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Layer Drying of Grains and its Potential for Rough Rice Drying

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Introduction

This fact sheet explores an alternative grain drying management technique, known as layer drying, emphasizing the potential benefits and limitations of drying grain in layers on the drying rate, energy conservation and quality of dried grains. Numerous on-farm grain drying and storage facilities have been constructed in recent decades. Many of these facilities have more than one grain bins equipped with high capacity aeration fans that can generate an airflow rate of more than one cubic foot per minute per bushel (cfm/bu). Many of these facilities can also add supplemental heat to the drying air before it passes through the grain to reduce drying time.

Most producers currently fill a single grain bin to the eave, then begin the drying process. Subsequently, they begin to fill other bins. This drying technique requires the least labor and control. However, there are two possible hazards associated with this technique: the possibility of overdrying the bottom layers, and the spoilage which can occur at the top due to the excessive moisture content of the grains.

Overdrying of grain can occur if too much heat is used. In such a scenario, the equilibrium moisture content (EMC) falls, drying the air. If the grain placed in the bin is too wet, spoilage can occur before the drying front reaches the top. EMC is the value of moisture content at which the grain is neither gaining nor losing moisture. Its value depends on the grain type and the relative humidity and temperature of the air with which it is in contact. Additionally, this technique may be the least efficient in energy consumption, and requires the most time to dry grain.

To prevent these problems, producers should follow specific guidelines regarding the amount of wet grain layered in the drying bin at any one time. Producers with a humidistat in their drying bins must set the humidistat properly to maintain the drying air's relative humidity to facilitate drying, and thus attain a safe final grain moisture content in grain bins.

Accordingly, many grain producers who harvest low rates of grain (200 to 500 bu/day), or have low annual harvest volumes (up to 10,000 bu/year), are looking for alternative drying techniques, such as layer drying. That could help them dry grain faster with the potential for rapid grain drying, without increasing the drying cost. Layer drying has significant advantages above conventional bin drying management techniques.

Grain Drying Management Strategies

The time required to dry grains is determined by three factors: the quantity of moisture that has to be removed from the grain to achieve the desired moisture content level that is safe for storage or milling, the rate of airflow through the grain per bushel (cfm/bu), and the drying air properties (i.e., temperature and relative humidity).

Controlling any of these parameters can be costly. As mentioned earlier, the most common practice of drying grains on-farm is to fill the bin to the eave and start the fan. This practice requires less labor, but is the least efficient management because of the lengthy drying duration required to dry the grains, and the eventual cost of energy.

One of the most energy-efficient solutions when drying grain is to reduce the grain depth so that less static pressure is required to move air through the grains. An example is given below to help understand the potential benefit of layer drying.

Assume that a producer has two grain bins (A and B). Grain bin A is 30 feet in diameter, and grain bin B is 36 feet in diameter. The producer has to hold 12,000 bushels of shelled corn and move 1.0 cfm/bu of drying air in each of the bins. Determine (1) the grain depth in bins A and B; (2) the static pressure in grain bins A and B and (3) the estimated fan power for grain bins A and B. Grain depth can be determined from the following equation:
Grain depth [ft] = Grain volume [bu] × 1.244 [ft^3/bu] / ((Pi/4) × (Diameter)^2 [ft^2]).

Grain depths in bins A and B are 21.1 feet and 14.7 feet, respectively. In other words, the smaller bin (A) requires 21.1 feet of grain depth, while the larger grain bin (B) requires only 14.7 feet of grain depth to hold 12,000 bushels.

The static pressure to overcome an airflow of one cfm/bu in grain bin A could be determined from Table 1 (between the depths of 20 feet and 22 feet). In bin A, the fan requires 4.02 inches of water as static pressure to provide one cfm/bu, while bin B requires about 1.98 inches of water in static pressure. It requires 2.03 times (4.02/1.98) more static pressure in bin A than bin B to maintain the same airflow rate. It is important to note that drying duration is a factor of airflow, drying air temperature and relative humidity and the initial moisture content of the grain; thus, the above comparison might have similar drying duration. The above example shows that shallow grain depth requires less static pressure, compared to the deeper one.

