MANAGEMENT OF NATURAL DRYING SYSTEMS FOR SASKATCHEWAN CLIMATE

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1. INTRODUCTION

In Saskatchewan and Canada, several grain crops, including canola, wheat and barley, should be harvested damp (at moisture contents greater than 13% for oilseeds and 20% for cereals) and then dried. Harvesting damp allows a longer harvest season earlier harvesting, and reduced field losses especially from shattering, while the drying prohibits any spoilage during storage. Forages are harvested fresh at moisture contents above 70% and then chopped or dried in the field before baling.

The most common method of drying is passing heated air through the store of the product to lower the moisture content. However, it is also possible to dry the product with ambient temperature air, i.e. natural air drying or aeration.

Natural air drying is the forced air drying method using unheated air as nature supplies it. As the ambient air passes through the product it picks up moisture, thereby drying the product. The principle of natural air drying is that when the moisture content of the product is greater than the equilibrium moisture content, moisture will move from the product into the air until equilibrium is reached.

One of the major management concerns in natural air drying is to provide enough air flow to keep the product cool and aerated throughout the drying season and prevent spoilage. Aeration is mainly used to even out any temperature variations in the grain thereby preventing moisture migration from warm grain to the cold surface layer. Aeration also produces some drying if the air temperature is more than 6 *C cooler than the grain since the relative humidity of the air will be reduced as it is heated in passing through the grain. When the grain is cooled below 18 *C, the activities of insects and molds is retarded. Under unfavorable natural air drying conditions, it may be necessary to provide supplemental air heating to promote faster drying and prevent product spoilage. In addition to capital and operating costs, natural air drying or supplemental heat drying could lead to product spoilage and serious losses if the drying is not managed properly.

This paper presents drying conditions and practices that could lead to a successful management of natural air drying, supplemental heat drying and aeration systems under Saskatchewan or prairie climate.

2. GRAIN QUALITY DETERIORATION AND SAFE STORAGE CONDITIONS

Grain quality deterioration during drying. aeration or storage is dependent on the moisture content, temperature, oxygen supply, and microorganism involved. The relative deterioration rate increases with an increase in temperature and moisture. For example, the quality deterioration for grain stored at 20% moisture content, wet basis, is about 50% when compared with zero deterioration for 14% moisture grain and 20% deterioration for grain at 18% moisture. Table 1 shows the relative grain deterioration rate as affected by moisture and temperature.

The data in Table 2 and Figure la indicate that the safe storage of canola depends strongly on the grain temperature and moisture content. For example, grain at 15% moisture and 15 *C may rot in three weeks, but grain cooled to 10 *C and moisture reduced to 9% or lower stores for more than five months. From Figure lb, at about 13% moisture content, barley can be stored safelyb for 160-240 days when the grain temperature is about 21 *C while at 24% moisture content and the same temperature it stores only for 3-5 days. Damp barley should therefore be dried if it is to be stored for more than a few days.

The storage stability of grain products depends on the temperature, moisture content and the time the grain has been under unfavorable storage conditions. Table 2 and Figure 1 show the relationship of grain moisture content and temperature to safe storage. Grains and other agricultural products absorb moisture from the air or give up moisture to the air depending upon the the relative humidity of the surrounding air and on the moisture content of the product. The moisture content of the product in equilibrium with its environment is Equilibrium Moisture Content (EMC). The oil fraction of the canola seed absorbs less moisture than the starch and fibre fractions, so the equilibrium moisture content of canola is much lower than for wheat or barley as indicated in Figure 2. Canola seeds must therefore be stored at a lower moisture content than cereal grains to prevent spoilage. The growth of molds is dependent largely on the humidity of the airb in the spaces between the Heeds. When the relative humidity increases over 75%, a sharp increase in mold growth takes place.

3. FORCED AIR NATURAL DRYING METHODS FOR GRAINS

3.1 Forced Air Drying in Storage Bins

Forced air drying with natural or ambient air is a method of removing excess moisture from the grain without the use of added heat. As the air passes through the grain it picks up moisture, thereby drying the grain. Moisture is evaporated from the grain by using the heat from the atmospheric air. A forced air drying system generally consists of a storage bin for holding the grain. a fan and a motor to force the air through the product, and an appropriate duct system for uniformly distributing the air through the product (Figure 3). One of the major concerns with natural air drying is to provide enough airflow to keep the grain cool throughout the drying season. Too little airflow allows the grain to mold.

3.2 Forced Air Drying in Piles Outside

As a temporary measure in unfavorable weather conditions (as was the case during the 1996 harvest in Saskatchewan and many other prairie locations in western Canada), the grain can be piled outside and dried by forced air circulation to reduce the risk of rapid grain deterioration that may occur due to moisture migration and heating when tough or high moisture grain is dried and stored in a bin. The grain pile height (Figure 4) is determined by the angle of repose or the angle the slant side of the pile makes with the horizontal. The angle of repose is a function of the product and increases with an increase in grain moisture and amount of foreign materials. The angle of repose for wheat, barley, oats and flax seed at 14% moisture are 25, 27, 28 and 24* respectively.

3.3 Maximum Economical Depth for Drying

The maximum economical depths for drying small grains and beans in storage bins are as follows:

Small Grains (wheat, barley, canola, oat, flax seed):	1.8 m or 6 ft
Larger Grains (peas, lentil, shelled corn)	2.4 m or 8 ft

Larger grain depths may be used for drying in piles.

The horsepower required to operate the fan becomes quite large for greater depths and is generally considered uneconomical for drying. The capacity of the fan required depends on the depth of the grain and airflow rate which depends upon the crop and its moisture content. It is therefore important that these maximum depths not be exceeded unless special consideration be given to the design.

3.4 Drying Rate and Grain Cooling

The drying rate or the amount of water removed from the grain per hour depends on the air temperature and humidity, grain moisture content, and airflow through the grain. The grain dries from bottom to top for air movement in that direction, and when the moisture on the top layer has been reduced to the amount required for safe storage, all the grain in the pile or bin is safe for storage. Little or no moisture is removed from the grain when the temperature is below 5 *C (40 *F) and the humidity is above 85%. but the fan can be operated as an aeration measure to cool the grain and prevent deterioration.

3.5 Airflow Requirements

For damp or high moisture grain, an airflow rate of 3 - 5 cfm/bu is recommended for small grains. Lower airflows can be used for lower moisture grain. The recommended minimum airflow rates to be used for cereal grains with various initial moisture contents for natural air drying are as shown in Table 3.

Air flow rates for natural air drying of oilseed canola typically would be in the range 5 - 25 L/s. m or 0.5 - 2 cfm/bu. The recommended natural airflow rates for Manitoba/Saskatchewan area are shown in Table 3.

