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RECONDITIONING CORN AND SOYBEANS TO OPTIMAL PROCESSING MOISTURE CONTENTS

M. D. Montross, D. E. Maier

ABSTRACT. *Experimental trials were carried out to evaluate the technical feasibility of reconditioning overly dry corn and soybeans to optimal market and processing moisture contents. Data obtained from experimental trials were used to validate an aeration simulation model. This model was used to evaluate the feasibility of reconditioning soybeans and corn. Reconditioning of grain was feasible at low airflow rates (0.11 m^3 min^{-1} t^{-1}) over a six-month period when an automatic aeration controller was used. Using downflow aeration and monthly unloading of the bin allowed for the greatest net economic gain. Predicted reconditioning in Des Moines, Iowa, had a lower net economic gain than in Indianapolis, Indiana, based on 29 years of historic weather records.*

Keywords. *Aeration, Aeration controllers, Reconditioning.*

Using aeration technology to manage the moisture content of a stored grain mass for the purpose of raising its moisture has long been a controversial subject. Frequently, soybeans are harvested at low moistures (8 to 10% w.b.*) and during artificial drying, corn is frequently overdried. Crops sold at less than market moisture weigh less and thus provide less revenue than crops sold at market moisture. Any moisture added back to overdried grain increases the weight of the grain sold. Direct addition of water to any grain for the purpose of increasing its weight for marketing is considered an illegal adulteration by U.S. regulatory authorities (Shipman, 1997; Kim, 1997). Incidental addition of moisture during aeration and intentional conditioning of grains and oilseeds to optimum moisture levels for processing have not been challenged.

For producers and elevators, significant economic incentive to recondition grain to higher moisture contents exists (figs. 1 and 2). Conditioning of low moisture grain during periods of high humidity is economically desirable but has been considered by many as technically infeasible (Foster and Tuite, 1992). A temperature front moves through grain about 20 to 30 times faster than a drying or wetting front. Thus, a typical aeration airflow rate of 0.11 m^3 min^{-1} t^{-1} (0.1 cfm/bu) that is adequate to complete a temperature change in one week of fan operating time may take six months to complete a desired moisture change throughout the same lot. However, research reported at the 1997 Grain Quality Conference at Urbana, Illinois, showed that it is technically feasible to increase moisture contents in grains and oilseeds using automatically controlled aeration systems within a shorter time period (Maier and Montross, 1997).

Hellevang (1995) investigated the addition of moisture to wheat by reversing the airflow through the bin. He concluded that it would cost $US 0.14/h to operate a fan for an economic gain of $0.34/h in 10% wheat. Wilcke et al. (1999) used 34 years of weather data to investigate the reconditioning of 7 and 10% moisture soybeans in St. Paul, Minnesota, Fargo, North Dakota, and Sioux Falls, South Dakota. They based their simulation work on fan operation above a set relative humidity of 50, 60, and 70%. The ratio of the value of water added to the cost of the fan energy supplied was greater than one in almost all cases. Removing layers of beans provided a greater uniformity in the final moisture and a somewhat higher value ratio.

A primary motivation for this research into the conditioning of grains and oilseeds stems from the need of processors of popcorn, food corn, soybeans, and other crops to achieve moisture contents that are optimum for processing. For example in popcorn, the popping volume is maximized when kernels are uniformly conditioned to around 13.5% moisture, while soybean processors prefer an optimum moisture content around 10.5% for the flaking of beans for oil extraction.

OBJECTIVE

The objective of this research was to quantify the technical feasibility and economic incentives for conditioning overly dry soybeans and corn toward the optimal market moisture content at two U.S. Corn Belt locations (Indianapolis, Indiana, vs Des Moines, Iowa).

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* All moisture contents are presented in wet basis unless otherwise noted.

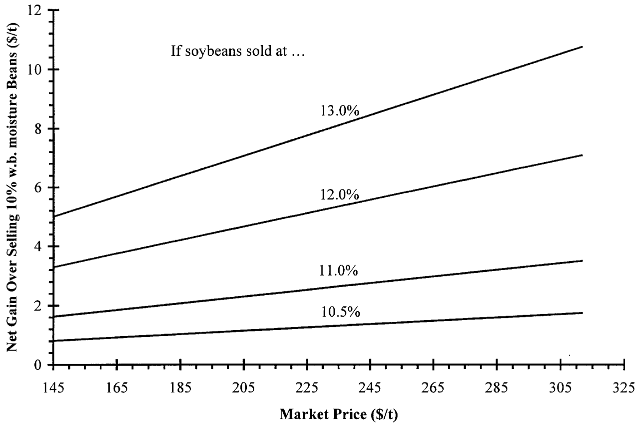

Figure 1–Economic incentive for adding moisture to soybeans (assuming a constant test weight of 772 kg/m^3).

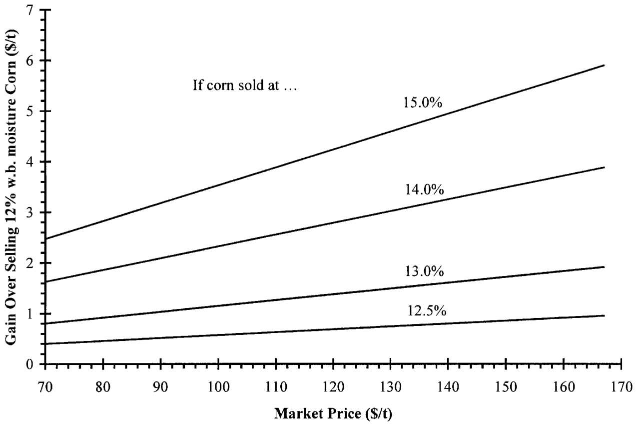

Figure 2–Economic incentive for adding moisture to corn (assuming a constant test weight of 721 kg/m^3).

AERATION SYSTEMS AND FAN CONTROLLERS

Aeration is the forced movement of ambient air through stored grain to decrease or increase the grain temperature to the desired level. Although standard design airflow rates of 0.11 m^3 min^{-1} t^{-1} (0.1 cfm/bu) or less are generally too low to significantly change grain moistures by more than 0.5 percentage points, excessive aeration can shrink grain, or cause swelling of grain kernels near the air inlet.

The primary conditioning technology available to farmers and elevator managers is the use of forced ambient air from drying or aeration fans installed on grain bins, tanks, flat storages, and concrete silos. The success of a conditioning strategy to achieve a significant moisture change in a bulk of grain depends on the right combination of aeration system design, airflow rate, air and grain conditions, available time, and direction of airflow. If ambient air conditions are unfavorable at a location, air could be conditioned with the help of a humidifier.

