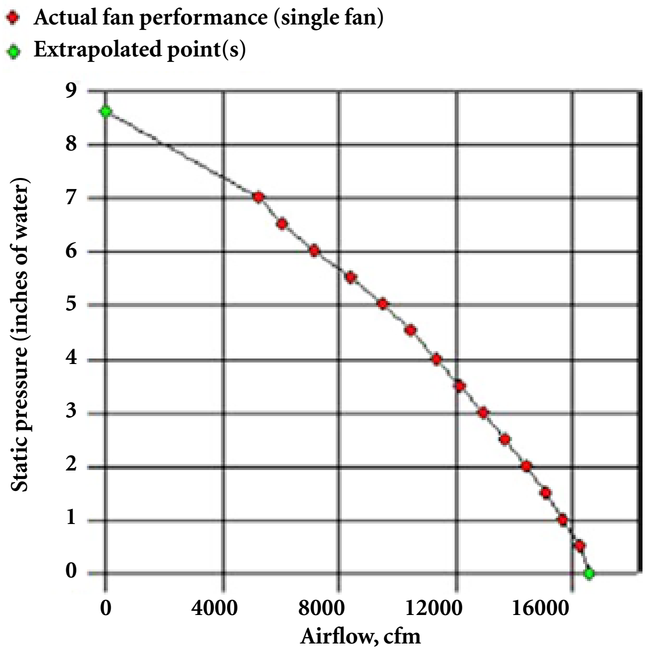

Figure 1. Typical aeration fan performance curve.

In a bin, higher static pressures are required to push a given rate of airflow (cfm/bu) through greater depths of grain. Likewise, higher static pressures are needed to push higher airflow rates through a given depth of grain.

The minimum recommended airflow for drying corn in a bin up to 18 percent moisture in Nebraska is 1.0 cfm/bu. For each 2 percentage points of additional moisture content above 18 percent, the recommended airflow is increased 0.25 cfm/bu. Many drying bins have fans capable of pushing 1.25 to 1.5 cfm/bu when the bin is filled to the eave. This ensures adequate airflow for drying, even in years when grain must be harvested at a higher than usual moisture content.

Most in-bin grain drying systems are designed for airflow and grain depths found in the lower right quadrant of *Table IV* (airflows greater than 1.0 cfm/bu and grain depth of more than 12 feet). Note the high static pressures required when grain depth exceeds 20 feet and airflows exceed 1.25 cfm/bu.

When deciding which **type** of fan to buy, refer to *Table IV*. This table shows the static pressure required for stated grain depths and airflows. Generally speaking, axial flow fans deliver more cfm per horsepower than centrifugal fans when static pressure is below 3 inches. Centrifugal fans deliver more cfm per horsepower than axial flow fans when static pressure exceeds 4 inches. As a class, either type of fan will deliver about the same airflow per horsepower when the static pressure is between 3 and 4 inches of water.

The trend in recent years has been to build very large on-farm grain bins. Many are 42 to 48 feet in diameter and 28 to 32 feet high to the eave. These bins work well as storage bins when equipped with aeration fans capable of pushing 0.2 to 0.3 cfm/bu through the grain to regulate grain temperature.

Assuming a 48-foot-diameter bin with 30-foot grain (corn) depth, the static pressure required for 0.3 cfm/bu airflow through the bin is 2.3 inches of water. Since the static pressure is less than 3 inches of water, one would expect the best fan choice to be an axial flow fan. Indeed,

Table IV. Airflow resistance for shelled corn.

Grain Depth Feet	*Airflow (cfm/bu)*						
	0.5	*0.75*	*1.0*	*1.25*	*1.5*	*1.75*	*2.0*
	Expected Static Pressure (inches of water)						
8	0.2	0.3	0.5	0.6	0.8	1.0	1.2
10	0.3	0.5	0.8	1.1	1.4	1.7	2.0
12	0.5	0.8	1.2	1.6	2.1	2.6	3.2
14	0.7	1.2	1.7	2.3	3.0	3.8	4.6
16	0.9	1.6	2.4	3.2	4.2	5.3	6.4
18	1.2	2.1	3.1	4.3	5.6	7.1	8.6
20	1.6	2.7	4.0	5.6	7.3	9.2	11.3
22	2.0	3.4	5.1	7.1	9.3	11.7	14.4
24	2.4	4.2	6.3	8.8	11.5	14.6	18.0
26	2.9	5.1	7.7	10.7	14.1	17.9	22.0
28	3.4	6.1	9.2	12.9	17.0	21.6	26.7
30	4.0	7.2	11.0	15.3	20.3	25.8	31.8

