Project No. 21517
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Portage la Prairie, Manitoba

Research Report

Final Report

On-Farm
Canola Storage Research in Large Bins

For:
Canola Council of Canada
Winnipeg, Manitoba

Innovative Solutions
for Agriculture and Beyond

Project No.21517
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On-Farm Canola Storage Research in Large Bins

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Table of Contents

1. Executive summary

One of the significant changes in on-farm storage in recent years has been the large increase in the average size of grain bins. Large bin sizes increase the airflow resistance and the mass of grain that needs to be conditioned in the same amount of time compared to smaller bins. This project was conducted to determine whether existing recommendations for safe canola storage developed 20-30 years ago still apply from small bins when the average bin size in the prairies has increased to 25,000 bu. For longer term storage over five months, the recommended canola storage target is a maximum of 8% moisture and cooled to 15°C or lower throughout the entire bin.

The specific objectives of this project were to compare the effects of a “peaked” vs. “spread” filling system on the grain distribution, to measure airflow rates and static pressures delivered from commonly recommended fans, to measure airflow uniformity, and to measure grain pressure distribution on the bin floor. The initial trial was to monitor the canola conditioning with a peaked center, which was created by loading canola into the center of the bin directly from an auger. The second trial emptied the partially conditioned canola into a second 25,000 bu bin to equalize the grain temperature and re-filled the first bin using a gravity driven spreader to produce a more level grain surface.

The gravity-driven spreader resulted in a more level surface than if discharged directly from an auger (“peaked”). However, the ‘spread’ grain surface was not completely level as the centre remained somewhat higher than the side and generated high spots several feet from the center. In these tests, actual airflow rates were 0.5 cfm/bu from the peaked test and 0.45 cfm/bu from the spread test at an average grain depth of about 20 to 22 feet. Measured static pressures were 6.1 and 6.7 in H_2O, respectively and these results were similar and actually slightly less than the predicted static pressure of 7 to 8.5 in H_2O developed previously from smaller bins.

This project determined that the typical 10 hp centrifugal fans available for single phase power were not adequate to provide the required static pressure and airflow to condition canola in a 25,000 bu bin. After filling to about 17,000 bu or 70% full in a 25,000 bu bin, two 10 hp centrifugal fans operating in parallel had reached their ‘stall’ static pressure and a single 10 hp centrifugal fan was nearing its stall static pressure.

The conventional method of comparing air distribution by observing the relative temperature ‘front’ movement was not suitable in this trial due to the many variable conditions including the ambient temperature change, partial established temperature fronts before the bin was full, and the unexpected grain distribution from the gravity driven spreader. Therefore, an alternate approach was used to obtain an indication of

relative airflow distribution by using temperature change ratios between the ambient temperature, and the initial and final grain temperatures. These ratios showed no clear indication that a gravity spreader provided any airflow benefits.

Although the grain pressure measurements did not provide a mathematical relationship between the five sensors at various distances from the bin center, some interesting results occurred. The vertical load steadily increased with grain depth as expected, but the sensors indicated a higher vertical force near the center for the peaked trial and a higher vertical force about 10 ft away from the center for the spread trial. The average load per grain depth suggested that the spreader increased the overall grain density.

In summary, the previous airflow/static pressure recommendations developed from small bins still seem applicable for safe long term canola storage. The recommended practices appear to be effective in conditioning canola for long term storage over 5 months. However, the fan requirements and grain monitoring practices may need to be adapted for larger bins. When comparing the two trials, the gravity spreader provided a marginal benefit in grain surface distribution, a small decrease in airflow rate, no differences in the airflow uniformity, and an increased grain density when storing canola. However, these conclusions are only applicable to a gravity spreader since the grain distribution did not completely produce a level grain surface as intended and were only measured on a partially filled bin.

Future work is recommended to adapt the previous grain storage research to larger bins. Because the fan limitation prevented filling the bin for these tests, another similar project to determine the suitable fan requirements should be conducted to determine the important aspects of conditioning canola for safe storage. In addition, a program of joint physical testing and computer simulation will provide the most accurate and cost effective approach to provide solutions to the outstanding producer questions that have arisen from the recent trend to large grain bins on farms.

2. Introduction

One of the significant changes in on-farm storage in recent years has been the average size of grain bins. The average bin size has increased (both diameter and height) more than 10 times from the average bin sizes used to develop the original canola safe storage recommendations. This significant increase may be a contributing factor to the storage losses experienced recently. Large bin sizes increase the airflow resistance that needs to be overcome to condition the mass of grain in the same amount of time.

The recommended practices were extrapolated from the small bin research, but the increase in grain bin sizes may not have a linear relationship. Also, peaked grain is expected to produce a greater airflow rate at the outside of the bin compared to the centre because of a higher back pressure from the mound of grain (greater height) and the theory that more fines accumulate in the centre, thus also restricting airflow. The reduced airflow poses a risk for grain spoilage in the central area of the bin.

The primary objective of the overall program is to determine whether existing recommendations for safe canola storage and conditioning are still the same considering the increase in bin sizes when compared to the original storage bins used 20-30 years ago. The specific objectives of this project were to:

- Compare the effect of peaked vs. spread grain filling systems in a 25,000 bu bin on the grain distribution.
- Measure the canola temperatures, airflow rates, airflow uniformity and static pressures when conditioned with commonly recommended fans.
- Measure grain pressure distribution on the bin floor to determine if those measurements can be correlated to the depth and packing density of the grain.

This project was ideally suited for the newly constructed grain storage research facility located at PAMI in Portage la Prairie, Manitoba and will build on existing grain storage research previously performed by PAMI. Grain storage is a complex relationship between grain properties (temperature, moisture, etc.), environmental factors (ambient temperature, humidity, etc.) and fan control methods. Producers will directly benefit from a better understanding of the factors that can result in canola spoilage during storage, which will also reduce the risk of lost revenue. This project was designed to clarify recommendations for producers and prevent bin losses, which can amount to $250,000/bin at $10/bu of canola in a 25,000 bu bin. The information gained can also be used by other researchers to refine future on-farm research, validate models and computer simulations of grain airflow patterns to further refine safe storage recommendations.

2.1 Safe storage recommendations

The combination of canola moisture and temperature determines the safe storage period. The Canadian Grain Commission provides multiple graphs outlining the potential risk of spoilage for various grain commodities based upon the initial grain conditions before storage (**Figure 1**). The figure illustrates the various seed moisture and temperature combinations, and plots the conditions to determine if the crop could be safely stored up to 5 months. If it falls in the "no spoilage" zone, it will likely be safe and if it falls in the "spoilage" zone, it will likely spoil. Generally, lowering the seed moisture and temperature below the center "white" line will reduce the risk of spoilage. The higher moisture and temperature will generally reduce the number of safe storage days. The center zone represents a 1% safety margin, which grain may still spoil under these conditions. However, these are general guidelines and grain can still spoil during storage when the moisture and temperature change, which can result in localized spoilage (White, 2013).