These recommendations may need to be increased or possibly decreased depending on the average weather conditions in a given geographic location. However, to ensure that the grain dries before mold damage occurs, it is highly recommended that an airflow which is greater than the recommended minimum be used

3.6 Drying Time

The drying time depends upon the initial and final moisture content of the grain, the ambient air conditions (temperature. and humidity), airflow and the amount of the grain to be dried. The drying times for various initial mosture contents and airflows for 3000 bu of wheat dried to 14.5% moisture under typical weather conditions in October in Saskatchewan are shown in Table 4. The table also shows the amount of water to be removed from 1 bu of wheat to obtain a product at 14.5% moisture.

The data in Table 4 show that drying of 18-20% moisture grain cannot be effectively completed in October with airflow less than 6000 cfm for a bin filled with 3000 bu.

The fan and static pressure (horsepower) requirements for drying of wheat from various initial moisture contents with ambient air at various practical depths are shown in Table 5. The static pressure increases as the depth and airflow increase. The maximum quantity of grain that can be dried per horsepower on the fan is also given in Table 5. The data are useful in estimating power requirements for the conditions represented.

4. MANAGEMENT OF NATURAL DRYING, AERATION AND SUPPLEMENTAL HEAT DRYING SYSTEMS

4.1 Classification of Conditioning Systems

Conditioning systems for agricultural products can be classified on the basis of both the purpose of the operation and the state of the air used in the operation. Conditioning systems are usually divided into four categories:

- Aeration
- Natural Air Drying
- Supplemental Heat Drying
  (air temperature raised just few degrees, about 5 *C or 10 *F, above ambient)
- Heated Air Drying
  (drying air temperature limited by product temperature tolerance and desired quality or end use)

Combinations of these systems, involving two or more of the operations, are also used.

4.2 Grain Spoilage Prevention or Conditioning Using Aeration

Aeration is the circulation air through stored or piled products for the primary purpose of maintaining a uniform moisture content and/or temperature throughout the storage or pile in order to prolong the storage life of the product. Small quantities of air are used to cool the product and eliminate temperature and moisture variations throughout the mass. The most common use of aeration is in cooling tough grain for long term storage or reducing the effects of moisture migration during storage. It can be used also between harvesting and drying operations or after heated air drying. Using aeration, safe storage can be provided for grain up to 1-2% moisture above that normally considered safe for storage. Aeration is used to prevent the accumulation of moisture migration from warm to cold layers. Aeration is not necessarily a drying process, despite the fact that 1-2% moisture can be removed under ideal conditions.

Aeration systems involve fans that move air the mass of the product. The quantity of air used for aeration is typically from 0.02 - 0.1 cfm/bu or 0.5 - 1 L/s. m^3 for cereals and 0.1 - 0.2 cfm/bu or 1 - 2 L/s. m^3 for oilseed canola. Note that to prevent spoilage the airflow rates are more than one order of magnitude less than what are required for drying. These low airflow rates are the reason why aeration is generally restricted to a product that is within 2% of dry condition. Very little drying will occur at these airflow rates. Aeration is especially valuable for sensitive seeds like canola. but it should also be considered for all sealed bins.

Aeration fans should be started as soon as the product is placed in the bin, so that immediate cooling can take place. The fans should be operated continuously until the temperature of the product is near the average outside temperature. Aeration can be continued periodically Over the winter until drying takes place in the spring. Approximately 5 to 10 days are required for the grain to approach ambient temperature by using 0.1 cfm/bu airflow. The grain should be cooled within one month of storage to prevent deterioration.

The operation of aeration equipment during extended periods of high relative humidities (over 80%) may promote mold growth, even in dry product. However, continuous aeration for one to two days of high relative humidity should not damage the product, as long as an equal time of dry weather follows. The temperature of the air is more important in aeration operation since aeration is essentially a cooling procedure.

Either negative or positive aeration system can be used. as illustrated in Figure 5. With either system, a tempering (cooling or warming) zone moves through the product. The movement of the tempering zone completely through the product is one cooling or warming cycle. Once a cycle had been started. operate the fan continuously until the zone moves completely through the product. In the positive pressure system(Figure 5), the tempering zone starts at the bottom of the bin and moves up. When moving air upwards, aeration progress can easily be determined by checking the grain temperature at the top centre. In the negative aeration. system, the tempering zone starts at the top of the bin and moves down. The main advantage is that it minimizes roof condensation when aerating warm product in cold weather. Not knowing when aerationis complete is the main disadvantage since the grain at the bottom is the hardest to check.

It should be noted that conditioning fans designed for aerating cereals may not produce adequate airflow for canola since the small size of both the canola seed and void spaces around the seeds increases the resistance of canola grain to airflow through it.. The conditioning fans must therefore operate at static pressures two to three times greater in canola than in cereals to avoid the risk of substantial damage to the canola seed.

4.3 Grain Spoilage Prevention or Conditioning Using Natural Air Drying and Supplemental Heat Drying

In natural drying systems, the drying potential of the ambient air at relatively high flow rates is used to remove 2-8 % moisture from grain products. The airflow requirements of a natural air drying system depend on the condition of the grain and weather. As indicated earlier, the time available before spoilage occurs is determined by the grain temperature and moisture content. The weather conditions determine the drying potential of the ambient air. The drying potential of the natural air may be a limiting factor since it cannot be controlled. The selection of satisfactory airflow rates is therefore critical to the success of a natural air drying system. Recommended minimum airflow rates for natural air drying are given in Table 3.

Supplemental heat drying is basically a natural air drying system which uses supplemental heat in sufficient amounts to raise drying air temperature a few degrees, typically about 5 *C or 10 *F above ambient temperature. The objective of using this heat is to reduce the relative humidity of the drying air when adverse weather conditions would reduce the drying rate or increase the drying time.

The major concern with supplemental heat drying is to provide enough airflow to keep the grain cool and just enough heat to maintain a lower relative humidity. The recommended airflow rates for natural air drying are also used for supplemental heat drying. The supplemental heat can be provided by a solar energy collector or by natural gas/propane burners. A well designed solar collector can be more cost effective than other sources of energy for low temperature drying of agricultural products.

Some specific advantages and disadvantages of natural air drying and supplemental heat drying are as follows:

Advantages

1. Low initial equipment and maintenance costs.
2. Low heat energy or fuel cost.
3. Reduces harvest time labor.
4. Reduces overdrying losses.
5. Reduces kernel damage and discoloration.

Disadvantages

1. Drying is slow- in some cases as long as 60 days.
2. Dependent on weather conditions.
3. Capacity is needed to store all of the crop.
4. All bins must have drying floors and fans.
5. Systems are less tolerant of overloading, fines or foreign materials in the grain or improper fan selection or operation.

In a natural air or supplemental heat drying system, the air enters the grain mass at a given potential and begins to absorb moisture from the product. As the air moves through the mass, the moisture exchange continues until some equilibrium moisture content is reached. From this point on, the air can alter the temperature of the grain, but will have no effect on the moisture content. This drying process results in the creation of three zones within a bin of grain as illustrated in Figure 6. The dry zone is closest to the air inlet, the drying zone is where moisture is being removed, and the grain in the wet zone may be cooled, but will undergo no moisture exchange. Grain located below the drying zone is in equilibrium with inlet or outside air conditions. as shown in Figure 2. The drying operation is complete when when the drying zone has moved through the entire grain mass.

