Auger Timing Effects on Performance of a Combine Unloading System

Todd Philip Cole

University of Nebraska-Lincoln

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Auger Timing Effects On Performance Of A Combine Unloading System

Todd Philip Cole, M.S.

University of Nebraska, 2002

Advisor: Michael F. Kocher

Performance effects were measured on a combine unloading system using three different auger timing settings. Performance measures included maximum startup torque, mean operating torque, standard deviation of the operating torque, flow rate of grain through the system, and mechanical damage to the grain. The performance effects were measured with the system unloading corn and soybeans.

The data were statistically analyzed to check for interactions between the grains and differences between the timings. Using an alpha value of 0.1 it was found that timing 1 for both grains had a 3% (< 2.4 L/s) higher flow rate over timings 2 and 3. Timings 1 and 2 for both grains had higher maximum startup torque, about 10% (60 N·m) more torque required than timing 3. In soybeans, timings 2 and 3 also had the smallest standard deviation in operating torque, about 30% (20 N·m) less than timing 1. We were unable to detect any differences in mechanical damage to corn or soybeans as a result of unloading auger timing. These findings suggest that timing 3, with the cross augers lagging 90° behind the vertical unloading auger, may require less maximum startup torque and less variation in torque for the cross augers to effectively fill the loosely filled space left after the vertical auger lifts the grain without extra torque effects of having the augers push against each other as they do in timing 1.
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Introduction

Screw conveyors, more commonly referred to as augers, are the most common equipment used for moving grain and feed on farms. They have a low initial cost, low maintenance, simple construction and easy mobility. Many researchers have worked on experiments to determine the power requirements, mechanical damage to the grain, and flow rates with various designs of augers. Some of the factors in their research have included grain types, moisture contents, and method used to dry the grain. By far the biggest concern with augers is the mechanical damage inflicted to the grain. Damaged grain can ultimately result in spoilage leading to lower value of the grain. When augers are not operated at their optimum efficiency it typically results in lower flow rates, increased damage, excessive power usage, and excessive wear to the auger. Although much work has been done to analyze the damaging effect that a single auger has on corn and soybeans with varying speeds, capacity, and flighting design, very little has been done to determine what effects occur when a horizontal auger feeds a vertical auger.

Objectives

It was the overall objective of this study to determine the effects that relative auger positioning (auger timing) has on flow rate, mechanical damage and power requirements of the system moving corn and soybeans, when two equal size horizontal augers feed a single vertical auger. Setups like this are commonly found in modern combines to unload the clean grain tank. Specific objectives were to determine:
1. For which of the three timings (relative position as specified by the combine manufacturer, 180° out of phase compared to the combine manufacturer’s specifications, and 90° out of phase compared to the combine manufacturer’s specification) was the grain flow rate the highest?

2. Which timing had the lowest maximum startup torque?

3. Did the average operating torque differ among the timings?

4. Which timing had the smallest standard deviation for the operating torque?

5. Was the interaction between grain types and timing significant for any of the performance parameters?

6. Did the timings have an effect on mechanical damage to corn or soybeans?

Review Of Literature
Auger Flighting Design

There are two basic types of auger flighting designs commonly used, single flighting and double flighting. With double flighting, at any point along the center axis of the auger there are two pieces of flighting attached to the center shaft, 180° apart from each other around the circumference of the center shaft. Double flighting should not be confused with short pitch flights. The pitch of the auger refers to the distance parallel to the center axis of the auger that the auger would move if it were screwed into a solid block as the auger rotated exactly one revolution. ASAE Standard EP 389.2 (ASAE, 2000a) states, “the most economical pitch on augers is equal to the flighting outside diameter. Pitches
shorter than 0.9 O.D. and longer than 1.5 O.D. are generally not recommended."

Reported in the Midwest Plan Service (1988) reports that “a pitch length equal to flight diameter (single pitch) gives the best performance under most conditions.”

Many researchers (Chang and Steele, 1995; Hall, 1974; Sands and Hall, 1971) have done studies trying to determine which style of flighting is most suitable for all around use. It is widely accepted that while double flighting does have a higher conveying capacity and higher energy efficiency it does inflict a higher rate of mechanical damage when compared to conveyors with single flighting.