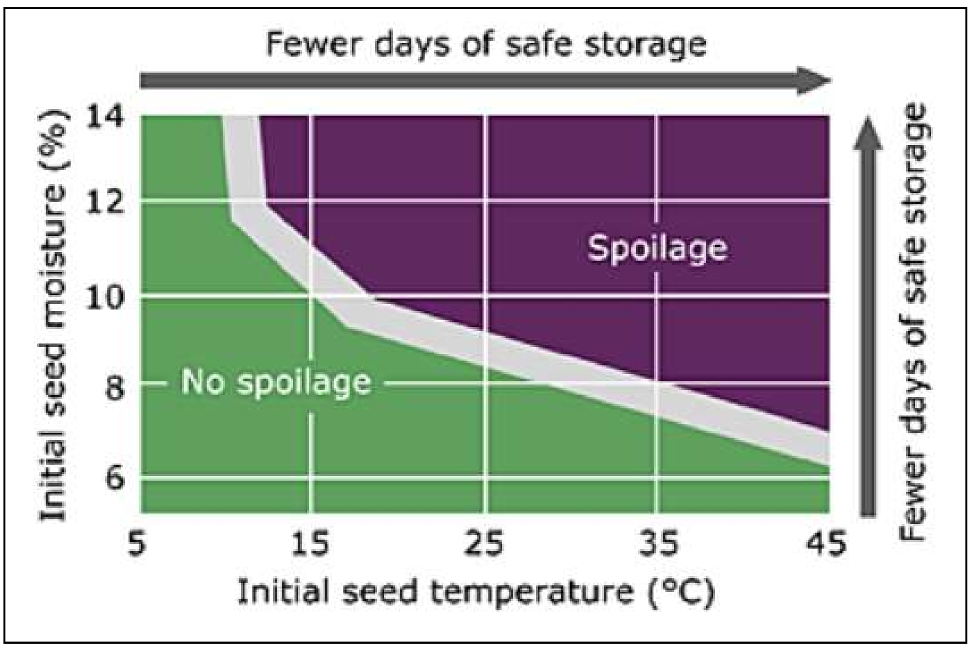

Figure 1. Safe storage chart for canola (White, 2013).

Canola is accepted as "dry" without penalty for up to 10% moisture content (MC) (Tough and damp moisture ranges for Canadian grains, 2016). Therefore, it would be most beneficial to a producer to sell their canola near the 10% moisture level to maximize the grain weight without any penalties. However, canola at this moisture level must be kept at low temperatures (<15°C) according to the storage recommendations to prevent major spoilage loses.

For longer term storage over five months, the canola should be stored at a maximum of 8% moisture and cooled to 15°C or lower throughout the entire bin (Mills & Hartman, 2011). For the most effective cooling and conditioning of canola, the aeration fans should be started as soon as the canola covers the bin floor. As the outside temperature drops below the canola temperature by 5 to 10°C, the grain should be cooled again. After the entire grain mass has reached the desired conditions, it is recommended to check periodically for evidence of localized heating or moisture migration. If heating is suspected, the grain could be turned to disrupt the moisture cycle and help equalize the grain conditions. Grain conditioning with aeration ranges from airflow rates between 0.1 to 0.2 cfm/bu, while natural air drying ranges between 1 to 2 cfm/bu. Natural air drying is similar to aeration, but can remove additional moisture if the outside air has the capacity to dry. The drying depends on the air's ambient temperature and relative humidity (RH).

2.2 Equilibrium moisture content

The air's capacity to dry is governed by the Equilibrium Moisture Content (EMC) (Stock, Agnew, Grieger, & Hill, 2014). The EMC is defined as the theoretical MC of the grain if the air conditions are constant and are able to reach a steady state with the grain over a long period of time. At the steady state condition, the air will not take or give any moisture to the grain. The EMC for the various air temperature and relative humidity combinations for canola are shown in **Table 1**. This table shows that at the right ambient conditions, water could be either added or removed from the canola. For example, introducing cool dry air at 13°C at 55% RH can condition grain to 8% MC if the conditions were constant over a long period of time. Unfortunately, the drying performance will never be constant due to the daily fluctuations and seasonal variability. It is not uncommon to experience few hours of drying followed with one or two hours of wetting.

Table 1. EMC of air for canola (Stock, Agnew, Grieger, & Hill, 2014).

Temp	Relative Humidity (%)										
(°C)	35	40	45	50	55	60	65	70	75	80	85
-2	6.7	7.5	8.2	8.9	9.7	10.5	11.3	12.2	13.2	14.3	15.7
2	6.4	7.0	7.7	8.4	9.1	9.9	10.7	11.6	12.5	13.6	14.9
5	6.1	6.8	7.4	8.1	8.8	9.5	10.3	11.1	12.0	13.1	14.3
8	5.9	6.5	7.1	7.8	8.5	9.2	9.9	10.7	11.6	12.6	13.8
10	5.7	6.3	7.0	7.6	8.3	8.9	9.7	10.5	11.3	12.3	13.5
13	5.5	6.1	6.7	7.3	8.0	8.6	9.4	10.1	11.0	11.9	13.1
15	5.4	6.0	6.6	7.2	7.8	8.5	9.2	9.9	10.7	11.7	12.8
18	5.2	5.8	6.4	7.0	7.6	8.2	8.9	9.6	10.4	11.3	12.4
22	5.0	5.6	6.1	6.7	7.3	7.9	8.5	9.3	10.0	10.9	12.0
26	4.8	5.4	5.9	6.5	7.0	7.6	8.2	8.9	9.7	10.5	11.6
28	4.8	5.3	5.8	6.3	6.9	7.5	8.1	8.8	9.5	10.4	11.4

2.3 Effect of grain depth on static pressure

The original research on the effect of canola depth on static pressure was performed up to 25 ft (**Figure 2**). The 25,000 bu bins in this project had eaves and total bin height of approximately 26 ft and 36 ft, respectively. With the larger bin sizes of 25,000 bu, it is not uncommon to have heights higher than 25 ft especially when current bin manufacturers offer even larger sizes in their catalogs. The previous research showed that the higher airflow (cfm/bu) and taller grain height will increase the static pressure required to overcome the grain mass. This recommendation shows that when natural air drying at 1 cfm/bu, canola will be limited to a maximum height of 17 ft with 10 in H_2O static pressure. As for canola conditioning/aeration, the curves only show as low as 0.5 cfm/bu which is more than the recommended aeration rate of 0.1 to 0.2 cfm/bu.

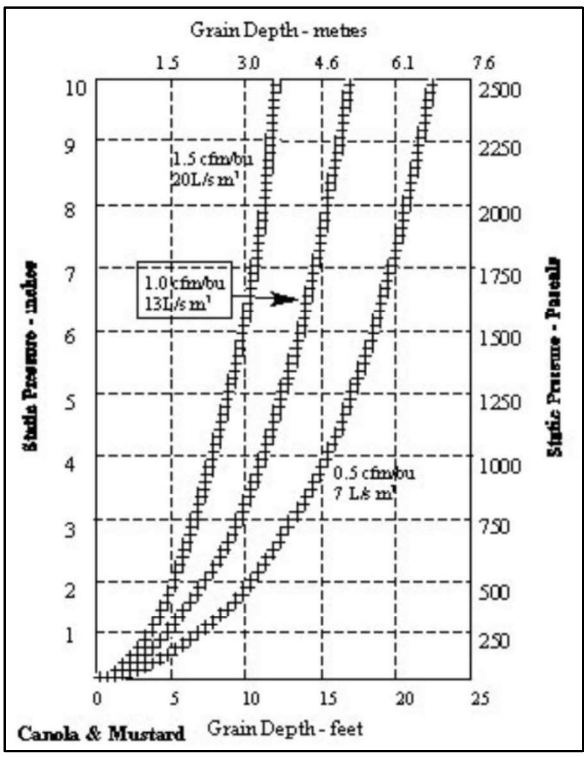

Figure 2. Effect of grain depth on static pressure (Mills & Hartman, 2011).