Unfortunately, significant overdrying of the grain nearest the air inlet can occur before the drying front has moved through the bin. For this reason a small drying front that moves rapidly through the bin is highly desirable. Under etablished weather conditions, the size and speed of the drying front is dependent on the airflow rates. In natural air drying, most of the moisture removal takes place in a 0.3 - 0.6 m or 1 - 2 ft thick drying zone. Since the grain above the drying zone is wet, it is susceptible to deterioration by storage molds.

In operating natural air or supplemental heat drying systems, as in aeration system, the fans should be started as soon as the grain covers the perforated areas of the bin floor. The fans should be operated continuously until the drying zonebhas moved through the entire grain mass.

Operation of the drying system on a cold and humid day is justified in any bin where drying zones have been established. In this case, the wet air loses moisture to the grain near the inlet, thereby reducing the problem of overdrying. After losing this moisture, the air will then be capable of advancing the drying front by drying the wet grain at the other end of the bin. Once the drying front has moved through the grain, the grain mass should be cooled for storage. If necessary, the drying process could be completed in the spring. One benefit of natural air drying that is often overlooked is the fact that cooling of the grain during the operation will prolong the storage life, even when no drying is taking place.

In some natural air drying systems, small quantities of supplemental heat are used to enhance the drying potential of the air, and subsequently increase the drying rate and reduce the drying time. Another effective method of making the drying process faster is to provide graiter airflow through the grain. If the ambient air conditions are favorable, delivering energy directly to the system, in the form of higher airflows, is more efficient than adding it in the form of supplemental heat.

4.4 Fan Selection and Operation, and Air Distribution

In aeration, natural air drying and supplemental heat drying systems, airflow rate, grain depth. and storage bin size are the factors that determine the size of the fan and power required for drying grain. Either a centrifugal or axial flow fan may used. Fans are rated by the manufacturers according to their ability to deliver various quantities of air against different static pressures. Typical specifications or performance charts for axial flow fans and in-line and high speed centrifugal fans are shown in Table 6. These specifications from the manufacturers are used in selecting fans for crop drying. Although axial flow fans seem to be popular among farmers, centrifugal fans are preferred especially in applications where relatively high static pressures are encountered.

In these aeration and drying systems, the air is delivered to the grain through perforated sections in ducts set either above or below the floor of a bin. The perforations must be small enough that grains cannot enter the air passages. A perforated area equal to 15 percent of the floor area is the minimum, but a fully perforated floor is ideal. However, square pads or cross ducts having perforated area greater than 50% are also suitable.

A manometer is used to measure the static pressure which the fan is operating against. The airflow, provided by the fan, can be determined by comparing the measured static pressure with the fan performane chart or specifications. One side of the manometer is connected to the plenum chamber or duct under the grain and the other side is open to the atmospheric air.

5. MANAGEMENT SCHEMES FOR IN-BIN DRYING OF GRAINS

Management schemes for successful in-bin drying of grains under Saskatchewan and prairie weather conditions and production practices have been developed by the authors as presented in Arinze et al.(1993,1994) and Sokhansanj et al.(1992). Simulation programs were developed to determine the drying times, uniformity of moisture content, degree of overdrying, degree of spoilage during drying, energy consumption (electricity, fuel or gas or solar energy), drying costs, overdrying costs, and risk costs for various drying conditions in natural air drying and supplemental heat drying systems.

Two drying policies were investigated: "average-dry", where the desired final average moisture content of the grain is attained by mixing or stirring the grain bulk after drying to mix grains of various moisture contents: and "through-dry" where the drying is continued until the the top layer of the bin has reached the desired final moisture content. The bin size selected for the study was 4.3 m or 14 ft in diameter and 4.3 m in height with a full holding capacity of about 50 tonnes or 1800 bu of grain.

The input ambient conditions to the simulation programs were Typical Meteorological Year (TMY) data for a typical Saskatchewan or prairie location (Saskatoon). The TMY data is a 30-year hourly average for dry-bulb temperatures, relative humidity, horizontal global solar radiation and wind speed. The drying data were computed for August 1. September 1 and October 1 start dates. with the grain dried to 10% or 8% moisture content for canola and 13% moisture content for cereals for various initial moisture contents. Airflow rates of 0.5, 1.0, 1.5 and 2.0 m/min per tonne of grain or approximately 0.5, 1.0, 1.5, and 2.0 cfm/bu of grain were used in the simulation. Management schemes such as the use of thermostat and humidistat to economise the use of supplemental heat were also investigated.

The tendency of the grain to spoil during drying was indicated by spoilage or storage index (SD. The grain was considered unsafe for storage if the SI was greater than one (SI>1) at the end of a drying operation. The risk cost was computed as a combination of the costs associated with loss of quality (SI>1) by downgrading the grain for inadequate drying, and late harvest cost when the grain was downgraded due to rain or frost damage by leaving the grain in the field unharvested.

Table 7 lists the combinations of minimum airflows, starting dates and initial moisture contents for which canola grain could be dried to 10% Or 8% "average-dry" and "through-dry" within 30 days and 15 days by natural air drying with no supplemental heat. The blanked entries in this table in the columns for "Drying days" indicate that drying was not completed within the specified time limit. The drying times were highest in October at the same in itial moisture contents and airflow. The time required for through-dry was approximately 40% longer than for average-dry at 1.0 m^3/min. t airflow rate, for all airflows the difference in time required decreased with in creasing airflow.

Tables 8a and 8b list the drying conditions by natural air drying and supplemental heat drying that yielded minimum drying costs for 10% and 8% through-dry for complete drying in 30 days or less and 15 days or less, respectively. For all months the minimum drying cost increased with increasing initial moisture content while the corresponding risk cost decreased with increasing moisture content except for conditions where the spoilage index was greater than 1.0.

Table 9 shows the drying time, electrical and heat energy costs, and drying costs associated with different drying systems for drying barley grain from 19% initial moisture content to 13% final average moisture content from August to October. The drying cos ranged from $5.1 l/tonne to $6.85/tonne for the natura air drying system, and $8.61/tonne to 10.27/tonne for supplemental heat drying systems in these months. Tables 10a and 10b list the optimum drying systems that yielded minimum drying costs for completedrying of barley grain within 30 days and 15 days, respectively, from 16, 19, 22 and 25% initial moisture contents to 13% average moisture in August to October. As indicated in these tables, the dried product was suitble for use as feed barley, malting barley or both. For drying within 15 days, natural air drying could not be used to dry feed or malting barley for all initial grain moisture contents and start dates.