Chang and Steele (1995) studied auger performance with corn that had been dried with low temperature or high temperature air. They found that single-flight, standard pitch (pitch equal to flight diameter) augers caused the least amount of mechanical damage when compared with a double-flight, standard pitch auger and a single-flight, standard pitch auger with a strip welded to the outer edge of the flighting. Their results showed a significant increase in flow rate with the double-flight auger when compared to the single-flight auger.

Capacities and Power Requirements

Midwest Plan Service (1988) reports that auger capacity and horsepower are affected by diameter, pitch, speed (RPM), exposed intake length, incline, and grain properties. Overall length of the auger affects power requirement, but not capacity. As the speed of an auger increases the capacity and required horsepower to operate the auger will also increase. The increase in capacity and required horsepower is less for an auger that is inclined compared to a horizontal auger, or has a short intake opening to the auger. The capacity of an auger
increases until the grain has difficulty entering the auger because the intake flighting throws it back out.

Hall (1974) showed the auger incline angle had a large effect on the rate of grain movement, but no significant effect on mechanical damage to soybeans. Midwest Plan Service (1988) indicates that for a given power, increased auger incline decreases capacity. As incline increases from horizontal, the power requirement increases to a maximum at inclines between 45° and 60°. At incline angles above 60°, capacity loss reduces the power requirement. At a 90° incline angle, the power required is about the same as for a horizontal auger, but the capacity is much less.

Midwest Plan Service (1988) also states grain type influences capacity and power requirements. An auger’s capacity for wheat, grain sorghum, oats, barley, and rye is a little less than for corn. With soybeans, an auger has lower capacity and higher power requirements than with corn. Higher grain moisture content results in reduced capacity and increased power requirements because wet grain is heavier and has more friction. Grain depth over the auger intake, as in bulk tanks, increases auger horsepower needs, especially with long exposed intakes. Half pitch flights (pitch = ½ auger diameter) run at rated speed can reduce the amount of grain entering the auger and increase leverage, thereby reducing power requirements.

**Corn Moisture Content and Kernel Damage**

Several studies have been done to determine the effects that augers have on dried corn. Hall (1974) reported that even though wetter (>24%) corn is more
elastic than drier corn, it is also more susceptible to damage due to the soft
pliable wrinkles on the surface of the wet corn. Hall and Johnson (1970) found
that the amount of corn/fine material that would pass through a 4.76 mm sieve
decreased with decreasing moisture content to a minimum level at about 20 to 24
percent and then increased as the moisture content continued to decrease.
Sands and Hall (1971) reported that a screw conveyor caused only a very small
amount of damage to dry shelled corn when operated at full capacity. Al-Mosawi
(1983) reported that in addition to economic losses, corn that is damaged at high
moisture contents is susceptible to mold growth that can cause spoilage. This
would seem to suggest that corn that is very low or high in moisture content will
have an increased amount of damage when compared to corn in the 20 –24
percent moisture content range.

**Corn Mechanical Damage Evaluation Test**

The evaluation of mechanical damage to grain is one of the most vague
problems associated with harvesting, handling, and marketing. Although many
different methods have been used to evaluate mechanical damage, no consistent
and conclusive method of damage evaluation is available. The Official Grain
Standard of the U.S. Department of Agriculture (USDA, 1996) defined broken
corn as the portion that readily passes through a 4.76 mm round hole sieve.

Chowdhury and Buchele (1975) developed a colorimetric test to determine
bulk grain damage. Their test was based on the idea that the severity of damage
would be proportional to the area of the exposed inner portion of the grain. They
soaked their corn samples in a 0.1% solution of FCF Green Dye and the dye was
absorbed by the exposed starchy area of the damaged grain. A solvent, 0.1% NaOH solution, was used to dissolve the absorbed dye from the damaged part of the grain. Then a simple colorimetric or an expensive spectrophotometer could be used to measure the amount of dye present in the solvent. The test was fast and accurate in describing the quality of the grain from the standpoint of mechanical damage.

Many researchers (Al-Mosawi, 1983; Chowdhury and Buchele, 1975; Pierce and Hanna, 1985; and Pierce et al., 1991) have used the FCF Green Dye test as the method to evaluate corn for damage. Each has chosen to have slight variations in the process. The dye facilitates the identification of damaged kernels by absorbing to and coloring the damaged, exposed portion of the kernel. Pierce and Hanna (1985) submerged corn samples in a solution of 0.1% FCF Green dye, allowed the sample to soak in the solution for 5 minutes, rinsed with tap water, and then spread the kernels out on paper towels to air dry for 24 hours. Since each kernel must be examined separately, sample sizes must be small. The labor, time, and element of human fatigue may influence the results of a test such as this.