a search of manufacturer fan models found several 10-horsepower axial flow fans able to push slightly more than 0.3 cfm/bu through this bin. However, if a centrifugal fan is chosen for this bin, a 15-horsepower fan would be required to deliver the same airflow as the 10 horsepower axial flow fan. In this situation, the axial flow fan will require one-third less horsepower and electricity than the centrifugal fan.

In-bin Grain Drying Management Practice 1: Fill each bin to the eave, turn on the drying fan(s), then start filling the next bin.

The management practice most grain producers use with in-bin drying systems is to fill a single bin to the eave before beginning to fill and dry other bins.

The advantage is that it requires the least labor and management of the three practices discussed in this publication. The disadvantages are that it is the least efficient in energy consumption, and it takes the most time to dry a bin of grain.

In-bin Grain Drying Management Practice 2: Reduce grain depth when drying grain in a bin for more energy efficient drying.

Example 1. Compare two drying bins, each drying equal volumes of corn with the same airflow (cfm/bu). Bin A is 30 feet in diameter and 17 feet to the eave. It is filled to the eave with 9,600 bushels of corn.

Bin B is a 36-foot-diameter bin also holding 9,600 bushels of corn. However, due to the greater volume per foot of depth in the larger diameter bin, the grain depth is only 11.8 feet.

To push 1.25 cfm/bu through 9,600 bushels (17 feet) of shelled corn in the 30-foot-diameter bin requires 3.74 inches of static pressure. To push the same airflow (1.25 cfm/bu) through 9,600 bushels (11.8 feet) of shelled corn in the 36-foot-diameter bin requires only 1.55 inches of static pressure.

In this example, it takes 2.4 times as much static pressure to achieve the same airflow (cfm/bu) in the 30-foot-diameter bin because of the greater grain depth required to hold 9,600 bushels compared to the 36-foot-diameter bin.

The horsepower and electrical energy required for the two bins demonstrates the relationship between static pressure and energy consumption. To push 1.25 cfm/bu through each of the two bins requires 11.8 horsepower in the 30-foot-diameter bin but only 4.9 horsepower to push 1.25 cfm/bu in the 36-foot-diameter drying bin holding the same volume of corn. Note 11.8 horsepower / 4.9 horsepower = 2.4. The smaller diameter bin with greater grain depth requires 2.4 times as much horsepower to dry the same volume of corn in the same time. This shows the horsepower and electricity consumed for grain drying are directly related to the static pressure required to achieve a given airflow.

Note*:* The inverse of 2.4 is 0.41. The larger bin requires only 41 percent as much horsepower as the smaller diameter bin when drying the same volume of corn.

Assuming the 220-volt single phase fan motor is 80 percent efficient, each horsepower required to power the fan for an hour draws 0.93 kilowatt-hour (kWh). This would require 22.32 kilowatt-hours per horsepower every day (24 hours).

Comparing these two bins, and assuming electricity costs $0.10 per kilowatt-hour, the electricity cost for the 30-foot-diameter bin is $15.40 more for each 24 hours of fan operation than the 36-foot-diameter bin.