6. MANAGEMENT RECOMMENDATIONS/SUGGESTIONS

The following suggestions are given as a general guide in management of conditioning systems for grains:

1. Screen out fines and bad grain and, spread grain uniformly throughout the bin.
2. Leave roof hatches open while drying to provide sufficient air exhaust area.
3. During natural air or supplemental heat drying, operate the fan continuously, even during periods of rain or high humidity weather.
4. Drying not completed before the. onset of cold weather in fall at below reezing temperatures can be completed in early spring. The grain should be aerated completely in fall.
5. Operate the fan at least once per week to check for heating and odors. Slowly warm grain in spring by aeration on clear afternoons.
6. Exercise caution in drying high-moisture grain or grain with moisture contents greater than 22% with low airflow rates when daily average temperatures is above 5 °C or 40 °F.
8. In humid weather conditions supplement heat is required to successfully dry the grain especially in September and October.
9. For long term storage of grains, all layers of grain in the bin should be dried to 8% moisture for canola and 13% for cereals
10. In planning drying equipment installations, the fan should be selected to supply 1.0 to 2.0 m/min or 1.0 to 2.0 cfm/bu airflow in order minimize overdrying and grain spoilage during drying operation.
11. Solar drying is more cost-effective than other conventional supplemental heat options

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TABLE 1 RELATIVE GRAIN DETERIORATION RATES AS AFFECTED BY MOISTURE AND TEMPERATURE

Grain Moisture Content % wet basis	Relative Deterioration Rate	Grain Temperature °C	°F	Relative Deterioration Rate
13	0.0	0	32	0.0
18	0.2	3	37	0.2
23	0.7	7	45	0.4
25	1.0	13	55	0.6
28	1.4	18	65	1.0
30	1.6	24	75	1.6

TABLE 2 TIME LIMITS IN DAYS FOR SAFE STORAGE OF CANOLA AS AFFECTED BY GRAIN MOISTURE CONTENT AND TEMPERATURE

Moisture Content, % W.B.	**Grain Temperature, o C**			
	0	**5**	**10**	**15**
19	35	21	7	
17	60	35	21	7
15	90	60	35	21
13	>150	105	60	45
11	>150	>150	120	90
9	>150			

Source: Appelquist and Loof, 1972

TABLE 3 MINIMUM AIR F-LOW RATES NEEDED FOR NATURAL AIR DRYING OF CEREAL GRAINS AND OILSEED CANOLA

Initial Moisture Content % wet basis	Minimum AirFlow Needed For Drying cfm/bu	L/s. m3
Cereal Grains		
24	3	40
22	1.5	20
20	0.75	10
18	0.375	5
16	0.25	3.5
Oilseed Canola		
11	1.25	17
13	1.5	20
15	1.75	24

TABLE 4 DRYING TIME FOR 3000 BU OF WHEAT WITH TYPICAL WEATHER CONDITIONS (5 - 12 °C, 60 - 70% RH) IN OCTOBER IN SASKATCHEWAN

Grain Moisture Content %, w.b.	Water Removed from 1 Bu to Obtain Product at 14.5 %, w.b. lb	Drying Time in Days for 3000 Bu — Airflow cfm 3000	6000	9000	12000
16	1.1	13	7	5	4
18	2.5	30	15	10	8
20	4.1	49	25	17	13

TABLE 5 **FAN REQUIREMENTS FOR DRYING WHEAT WITH UNHEATED AMBIENT AIR FROM DIFFERENT PERCENTAGES OF MOISTURE CONTENT AND VARIOUS PRACTICAL DEPTHS**

Grain Moisture Content t, %	Recommended Minimum Airflow		Practical Grain Depths		Static Pressure		Maximum Quantity That Can Be Dried/Fan Horsepower[2]	
	m^3/m^3s	cfm/bu	m	ft	kPa	in Water	m^3	bu
Wheat								
20	0.04	3	1.2	4	0.3	1.2	29.0	830
				6	0.27	2.3	65.8	440
18	0.026	2	1.2	4	0.6	0.8	21.0	1880
				8			[illegible]	600
				8	0.3	7.36	80.5	2300
18	0.013	1	3.0	10	0.5	2.0	62.6	1500

Source: Hall (1980) and USDA

[1] Static pressure includes 0.25 in allowance for loss from duct friction.

[2] Airflow (cfm)/horsepower based on 3000 cfm of air at 1 iu. static pressure; 0.746 kW – 1 hp.

TABLE 6a MANUFACTURER'S Performance SPECIFICATIONS FOR AXIAL FLOW FANS OPERATEDON 115 and 230 Volts Power Supply

FAN POWER, FAN SIZE	STATIC PRESSURE (INCHES OF WATER GAUGE)													
	0.5	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.0	6.50	7.50
VOLTAGE	AIR FLOW RATINGS - CFM													
0.75 hp, 12 in - V	2200	1920	1050	480	240	.	.	.	.	.	.	.	.	.
1.0 hp, 14 in 115/230 V	2820	2550	2250	1350	920	640	350	-	-	-	-	-	-	-
I .5 hp, 18 in 230 V	4825	4450	3825	3250	2150	1450	900	-	-	-	-	-	-	-
3.0 hp, 18 in 230 V	5650	5400	5100	4700	4300	3250	2400	1800	1200	-	-	-	-	-
5.0 hp, 24 in 230 V	12250	11600	10900	10100	9150	8000	6500	4950	3900	3000	-	-	-	-
7.0 hp, 24 in 230 V	12603	12130	11630	11157	10617	10025	9432	6739	5250	4400	3880	-	-	-
10.0 hp, 24 in 230 V	14000	13800	13300	13000	12350	11400	10150	7000	5300	4300	3400	25UU	1500	600
12.0 hp, 28 in 230 V	16300	15700	15100	14435	13700	12950	12200	11350	10500	9550	8400	7150	6050	5250

Manufacturer's Performance Specifications for In-Line AND High Speed Centrifugal Fans Operated on 230 Volts Power Supply

IN-LINE CENTRIFUGAL (IL) Airflow **(CFM)** at Static **Pressure (In. Water** Gauge)

FAN SIZE POWER In - hp	STATIC PRESSURE 1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	22
18-3	3980	3690	3370	3020	2620	2130	1200	0										
24-5	5400	5230	5040	4700	4460	4160	3630	1650	400	0								
24-7	6910	6510	8370	6060	5820	5250'	4960	4460	3340	1570	0							
28-10	7960	7750	7500	7220	6850	6550	6210	5650	5440	4960	4460	3640	0					

HIGH SPEED CENTRIFUGAL (C)

FAN SIZE POWER In - hp	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	22
18-3	3590	3430	3260	3120	2940	2740	2510	2260	1640	0								
18-5	4910	4600	4470	4100	3770	3530	3350	3140	2750	1980	547	0						
24-7.5	5700	5500	5320	5140	4670	4560	4360	4140	3690	3460	2960	2410	1620	0				
24-10	5730	5660	5400	5190	4960	4550	4690	4470	4320	4090	3890	3690	3310	2950	0			
24-15	6100	8000	7800	7600	7390	7100	7040	6900	6550	6200	5920	5650	5170	4700	0			
28-20	7550	7400	7270	7150	7020	6900	6760	6620	6460	6310	6160	6000	6630	6670	5350	4980	4470	0
28-25	9040	8880	6730	8600	6420	8250	5010	7780	7690	7600	7420	7250	7035	6520	6450	6000	5400	0
28-30	10760	10550	10370	10200	10010	9830	9620	9420	9200	9000	8800	5600	5350	5100	7660	7100	6400	0
28-40	14490	14200	13950	13700	13450	13200	12920	12650	12320	12000	11750	11550	11200	10850	10250	9550	6600	0
28-50	16100	17750	17470	17200	16900	16600	16200	15800	15550	15300	14850	4400	14000	13600	12500	11900	10750	0