**Soybean Moisture Content and Damage**

Fernando (2001) reported that a substantial increase in mechanical damage occurred when soybeans below 11% to 12% moisture content were handled by threshing devices. Hall (1974) found that during handling, soybeans reached a minimum damage level at moisture contents of about 18% or 19%, while corn will have its minimum damage level at 24% to 25% moisture content.
He also noted that soybeans below 13% in moisture content were brittle and very susceptible to damage. This was especially the case when the auger was operated at less than full capacity and at a higher than normal speed.

Paulsen and Nave (1977) used a 0.1% indoxyl acetate-ethanol solution to identify soybeans with damaged seedcoats. They concluded that their test detected 84% to 100% of the soybeans known to have seed coat cracks. In addition, the test also found another 4% to 16% of the seed with minute seed coat damage that would have otherwise gone undetected by visual observation alone. In their study they compared their method to the sodium hypochlorite test and found very small differences in detection of damaged seed coats.

Fernando (2001) stated that rapid determination of soybean seed coat damage can be made with the sodium hypochlorite soak test. In his test, he immersed the soybean sample in a 0.1% sodium hypochlorite solution for 5 minutes, spread out the sample on paper towels, and recorded the soybeans that swelled to 2 to 3 times their normal size as damaged but unbroken. The sodium hypochlorite soak test is widely used by many researchers (Fernando, 2001; Paulsen and Nave, 1977; and Rodda et al., 1973) as the method to evaluate soybeans for mechanical damage.

**Equipment and Procedure**

A considerable amount of equipment was needed to carry out the experiment to evaluate the effects of unloading auger timing on system performance. This equipment included a torque transducer and calibration setup, a shaft speed sensor, a grain diverting system to determine the system flow rate,
a computerized data acquisition and control system, and lab equipment to evaluate grain samples for mechanical damage. Most of this equipment was used in combination during each test run to obtain the necessary data. For ease of explanation each equipment set will be described separately.

**Combine Harvester Specifications**

A 2000 model year Caterpillar Lexion combine, model #460, serial # 9SW 553 was used for the entire unloading auger testing. At the end of the test the combine harvester's hour meter indicated it had been used for 759 hours on the unit, roughly 12 of those hours were put on the machine during these tests. The amount of time that the unloading augers had been used prior to our testing was unknown. The chopping unit attached to the rear of the combine harvester was engaged throughout the testing period.

The two cross augers in the bottom of the clean grain tank were identical with the exception that one had right-handed flighting and the other had left-handed flighting (Figure 1). The diameter of the cross augers was 190 mm (7.48 in) and the pitch was 180 mm (7.09 in). The overall length of these augers was 2349.5 mm (92.5 in). Of that length, 155 mm (6.11 in) was the length of the paddles at the discharge end of the horizontal cross augers.

The vertical unloading auger was equipped with double flighting on the first 250 mm (10.00 in) of the lower portion where grain is picked up from the two horizontal augers, with a flight-to-flight dimension of about 125 mm (5.00 in). Where there was not double flighting the flight-to-flight dimension (pitch)
measured 225 mm (8.86 in). The diameter measured 340 mm (13.39 in) and the overall length of the auger was 1540 mm (60.63 in).

The diameter of the swing out auger was 300 mm (11.81 in), the pitch was 250 mm (9.84 in) and the overall length was 5532 mm (18 feet, 2 inches). The end of the swing out auger was equipped with a spout that would discharge the grain out and down from the end of the auger. Inside the grain tank, the tent covers over the unloading cross augers were positioned to allow the maximum amount of open inlet area on the inside of the two augers (side closest to the space between the two augers) and the covers on the outside of the augers were opened as far as possible throughout the testing period.