3. Project Description

The project equipment and procedures are outlined in the following sections.

3.1 Project equipment

The project was conducted at PAMI's grain storage research facility in Portage la Prairie, MB. Two 25,000 bu bins, a grain gravity spreader, centrifugal fans, augers, and data acquisition equipment were used to investigate 'full scale' grain storage research that aligns with current farm bin sizes.

3.1.1 Grain handling and supporting equipment

Two 25,000 bu bins with fully perforated floors were available to be filled with canola (**Figure 3**). One bin was used for instrumentation and monitoring, while the other bin was used for transfer, storage and re-distribution of canola. To create the "peaked" and "spread" grain conditions, the bin used the conventional method of loading grain directly into the bin from the discharge spout of a filling auger. When the grain was filled from the center top opening, the grain will naturally form a peak in the middle of the bin and slowly rise with the grain volume. The cone shaped grain condition will be defined as the "peaked" treatment in this report. The 25,000 bu grain bin capacity and specifications are listed in **Appendix A**.

Figure 3. Two 25,000 bu bins.

Alternatively, the "spread" condition was conducted by dropping the grain into a 'gravity driven' spreader, which consisted of an intake hopper and a discharge arm that rotated while discharging controlled streams of grain at various distances from the centre (**Figure 4**). The spreader was intended to produce a level grain surface compared to discharging directly from an auger. With this specific spreader, four grain streams delivered canola to various parts of the bin while being loaded. The leveled grain surface created by the spreader will be defined as the “spread” treatment in this report.

Figure 4. ‘Gravity-driven’ spreader (as viewed from the bottom).

Airflow was provided by two 10 hp centrifugal fans operating in parallel in each bin (**Figure 5**). For many Canadian farmers where 3-phase power is not available or is cost prohibitive, a 10 hp centrifugal fan is typically the largest fan available. Several manufacturers have newer models that exceed 10 hp, but 10 hp fans are the most common. Therefore, the 10 hp fans were evaluated for this trial. This fan can operate between a static pressure of 1 to 7 inch of H_2O while delivering 13,300 to 7,300 cfm of air, respectively. The two fans were located on the west side of the bin and mounted 90° apart from each other. The operation of a single and double fan was used during this process to understand the effect of airflow and static pressures in a large 25,000 bu bin. The detailed fan specification and performance curve information is listed in **Appendix B**. The static pressure was measured with a manometer and the air flow was calculated from the manufacturer fan performance curve.

Figure 5. 10 hp Centrifugal fans.

3.1.2 Data acquisition equipment

The in-bin grain condition was monitored by OPI sensor cables that measured temperature and relative humidity, which also allows the calculation of grain MC (**Figure 6**). A total of four cables were installed to monitor the grain conditions labelled A1 to A4. A1 to A3 are the perimeter cables located 8.5 ft from the center of the bin and A4 is the center cable. A4 was anchored slightly off-center to avoid interference with the clean-out auger. Each cable had 7 sensors, labelled as S1 to S7 with S1 being at the bottom and S7 at the top. S1 was 5 ft above the perforated bin floor; the remaining sensors were at 4 ft intervals up to S7 at 29 ft.

Figure 6. OPI temperature and humidity sensor cables.

Five load cells were configured to be pressure sensors to measure the vertical load of the grain on the perforated floor as the grain was loaded into the bin (**Figure 7**). The load cells were anchored to the bin floor along one radius length and spaced equally approximately 44” (3.6 ft) apart. “Load cell 1” was near the bin wall with “Load cell 5” being the closest to the center. The load readings and grain heights were recorded periodically or with each semi-trailer of grain to determine the density/compaction along the bin floor. The load cell had adapters with a specific area to measure the pressure (force divided by area equals pressure). The pressure distribution along the bin floor was intended to correlate the depth and packing density of the grain to assist in future computer simulations. The detailed layout of the sensor cables and load cells are visually summarized in **Figure 8**.

Figure 7. Five grain pressure sensors (blue).

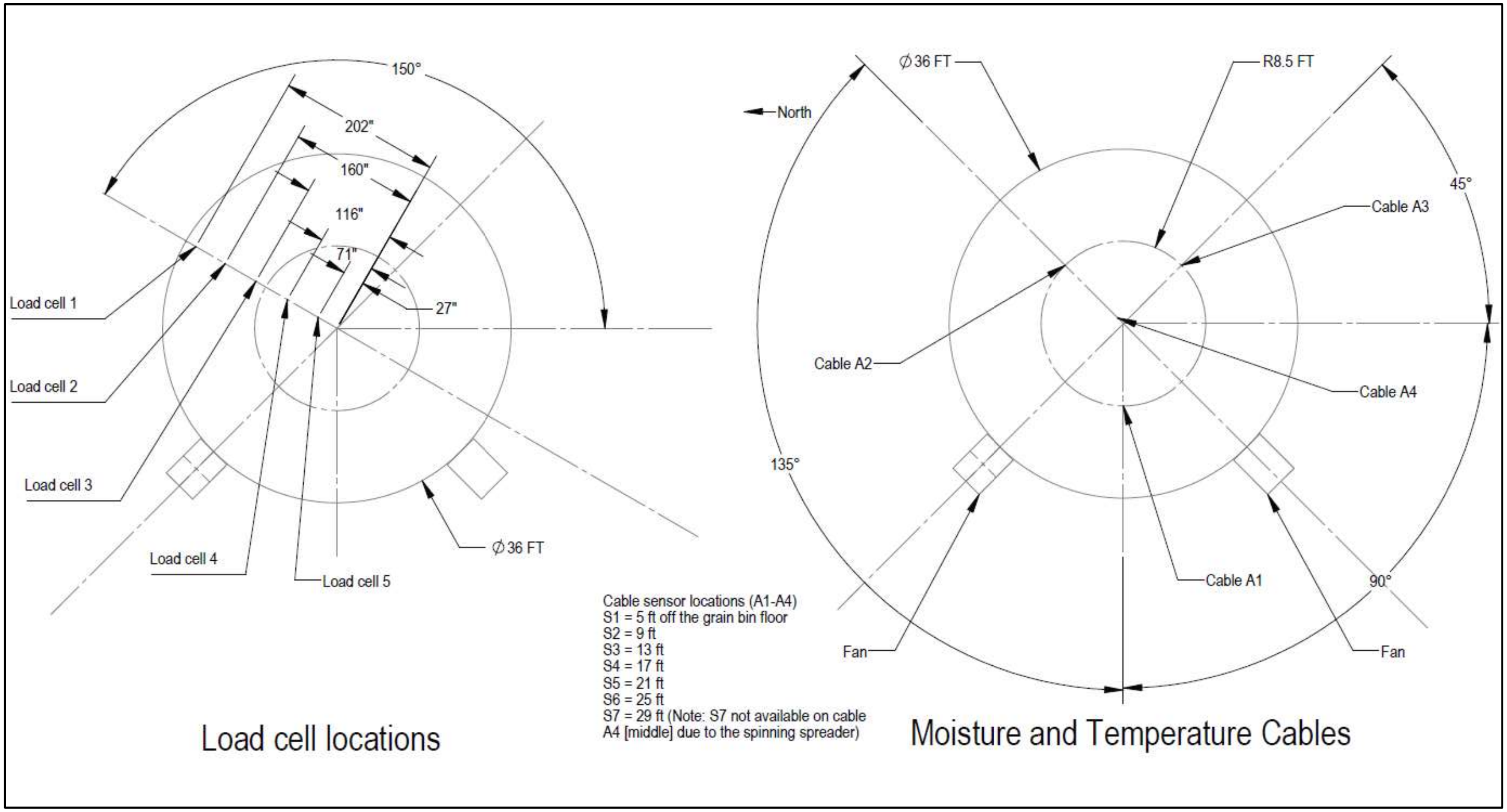

Figure 8. Grain pressure sensors and OPI cable layout.