As grain is aerated, its moisture content gradually comes into equilibrium with the surrounding (interstitial) air relative humidity (r.h.). If air temperature increases while r.h. is constant, the grain's equilibrium moisture content (EMC) will decrease. If r.h. increases at constant temperature, EMC will increase. Knowing the relationship between EMC and air conditions is important in properly managing aeration systems to prevent overdrying, condensation, or absorption.

Aeration based on the EMC of grain is critical for achieving the conditioning objective. A microprocessor (or computer) can be used to calculate EMC from the measured ambient temperature and relative humidity. EMC equations for corn and soybeans are available (ASAE, 1997). Microprocessor- and computer-based aeration controllers are commercially available and can be programmed to achieve a specific target moisture content either by operating fans to reduce or increase the average moisture in the grain mass. The success of such a strategy depends primarily on exposing the grain to the right combination of ambient conditions (temperature and r.h.) for a sufficient length of time.

In order to accomplish a desired outcome, a microprocessor-based controller must reliably sense the air temperature and humidity to determine the EMC, and be able to provide the right amount of fan operating time for the airflow rate of the system to produce the desired grain temperature and moisture. These sophisticated control strategies require not only reliable sensors that are regularly calibrated, but also programmable microprocessors that are well understood by the user.

A NEW APPROACH TO RECONDITIONING

A new approach to reconditioning overly dry grain was evaluated as part of a research experiment. It involves directing the airflow through the grain from the top to the bottom. This was chosen for several practical reasons. First, pulling air through the grain avoids any prewarming of the air due to fan compression, which would lower the actual air EMC. Second, during conditioning it is possible for the grain to swell. It was assumed that swelling of the grain could take place in the upper layers of the bin more readily than in the lower portions, which carry the weight of the grain above. Thirdly, any problem of spoilage or heating of the grain was expected to occur most readily in the rewetted grain. Managing such problems is easier when the rewetted layer is near the top of the bin than when it is near the bottom. Fourth, because conditioning fronts move slowly, rewetting grain from the top down is more effective because it allows for the partial unloading of the conditioned grain assuming there is a funnel flow pattern during unloading of the bin (last in—first out). If grain was conditioned from the bottom up, the benefit of rewetting would generally not become apparent until the last part of the bin was unloaded because of the relatively slow movement of a moisture front.

EXPERIMENTAL CONDITIONING

CONDITIONING OF SOYBEANS

Three small corrugated steel bins were each filled with 5.51 t (213 bu) of soybeans harvested at 9.6 to 10.6% moisture content between 1 November 1994 and 13 June 1995 at a site near the Purdue University Airport, West Lafayette, Indiana. The fans were controlled with a SentryPAC (Sentry Technologies, Chico, California) controller, which was equipped with an ambient air temperature and relative humidity sensor, and set to operate whenever the EMC of the ambient air was above 13% w.b. No other limits were set. Each fan and bin combination was set up to deliver one of three typical airflow rates. Bin 1 was initially designed with a fan to deliver the typical aeration airflow of 0.11 m^3 min^{-1} t^{-1} (0.1 cfm/bu). However, the selected fan actually only delivered 0.06 m^3 min^{-1} t^{-1} (0.05 cfm/bu). The fan in Bin 2 was designed to deliver 0.56 m^3 min^{-1} t^{-1} (0.5 cfm/bu), which is typical for bins used to cool hot corn after transfer from a dryer. Bin 3 was designed with a fan to deliver 1.1 m^3 min^{-1} t^{-1} (1.0 cfm/bu), which is representative of a natural air/low temperature drying bin. All three bins were set to pull air from the headspace down through the soybeans. Airflow rates were determined based on manufacturer-supplied fan performance curves and by measuring static pressure drop through the soybeans. Total cost was calculated by multiplying the amount of fan run time by the electric power drawn and electricity cost. The gain was the mass of water added to the bin multiplied by the price of grain. No discounts were taken for grain that was above the market moisture content. It was assumed that grain in excess of the desirable market moisture content could be blended with grain that was below the market moisture content. The total net gain ($/tonne) was then calculated by dividing the difference between the total cost ($) and the value of the water gain ($) by the original mass of grain in the bin (tonne).

The results indicated an economic benefit for each rewetting scenario (table 1). As expected, the higher the airflow rate, the more moisture was gained during a given conditioning period. However, the increase in economic gain was disproportionate to the airflow rate. Increasing the airflow rate by 10 times increased the economic gain by only four times, while increasing the airflow rate by 20 times increased the economic gain by only five times. The economic gain increased by only 16% when doubling the airflow from 0.56 to 1.1 m^3 min^{-1} t^{-1} (0.5 to 1.0 cfm/bu). With both the 0.56 to 1.1 m^3 min^{-1} t^{-1} (0.5 and 1.0 cfm/bu) airflows, the average of the grain mass, which was determined from samples collected during unloading of the bins, approached the desired market moisture content of 13% w.b. during the 7.5 months of conditioning.

The experimental conditioning of the soybeans created a significant moisture gradient between the top and bottom layers of the 2.13-m (7-ft) deep bins (fig. 3). For the 1.1 m^3 min^{-1} t^{-1} (1.0 cfm/bu) airflow, a maximum moisture of about 21% w.b. was measured near the grain surface on 18/5/95. The beans swelled so much that probing below 0.61 m (2 ft) from the top of Bin 3 was impossible after the January sampling date.

Table 1. Economic gain from site-specific conditioning of three 5.51 t (213 bu) bins of soybeans*

	Airflow m^3 min^{-1} t^{-1} (cfm/bu)	Initial Average Moisture	Final Average Moisture	Net Gain t (bu)	Energy Input (kWh)	Economic Net Gain $/t ($/bu)
Bin 1	0.06 (0.05)	10.2	10.8	0.036 (1.4)	6	1.6 (0.044)
Bin 2	0.56 (0.50)	10.6	13.0	0.153 (5.9)	30	6.76 (0.184)
Bin 3	1.11 (1.00)	9.6	12.5	0.183 (7.1)	60	7.86 (0.214)

* 1200 total fan hours using an automatic fan controller set to operate whenever the ambient air equilibrium moisture content was greater than 13%. Soybeans at $257.2/t ($7/bu), electricity at $0.07/kWh, and test weight constant at 734 kg/m^3 (57 lb/bu).