Table 1. Static pressure (inches of water) for corn at different grain depth and airflow rates.

GRAIN DEPTH (FT)	AIRFLOW RATE (CFM/BUSHEL)*					
	0.25	0.5	0.75	1.0	2.0	3.0
2	0.52	0.51	0.51	0.52	0.54	0.56
4	0.54	0.53	0.55	0.58	0.68	0.80
6	0.57	0.58	0.63	0.69	0.95	1.29
8	0.61	0.65	0.75	0.86	1.40	2.10
10	0.66	0.75	0.91	1.09	2.04	3.28
12	0.73	0.87	1.12	1.41	2.90	4.90
14	0.80	1.03	1.39	1.81	4.02	7.00
16	0.89	1.21	1.71	2.30	5.41	9.63
18	1.00	1.43	2.10	2.88	7.10	12.86
20	1.11	1.69	2.55	3.58	9.11	16.72
22	1.24	1.98	3.08	4.38	11.47	
24	1.39	2.32	3.68	5.31	14.20	
26	1.55	2.69	4.36	6.35	17.32	
28	1.73	3.11	5.12	7.53		
30	1.92	3.58	5.97	8.85		

*0.5" water column has been added to the static pressure to account for ducts and vents.

The fan horsepower can be estimated from the following equation:
Fan power [HP] = airflow [cfm/bu] × number of bushels [bu] × static pressure [in] ÷ 3,814

Grain bin A requires a 12.6 hp fan motor, while grain bin B requires a 6.2 hp fan. This example illustrates that to push one cfm/bu through each of the two bins, 12.6 hp is required in the 30-foot diameter bin, but only 6.2 hp in the 36-foot diameter bin (note that 12.6 hp/6.2 hp = 2.03). The grain bin with a smaller diameter and greater grain depth requires 2.03 times more power to dry the same capacity of corn at the same time as compared to the grain bin with the larger diameter and shallower depth. It should be mentioned that the horsepower and electricity utilized for grain drying are associated with the static pressure needed to achieve a given airflow.

Looking at the previous example from another perspective, by connecting similar fans to both drying bins, the airflow rate per bushel of grain is higher in the 36 feet bin as compared to the 30 feet bin due to the reduced static pressure (Table 1). Accordingly, increasing the grain depth will decrease the airflow rate per bushel. This management practice could be altered by placing grain in the bin incrementally by layers with a shallow depth, enhancing the drying rate and reducing both the drying duration and energy consumption. Layer drying uses the principle of maintaining the grain layer as shallow as possible to keep the grain's static pressure as small as possible.

Researchers from Nebraska reported that layer drying of corn using natural air reduced the electricity cost by 37 percent and the drying time by 45 percent, as compared to filling the bin on a single day. Layer drying is most beneficial if multiple bins are used, especially in humid climates.

The use of layer drying helps expedite harvest. Grains harvested early in the season, with higher moisture content, can be dried at the bottom of the bin where the air drying capacity is high.

Layer Drying

Typically, layer drying is used in grain systems when relatively low harvest rates (200 to 500 bu/day) and low harvest volumes (10,000 bu/year or less) occur. The drying air temperature should be limited to no more than a 20°F rise above ambient conditions to prevent excessive overdrying. Layer drying is very comparable to natural air/low-temperature drying, except that the grain bin is filled in layers approximately four to five feet deep. The first layer of grain is placed in the bin, and drying is started. A drying front is initiated (Fig. 1), and the drying of the grain layer continues until the grain moisture content is reduced to an acceptable moisture level.