**Unloading Auger Timing**

The timing of the three unloading augers (rotational position relative to the other two) was the main independent variable in the experiment. Three levels of auger timing were used, including the correct timing (manufacturer's recommendation), 180° out of time, and 90° out of time. The drive sprockets for each auger had 40 teeth so the augers maintained the set timing as long as none of the sprockets jumped one (or more) teeth on the chain. Details of adjusting the auger to each timing level are as follows (see Figure 1):

Auger timing #1: Turn the vertical unloading auger so the leading edge (Correct timing) (B) of the flighting that is continuous throughout the length of the auger (the lower portion of the auger has double flighting) points towards the front of the combine harvester.

Turn the rear horizontal cross auger (4, feeding the grain from
the bin to the vertical unloading auger) until leading edge (C) is pointing vertically to the top of the combine harvester.

Turn the front horizontal cross auger (5) until the leading edge (A) is pointing vertically to the bottom of the combine harvester. Assemble the drive chain for these augers while maintaining these respective positions.

Auger timing # 2: Turn the vertical unloading auger so the leading edge (180° out of time) (B) of the flighting that is continuous through out the length of the auger points towards the front of the combine harvester.

Turn the rear horizontal cross auger (4) until the leading edge (C) is pointing vertically to the bottom of the combine harvester. Turn the front horizontal cross auger (5) until the leading edge (A) is pointing vertically to the top of the combine harvester. Assemble the drive chain for these augers while maintaining these respective positions.

Auger timing # 3: Turn the vertical unloading auger to have the leading edge (B) (horizontal cross of the flighting that is continuous through out the length of the augers lag 90° behind the vertical unloading auger) (C) is pointing horizontally towards the front of the combine harvester. Turn the rear horizontal cross auger (4) until the leading edge (C) is pointing horizontally towards the front of the combine harvester. Turn the front horizontal cross auger (5) until the
leading edge (A) is pointing horizontally towards the front of the combine harvester. Assemble the drive chain for these augers while maintaining these respective positions.

Figure 1. Schematic drawing of the front (5) and rear (4) horizontal cross augers and the vertical (3) unloading auger set at the manufacturer’s recommended timing. Source: Used with permission from Lexion (Caterpillar, 1998) Combine Operator’s Manual.
Unloading Auger System Drive Shaft Torque

The horizontal cross augers and the vertical unloading auger were all driven from a single shaft (Figure 2). The sprocket for the chain drive of the unloading augers was on one end of this drive shaft and a v-belt sheave on the opposite end supplied input power to the unloading auger drive system. Start up and operating torque were monitored through the use of full bridge torque transducer constructed on the middle of this drive shaft using torque strain gages (Micro Measurement CEA-06-187UV-350, Measurements Group, Inc., Raleigh, NC). A slip ring (S4, Michigan Scientific Corp., Milford, MI) was attached to the v-belt sheave end of the shaft, for conducting supply voltage to the torque transducer, and conducting the output signal to the data acquisition and control computer.

Figure 2. Schematic drawing of the chain drive for the auger system. Source: Used with permission from Lexion (Caterpillar, 1998) Combine Operators Manual.

The data acquisition computer was used to supply a regulated excitation voltage of 5VDC to the torque transducer. The torque cell output voltage was amplified with an instrumentation amplifier (Analog Devices AD624, One
Technology Way. Norwood, MA) configured with a nominal gain of 375. The output from the amplifier was connected to one of the 12 bit analog-to-digital converter channels on the data acquisition computer. A calibration jig was built to hold the shaft stationary while known torques were applied to the shaft with weights hung from a lever arm. The calibration was done with the slip ring and all the lead wires that would be used once the torque cell was in place in the combine harvester and the data acquisition computer to account for all system components in the calibration. The calibration and verification data for the torque transducer are shown in Figure 3. The $R^2$ for the calibration equation was 0.997 and the maximum error in the verification data was 4.44 N•m, indicating a 3.36 percent resolution.

![Torque Cell Calibration](image)

Figure 3. Graph showing calibration and verification data from calibrating the torque cell on the unloading auger drive shaft.
Rotational Speed of Unloading Auger System Drive Shaft

The rotational speed of the drive shaft for the unloading auger system was obtained using an inductive proximity sensor (NJ5-18GM50-E0. Pepperl+Fuchs Inc. Twinsburg, OH). The sensor was set up so each time a tooth of the unloading system drive sprocket passed in front of the sensor it sent a 5VDC square wave pulse to the data acquisition computer. The data acquisition computer monitored the period of these pulses and was programmed to record the rotational speed of the drive shaft in revolutions per minute.