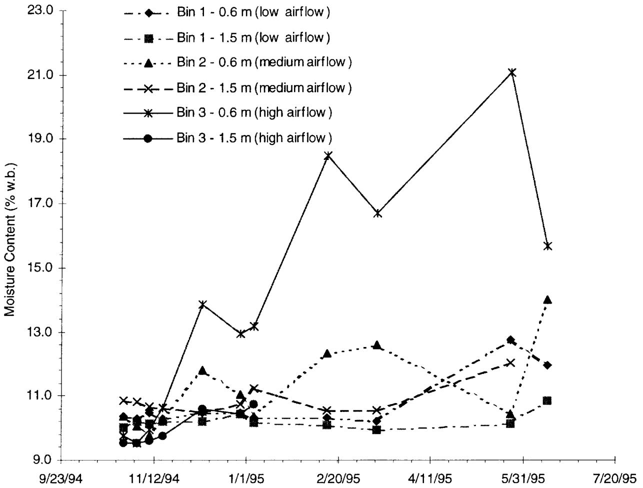

Figure 3–Change in moisture content of soybeans in three experimental bins conditioned in West Lafayette, Indiana, between 1 November 1994 and 13 June 1995. Soybean depth was 2.1 m, and sampling depths were from the top surface downward. Airflow rates were 0.06 $m^3min^{-1}t^{-1}$ (low), 0.56 $m^3min^{-1}t^{-1}$ (medium), and 1.11 $m^3min^{-1}t^{-1}$ (high).

In order to evaluate the reconditioning of soybeans in larger bins with historic weather data for other locations, computer simulation can be used as an analysis tool. The Purdue University Post-Harvest Aeration & Storage Simulation Tool (PHAST) is a computer program that was previously developed and validated for in-bin drying and conditioning of yellow corn, white corn, popcorn, rice, wheat, oats, barley, and rye (Maier et al., 1996; Saksena et al., 1997; Zink et al., 1997). PHAST was validated for the subsequent soybean reconditioning analysis using the above field experiments. It was found to predict the experimental results in the three test bins with acceptable accuracy.

CONDITIONING OF CORN

During the autumn of 1996, corn in two natural-air drying bins was overdried. Table 2 lists the data during the reconditioning of the corn in the spring of 1997 before marketing. Bin 1 had an airflow rate of 1.1 m^3min^{-1} t^{-1} (1.0 cfm/bu) and Bin 2 used an airflow rate of 2.2 m^3 min^{-1} t^{-1} (2.0 cfm/bu). During the natural-air drying process, Bin 1 had reached a moisture content of 14.0%, and Bin 2 was 13.4%. The airflow through the bins was set up as a push (or pressure) aeration system, and was not reversed during reconditioning. The aeration controller was programmed to operate the fans whenever the EMC of the ambient air was greater than 15%, and the temperature was between –3.3 and 15.6°C (26 and 60°F). After a total of 235 h of fan run time, Bin 1 had increased in moisture by 0.7 points, and Bin 2 increased by 1.2 points. The net economic gain in Bin 1 was $0.6/t ($0.017/bu), and in Bin 2 the net economic gain was $0.2/t ($0.006/bu). Although the total moisture gain in Bin 2 was greater, the higher cost of electricity to operate the larger fan exceeded the value of the extra moisture increase.

Table 2. Economic gain for reconditioning two 64.6 t (2,500 bu) bins of corn from 26/3/96 to 10/4/96*

	Airflow $m^3\ min^{-1}\ t^{-1}$ (cfm/bu)	Initial Average Moisture	Final Average Moisture	Net Gain t (bu)	Energy Input (kWh)	Economic Net Gain \$/t (\$/bu)
Bin 1	1.1 (1.0)	14.0	14.7	0.47 (18.3)	235	0.6 (0.017)
Bin 2	2.2 (2.0)	13.4	14.6	0.82 (31.7)	1,175	0.2 (0.006)

* 235 total fan hours using an automatic fan controller set to operate whenever the ambient air equilibrium moisture content was greater than 15% w.b. Corn at \$118.1/t (\$3.00/bu), electricity \$0.07/kWh, test weight constant at 734 kg/m^3 (57 lb/bu).

SITE-SPECIFIC WEATHER ANALYSIS

Four U.S. Corn Belt locations were investigated to determine the number of hours available to recondition soybeans and corn. The primary concern with respect to setting certain temperature and relative humidity limits for moisture conditioning with an automatic fan controller is whether adequate fan run time is available to achieve the desired moisture content. Weather data between October and June for the years 1961 to 1990 were analyzed for the number of available hours when ambient conditions were such that the EMC for corn was above 15% and temperatures were between –3.3 and 15.6°C (26 and 60°F). The limits on the temperatures were chosen to prevent air that was significantly below freezing from entering the bin in the winter and excessively warm air from entering and spoiling wetter corn during the spring.

The suitable fan run time hours for the season for reconditioning corn are summarized in table 3 for 1961 through 1990. The available fan run time for October through March ranged from 1,848 to 2,943 h with an average of 2,264 h for Indianapolis; for Des Moines it ranged from 1,132 to 2,564 h with an average of 1,815 h. The variation in available conditioning hours was most significant between Indianapolis and Des Moines. Des Moines had on average around 400 fewer hours to condition corn. The standard deviation was greatest for Des Moines and lowest for Indianapolis for the four locations investigated.

The weather data were also analyzed for soybeans with an EMC limit of 13% and temperature limits of –3.3 to 15.6°C (26 to 60°F) (table 4). Indianapolis had a greater amount of suitable fan run time than Des Moines. However, the total number of hours available for reconditioning soybeans was slightly less than for corn. As a result of the weather analysis, Indianapolis, Indiana, and Des Moines, Iowa, were further investigated because they represent large production areas in the eastern and western Corn Belt, respectively.

Table 3. Total run time, range, and standard deviation (h) for four Corn Belt locations and storage periods when reconditioning corn [Air EMC > 15% and ambient temperature within –3.3 to 15.6°C (26 to 60°F)] for weather data 1961 through 1990

	1/10 - 1/4	1/10 - 1/6	1/11 - 1/4	1/11 - 1/6
Indianapolis, Ind.	2264 1848-2943 260	2548 2109-3222 287	1930 1423-2584 243	2213 1684-2863 270
Des Moines, Iowa	1815 1132-2564 322	2112 1296-2885 351	1508 849-2152 292	1805 1013-2531 323
Peoria, Ill.	2159 1386-2691 270	2454 1593-2983 307	1819 1256-2370 269	2114 1463-2686 309
St. Louis, Mo.	2035 1466-2716 337	2274 1633-3042 388	1770 1064-2358 307	2009 1231-2690 355

Table 4. Total run time, range, and standard deviation (h) for four Corn Belt locations and storage periods when reconditioning soybeans [Air EMC > 13% and ambient temperature within –3.3 to 15.6°C (26 to 60°F)] for weather data 1961 through 1990