Other layers of the grains are intermittently added to maintain the depth of wet grain on top of the dried grain. The main idea of grain drying in layers is to

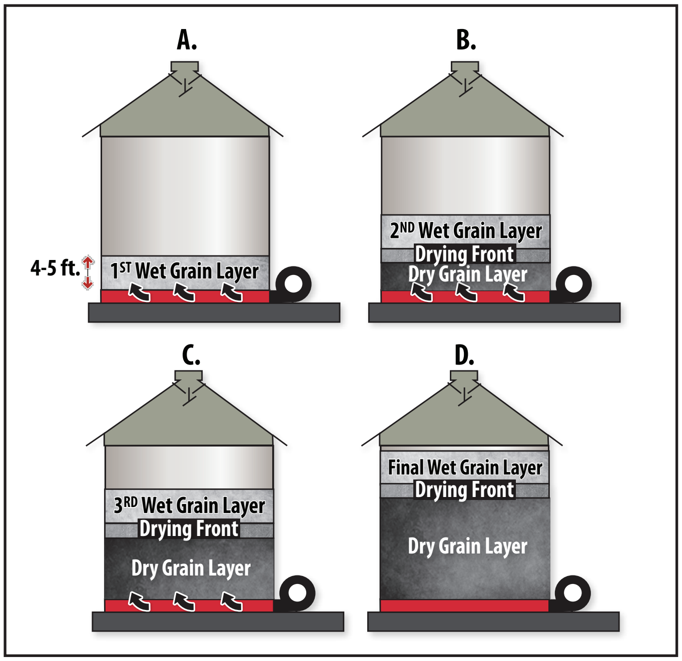

Figure 1. Layer drying of grains in on-farm setting (A) first layer of wet grain 4-5 ft deep dries to acceptable moisture content, and (B through D) consecutive layers of the wet grains are added.

limit the grain depth and to increase the airflow rate per bushel, which allows drying higher moisture content grains than the system can handle on a full-bin basis.

For simplification, in a bin designed for one cfm/bu on a full-bin basis, the airflow rate is estimated to be about four cfm/bu if the bin is one-fourth full. The drying front can be determined by inserting a grain probe into the grain to measure the grain moisture content at various levels. Grain samples from several spots should be checked since the progress of the drying front will not be even in the bin because of fines accumulation.

Avoid adding moist grain too quickly — it will result in spoilage of the upper layers. Producers are advised to follow specific guidelines on the amount of wet grain placed in the drying bin at any one time to prevent the above problem.

System Equipment

The equipment for layer drying includes a bin with a perforated floor, a fan, a grain spreader, a sweep auger and an unloading auger. Fan horsepower depends on the bin size and the estimated grain static pressure to overcome. Typically, the fan size is between 5 and 10 horsepower. Bin diameter and eave heights are usually around 27 feet and 16 feet, respectively. The bin eave is generally no higher than 16 feet because most fans do not deliver sufficient airflow for drying depths above this level.

Grain bins equipped with legs can handle the layer drying easier than the grain bins equipped with portable augers, because grain can be added to the leg-equipped bins with minimal labor. On the other hand, grain bins with portable augers require more labor to move and set the auger several times for each bin. It should be mentioned that the advantages of layer drying are reduced with the increase in the number of layers. The stirring device should not be activated while drying grain in layers is in progress – it should be activated only after adding the last layer.

In layer drying, the amount of grain that can be placed in any one layer is limited to the amount that can be dried before excessive mold growth or aflatoxin develops in the top of that layer. The capacity for handling high moisture content grains in layer drying is not critical due to the high airflow rate per bushel. Corn with high moisture content — up to 25 percent water base — could be handled in layer drying, as shown in the following section. However, care should be taken to have wet grains ahead of the drying front to prevent overdrying.

The central handling unit should provide sufficient handling capacity to discharge the grain from the bin to a semi-trailer in no more than two hours. The handling capacity means a minimum handling capacity of 400 to 500 bushels per hour for layer drying systems. Generally, a 6 or 8-inch tube-type auger is used for unloading the bin, and its capacity should be designed to match that of the central handling unit, whether it is a transport auger or bucket elevator. A heating unit with a

Table 2. Airflow Rate (CFM) as affected by static pressure (inches of water) for low-speed centrifugal fans (1750 RPM).