3.2 Project procedure

To evaluate the specific objectives of this project, the trial was designed to perform the peaked treatment first and perform the spread treatment next by emptying the grain into the transfer bin and refilling the instrumented bin through a grain spreader. The aeration fans were started as soon as the canola covered the bin floor to immediately cool the grain. All other procedures were the same between the two treatments.

3.2.1 Peaked grain treatment

The peaked treatment loaded canola from multiple semi-trailers between Sept 12 and Sept 21, 2018. The grain was dropped directly from a portable auger discharge into the bin centre. As the grain was loaded, a composite canola sample was obtained to measure the temperature and moisture of the grain on a Labtronic 919 moisture meter. The initial average grain condition was 20.5°C and 7.3% MC.

After each load, multiple measurements were taken to characterize the grain. It consisted of measuring static pressures, grain heights, load cell readings, and monitoring the in-bin grain conditions. The fans were operated and the static pressure was measured to determine the airflow from the fan manufacturer's airflow chart. Height of the grain surface was also measured at the peak and at the side wall, and for the 'spread' test, grain height was also measured 7 ft from the wall. The additional measurement was added for the second treatment after observing the irregular grain surface. Similarly, the load cell readings and the in-bin grain conditions were measured and documented after each semi-trailer of grain.

Initially, the intent was to completely fill the bin to 25,000 bu but the static pressure measurements indicated that the fans were near their stall condition, therefore, filling was concluded at about 17,000 bu with a single fan or about 70% full in a 25,000 bu bin. After filling the bin, the grain was conditioned several days and operated only when the ambient conditions allowed cooling without adding a significant amount of water. Some fan operation and grain conditioning occurred while the bin was being filled, however to analyze a common test period between the two treatments, the grain temperature analysis was confined to the final 24 hours of fan operation for each trial. With the amount of grain and potential liability of $250,000 if the canola spoiled, the fans were not operated in non-ideal conditions due to the overall airflow rate. The project results will be discussed in the next section.

3.2.2 Spread grain treatment

After the first trial, the grain was temporarily transferred from the first bin into the second bin to mix and equalize any temperature variation generated from the first trial. The grain was later mixed back into the first bin through a gravity spreader. The average grain condition after mixing was 15.2°C and 6.9% MC. The total volume of grain was staged into approximately eight equal loads during the second trial. Similar to the first trial, the same data collection procedure was repeated after each load of grain. The second test occurred between Oct 11 and Oct 23, 2018.

4. Results and Discussion

The effect of the spreader, airflow rates, static pressures, air distribution, and grain pressure are discussed in the following section.

4.1 Airflow rate and static pressure

The static pressure (in H_20) and airflow rate (cfm/bu) for a single and double fan configuration as a function of the grain amount are shown in **Figure 9** for the peaked bin and in **Figure 10** for the spread bin. As the bin was being filled, static pressure and grain measurements were taken several times. The bin static pressure increased linearly for the peak configuration until about 9,000 bu and nearly reached the fan's capacity of 7 in H_2O (**Figure 9**). This was the stall condition causing the two fans to operate erratically, so only one fan was operated afterwards. Static pressure then dropped to about 4.5 in H_2O for a single fan, therefore filling continued until about 17,000 bu. Static pressure was around 6 in H_2O at 17,000 bu, therefore the decision was made to stop filling to avoid the stall condition for the next spreader treatment when considering the theory of the increased static pressure for a spread grain treatment.

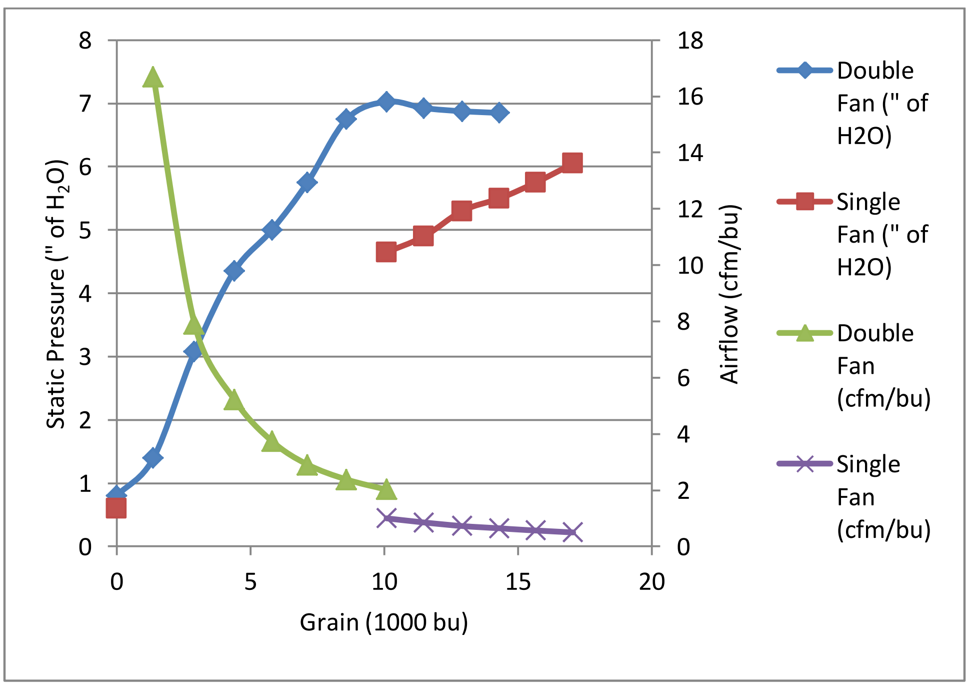

Figure 9. Peaked grain static pressure and airflow as function of canola volume.

Similarly, the static pressure from the spread treatment only allowed the double fan configuration to operate between 5,600 and 8,400 bu of canola before reaching 7 in H_2O (**Figure 10**). After that, the double fans were operated for only a short period at 11,700 and 14,000 bu to measure the fan performance. The fans operated very violently and had a different sound pitch, therefore, they were shut down to prevent any damage. A single fan operation was continued until the remaining canola was filled. Static pressure was higher in this test as the double fan configuration reached 7 in H_2O at about 7,500 bu and the single fan operation was about 7 in H_2O at 17,000 bu.