TABLE 7a Combinations of Drying Dams, Moisture Contents. and Minimum Airflow Rates that Resulted in Complete Drying within 30 Days and with Natural Air Drying only

Start Date	Initial MC. %	Airflow Rate $m^3/min \cdot t$	Drying Days "avg-dry" 10%	Drying Days "avg-dry" 8%	Drying Days "thru-dry" 10%	Drying Days "thru-dry" 8%
Aug. 1	13	1.0	10	16	16	21
	16	1.0	14	17	19	25
	19	1.0	15	19	21	28
Sept. 1	13	1.0	12	21	19	29
	16	1.5	14	22	20	26
	19	1.5	17	24	23	30
October	13	1.0	13	27	24	-
	16	1.5	18	29	24	-
	19	2.0	19	-	26	-

TABLE 7b Combinations of Drying Dates, Moisture Contents, Minimum Airflow Rates that Resulted in Complete Drying Within 15 Days and with Natural Air Drying only

Start Date	Initial M.C. %	Airflow Rate! $m^3/min \cdot t$	Drying Days "avg-dry" 10%	Drying Days "avg-dry" 8%	Drying Days "thru-dry" 10%	Drying Days "thru-dry" 8%
Aug. 1	13	1.5	7	14	12	-
	16	1.5	11	15	15	-
	19	2.0	12	15	15	-
Sept. 1	13	2.0	9	15	13	-
	16	2.0	13	-	-	-
	19	2.0	15	-	-	-
Oct. 1	13	2.0	6	-	12	-
	16	2.0	15	-		-
	19	2.0	-			-

8a Drying schemes that yielded minimum drying costs, overdrying cost, total drying and overdrying cost and risk cost for these schemes for complete drying within 15 days for 10% and 8% "thru-dry" policies.

Start Date	Initial Moisture Content %	Drying Air Condition	Airflow m^3/min.t	Drying Cost $/t "thru-dry" 10%	Drying Cost $/t "thru-dry" 8%	Overdrying Cost $/t "thru-dry" 10%	Overdrying Cost $/t "thru-dry" 8%	Total Drying & Overdrying Cost $/t "thru-dry" 10%	Total Drying & Overdrying Cost $/t "thru-dry" 8%	Risk Cost $/t "thru-dry" 10%	Risk Cost $/t "thru-dry" 8%
Aug 01	13	Amb. Temp.	2.0	4.28	4.41	2.87	1.83	7.15	6.24	2.36	2.67
	16	Amb. Temp.	2.0	4.36	4.46	2.96	1.44	7.32	5.90	1.68	1.93
	19	Amb. Temp.+5°C	2.0	7.53	7.90	4.15	2.35	11.68	10.25	13.75	13.87
Sep 01	13	Amb. Temp.+10°C*	1.0	6.34	6.64	5.23	3.75	11.59	10.39	3.22	3.47
		Solar Heating	1.5	6.14	6.23	4.29	1.72	10.43	7.95	3.22	3.54
	16	Amb. Temp.+ 10°C	1.5	7.31	7.63	5.45	3.41	12.76	11.12	1.99	2.17
	19	Amb. Temp.+ 10°C	2.0	8.28	8.57	4.34	3.05	12.62	11.62	13.75	13.87
Oct 01	13	Plenum Temp. ≥ 20°C	1.0	6.29	6.63	6.02	3.88	12.31	10.51	4.15	4.46
	16	Plenum Temp. ≥ 20°C	1.5	7.24	7.63	5.72	3.53	12.96	11.16	2.48	2.67
	19	Plenum Temp. ≥ 20°C	2.0	8.05	8.56	4.63	3.02	12.68	11.58	0.75	0.94

* Optimum condition for gas-heated schemes

TABLE 8b Drying schemes that yielded minimum drying costs, overdrying cost, total drying and overdrying cost and risk cost for these schemes for complete drying within 30 days for 10% and 8% "thru-dry" policies.

Start Dale	Initial Moisture Content %	Drying Air Condition	Airflow m^3/min.t	Drying Cost $/t "thru-dry" 10%	Drying Cost $/t "thru-dry" 8%	Overdrying Cost $/t "thru-dry" 10%	Overdrying Cost $/t "thru-dry" 8%	Total Drying & Overdrying Cost $/t "thru-dry" 10%	Total Drying & Overdrying Cost $/t "thru-dry" 8%	Risk Cost $/t "lhru-dry" 10%	Risk Cost $/t "lhru-dry" 8%
Aug 1	13	Amb. Temp.	1.0	3.31	3.37	5.32	2.06	8.63	5.43	2.73	3.04
	16	Amb. Temp.	1.0	3.35	$42	4.78	1.88	8.13	5.30	2.05	2.43
	19	Amb. Temp.	1.0	3.37	3.46	5.00	1.68	8.37	5.14	14.31	14.75
Sep 1	13	Amb. Temp.	1.0	3.92	4.04	4.06	1.44	7.98	5.48	3.78	4.41
	16	Amb. Temp.	1.5	4.55	4.66	4.14	1.66	8.69	6.32	2.55	2.92
	19	Amb. Temp.	1.5	4.60	4.74	4.10	0.95	8.70	5.69	1.43	1.87
Oct 1	13	Amb. Temp.	2.0	4.33	4.76	2.03	0.33	6.36	5.09	4.21	5.27
	16	Plenum Temp..									
		≥ 2ooc •	1.0	6.71	6.96	6.59	4.40	13.30	11.36	2.73	2.98
		Solar Heating	1.5	6.25	6.35	4.14	1.55	10.39	7.90	2.73	3.04
	19	Plenum Temp..									
		≥ 20°C	1.0	6.89	7.27	6.48	4.91	14.16	12.12	1.18	1.43
		Solar Healing	1.5	6.31	6.44	2.89	0.76	9.20	7.20	1.18	1.62

* Optimum condition for gas-healed schemes

TABLE 9

Electrical and heat energy costs, and drying costs associated wilb different drying syslem controls for drying barley grain from 19% initial moisture content lo 13% final acerage moisture content for August 1, September 1, and October 1 start dales. The airflow rate was 1·0 m^3 min^{-1} t^{-1}