Data Acquisition Computer

A single board data acquisition and control computer (TFX-11, Onset Computer Corporation. Bourne, MA.) was used to collect data from the torque cell, and shaft speed sensor, and to operate a directional control valve controlling the grain diverting system. A toggle switch was used to signal the computer when to start collecting data. After each test run, the data collected by the computer was downloaded to a laptop computer. The single-board data acquisition computer was housed in a standard 5 gallon plastic bucket with a tight-fitting rubber-gasketed lid for portability and protection from the elements during the tests. The computer program used to obtain data and control the grain diverter system during each test run is presented in Appendix A.

Grain Flow Rate

The mass flow rate of grain out of the unloading system was measured following ISO Standard 5687:1999 (ISO, 1999). For this experiment, corn (#2 yellow corn) and soybeans (#1 yellow soybeans) were used instead of wheat as
described in the Standard. Before each test run about 100 bushels of the test grain was moved from storage through an inclined auger (separate from the combine harvester) and dumped into the clean grain tank of the combine from above.

At the start of each test run the unloading augers were operated for about six seconds after they first started rotating to allow time for full steady flow to develop. During this startup time, the grain diverting system directed the discharge from the combine harvester unloading auger into the grain truck. At the end of the six second startup time the diverting system was triggered by the data acquisition computer to direct the discharge from the combine harvester into the weigh wagon (Brent, 470, Kalida, OH). Grain was discharged into the weigh wagon for about 25 seconds and then the data acquisition computer triggered the grain diverting system to direct the discharge back into the truck until the combine harvester was empty. At the end of the test, the weight of the grain in the weigh wagon was recorded.

Two separate samples of the grain were collected from the stream of grain as the separate auger was used to move grain into the combine harvester grain tank. A 19 L (5 gal) bucket was used to collect the grain sample which was used to determine the grain test weight and moisture content. A 76mm (3 in) diameter PVC pipe with a 25 x 130mm (1 x 5 in) slot cut into the side of one end of the pipe was used to collect the grain samples used to determine the level of damage in the grain before each test run. The PVC pipe sampling device was also used to obtain samples from the grain stream discharge from the combine
unloading system to determine the level of damage in the grain after each test run. The openings of both collection devices were passed through the grain stream at least 3 times to get a representative sample of the grain. This procedure was used for both soybeans and corn.

**Calculation of Flow Rate**

A grain diverter system was built to divert the discharge from the combine harvester unloading auger into either a grain truck or a weigh wagon (Figure 4 and 5). The diverter measured approximately 0.91 m by 0.91 m (3.0 ft by 3.0 ft) and 0.61 m (2.0 ft) tall with a plate (butterfly) that pivoted on a horizontal shaft in the center to direct the flow. The butterfly plate was actuated with a 26.9 mm (1.06 in) bore by 203.2 mm (8.00 in) stroke pneumatic cylinder (Select, SLD11-CBP-080, Indianapolis, IN). The pneumatic cylinder was operated by a 12 Volt DC, 2 position, 5 way, solenoid operated, spring return directional control valve (NVS 4114-25510TN, SMC Pneumatic Inc. Indianapolis, IN), controlled by the data acquisition computer. The on/off operating pressures for the compressor that provided the air to operate the cylinder were set at about 620 and 960 kPa (90 and 140 psi). The time that actual flow was diverted into the weigh wagon was monitored by the use of two Hall-Effect switches (SS41/SS41D Honeywell Inc. Freeport, IL) triggered by magnets (PK 8909 3 Honeywell Inc. Freeport, IL) attached to the bottom side of the butterfly plate (Figure 6). A digital storage oscilloscope (Nicolet Pro, Madison, WI) was used to record the output voltage from each channel of the Hall-Effect switches with time.
Figure 4. Grain diverter system used to divert the discharge from the combine harvester unloading auger into either the grain truck or the weigh wagon. Note that the butterfly plate as shown is set to divert the discharge (which falls on top of the butterfly plate) into the grain truck.
Figure 5. Combine harvester discharging corn out the unloading auger into the grain diverting system. In this picture the grain diverting system is directing the grain flow into the grain truck.
During a complete cycle, three time measurements were recorded to determine the time during which the grain discharge from the combine unloading auger was directed into the weigh wagon. At the start of each test run the butterfly plate of the grain diverting system was set to direct the flow into the grain truck. With the butterfly plate in this position, both Hall-Effect sensors (channel 1 on the grain truck side and channel 2 on the weigh wagon side) were set to output a high voltage (5VDC) (Figure 7). After steady flow developed, the data acquisition computer triggered the solenoid valve to move the butterfly plate so grain flow was directed into the weigh wagon instead of the grain truck. As the butterfly plate began to move, the magnet on the grain truck side of the butterfly plate moved out of range of the Hall-Effect sensor channel 1 (grain truck side)
and the voltage on this channel dropped to almost 0VDC. Thus the first voltage change on channel 1, from 5V to 0V signaled the start of the movement of the butterfly plate to switch the grain flow into the weight wagon. As the butterfly plate completed its movement to switch the grain flow into the weigh wagon, the magnet on the weigh wagon side of the butterfly plate came into range of the Hall-Effect sensor on that side and the voltage (channel 2) dropped from 5V to near 0V.