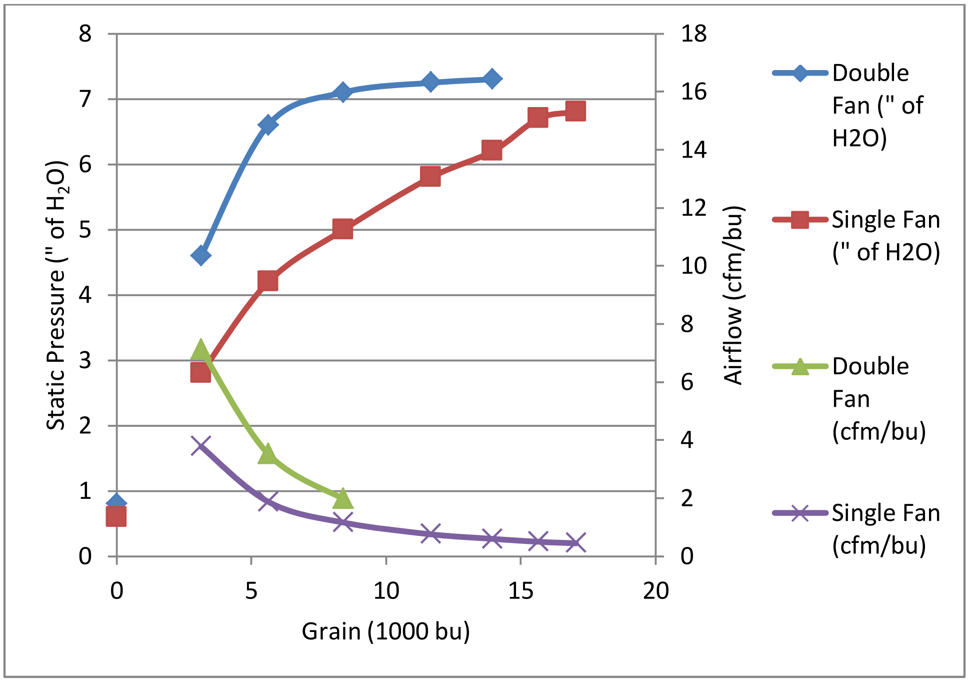

Figure 10. Spread grain static pressure and airflow as function canola volume.

The overall static pressure and airflow results are summarized in **Table 2** for 17,000 bu of canola with a single fan system. The peaked bin had an airflow of 8,500 cfm (0.50 cfm/bu) and a static pressure of 6.1 in H_2O. The spread bin had an airflow of 7,600 cfm (0.45 cfm/bu) and a static pressure of 6.7 in H_2O. While these results favor the peaked bin, it is also important to consider the air and pressure distribution, as an unevenly distributed higher airflow may be less desirable than a slightly lower airflow rate that is evenly distributed.

Table 2. Summary of static pressure and airflow results.

	Grain volume	Airflow		Static pressure
	(bu)	Total (cfm)	Rate (cfm/bu)	(in H_2O)
Peaked	17,000	8500	0.50	6.1
Spread	17,000	7600	0.45	6.7

An airflow rate of 0.5 cfm/bu is marginal for drying grain; 1 to 2 cfm/bu is the desired target (Mills & Hartman, 2011). Therefore, these conditions are more suitable for aeration or grain conditioning. The above airflow rates were achieved with the bin partially filled. If the bin would have been completely filled, much lower airflow rates would have resulted. From this, it became clear that the single or double 10 hp centrifugal fans were not adequate to condition a 25,000 bu bin of canola as they reached a 'stall pressure' when the bin was filled to less than 10,000 bu for a double fan configuration and 17,000 bu for a single fan. Further research should be conducted to determine the appropriate fan size to supply air to a 25,000 bu bin.

4.2 Grain distribution and spreader performance

Grain that is discharged directly from an auger into a bin will typically result in a peaked grain surface. Historically, this was desirable as the peaked grain surface matched the roof of the bin and therefore would fully fill the bin. However, a peaked grain surface may no longer be desirable in cases where conditioning is required. For example, previous work by PAMI indicated that a hopper bin with peaked grain could take 20 to 30% longer to completely dry (Wassermann, Lischynski, & Stock, 1989). The purpose of a grain bin spreader is to achieve a relatively level grain surface which is beneficial to promote uniform air distribution through the grain mass. Some spreaders are externally powered which usually requires an electrical connection, which can be cumbersome and costly. This gravity spreader used the energy of the falling grain from the auger to rotate the discharge arm. It also had dividers on it that separated the flowing grain into a number of streams and discharged the grain at different distances from the centre. The combination of the rotating arm and the multiple discharge locations created a more level surface than the peaked treatment. **Table 3** shows the resulting grain depths when discharged directly from an auger and when discharged from the spreader. Grain depths are shown at a number of loading amounts ranging up to about 17,000 bu.

Table 3. Grain depth comparisons between peaked and spread bin filling.

PEAKED				SPREAD				
Grain	Depth (ft)		Difference	Grain	Depth (ft)			Difference
(bu)	Side	Peak	(ft)	(bu)	Side	7 ft in	Peak	(ft)
0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0
2,900	1.4	7.5	6.1	3,000	2.4	3.2	3.7	1.3
5,800	4.2	10.9	6.8	5,600	5.0	6.2	6.3	1.3
8,600	7.5	14.4	6.9	8,400	7.8	9.5	9.3	1.6
11,500	10.3	17.9	7.7	11,400	10.6	12.6	13.3	2.7
14,300	14.2	21.7	7.5	14,600	12.7	14.3	16.3	3.6
15,700	15.3	22.8	7.6	15,700	16.0	18.3	20.5	4.5
17,000	19.4	24.2	4.8	17,000	17.6	20.0	22.2	4.6

The spreader resulted in a more level surface than if discharged directly from an auger. However, the ‘spread’ grain surface was not completely level as the centre remained higher than the sidewall (**Figure 11**). The effect on air distribution is discussed in the next section.

Figure 11. Grain profile from inside the bin when filling with the spreader.

The average grain heights, static pressures, and airflow rates were compared to the predicted static pressures from **Figure 2**. In these tests, the grain depth averaged to about 20 to 22 ft and the measured airflow were 0.5 cfm/bu from the peaked test and 0.45 cfm/bu from the spread test. The measured static pressures were 6.1 and 6.7 in H_2O, respectively. The previous research predicted a static pressure of 7 to 8.5 in H_2O at 20 to 22 ft with 0.5 cfm/bu. Therefore, these results indicated that the previous research developed for smaller bins are similar to the large grain bin fan requirements.

4.3 Airflow Distribution

OPI cables were hung vertically to indicate the grain temperatures at four locations in the bin with each cable having seven sensors measuring temperature and relative humidity at various heights approximately 4 ft apart. Measurements were recorded approximately twice per day. Typically the air distribution pattern is compared between different systems by observing the relative migration speed of the temperature 'fronts' as they move through the grain mass. In these tests, this would be difficult to analyze as the fans had been operated for data collection, so differing temperature fronts were already established at the start of each test. Because of that and all the other variables, observing the relative temperature 'fronts' could not be used so an alternate approach was used to obtain an indication of relative airflow distribution. The goal was to condition the canola temperature to the average outside temperature, therefore, the temperature difference between the canola and ambient conditions were used to determine the airflow pattern inside the bin.