	STATIC PRESSURE (INCHES OF WATER)										
HP	0	1	2	3	4	5	6	7	8	9	10
3.0	5,564	5,203	4,742	4,183	3,526	2,769					
5.0	9,095	8,504	7,752	6,838	5,763	4,526					
7.5	11,745	11,112	10,377	9,542	8,606	7,569	6,431				
10.0	13,475	12,803	12,047	11,207	10,283	9,275	8,183	7,007			
15.0	19,250	18,290	17,210	16,010	14,690	13,250	11,690	10,010			
20.0	20,792	19,989	19,094	18,105	17,019	15,834	14,549	13,161			
25.0	24,857	24,171	23,352	22,400	21,314	20,095	18,743	17,257	15,638	13,886	
30.0	26,100	25,380	24,520	23,520	22,380	21,100	19,680	18,120	16,420	14,580	
40.0	34,080	32,801	31,508	30,198	28,872	27,528	26,165	24,781	23,376	21,948	20,496
50.0	37,000	35,887	34,746	33,572	32,361	31,108	29,808	28,458	27,053	25,589	24,060

transition could be added to the system. For typical drying situations, heater capacities vary between 300,000 and 800,000 btu/h.

Layer Drying Filling Techniques

Layer drying is an excellent drying technique for low harvest rates and harvest volumes. The method is simple, but requires some labor input and necessitates superior management skills. The system has little reserve capacity to overcome any mistakes and is not readily adaptable when the expansion is required. When layer drying is used with the appropriate equipment and correct management practices, the grain drying results can be excellent.

Four Layers Batches

As mentioned earlier, layer drying is the method to dry and store grains in the same bin. The "four layers batches" method technique works as follows:

1. Check the initial moisture content of the grain and decide the grain depth (four to five feet).
2. Use the grain spreader to fill the first layer of wet grain up to five feet deep. The grain spreader is crucial to level the layer for uniform drying. It also prevents fines from concentrating at the center and creating a hot spot.
3. Turn on the fan as soon as the first layer is in, and maintain the airflow until all the grain is dried in the bin.
4. Check the grain moisture content every 24 hours, and fill in the next layer once an acceptable moisture content level is achieved in the previous layer.
5. Fill the grain bin with one wet layer at a time, over the previous layer after it has adequately dried. Continue filling the bin until the bin is full to the fourth layer.
6. Unload several bushels of grain each day from the bin to prevent rewetting of dried grain at the bottom of the bin.
7. Aerate the bin to avoid heating spots.

Filling Grain Bins with Layers Based on a Computer Simulation

A computer model (Bridges et al., 1982) has been developed to aid grain producers in determining the filling schedule for their layer drying systems. The model uses specific drying fan and bin information, as well as the projected drying conditions during harvest. The output from the model provides the producer with a tentative filling schedule for a specific set of input conditions, while considering the potential of mold growth and aflatoxin development.

Table 3 presents the filling schedule for shelled corn developed using the computer model for an 18-foot diameter drying bin with a 16-foot eave, a five hp motor fan, and four initial grain moisture contents of 25 percent, 23 percent, 21 percent and 19 percent w.b.

Table 3. Layer drying schedule for corn at different initial moisture contents and average outside air conditions of 60°F and 65% relative humidity.