Drying air condition	August				September				October			
	Drying rime, d	Electrical energey cost, $/t	Heat energy cost, $/t	Drying cost, $/t	Drying rime, d	Electrical energy cost, $/t	Heat energy cost, $/t	Drying cost, $/t	Drying rime, d	Electrical energy cost, $/t	Heat energy cost, $/t	Drying cost $/t
Ambient temp-erature	46	0·57	0	5·11	38'	0.94	0	6.43	55*	1·36	0	6·85
Ambient temp. + 5°C	17	0·21	1·28	8·82	26	0·32	1·99	9·65	31	0·38	2·37	10·09
Ambient temp. + 10°C	13	0·16	1·91	9·41	18	0·22	2·71	10·27	20	0·25	3·02	IO-61
Inlet temp. = 30°C	13	0·16	1·92	9·42	6	0·12	2·56	10·02	6	0·12	3·36	10·82
Inlet temp. = 40°C	7	0·09	1-85	9·27	5	0·07	2·25	9·66	5	0·07	3·02	10·43
Inlet RH ≤ 50%	20	0·25	1·03	8·61	31	0·40	1·85	9·48	37	o-45	2·25	10·05

* The airflow rate had to be increased to 2 m^3 min^{-1} t^{-1} to complete drying with unheated air in September and October.

TABLE 10a

Optimum drving systems that yield minimum drying costs for complete drying of barley within 30 days from various initial grain moisture contents to 13% final average moisture content at different start dates for feed and malting product

Start date	*initial moisture content. % w.b.*	*Drying air condition*	*Airflow rate, $m^3 min^{-1} t^{-1}$*	*Drying time. d*	*Drying cost, $/t*	*Product use*
August 1	16	Ambient temp.	1·0	19	4.65	Feed and malt
	19	Ambient temp.	2·0	20	5·99	Feed and malt
	22	Ambient temp. +5°C	1·0	23	9·37	Feed
	2s	Ambient temp. +5°C	1·0	30	10.01	*Lower **grade feed**
September 1	16	**Ambient temp.**	2·0	26	6·14	Feed and malt
	19	Inlet temp. = 40°C	1·0	6	9-64	Feed
		Ambient temp. +5°C	1·0	26	9-65	Malt
	22	Inlet temp. = 40°C	1·0	8	10·81	Feed
		Ambient temp. = +5°C	1·5	28	11·66	Malt
	25	**Inlet temp. 40°C**	1-0	10	1·70	Feed
October 1	16	Inlet temp. = 30°C	1-o	5	8·37	Feed
		Ambient temp. +10°C	1-o	9	8·72	Malt
	19	Inlet temp. = 40°C	1·0	6	9·75	Feed
		Ambient temp. + 10°C	1·0	20	10.61	Malt
	22	Inlet temp. = 40°C	1·0	8	10.55	Feed
		Inlet temp. = 20°C	1-o	24	12.44	Malt
	25	Inlet temp. 40°C	1·0	10	11·79	Feed only

* STR or SI > 1·0.

TABLE 10b

Optimum drying systems that yielded minimum drying costs for complete drying of barley within 15 days from various initial grain moisture contents to 13% final average moisture content at different start dates for feed and malting product use

Starr date	*Initial moisture content. % w.b.*	*Drying air condition*	*Airflow rate $m^3 min^{-1} t^{-1}$*	*Drying time, d*	*Drying cost. $/t*	*Product use*
August 1	16	Inlet temp. = WC	1·0	4	8·27	feed
		Ambient temp. = +5°C	1·0	13	8·50	Malt
	19	Inlet temp. = 40°C	1·0	7	9·27	Feed
		Ambient temp. +5°C	1·5	14·5	9.86	Malt
	22	Inlet temp. = 40°C	1·0	9	10·03	Feed
		Ambient temp. +5°C	2·0	15	11·38	malt
	25	Inlet temp. = 40°C	1·0	11	IO-62	***Lower** grade feed
September 1	16	Plenum temp. = 30°C	1-o	6	8·87	Feed
		Ambient temp. +10°C	1·0	11	9·07	**Mult**
	19	Inlet temp. = WC	1-o	6	9·66	Feed
		Ambient temp. +10°C	1·5	15	11·34	Malt
	22	Inlet temp. = 40°C	1·0	8	10·81	Feed
		Inlet temp. = 20°C	1·5	13	11·06	Malt
	25	Inlet temp. = 40°C	t-0	10	11·70	Feed
October 1	16	**Inlet** temp. = 30°C	1-o	5	8·37	Feed
		Ambient temp. +10°C	1·0	9	8·72	Malt
	19	Inlet temp. = 40°C	1·0	6	9·75	**Feed**
		Inlet temp. = 20°C	1·0	15	13·85	**Malt**
	22	Inlet temp. = 40°C	1·0	8	10·55	**Feed**
		Inlet temp. = 25°C	1·5	13	13·92	**Malt**
	25	Inlet temp. = 40°C	1·0	10	11·79	**Feed** only

* STR or SI > 1-O.

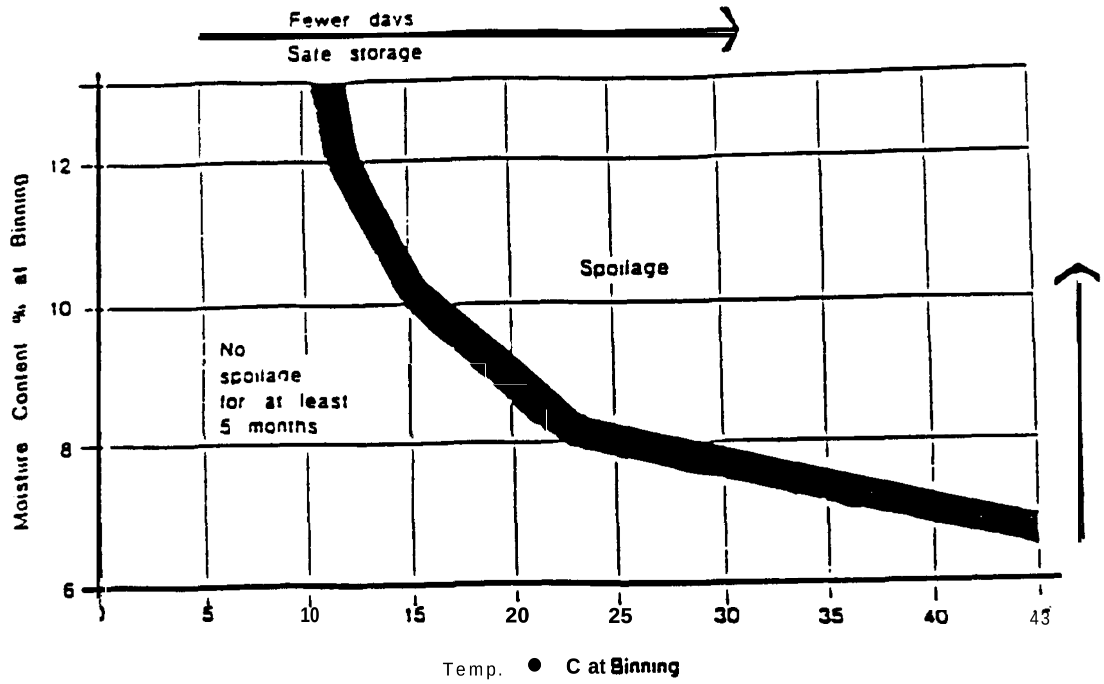


Fig. la Canola Storage Time Chart (Adapted from Muir et al., 1989)