	1/10 - 1/4	1/10 - 1/6	1/11 - 1/4	1/11 - 1/6
Indianapolis, Ind.	2079 1702-2787 273	2512 2014-3199 307	1760 1302-2448 249	2019 1555-2690 276
Des Moines, Iowa	1614 816-2457 343	2054 1005-2949 400	1330 573-2016 304	1602 721-2309 337
Peoria, Ill.	1975 1249-2595 284	2438 1463-3196 336	1654 875-2195 275	1923 1020-2467 312
St. Louis, Mo.	1868 1249-2595 351	2234 1463-3196 424	1613 875-2195 315	1837 1020-2467 367

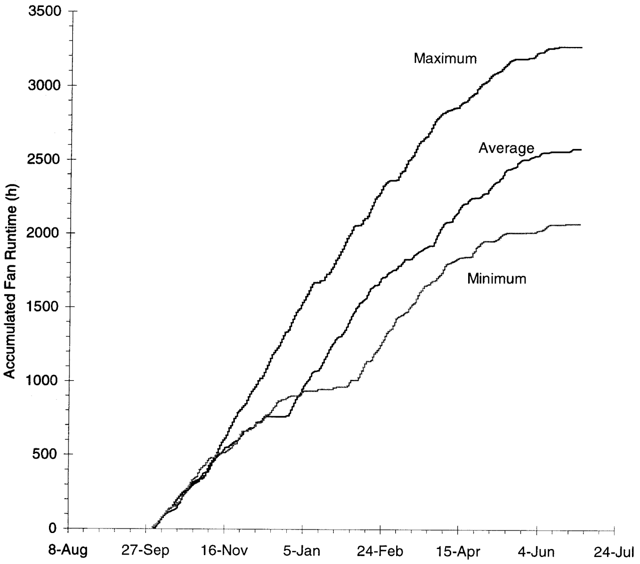

Figure 4–Accumulated run time for the minimum, maximum and average years for Indianapolis, Indiana, when rewetting soybeans with an EMC > 13% and temperatures falling within the –3.3 to 15.6°C (26 to 60°F).

An ending date of 1 April was chosen because the number of available hours to run the fan decreased rapidly in the late spring/early summer (fig. 4). The weather data were sorted and the year with the minimum run time was 1976-1977, the maximum was 1974-1975, and 1989-1990 was closest to the 29-year average. Extending the conditioning period beyond June resulted in limited additional run time. Similar data were found for corn, and the same trends existed for Des Moines.

SIMULATED SITE-SPECIFIC CONDITIONING

Using Indianapolis and Des Moines weather data for 29 years (1961-1990), the conditioning of corn and soybeans in corrugated steel bins was investigated using

Table 5. Airflow rates, $m^3\ min^{-1}\ t^{-1}$, (cfm/bu) in a 9.14 m (30 ft) diameter farm bin for different fill depths

	Corn		Soybeans	
Depth, m (ft)	0.75-kW Fan (1-hp)	5.6-kW Fan (7.5-hp)	0.75-kW Fan (1-hp)	5.6-kW Fan (7.5-hp)
1.52 (5)	1.20 (1.08)	4.56 (4.09)	1.21 (1.09)	4.62 (4.15)
3.05 (10)	0.56 (0.50)	2.14 (1.92)	0.57 (0.51)	2.22 (1.99)
4.57 (15)	0.38 (0.31)	1.35 (1.21)	0.36 (0.32)	1.41 (1.27)
6.08 (20)	0.23 (0.21)	0.96 (0.86)	0.26 (0.23)	1.01 (0.91)
7.60 (25)	0.18 (0.16)	0.74 (0.66)	0.19 (0.17)	0.78 (0.70)
9.12 (30)	0.14 (0.13)	0.58 (0.52)	0.14 (0.13)	0.62 (0.56)

Table 6. Airflow rates, $m^3\ min^{-1}\ t^{-1}$, (cfm/bu) in a 18.29 m (60 ft) commercial tank for different fill depths

	Corn		Soybeans	
Depth, m (ft)	11.2-kW Fan (15-hp)	Two 14.9-kW Fans (two 20-hp)	11.2-kW Fan (15-hp)	Two 14.9-kW Fans (two 20-hp)
3.05 (10)	0.81 (0.73)	1.89 (1.70)	0.81 (0.73)	1.84 (1.65)
6.08 (20)	0.39 (0.35)	0.89 (0.80)	0.41 (0.37)	0.90 (0.81)
9.12 (30)	0.26 (0.23)	0.56 (0.50)	0.26 (0.23)	0.56 (0.50)
12.20 (40)	0.19 (0.17)	0.40 (0.36)	0.20 (0.18)	0.40 (0.36)
15.25 (50)	0.14 (0.13)	0.31 (0.28)	0.14 (0.13)	0.30 (0.27)
18.30 (60)	0.12 (0.11)	0.25 (0.22)	0.12 (0.11)	0.25 (0.22)

PHAST. Two bin types (a typical farm bin and a typical commercial tank) with two fan sizes were investigated. The selected farm bin was a 9.1-m (30-ft) diameter, 9.1-m (30 ft) deep bin that held 598 m^3 (16,965 bu) level filled. The commercial tank was 18.3 m (60 ft) in diameter and 18.3 m (60 ft) deep and held 4782.1 m^3 (135,700 bu) level filled. Two airflow rates were investigated for both locations and bin types.

Simulated conditioning started on 1 October and ended on 1 April. Three unloading scenarios were investigated: a single unloading on 1 April; three partial unloadings on 15 December, 1 February, and 1 April; and six monthly partial unloadings. After each partial unloading of the top layer of grain, the downward airflow rate was increased accordingly. Airflow rates for different grain depths and bin types are given in tables 5 and 6. Commercially available fan performance curves (The GSI Group, Assumption, Illinois) were used to estimate the airflow rate during conditioning. The farm bin was evaluated for either a 0.75-kW (1-hp) fan or a 5.6-kW (7.5-hp) fan. The commercial tank used a 11.2-kW (15-hp) or two 14.9-kW (20-hp) fans. The controller was set for temperature limits of –3.3 and 15.6°C (26 and 60°F) for all modeling program scenarios and the low EMC limit for fan operation was set to 15% for corn and 13% for soybeans. A level grain surface was assumed for each unloading scenario.

The net economic gain was calculated as the value of the weight gain in conditioned grain quantity minus fan operating costs. During reconditioning of corn, it was assumed that the test weight was constant at 721 kg/m^3 (56 lb/bu) with an initial uniform moisture content of 13% in level filled bins. For soybeans, the test weight was 772 kg/m^3 (60 lb/bu) with an initial moisture content of 10%. In all cases electricity was assumed to cost \$0.07/kWh, and the price of corn was \$118/t (\$3.00/bu) and soybeans \$257/t (\$7.00/bu).