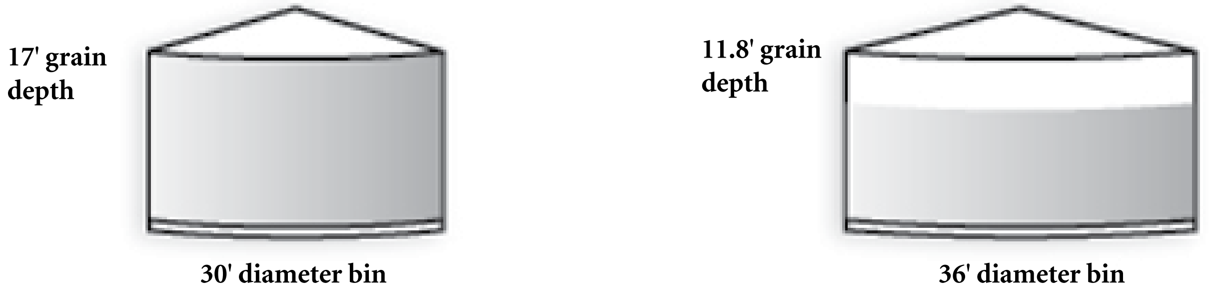

Figure 2. 30 foot and 36 foot-diameter drying bins with 9,600 bushels.

Assuming it takes 17 days to dry 9,600 bushels using natural air in both bins, the electricity cost for the 30-foot-diameter bin would be $262 more than the 36-foot-diameter bin when both are drying the same volume of corn in the same period of time.

Looking at this example from another perspective, how many bushels of corn could be dried in the 36-foot-diameter bin in the same time and with the same electricity consumption required to dry 9,600 bushels in the 30-foot-diameter bin?

As demonstrated above, the horsepower required for the aeration fan depends on the volume of air moved and the static pressure the fan must overcome to move the air. As shown in *Table IV*, the static pressure required for a given airflow (cfm/bu) is a function of grain depth. Bin A with 17 feet of grain depth requires 11.56 horsepower to push 1.25 cfm/bu through the 9,600 bushels of corn in the 30-foot-diameter bin.

The 36-foot-diameter bin requires the same horsepower (11.55 hp) to push the same airflow (1.25 cfm/bu) through 15.28 feet (12,443 bushels) of corn.

Remember, the time to dry grain is directly proportional to the rate of airflow (cfm/bu). The airflow (1.25 cfm/bu) is identical in both bins. Therefore, the time to dry is the same in both bins.

In this example, the 36-foot-diameter bin is able to dry 2,843 more bushels (30 percent more corn) in the same time using the same amount of electricity, compared to drying in the 30-foot-diameter bin.

The trend in recent years has been to build very large on-farm grain bins. Many new bins are 42 to 48 feet in diameter and 28 to 32 feet to the eave.

Remember, the minimum recommended airflow rate when drying corn is 1.0 cfm/bu up to 18 percent moisture content. Drying time in a bin is directly related to airflow (cfm/bu). Shallower grain depths reduce the static pressure required to push a given airflow through grain. Since all fans can move more air when the static pressure is lower, keeping grain depth as shallow as possible results in greater airflow through the grain mass. Pushing more airflow (cfm) through fewer bushels in the bin results in much greater airflow cfm/bu, which results in considerably shorter drying times as opposed to Practice 1 in which the fan(s) must overcome the maximum static pressure for nearly the entire time the grain is being dried.

Remember, *Table IV* presents the static pressure required to push incremental rates of airflow through progressively greater grain depths. Energy cost and drying time can be reduced by reducing grain depth, which reduces the static pressure the fan must overcome.

When building new drying bins, consider building large diameter bins, but reduce drying time and electricity cost by building shorter drying bins or partially filling bins taller than 18 to 20 feet to keep static pressure as low as possible.

Example 2. Assume a 48-foot-diameter bin set up for drying corn.

- Three 40 horsepower centrifugal fans on separate transition ducts would be required to push 1.0 cfm/bu[1] through a 48-foot-diameter bin with 30-foot corn depth. (43,429 bushels).
- Two of these fans would push 1.0 cfm/bu[1] if the grain depth is reduced to 25 feet (36,191 bushels).
- One of these fans would push 1.0 cfm/bu[1] if the grain depth is reduced to 18 feet of depth (26,057 bushels).

Reducing maximum grain depth 16.7 percent, from 30 feet to 25 feet, reduces the capital investment in fans, electrical wiring, switches, transition ducts, and electricity consumption by 33.3 percent.

Reducing maximum grain depth 40 percent, from 30 feet to 18 feet, reduces the capital investment in fans, electrical wiring, switches, transition ducts, and electricity consumption by 66.7 percent.