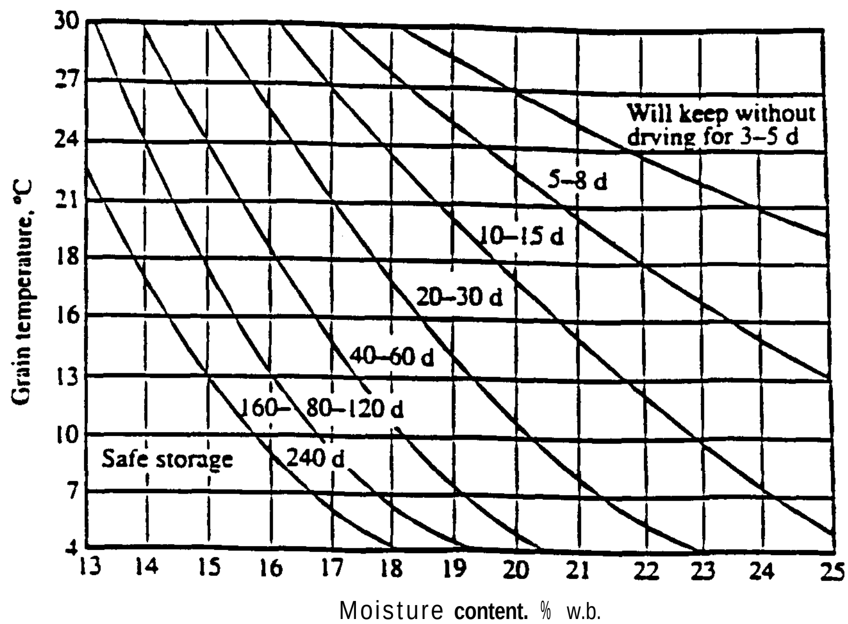


Fig. lb Safe Storage Time for Barley Grain at Various Temperatures and Moisture Contents (McLelland, 1984)