4.3.1 Ambient air and grain temperatures

The first trial (peaked) was performed about 1 month before the second trial, so the ambient conditions were much different compared to the spread trial (**Figure 12**). There were periods of rainy and humid weather, so the fans were shut down on several occasions, and more often during the first test. Because the bin could not be filled due to fan limitation, only the 4-5 bottom sensors on the cables were in the grain. Additionally, the anchored sensor cables (A1 and A4) loosened during the peaked trial and caused the cables to angle toward the sidewall as the canola was filled. Thus their sensors were closer to the wall when compared to the same cable sensors in the 'spread' test.

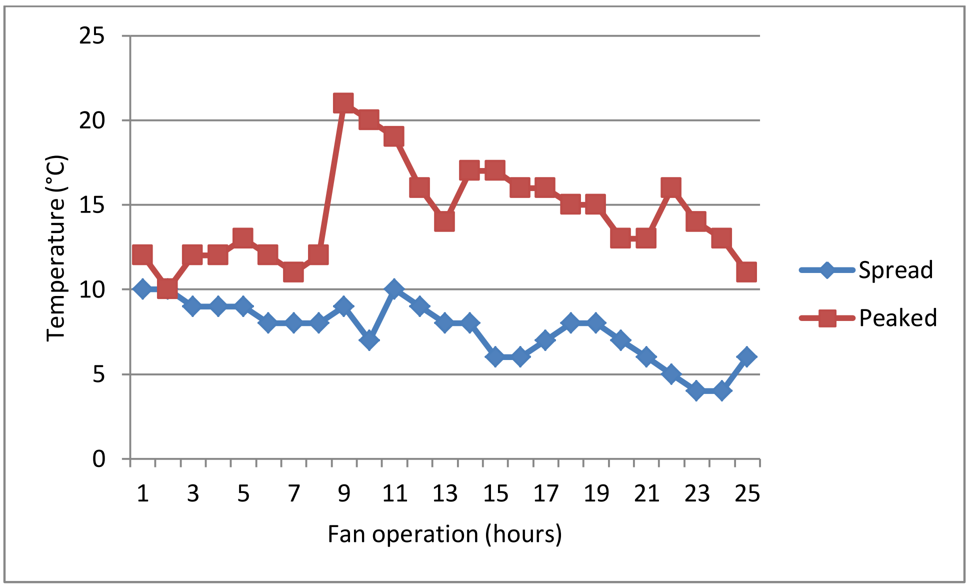

Figure 12. Ambient temperatures (°C) during the two 24 hour test runs.

Table 4 provides an indication of relative airflow distribution through the bin. The average grain temperature of the bottom four sensors for each cable were calculated prior and after each test, which allowed the average grain temperature drop at each cable to be determined. The difference between the average initial grain temperature and the average ambient air temperature during each run was also determined. From those calculations, a ratio between the initial-to-final grain temperature difference and the ambient-to-initial grain temperature difference was determined to indicate relative airflow at each cable. A higher ratio would indicate a higher relative airflow at that location.

Table 4. Relative airflow distribution as indicated by temperature drop ratio.

		Cable ID				
		A1*	A2	A3	A4*	**Avg**
Peaked	Initial grain temp (°C)	18.8	18.7	20.2	20.3	**19.5**
	Diff from ambient (14.5°C)	4.3	4.2	5.7	5.8	**5**
	Grain temp drop	3.2	2.4	2.2	3.1	**2.7**
	Temp drop ratio	**0.7**	**0.6**	**0.4**	**0.5**	**0.55**
Spread	Initial grain temp (°C)	16.0	15.8	15.9	16.0	**15.9**
	Diff from ambient (8.0°C)	8.0	7.8	7.9	8.0	**7.9**
	Grain temp drop	3.5	3.8	3.1	4.0	**3.6**
	Temp drop ratio	**0.4**	**0.5**	**0.4**	**0.5**	**0.45**

*Note: In the peaked test, Cables A1 and A4's ties to the floor broke during filling so the subsequent filling caused those sensors to angle toward the wall and upwards.

4.3.2 Analysis

An expected outcome is that Cables A1, A2 and A3 would have similar ratios as they are all at equal distances from the centre and thus would have similar grain depth and density conditions, resulting in similar airflow. Similarly, it is expected that Cable A4, which is in the centre, would have a lower ratio during the peaked test due to the greater grain depth at that location. The calculated ratios of Cables A1, A2, and A3 in all tests ranged from 0.4 to 0.7. However, these results should be used cautiously due to the cable (A1 and A4) movement from the peaked trial. The average "temp drop ratio" was slightly higher for the peaked compared to the spread, which aligns with the airflow reported in **Section 4.1** which indicated that the peaked test allowed more airflow than the spread test.

The ratios of the center cables (A4) were actually similar whereas it was expected that the centre peaked test would have a lower ratio due to the expected lower airflow through the higher grain depth. The similar ratios have been attributed to the fact that the spreader didn't create a very level surface. The measured grain heights and visual observations were combined to compare the two grain surface profiles between the peaked and spread treatments (**Figure 13**). The grain surface slopes were very similar between the two trials except that the spread profile was approximately 2 ft lower than the peaked trial. Some of the grain height differences could be explained by the small losses during the canola transportation between augers, while the remaining height reduction could be explained by the theory that the spreader packed the grain tighter in more areas compared to just the center from the peaked trial.

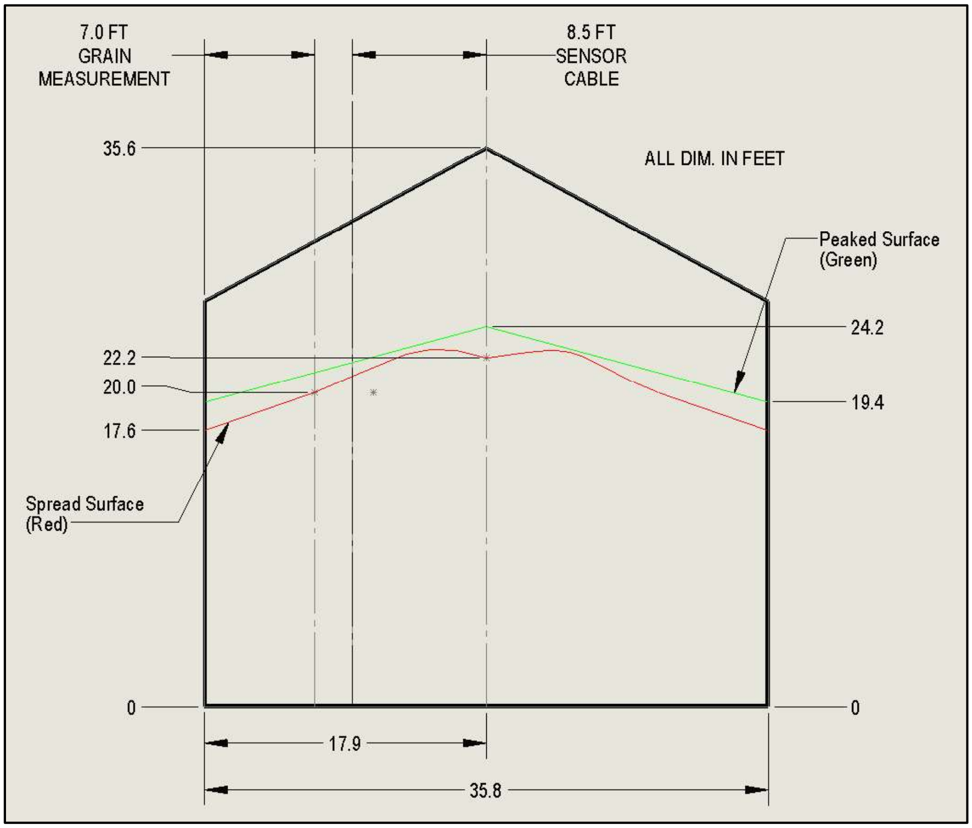

Figure 13. Grain height comparison between peaked vs spread treatment.