Note: When a bin will be partially filled when drying grain, a ladder, attached to the inside bin wall next to the access hatch, would be necessary to gain access to the grain surface to manually level the grain or to manually check grain moisture and temperature.

Grain Drying Management Practice 3: Layer Drying

Drying time and electrical energy consumption can be significantly reduced by taking the general principle discussed in Practice 2, reducing grain depth, to its ultimate extreme. All that is required is to be willing and able to partially fill and dry bins sequentially.

The logic is: Rather than overcoming the static pressure required for the entire grain depth for the entire time grain is being dried, why not keep grain depth as

---

[1] Actual airflow depends on the fan make and model.

shallow as possible for as long as possible by filling the bin a layer at a time?

The most often recommended layer drying scheme is to fill the bin in four steps, adding one-fourth of the capacity of the bin each time the drying front has nearly reached the top of the previous layer being dried.

A computer simulation was run comparing layer drying versus filling the bin on day one when using natural air (60°F plus 2 degrees of added heat from the fan [62°F] and 50 percent relative humidity). Exhaust air was assumed to be 85 percent relative humidity and 53.4°F due to the cooling effect when air is humidified.[2]

The results of layer drying using natural (unheated) air showed layer drying reduced drying time and electrical energy cost by 37 percent compared to filling the bin on day one. This estimate was unofficially confirmed by a large grain producer in northern Nebraska in 2009 who reported he reduced drying time by more than 45 percent when he used layer drying compared to his former practice of filling his bins on day one.

Layer drying is easily accomplished on farms with a grain leg because grain can be added to bins with minimal effort. Farms using portable augers to fill multiple bins would require more labor to move and set the auger multiple times for each bin. A compromise would be to fill bins in fewer layers to reduce the time and labor required to set the filling auger. Obviously, the advantages of layer drying are diminished as the number of layers is reduced.

Note: Stirring devices should not be activated in layer drying systems until the final layer of grain is added. Long distances to the grain mass can cause unpredictable behavior in partially filled bins that could damage the stirring device or the bin sidewalls. Once the final layer of grain has been added, consider using the stirring system, if installed, to blend the newly added wet grain with the remaining grain. Then use natural (unheated) air to help the migration of moisture from the moist kernels to those that are likely overdry.

Summary

Understanding the physical processes involved when drying grain in a bin, then making management changes recommended in this publication can result in significant time and energy savings. Examples include:

- Picking the right **type** of fan, based on the anticipated static pressure required, saved 33 percent of the horsepower and electrical energy cost compared to making the wrong choice of fan type.
- Relatively small differences in bin diameter can make big differences in the horsepower and electricity consumption when drying equal volumes of grain in the same amount of time. A 36-foot-diameter bin was shown to dry the same volume of corn (9,600 bushels) as a 30-foot bin while using only 41 percent as much electricity when both bins have the same airflow (cfm/bu), and, therefore, the same drying time.
- When 48-foot-diameter bins were used for drying grain, small reductions in grain depth resulted in large reductions in capital expense. If a 48-foot-diameter bin was filled to the eave, three 40-horsepower fans in parallel were required to push 1.0 cfm/bu when grain depth was 30 feet.

  For a grain depth of 25 feet, two 40-horsepower fans in parallel would push 1.0 cfm/bu in this 48-foot-diameter bin.

  If overall grain depth was reduced to 18 feet, one of these fans would be able to push 1.0 cfm/bu.

  The one remaining 40-horsepower fan was able to dry 60 percent as much grain as three of the same fans can when the bin is filled to the top.

  If the plan was to dry 18 feet of depth before the bin is constructed, the capital investment for the fans, transition ducts, wiring, and switches could be reduced by 66 percent and the electricity for fan operation would be reduced 66 percent as well.
- Layer drying was shown to result in savings of 37 to 45 percent in drying time and energy consumption for fan operation using the same equipment.

This publication has been peer reviewed.

UNL Extension publications are available online at *http://extension.unl.edu/publications.*

---

[2] Note the simulation assumed the corn would lose 0.25 points of moisture in the field for every day it took the previous layer to reach the target moisture content of 15 percent.