SIMULATED CONDITIONING OF CORN IN A FARM BIN

Reconditioning corn and unloading the bin once resulted in an average gain of \$2.2/t (\$0.056/bu) and a final moisture content of 14.9% in Indianapolis, and a gain of \$1.9/t (\$0.047/bu) and a final moisture content of 14.5% in Des Moines at the low airflow rate (table 7). Over the 29 years there was a large variation in the final net gain and moisture content for each of the years. The net gain for Indianapolis varied from 1.0 to \$3.9/t (0.026 to \$0.089/bu) with a standard deviation of \$0.63/t (\$0.159/bu). If the bin was partially unloaded during conditioning, the average net gain and average final moisture content increased. Also, the standard deviation decreased as the frequency of unloading increased, from \$0.63/t (\$0.0159/bu) with one unload to \$0.55/t (\$0.0139/bu) for six unloads in Indianapolis. With the low airflow rate and six months of conditioning, the desired market moisture content of approximately 15% was reached in most years. Using the high airflow rate, the moisture content could be increased excessively high to 17 to 18% in six months, or the desired 15% moisture content could be reached well before 1 April during most of the years. No shrink factor was applied if the moisture content was increased above the desired market moisture content of 15%.

When the airflow rate was increased, the variability in the final moisture content and net economic gain increased. The standard deviation increased from \$0.55/t (\$.014/bu) with six unloads in Indianapolis at the low airflow rate to

Table 7. Net gain and final average moisture content when rewetting corn in a farm bin in Indianapolis and Des Moines at two airflow rates and for three unloading schedules (results are average, range, and standard deviation over 29 years)

	Low Airflow Rate			High Airflow Rate		
Location	6 Unloads	3 Unloads	1 Unload	6 Unloads	3 Unloads	1 Unload
Indiana	3.1 (0.078)	2.7 (0.069)	2.2 (0.056)	4.6 (0.116)	4.1 (0.103)	3.3 (0.084)
net gain	1.7-3.9 (0.043-0.100)	1.6-3.7 (0.041-0.094)	1.0-3.5 (0.026-0.089)	2.4-6.4 (0.061-0.162)	2.9-5.5 (0.073-0.139)	2.1-5.2 (0.053-0.133)
\$/t (\$/bu)	0.55 (0.014)	0.56 (0.014)	0.63 (0.016)	0.84 (0.0214)	0.68 (0.0172)	0.76 (0.0193)
Indiana	15.5	15.2	14.9	18.1	17.8	17.3
final MC,	14.5-16.1	14.4-15.9	14.0-15.8	16.4-19.4	16.7-18.8	16.2-18.2
% w.b.	0.40	0.40	0.45	0.65	0.50	0.54
Iowa	2.6 (0.067)	2.3 (0.059)	1.9 (0.047)	4.3 (0.108)	3.9 (0.099)	3.3 (0.084)
net gain	1.3-4.1 (0.032-0.103)	0.6-4.1 (0.016-0.103)	0.3-3.9 (0.07-0.100)	3.3-6.0 (0.083-0.153)	2.6-5.7 (0.065-0.145)	1.9-6.1 (0.048-0.154)
(\$/t, \$/bu)	0.62 (0.016)	0.70 (0.018)	0.73 (0.019)	0.73 (0.019)	0.73 (0.019)	0.94 (0.024)
Iowa	15.1	14.9	14.5	17.5	17.3	16.9
final MC,	14.1-16.2	13.6-16.1	13.3-16.0	16.4-18.9	16.2-18.5	15.8-18.8
% w.b.	0.46	0.51	0.54	0.64	0.56	0.66

$0.84/t ($.021/bu) at the high airflow rate. Des Moines had a higher variability than Indianapolis. For instance, when three unloads were used at the low airflow rate, the standard deviation in the net gain in Des Moines was $0.70/t ($0.0177/bu) compared to $0.56/t ($0.0141/bu) in Indianapolis. The standard deviation of the net gain increased as the airflow rate increased. The standard deviation of the net gain in Indianapolis for three unloads and the low airflow rate was $0.56/t ($.014/bu) and increased to $0.68/t ($0.0172/bu) with the high airflow rate.

SIMULATED CONDITIONING OF CORN IN A COMMERCIAL TANK

Table 8 presents the data for conditioning corn in a commercial tank. The same trends occurred in the commercial tank as in the farm bin. On average, the net gain in Indianapolis was greater than in Des Moines. During six months of conditioning, the corn increased in moisture to approximately 15% at the low airflow rate. However, the net gain in the commercial tank was 0.63 to $0.91/t (0.016 to $0.023/bu) less than the net gain in the farm bin at approximately the same airflow rate for Indianapolis, and 0.47 to $0.83/t (0.012 to $0.021/bu) less for Des Moines. During one year (1980) in Des Moines, the net gain was negative when the bin was unloaded once. The increase in moisture content was not as large in Des Moines, yet approximately 1.5 points of moisture were added even at the low airflow rate. The net gain was greater at the higher airflow rate as the moisture content increased to nearly 16.5% in Indianapolis, and 16.2% in Des Moines. By using a higher airflow rate, reconditioning to the optimal market moisture could have been achieved before 1 April for most years. However, the interrelationship between airflow rate and time to the optimal moisture content needs further investigation.

SIMULATED CONDITIONING OF SOYBEANS IN A FARM BIN

The average net gain when conditioning soybeans in a farm bin was greater than for corn although slightly less moisture was added to the soybeans. The lower moisture gain was a result of the fewer hours available for rewetting soybeans due to the different EMC relationship compared to corn. The market moisture content of 13% was not reached when the low airflow rate was used (table 9). However, the market moisture content was exceeded when the high airflow rate was used. The same trends occurred with soybeans as with corn. The net economic gain increased when partial unloading was used, and the net gain was greater in Indianapolis than in Des Moines.

Using the low airflow rate in Indianapolis, the average net gain was $4.8/t ($0.13/bu), yielding an average moisture content of 11.7% over 29 years with the low airflow rate and three unloads. However, the average net gain was only $3.2/t ($0.087/bu) in Des Moines with an average moisture content of 11.1% when using the low airflow rate and three unloads. The standard deviation when reconditioning soybeans was greater in Des Moines. With three unloads and the low airflow rate, the standard deviation of the net gain was $1.03/t ($0.028/bu) in Indianapolis versus $1.14/t ($0.031/bu) in Des Moines.

The standard deviation of the net gain was greater for soybeans than for corn. When using three unloads and the low airflow rate, the standard deviation was $0.56/t ($0.014/bu) in Indianapolis for corn, and $1.18/t ($0.032/bu) in Indianapolis when soybeans were reconditioned. The standard deviation in the final moisture contents was approximately the same, i.e., 0.65% at the high airflow rate when three unloads were used during reconditioning of corn in Des Moines, and 0.69% when soybeans were reconditioned.