In summary, there was no clear indication from these tests that spreading canola with a gravity driven spreader provided any airflow distribution benefits. However, the previous airflow/static pressure recommendations for small bins seemed to apply for this large bin. These results were subjected to various different conditions not foreseen before the trial, such as the partial temperature fronts before filling the bin and the unexpected non-uniform grain distribution of the gravity spreader. It is also important to understand that statistical analysis was not conducted so it is unknown whether the differences were statistically significant.

4.4 Grain pressure sensors

Five sensors on the bin floor measured the vertical load at various fill heights. The grain pressure readings for the peaked and spread trial are shown in **Figure 14** and **Figure 15**, respectively**.** As expected, the vertical force increased with the additional grain loaded into the bin. The peaked pressure curves also indicated a higher vertical force was measured near the center, while the spread curve indicated a higher reading at approximately 10 ft away from the bin center. This may be explained by the theory that the densest packing occurs where the grain stream has the greatest impact on the grain pile and where the fines accumulate. For the peaked trial this occurs near the centre while the gravity spreader seemed to create mini-peaks away from the center depending on the grain height.

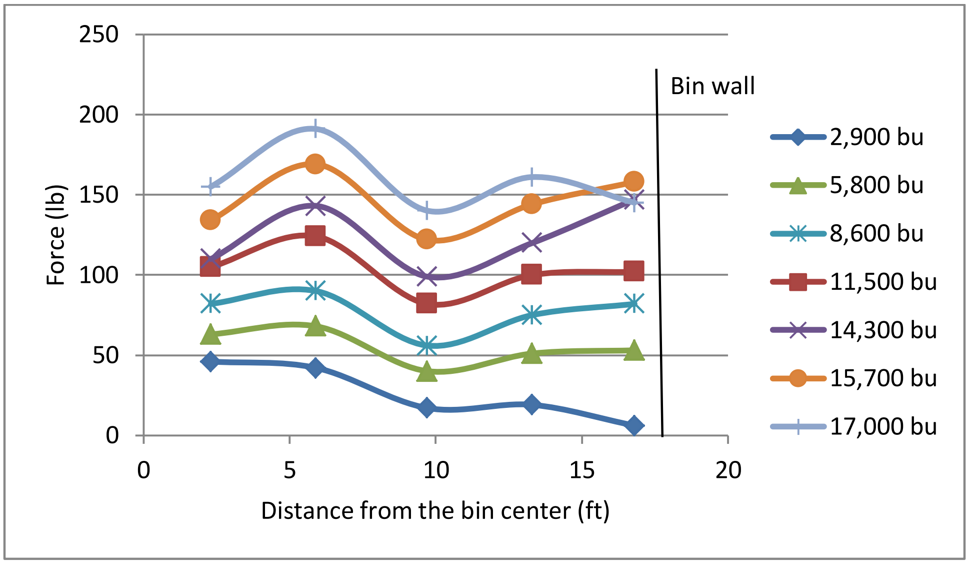

Figure 14. Peaked grain pressure measurements.

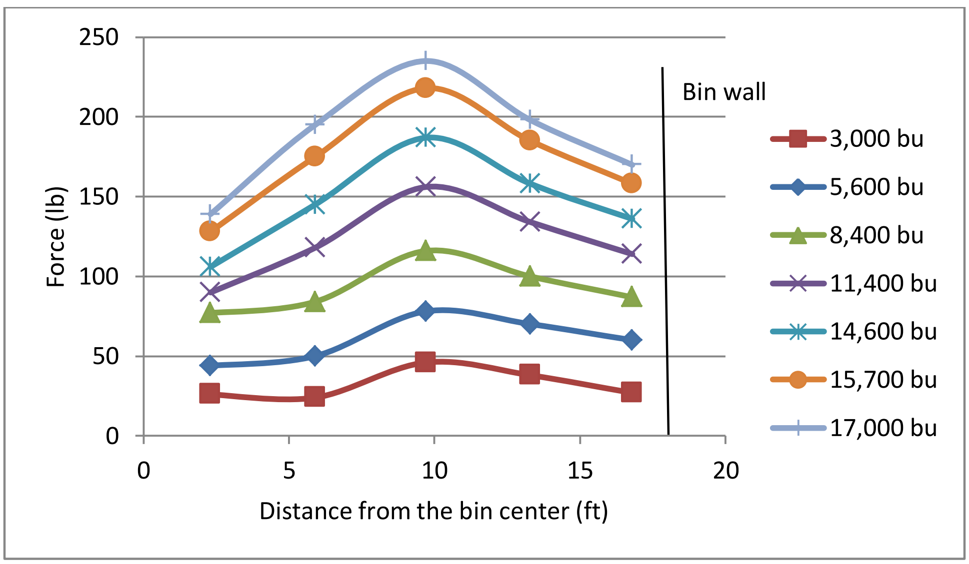

Figure 15. Spread grain pressure measurements.

The average grain height at about 17,000 bu for the peaked and spread trial was 21.8 and 19.9 ft, while the average load was 158 and 188 lb from the 5 load cells, respectively (**Table 5**). The average load per foot of grain suggests that the spreading trial increased the grain density. These trends are suggesting that the sensors may be able to provide some indication of grain height and compaction, which would be a very useful measurement. However, because the individual lines did not follow a clear mathematical trend, the pressure data and grain heights are recommended for further study in combination with Discrete Element Modeling (DEM) and Computational Fluid Dynamics (CFD) models to calculate the bulk density or packing factor.

Table 5. Average grain vertical loads for the peaked and spread trial at 17,000 bu.

	Peaked	Spread
Average vertical load (lb)	158	188
Average grain depth (ft)	21.8	19.9
Average grain load/depth (lb/ft)	7.2	9.4

4.5 Extension and future recommendations

Results of this project have been presented at Crop Connect in February 2018 and a copy of the poster is shown in **Appendix C**. PAMI will also make this report available on our website and will present the results at future producer meetings. The preliminary discussions at Crop Connect were very favourable and generated many discussions with the attendees.

Future work is recommended to adapt the previous grain storage research to larger bins. Because the fan limitation prevented filling the bin for these tests, another similar project to determine the suitable fan requirements should be conducted to determine the important aspects of conditioning canola for safe storage. The initial large scale grain storage research has indicated a few recommendations for any future trials. Additional measurements are recommended for generating the grain surface profile since the grain surface profile rarely follows a simple shape. For grain monitoring in large bins, additional sensor cables may be necessary to capture additional areas of the bin. When evaluating airflow distribution, the cables could be distributed differently to measure the airflow differences from the center to the sidewall.