LAYER NO.	LAYER DEPTH (FT)	TOTAL DEPTH (FT)	LAYER VOLUME (BU)	TOTAL VOLUME (BU)	DRYING TIME PER LAYER (DAYS)	TOTAL DRY ING TIME (DAYS)
Schedule 1. Initial Moisture = 25% wb						
1	3.0	3.0	611	611	2.7	2.7
2	2.0	5.0	407	1018	2.2	4.9
3	2.0	7.0	407	1425	2.6	7.5
4	1.5	8.5	305	1730	2.2	9.7
5	1.5	10.0	305	2035	2.3	12.0
6	1.5	11.5	305	2340	2.6	14.6
7	1.0	12.5	207	2544	1.8	16.4
8	1.0	13.5	204	2748	1.9	18.3
9	1.0	14.5	204	2952	2.0	20.3
10	1.0	15.5	204	3256	2.1	22.4
11	0.5	16.0	101	3257	1.1	23.5
Schedule 2. Initial Moisture = 23% wb						
1	3.5	3.5	713	713	2.9	2.9
2	2.5	6.0	509	1222	2.6	5.5
3	2.0	8.0	407	1631	2.4	7.9
4	2.0	10.0	407	2038	2.7	10.6
5	1.5	11.5	305	2343	2.2	12.8
6	1.5	13.0	305	2648	2.4	15.2
7	1.5	14.5	305	2953	2.6	17.8
8	1.5	16.0	305	3257	2.7	20.5
Schedule 3. Initial Moisture = 21% wb						
1	4.5	4.5	916	916	3.5	3.5
2	3.0	7.5	611	1527	3.0	6.5
3	3.0	10.5	611	2138	3.5	10.0
4	2.5	13.0	509	2647	3.4	13.4
5	2.0	15.0	407	3054	3.0	16.4
6	1.0	16.0	203	3257	1.6	18.0
Schedule 4. Initial Moisture = 19% wb						
1	5.0	5.0	1018	1018	3.4	3.4
2	3.5	8.5	713	1731	3.1	6.5
3	3.0	11.5	611	2342	3.2	9.7
4	2.5	14.0	509	2851	3.0	12.7
5	2.0	16.0	406	3257	2.6	15.3

*The following drying conditions were assumed during the computer simulation model: 18-feet drying bin with 16-feet eaves, 5-hp drying fan, a humidistat control value of 55%, and final grain moisture of 13% wb.

Each schedule in table 3 was determined for average outside air conditions of 60°F and 65 percent RH. Using corn as an example, the equilibrium moisture contents associated with a relative humidity below 55 percent are undesirably low, and there is a significant potential for overdrying in the bottom layers of the grain (Sadaka and Bautista, 2014. FSA, 1074).

The specified final grain moisture content was

13 percent (w.b.). A humidistat control value of 55 percent was used to limit drying air temperature to no more than 20°F rise. The various schedules provide such management information as the number of fillings or layers required to fill the bin for mold growth to be minimal.

The trade-off in this situation is that if heat input is limited (to minimize overdrying), the drying times are somewhat more significant than for the conditions in Table 3 at comparable initial grain moisture contents. So, while colder and drier climates generally allow more grain to be placed in the individual layers, the drying process may be extended because the drying potential is reduced. It should be mentioned that if the relative humidity of air is expected to be below 55 percent for a long time, producers could fill the bin to the eave and follow the traditional drying technique to avoid grain overdrying.

For example, regarding the situation in Table 3, the initial moisture content is reduced from 25 percent to 19 percent w.b. As a result, the number of layers of fillings per schedule decreases from 11 to five, while the total drying time decreases from 23.5 to 15.3 days. For all four schedules, there is potential for aflatoxin development, so the single layer sizes are limited to prevent its occurrence.

Layer Drying Tips

The following tips are useful during the layer drying of grains:

1. Test the orginal moisture content to determine the maximum wet grain depth allowed for the system.
2. Use a grain cleaner to eliminate fines and foreign material, which will increase both drying airflow and the allowable storage time.
3. Use a grain spreader: level spreading is essential.
4. Grain dries faster in lower spots, resulting in overdried grain and increased drying costs. A grain spreader also prevents fines from concentrating in the center of the bin.
5. Start the fan and heater once the floor is covered with grain. Open roof hatches, leave the fan and heater running and all the hatches open for 24 hours. Damp evenings or hot, dry days will not affect the drying process.
6. Adjust the humidistat to the proper setting based on the final desired moisture content. Adjust the burner gas pressure to give a 20°F maximum temperature rise. The humidistat will turn the heater on whenever the humidity of the drying air is higher than the humidistat setting, and turn it off after the humidity setpoint has been lowered or reached.
7. After 24 hours, take grain samples from the bottom of the bin. Humidistats can provide reasonable, but not exact, control of the final moisture content. If the grain is still too wet, lower the humidistat setting 10 percent for each point of moisture beyond the desired moisture content. If too dry, raise the humidistat setting. Once adjusted, do not change it, or a new drying front may result. For future reference, remember the changed amount of the setting and its effect on the final moisture content.
8. Continue filling, but do not exceed the maximum wet grain depth. Spoilage will result if the wet grain is placed ahead of the drying front. You can locate the drying front by pushing a half inch steel rod into the wet grain. The rod will push easier or sink when you reach the drying front.
9. Inspect grain daily. If crusting appears, you should break it up and spread the grain evenly over the surface.
10. Turn off the burner and cool with a fan. Begin cooling when the surface is uniformly dry. Cool to within 5-10°F of outside temperatures.
11. Aerate and inspect grain periodically.