At the end of the time period during which the grain discharge from the combine unloading auger was collected in the weigh wagon, the computer triggered the solenoid valve to move the butterfly plate so the discharge was directed into the grain truck instead of the weigh wagon. As the butterfly plate began this movement, the voltage on channel 2 (weigh wagon side) increased from 0V to 5V. As the butterfly plate completed this movement, the voltage on channel 1 (grain truck side) increased from 0V to 5V. These two voltage-time traces were recorded on the oscilloscope and the following three time intervals were measured from these data to determine the time interval during which the grain discharge from the combine unloading auger was collected in the weigh wagon.

\[ t_1 \] — time from start of voltage drop on channel 1 to end of voltage drop on channel 2

\[ t_2 \] — time from start of voltage drop on channel 1 to start of voltage increase on channel 2
t_3 — time from start of voltage drop on channel 1 to end of voltage increase on channel 1

Figure 7. Hall-Effect sensor voltage-time traces recorded on the oscilloscope for determination of the time interval during which the grain discharged from the combine unloading auger was collected in the weigh wagon.

Using these time measurements, the time interval during which the grain discharge from the combine unloading auger was collected in the weigh wagon was estimated as the total time, t_3, minus one-half the time it took for each of the two butterfly plate movements, t_1 and t_3 - t_2. Thus flow time was then calculated by equation 1:

\[
Flow\ time = t_3 - \frac{(t_3 - t_2)}{2} - \frac{t_1}{2}
\]  

[1]

The test weight of the grain for each test run was measured at the end of each days' testing using a test weight device (Test Weight Device Seedburo Equipment Co., Chicago, IL) using the sample taken with the 5 gallon bucket from the grain stream as the combine harvester was being loaded with the test
grain. This measurement was necessary to convert the weight measurement of grain in the weigh wagon to number of bushels. A mean flow rate of the unloading auger could then be calculated using equation 2.

\[
F = \frac{W_w}{T_w \cdot t}
\]  

[2]

where:
- \( F \) is the mean flow rate, liters per second (bu/s)
- \( W_w \) is the mass (weight) of the grain collected in the weigh wagon, kg (lb)
- \( T_w \) is the test weight of the grain, kg/L (lb/bu)
- \( t \) is the time interval during which the discharge from the combine harvester unloading auger was directed into the weigh wagon, s.

The same sample of grain that was used for measurement of test weight was also used for measurement of moisture content, at the end of each days' testing. Moisture content was determined using a moisture meter (Model #SS250, Steinlite Moisturemeter, Fred Stein Laboratories, Inc. Atchison, KS).

**Operational Procedures**

The tests were performed from August 12 to August 22, 2002 at the Biological Systems Engineering Department Rogers Memorial Farm approximately 10 miles east of Lincoln, Nebraska. Four replications of each of the three timing treatment levels were done to provide necessary data for
statistical analysis. The order in which the timing treatments were applied was randomized (Appendix B).

After all equipment was readied and people were in place, the following steps were used to begin a test run:

1. Engage the threshing unit with the combine harvester’s engine at idle.
2. Throttle engine up to rated speed.
3. Switch header to operating position.

The machine was now ready to make a test run. The following series of events occurred to gather the required data.