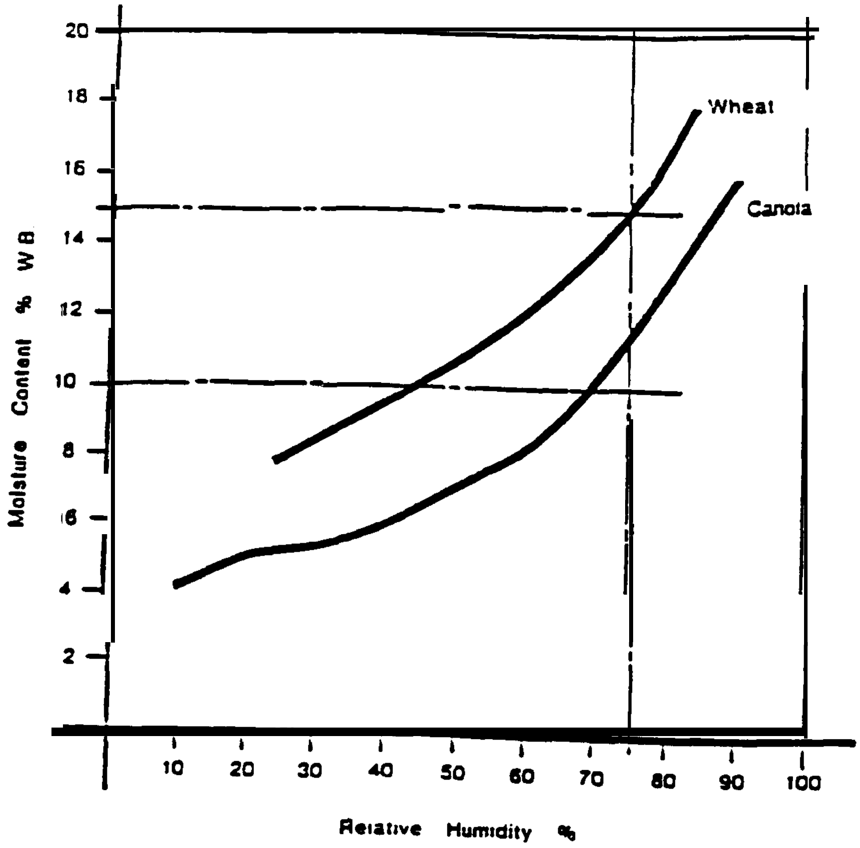


Fig. 2 Equilibrium Moisture Content of Canola and Wheat Seeds

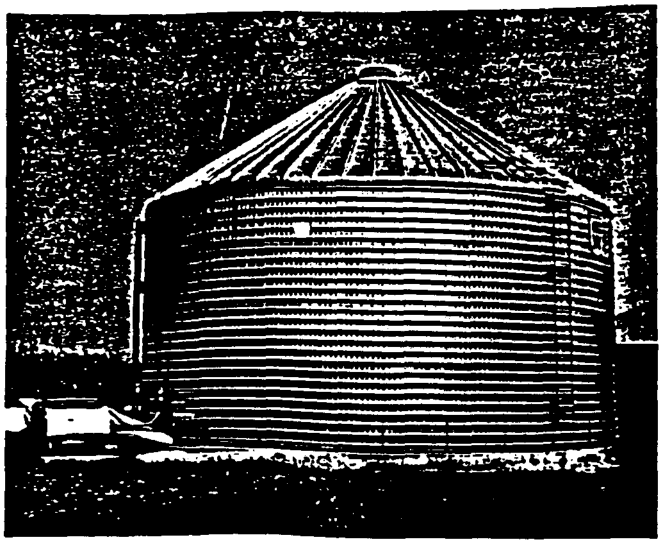


Fig. 3 Forced Natural Air Drying or Aeration System

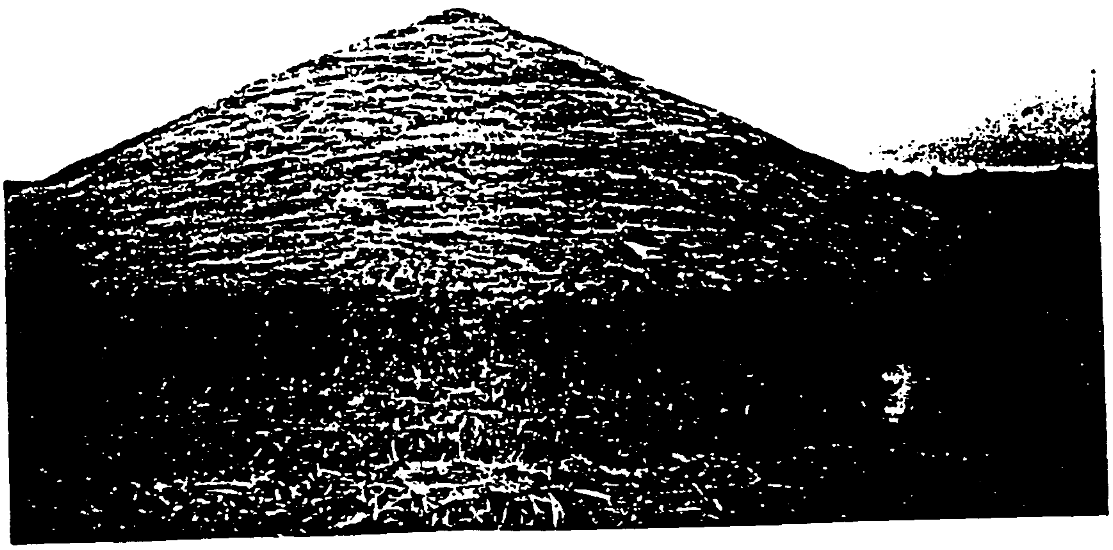


Fig. 4 A Damp Wheat Grain Pile Left Outside During the 1996 Harvest in Melfort Area, Saskatchewan

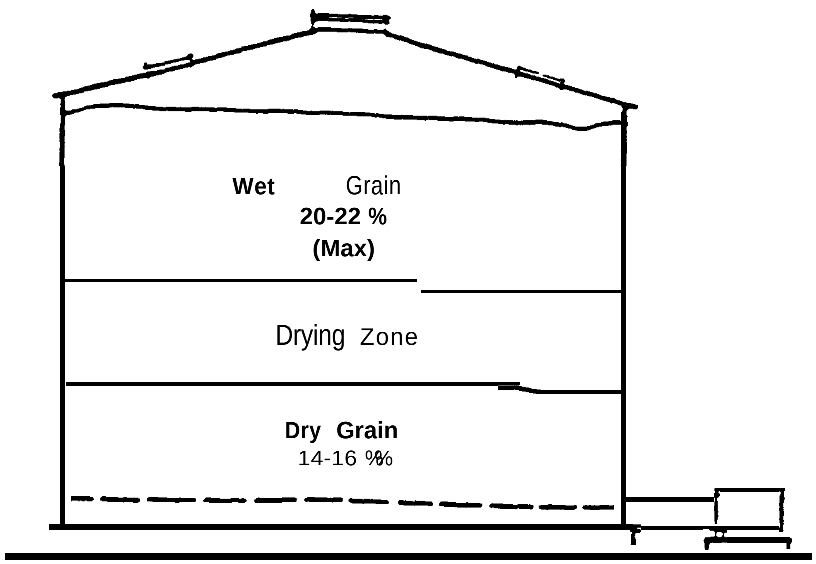
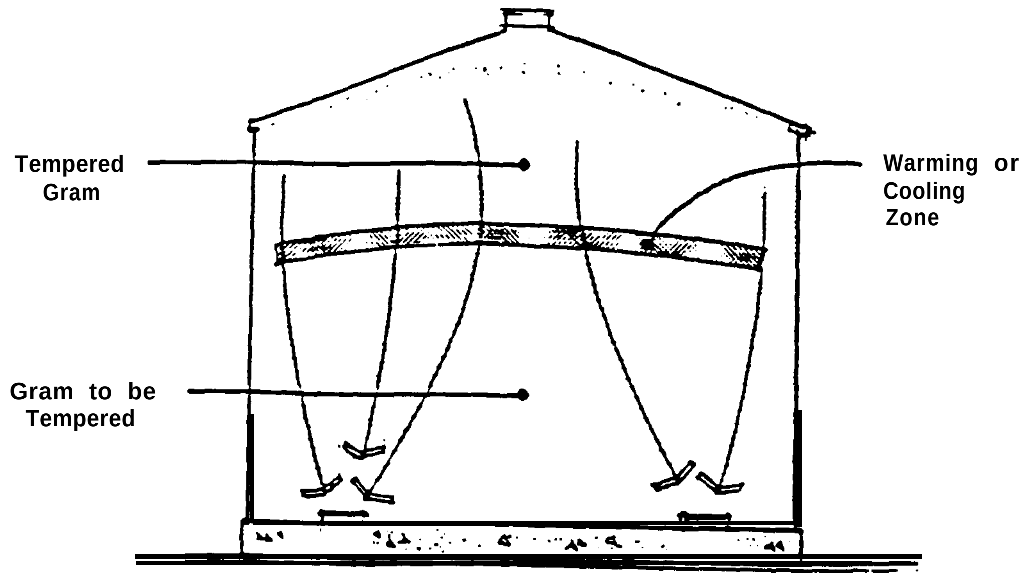
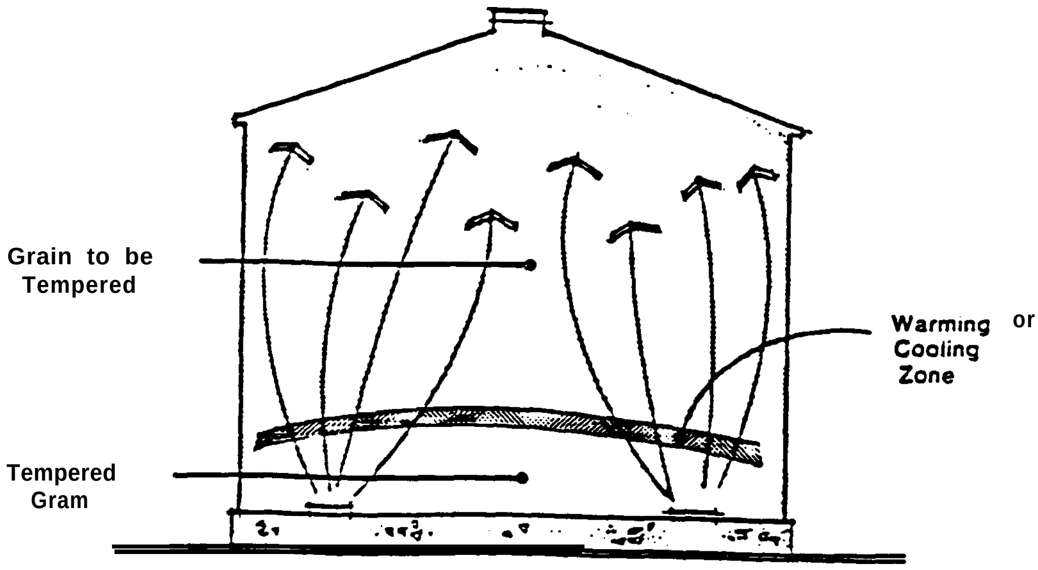


Fig. 6 Moisture Zones in Stored Grain with Natural Air Drying



Negative Pressure



Positive Pressure

Fig. 5 Aerating to Change Grain Temperature