System Performance

In addition to the typical problems of mold growth associated with grain spoilage, producers may also face the potential for aflatoxin development – especially during periods when the grain contains high moisture content. While taking these restraints into account when determining a layer drying schedule, the producer must also consider the following parameters: airflow of the drying fan, outside temperature and humidity, humidistat setting, the initial moisture content of the wet grain and desired final moisture content.

Management of layer drying involves tracking the drying front and adjusting the filling rates accordingly to minimize potential spoilage. The position of the drying front can be determined at any time by probing the grain mass from above and locating the point where the grain temperature begins to increase significantly. The drying front may usually be detected by feeling the temperature difference along the bin wall. Again, management in layer drying is critical because the operator will have only one learning experience per year.

Advantages and Disadvantages of Layer Drying

Layer drying possesses multiple advantages over the conventional on-farm, in-bin batch drying. Layer drying, in most cases, does not require a heater, but even if it is used, the electrical cost of running a heater and a fan is low, making layer drying one of the more cost-efficient options. Layer drying allows harvesting grain at a higher moisture content as compared to the full-bin drying bins. The grain remains in place in the storage structure after being dried, thus requiring minimum handling and labor. By combining the dryer and storage unit into one structure, layer drying presents an economical drying alternative for those producers with low harvest rates and harvest volumes. Layer drying decreases the drying time and electrical energy cost as compared to filling the bin on the same day.

Several inherent disadvantages are associated with the layer drying system. The speed of the system is slow when compared to most other types of drying systems, requiring higher system management. The slow speed of the system may impede harvest rates and can eliminate the chance of using the same bin and associated drying equipment more than once during the drying season. This may limit the operator to one drying experience per bin per year, which would require prudent management during operation. A layer drying system has little reserve capacity to overcome any mistakes that may result in the loss of an entire bin of grain. The clear disadvantage is the slow speed of the layer drying system, and if you have fewer bins and high harvest rate, it will create a problem.

Economic Considerations

If an increase in harvest volume is expected, there must be an increase in the harvest rate. Therefore, to accommodate layer drying, either more fans should be used per bin, or higher horsepower fans should be used. Additional horsepower, or the increased number of fans, may add extra cost to the drying process. Thus, the layer drying system can be undesirable for situations where higher drying rates are needed per bin.

The drying capacity of a layer drying system may be increased by adding multiple fan units per storage structure. However, this additional horsepower may prove to be expensive, and the increased drying capacity may not be significant when related to the cost; it may be more cost-prohibitive than selecting another drying method. This would suggest that layer drying is physically and economically undesirable when higher drying rates are needed.

Potential of Layer Drying of Rough Rice

As previously mentioned, drying time and electrical energy consumption could be reduced significantly by taking the general principle of reducing grain depth to its ultimate level. All that is required is to fill and dry sequentially and partially.

The most frequently suggested layer-drying arrangement is to add the rough rice in four layers in the bin. Producers need to add one-fourth of the bin volume each time. They also need a new layer when the drying front reaches the top of the previous layer. They can reduce the rice drying duration for the entire bin by turning up the heat and batch drying the first layer. This batch-dried layer will be overdried slightly on the bottom, but it should regain some moisture by the time the entire bin is finished.

Layer drying is a good management practice for drying rough rice with low harvest rates and harvest volumes. It requires more labor compared to other drying techniques, and subsequently, it requires excellent management skills. Filling grain bins in layers could be among the best grain drying management techniques. Layer drying could be an excellent drying technique for rough rice.

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