If reconditioning was done in a bin with a high airflow rate, the final average moisture content on 1 April was approximately 15.8% in Indianapolis and 14.7% in Des Moines. By using a higher airflow rate, reconditioning could have been stopped earlier when the average moisture content had reached the desired market moisture of 13%.

SIMULATED CONDITIONING OF SOYBEANS IN A COMMERCIAL TANK

Table 10 presents the simulated results of conditioning soybeans in a commercial tank. The same general trends occurred when reconditioning soybeans in a commercial tank as for reconditioning in a farm bin. It is interesting to note that using three unloads instead of one unload at the low airflow rate led to a slightly lower net economic gain in both Des Moines and Indianapolis. This could be due to the fact that the airflow rate was too low so that it took too long to establish a moisture front. However, with one unload the moisture gradient within the bin was much greater than with three unloads.

Table 8. Net gain and final average moisture content when rewetting corn in a commercial tank in Indianapolis and Des Moines at two airflow rates and for three unloading schedules (results are average, range, and standard deviation over 29 years)

	Low Airflow Rate			High Airflow Rate		
Location	6 Unloads	3 Unloads	1 Unload	6 Unloads	3 Unloads	1 Unload
Indiana net gain $/t ($/bu)	2.2 (0.056) 1.1-3.0 (0.027-0.075) 0.45 (0.011)	1.7 (0.043) 0.7-2.7 (0.017-0.069) 0.54 (0.014)	1.3 (0.033) 0.2-2.6 (0.004-0.066) 0.64 (0.016)	3.7 (0.095) 2.0-4.8 (0.051-0.122) 0.67 (0.017)	3.3 (0.084) 2.1-4.4 (0.054-0.112) 0.59 (0.015)	2.8 (0.072) 1.6-4.4 (0.04-0.113) 0.71 (0.018)
Indiana final MC, % w.b.	15.1 14.2-15.7 0.35	14.7 14.0-15.4 0.36	14.5 13.7-15.4 0.42	16.7 15.4-17.5 0.51	16.6 15.7-17.5 0.45	16.3 15.3-17.3 0.52
Iowa net gain $/t ($/bu)	2.2 (0.055) 1.0-3.4 (0.025-0.086) 0.53 (0.014)	1.4 (0.036) 0.1-2.9 (0.002-0.074) 0.57 (0.015)	1.1 (0.028) –0.2-3.0 (-0.006-0.076) 0.64 (0.016)	3.1 (0.079) 1.8-4.4 (0.045-0.112) 0.67 (0.017)	3.0 (0.077) 1.3-4.9 (0.034-0.125) 0.74 (0.019)	2.6 (0.067) 0.8-5.1 (0.021-0.13) 0.85 (0.022)
Iowa final MC, % w.b.	14.8 13.9-15.7 0.40	14.4 13.3-15.5 0.45	14.2 13.1-15.5 0.49	16.2 14.9-17.5 0.58	16.2 14.7-17.5 0.61	15.9 14.3-17.7 0.67

Table 9. Net gain and final average moisture content when rewetting soybeans in a farm bin in Indianapolis and Des Moines at two airflow rates and for three unloading schedules (results are average, range, and standard deviation over 29 years)

	Low Airflow Rate			High Airflow Rate		
Location	6 Unloads	3 Unloads	1 Unload	6 Unloads	3 Unloads	1 Unload
Indiana	4.9 (0.133)	4.8 (0.13)	4.5 (0.0122)	15.8 (0.428)	15.4 (0.416)	15.2 (0.410)
net gain	3.1-7.7 (0.084-0.208)	3.0-7.6 (0.082-0.206)	3.0-7.1 (0.080-0.193)	10.1-20.4 (0.273-0.552)	12.0-19.0 (0.323-0.513)	11.8-18.7 (0.319-0.505)
$/t ($/bu)	1.08 (0.029)	1.05 (0.028)	1.02 (0.028)	2.41 (0.065)	1.78 (0.048)	1.68 (0.046)
Indiana	11.8	11.7	11.6	15.9	15.8	15.7
final MC,	11.2-12.7	11.1-12.7	11.1-12.5	14.0-17.4	14.6-17.1	14.6-17.0
% w.b.	0.37	0.36	0.35	0.80	0.61	0.58
Iowa	3.6 (0.096)	3.0 (0.081)	2.7 (0.074)	13.2 (0.356)	12.4 (0.334)	12.2 (0.329)
net gain,	0.5-6.3 (0.013-0.170)	0.7-6.4 (0.020-0.173)	0.7-6.1 (0.019-0.164)	5.8-18.5 (0.158-0.500)	5.4-17.8 (0.147-0.480)	6.0-17.7 (0.163-0.478)
$/t ($/bu)	1.28 (0.035)	1.14 (0.031)	1.08 (0.029)	2.70 (0.073)	2.51 (0.068)	2.40 (0.066)
Iowa	11.3	11.1	11.0	14.9	14.7	14.6
final MC,	10.2-12.3	10.3-12.3	10.3-12.2	12.3-16.8	12.2-16.6	12.4-16.6
% w.b.	0.45	0.40	0.38	0.95	0.90	0.87

When the bin was unloaded six times, the net gain was greater than either the one unload or three unload cases. The airflow rate increased fast enough that the frequent unloading of the bin did not interfere as much with moisture fronts becoming re-established. The net gain when reconditioning soybeans in a commercial tank was greater than the net gain when reconditioning corn. When corn was reconditioned in Indianapolis in the commercial tank, partially unloaded three times, and a low airflow rate was used, the net gain was $1.58/t ($0.043/bu). However, when soybeans were reconditioned under the same conditioning, the average net gain was $3.16/t ($0.086/bu). Using the high airflow rate allowed for soybeans to be reconditioned to nearly 13.0% moisture in Indianapolis by 1 April. The soybeans were only reconditioned to approximately 12.1% in Des Moines by 1 April.

Variability as indicated by the standard deviation was much higher when reconditioning soybeans compared to corn. When corn was reconditioned at the low airflow rate in Indianapolis, the standard deviation of the average net gain varied between 0.55 and $0.63/t (0.014 and $0.016/bu); for soybeans the standard deviation ranged between 0.81 and $1.19/t (0.022 and $0.0323/bu). The trends in the standard deviation of the average net gain were reversed for soybeans and corn. The standard deviation of the net gain increased as the unloading frequency increased with soybeans, while the opposite was true for corn. This was caused by a decrease in the standard deviation of the average moisture content in corn when partial unloading was used, and an increase in the standard deviation of the average moisture content when soybeans were reconditioned.