Full scale testing of 25,000 bu bins is complicated and expensive, thus computer simulation would be a very useful tool to support and expand on physical testing programs. A program of joint physical testing and computer simulation will provide the most accurate and cost effective approach to provide solutions to the outstanding producer questions that have arisen from the recent trend to large grain bins on farms. However, full scale testing is still required to validate the various computer simulations generated from the initial study. One incorrect setting or assumption can change the results dramatically.

5. Conclusions

In summary, the previous airflow/static pressure recommendations developed from small bins still seem applicable for safe long term canola storage. The recommended practices should be effective in conditioning the canola for long term storage over 5 months. However, the fan requirements and grain monitoring practices may need to be adapted for larger bins. This project determined that the typical 10 hp centrifugal fans available for single phase power were not adequate to provide the required static pressure and airflow to condition canola in a 25,000 bu bin. After filling to about 17,000 bu or 70% full in a 25,000 bu bin, two 10 hp centrifugal fans operating in parallel had reached their ‘stall’ static pressure and a single 10 hp centrifugal fan was nearing its stall static pressure.

When comparing the two trials (peaked vs spread), the gravity driven spreader provided a marginal benefit in grain surface distribution, a small decrease in airflow rate, no differences in the airflow uniformity, and an increased grain density when storing canola. The gravity-driven spreader resulted in a more level surface than if discharged directly from an auger (“peaked”). However, the ‘spread’ grain surface was not completely level as the centre remained somewhat higher than the side and generated high spots several feet from the center. In these tests, actual airflow rates were 0.5 cfm/bu from the peaked test and 0.45 cfm/bu from the spread test with grain depth averaging out to about 20 to 22 feet. Measured static pressures were 6.1 and 6.7 in H_2O, respectively and these results were similar to the expected resistance to airflow of 7 to 8.5 in H_2O developed from smaller bins. The ratio between the initial-to-final grain temperature difference and the ambient-to-initial grain temperature difference showed no clear indication that a gravity spreader provided any airflow distribution benefits. The vertical load measured at the bin floor steadily increased with grain depth as expected, but indicated a higher vertical force near the center for the peaked trial and a higher vertical force about 10 ft away from the center for the spread trial. The average load per grain depth suggested that the spreader increased the overall grain density. However, these conclusions are only applicable to a gravity spreader since the grain distribution did not produce a completely level grain surface as intended. A different style of spreader may have very different results.

This project is a start to validating safe storage practices developed 20-30 years ago for large grain storage bins. Additional work is recommended to test the existing best practices in large bins to determine if any recommendations require any modifications for the larger volume of grain.

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Appendix A

Grain Bin Specifications

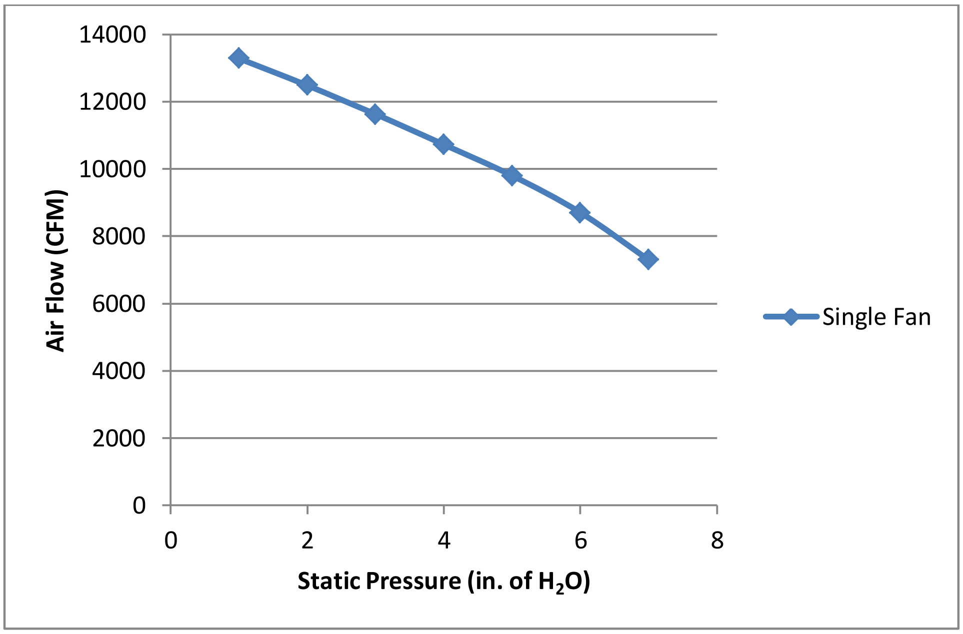
	7 Tier	
Diameter	35.8	ft
Capacity	24,740	bu
	827	m^3
	671	tonnes
Eaves Ht	25.8	ft
	7.9	m
Overall Ht	35.6	ft
	10.9	m

Appendix B

Fan Specifications

Centrifugal fan	
Phase	3 phase
Horsepower	10 hp
Voltage	575 Volts
RPM	1750
Size	27” Diameter wheel

Fan Performance Curve



Appendix C

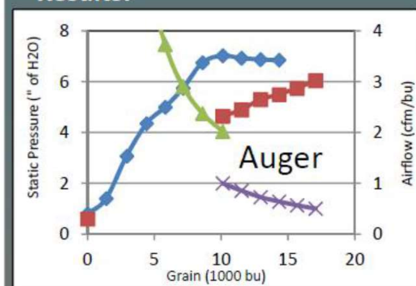
Project Poster (Updated since Crop Connect)

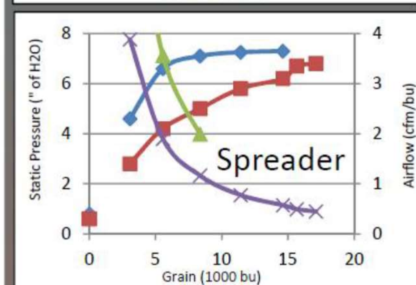
Canola Storage Research in Large Bins

Objectives:
- Determine the filling and conditioning differences between large canola bins that are filled through a spreader compared to being filled directly from an auger
- Determine fan and airflow information for large canola bins

Treatments:
- A 25,000 bu bin filled with canola using 2 methods
  - Direct fill from an auger spout
  - Spreader driven by the force of flowing grain
- Aeration provided by two 10 hp centrifugal fans (7" H_2O max)
- Grain condition monitored by sensor cables that measure temperature and moisture content
- Bins filled with about 17,000 bushels
- Fans operated when weather conditions were favorable

Results:





Comparison of Treatments

	Grain Volume (bu)	Grain Height (ft)				Airflow Rate – Single Fan		Static Pressure (in H_2O)
		Center	7 ft from wall	Side Wall	Average	Total (cfm)	CFM/BU	
From Auger	17,000	24.2	N/A	19.4	21.8	8500	0.50	6.1
Spreader	17,000	22.2	20.0	17.6	19.9	7600	0.45	6.7

Conclusions:
- Fan selection is important; fans with high static pressure capabilities will be required for large bins of canola
  - Fans will be in stall condition before bins are full (25,000 bu)
- The spreader treatment resulted in a more level grain surface
  - However, the installed spreader did not create a completely level surface
- The spreader treatment had a higher static pressure (or a lower airflow rate)
  - Work is on-going to determine the air flow patterns in the bin

Partners:
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