DISCUSSION

In general, by increasing the unloading frequency, the final average moisture content and thus the average net gain increased. With one complete unload, the airflow stayed constant. However, as the bin was partially unloaded more frequently, the airflow rate per unit volume of grain increased, which resulted in more moisture added per hour of fan operation.

Another advantage of more frequent partial unloading was the increase in uniformity of the final moisture content. During rewetting of soybeans, only about the top third of the bin was rewetted when using one unload (fig. 5). The bottom two-thirds of the bin remained unchanged at approximately 10%. However, when three partial unloads were used, the soybeans had a more uniform final moisture content of 12.5, 11.5, and 10.7% Also, the soybeans during the one unload reached a higher moisture content in the top portions of the bin; soybeans wetter than 13% moisture have a higher risk of spoilage.

Soybeans have a higher net economic gain than corn because soybeans are a higher valued crop. Therefore, the

Table 10. Net gain and final average moisture content when rewetting soybeans in a commercial tank in Indianapolis and Des Moines at two airflow rates and for three unloading schedules (results are average, range, and standard deviation over 29 years)

	Low Airflow Rate			High Airflow Rate		
Location	6 Unloads	3 Unloads	1 Unload	6 Unloads	3 Unloads	1 Unload
Indiana	3.7 (0.100)	3.2 (0.086)	3.3 (0.089)	8.1 (0.218)	7.5 (0.202)	7.3 (0.198)
net gain	1.4-5.7 (0.039-0.155)	1.9-5.3 (0.050-0.142)	2.0-5.4 (0.054-0.145)	4.0-11.5 (0.109-0.310)	5.0-10.9 (0.134-0.295)	5.1-10.8 (0.137-0.292)
$/t ($/bu)	1.20 (0.032)	0.78 (0.021)	0.81 (0.022)	1.97 (0.053)	1.43 (0.039)	1.41 (0.038)
Indiana	11.5	11.3	11.3	13.2	13.0	13.0
final MC,	10.7-12.2	10.8-12.0	10.9-12.1	11.8-14.4	12.1-14.3	12.2-14.3
% w.b.	0.42	0.29	0.30	0.69	0.52	0.52
Iowa	2.3 (0.063)	1.9 (0.050)	1.9 (0.051)	5.7 (0.154)	4.9 (0.133)	4.7 (0.127)
net gain	0.0-4.6 (0.0-0.124)	0.2-4.4 (0.005-0.118)	0.3-4.6 (0.01-0.125)	1.2-9.8 (0.032-0.266)	1.4-9.4 (0.037-0.255)	1.5-9.5 (0.041-0.256)
$/t ($/bu)	1.01 (0.027)	0.85 (0.023)	0.88 (0.024)	1.87 (0.051)	1.65 (0.045)	1.62 (0.0439)
Iowa	11.0	10.8	10.8	12.3	12.1	12.0
final MC,	10.1-11.8	10.1-11.7	10.2-11.8	10.6-13.8	10.7-13.8	10.7-13.8
% w.b.	0.37	0.32	0.33	0.69	0.63	0.62

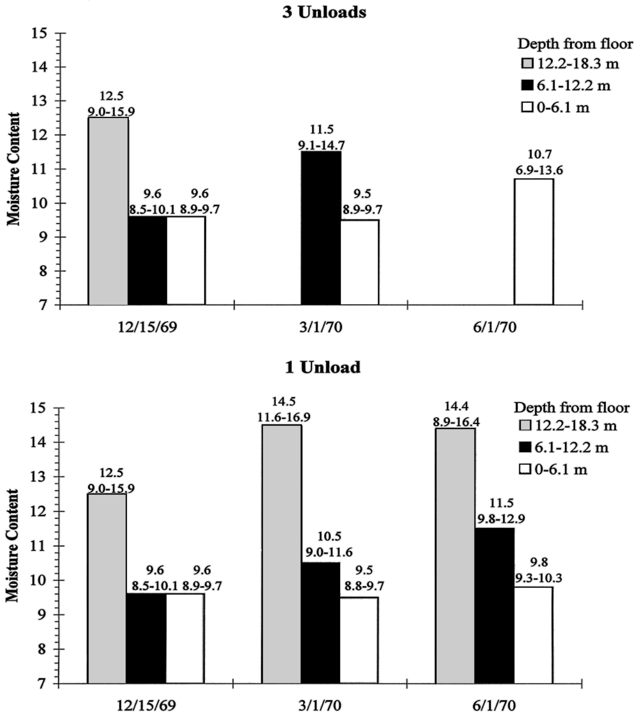

Figure 5–Average moisture contents and ranges at different depths above the floor in a commercial 3693 t soybean tank when using a single unload and three unloads and two 14.9-kW (20-hp) fans in Indianapolis, Indiana, during 1969-1970.

water absorbed by soybeans would be worth more than the water gained by corn. The price of electricity and the value of the grain also influence the average net economic gain. Table 11 shows the effect of market price and electricity cost on the net economic gain of soybeans when rewetting in a commercial tank at the low airflow rate with three unloads. If the price of soybeans decreased by \$19.7/t (\$0.50/bu), then the average net economic gain decreased by \$0.3/t (\$0.007/bu). If the electricity price increased by \$0.02/kWh, the average net gain decreased by \$0.1/t (\$0.005/bu).

For each combination of airflow rate, location, and allowable conditioning time, an optimal lower limit for the EMC window can be determined. For example, a commercial tank unloaded once on 1 April, using an airflow rate of 0.12 m^3 min^{-1} t^{-1} (0.11 cfm/bu) would have an optimal EMC minimum limit setting of 10% for soybeans in Indianapolis (table 12). However, if the airflow rate was 0.32 m^3 min^{-1} t^{-1} (0.29 cfm/bu), the optimal EMC minimum limit would be around 12%. The interrelationship of time, airflow rate, location, and controller limits has not been fully investigated.

Table 11. Sensitivity of average net economic gain, \$/t (\$/bu) over 29 years when reconditioning soybeans in a commercial tank with three unload schedules and the low airflow rate (Indianapolis, Indiana)

Electricity	Soybean Price (\$/t, \$/bu)			
(\$/kWh)	202.1 (5.50)	220.5 (6.00)	238.9 (6.50)	257.3 (7.00)
0.03	2.7 (0.074)	3.0 (0.081)	3.3 (0.088)	3.6 (0.096)
0.05	2.6 (0.069)	2.8 (0.076)	3.1 (0.084)	3.4 (0.091)
0.07	2.4 (0.065)	2.7 (0.072)	2.9 (0.079)	3.2 (0.086)
0.09	2.2 (0.060)	2.5 (0.067)	2.8 (0.075)	3.0 (0.082)
0.11	2.0 (0.055)	2.3 (0.063)	2.6 (0.070)	2.8 (0.077)

Table 12. Effect of airflow rate and EMC minimum limit on net economic gain, \$/t (\$/bu) during the reconditioning of soybeans in a commercial tank unloaded once (Indianapolis, Indiana, 1971-1972)

Airflow m^3 min^{-1} t^{-1}	Low Limit of EMC Window			
(cfm/bu)	10	11	12	13
0.04 (0.04)	0.6 (0.016)	0.6 (0.017)	0.7 (0.018)	0.7 (0.018)
0.12 (0.11)	3.3 (0.089)	3.3 (0.088)	3.2 (0.087)	3.1 (0.084)
0.21 (0.19)	6.7 (0.180)	5.9 (0.179)	6.5 (0.176)	6.3 (0.169)
0.32 (0.29)	8.8 (0.239)	9.1 (0.246)	9.3 (0.250)	9.2 (0.249)
0.43 (0.39)	6.6 (0.178)	7.4 (0.199)	8.3 (0.223)	8.8 (0.239)

Obviously, the examples explored here do not represent an exhaustive analysis of the potential economic gain matrix. When implementing a specific conditioning strategy for a site, the operator must consider historic weather data in combination with the proper settings for an automatic fan controller, down flow aeration, and intermittent unloading of farm bins and commercial tanks. Even at the same airflow rate 0.11 m^3 min^{-1} t^{-1} (0.1 cfm/bu), a higher net economic gain can be achieved in the farm bin compared to the commercial tank. The reason lies in the advantage of conditioning a shallower depth of grain, which requires less fan power to achieve the same airflow as in a deeper bin. Final moistures and moisture uniformity would also be higher in shallower bins. Thus, it would be preferable and more profitable to condition grain to optimum market moisture in shallower bins for commercial as well as farm installations.

Caution should be exercised because the potential for spoilage is significant especially when conditioning extends into the late spring and early summer period. In the examples explored, safe storage moistures were generally exceeded in the upper grain layers and fairly significant gradients developed within the bin. Stirring machines in on-farm bins are a tool that could be used to achieve better moisture uniformity during conditioning. This would also avoid the need to reverse the airflow in push aeration systems. Another physical challenge of grain conditioning is leveling grain surfaces especially in larger diameter bins.

The complexity of the automatic controller needs to be fully understood by the operator. Setting limits on the programmable variables can create an operational window that can be too narrow or too wide. The reliability of an automatic fan controller also should be considered. Air temperature and humidity sensors must be regularly checked for accuracy, and calibration procedures should be carefully followed.

CONCLUSIONS

A number of conclusions can be drawn from this study of reconditioning corn and soybeans:

1. Reconditioning corn and soybeans using aeration and an automatic fan controller was technically and economically feasible. For the scenarios evaluated, average net economic gains varied from 1.10 to \$6.81/t (0.028 to \$0.173/bu) for reconditioning 13% corn, and from 1.87 to \$15.80/t (0.051 to \$0.43/bu) when reconditioning 10% soybeans.

2. The ability to recondition was dependent on location. The western Corn Belt appeared to be less conducive to reconditioning than the eastern Corn Belt. The average moisture content increase in corn was 0.3 to 0.4 percentage points less and in soybeans 0.5 to 0.6% percentage points less at low airflow rates for Des Moines than for Indianapolis.
3. Large yearly variations occurred in the net economic gain when reconditioning grain. In Des Moines, the average net gain varied from 0.28 to $3.94/t (0.007 to $0.10/bu) in corn and 0.70 to $6.03/t (0.019 to $0.164/bu) in soybeans over 29 years in the farm bin with only a single unload and low airflow.
4. Soybeans were more attractive to rewet than corn due to their higher value. The average net gain with monthly unloading was nearly double when soybeans were reconditioned compared to corn.
5. A farm-sized bin was more economical for reconditioning than a commercial tank. The deeper depths in commercial tanks required higher horsepower fans to achieve the same airflow rate, which negatively affected the net gain.
6. Ethical and legal considerations need to be carefully weighed before ambient or humidified air is used for the purpose of increasing the moisture content of a grain mass.

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REFERENCES

ASAE Standards, 44th Ed. 1997. ASAE D245.4. Moisture relationships of grains. St. Joseph, Mich.: ASAE.

Foster, G. H., and J. Tuite. 1992. Aeration and stored grain management. In *Storage of Cereal Grains and Their Products,* ed. D. B. Sauer, 219-247. St. Paul, Minn.: AACC.

Kim, H. 1997. Interpreting FDA regulations on the addition of water to grain. In *Proc. 1997 Grain Quality Conference—Managing Moisture in Grains and Oilseeds,* Urbana, Illinois, 26-27 March 1997. Urbana-Champaign, Ill.: Depts. of Agric. and Consumer Economics, and Agric. Engineering, University of Illinois.

Hellevang, K. J. 1995. Grain moisture content effects and management. AE-905. Fargo, N.Dak.: North Dakota Extension Service.

Maier, D. E., and M. D. Montross. 1997. Aeration technology for moisture management. In *Proc. 1997 Grain Quality Conference—Managing Moisture in Grains and Oilseeds,* 50-71, Urbana, Illinois, 26-27 March 1997. Urbana-Champaign, Ill.: Depts. of Agric. and Consumer Economics, and Agric. Engineering, University of Illinois.

Maier, D. E., W. H. Adams, J. E. Throne, and L. J. Mason. 1996. Temperature management of the maize weevil, *Sitophilus zeamais* Motsch. (*Coleoptera*: *Curculionidae*), in three locations in the United States. *J. Stored Prod. Res.* 32(3): 255-273.

Saksena, V., M. D. Montross, and D. E. Maier. 1997. Site-specific NA/LT drying strategies for white food corn. ASAE Paper No. 97-6033. St. Joseph, Mich.: ASAE.

Shipman, D. 1997. Implementing the FGIS prohibition on rewetting grains. In *Proc. 1997 Grain Quality Conference—Managing Moisture in Grains and Oilseeds,* Urbana, Illinois, 26-27 March 1997. Urbana-Champaign, Ill.: Depts. of Agric. and Consumer Economics, and Agric. Engineering, University of Illinois.

Wilcke, W. F., R. V. Morey, D. J. Hansen, and R. A. Meronuck. 1999. Aeration strategies for reconditioning dry soybeans. ASAE Paper No. 99-6046. St. Joseph, Mich.: ASAE.

Zink, D. J., M. D. Montross, and D. E. Maier. 1997. Conditioning and pest management of popcorn. ASAE Paper No. 97-6067. St. Joseph, Mich.: ASAE.