1. The start switch for the data acquisition computer and start switch for the unloading auger system were triggered simultaneously.
2. The computer waited for 4.5 seconds to account for the unloading auger system startup delay.
3. The computer then recorded 200 torque values at 0.01 second intervals, to obtain peak start-up torque.
4. The torque readings were immediately followed by recording the rotational speed of the unloading auger system drive shaft.
5. The computer waited 6 seconds to allow time for full steady flow to develop.
6. The solenoid was activated to extend the pneumatic cylinder to move the butterfly plate of the grain diverting system so grain flow was directed into the weigh wagon instead of the grain truck.
7. 11.5 seconds after flow was directed into the weigh wagon 100 torque values were recorded at 0.01 second intervals to obtain operating torque requirements.

8. The torque readings were immediately followed by measuring (about 1 s) and recording the operating rotational speed of the unloading auger system drive shaft.

9. 11.5 seconds after the operating speed was taken the solenoid was deactivated (cylinder retracted) so grain flow was directed into the grain truck instead of the weigh wagon, until the combine harvester’s grain tank was empty.

**Sampling Procedure for Grain Quality**

Samples of the grain were taken before and after each test run so these samples could be evaluated for grain quality. The change in grain quality was attributed to the treatment. It was estimated that the grain had already been through as many as seven different augers by the time it was loaded into the combine harvester grain tank. The pre-treatment sample was collected across the full width of the flow stream of the grain as it left the auger used to fill the combine harvester grain tank. The post-treatment sample was collected from across the full width of the flow stream of the grain as it left the discharge end of the combine harvester unloading auger, after the timed collection of grain flow in the weigh wagon.

Both the pre- and post-treatment samples obtained with the collection device were randomly divided into two 100 g samples. The samples were double
bagged in plastic zippered freezer bags and then stored in a refrigerator at 5°C until the time of damage evaluation.

**Evaluation of Mechanical Damage to Corn**

To prepare the pre- and post-treatment samples for quality evaluation, each sample was spread out onto a tray where dockage was removed (other grains, insects, pieces of plant material, etc). The dockage free sample was then weighed and the sample weight was recorded. Next the broken corn (BC) was screened out with at least 20 strokes of a standard dockage sieve for corn (4.76 mm diameter round hole). Material that passed through the sieve was weighed and recorded as BC.

Kernel damage was evaluated by treating the corn remaining on top of the dockage sieve with 0.1% Fast Green Dye solution to facilitate the identification of damaged kernels. Samples were immersed for 5 minutes in the solution, thoroughly rinsed in running water, then spread on a paper towel for a few hours to air dry before being analyzed. After drying, the samples were visually inspected and divided between no damage, minor damage and severe damage. Samples were classified into the following categories (Figure 8) according to the severity of damage:

1. Severe damage — Broken pieces, large pericarp (hull) cracks or missing endosperm
2. Minor damage — Absorbed FCF or pericarp (hull) cracks
3. No damage — Slight amount of FCF on tip cap
The damage categories were reported as a percentage of the sample weight after the dockage had been removed. Since the minor and severe damage portions had been exposed to moisture in the dying process the weight of these portions of the sample had changed. Thus, these portions weights needed to be recorded with some way of representing their weight prior to being immersed in the green dye solution. Therefore, the damaged portions were dried at 105°C for 72 hours to get dry weights, and then Equation 3 (ASAE, 200b) was used to convert the dry weights of these portions to wet basis weights at the moisture content originally record for the sample:

\[ G_w = \frac{100 \ G_d}{100 - MC_{wb}} \]  

where:

- \( G_w \) is the mass of wet material
- \( G_d \) is the mass of dry material
- \( MC_{wb} \) is the wet basis moisture content of sample at time of collection

**Evaluation of Mechanical Damage to Soybeans**

To prepare the pre- and post-treatment samples for quality evaluation, each sample was spread out onto a tray where dockage was removed (other grains, insects, plant material, etc). The sample was sieved with at least 20 strokes through a 4.00 mm round hole sieve. Material that passed through the sieve was recorded as “splits”. The splits were weighed to get a percent (by weight). No splits were recorded throughout all the samples. The fraction of
mechanically damaged but unbroken seeds was determined by the sodium hypochlorite test. Two replicates of one hundred soybeans were randomly selected from each sample and immersed in a 0.1% sodium hypochlorite solution for 5 minutes. The sample was spread out onto paper towels (Figure 9) and the enlarged soybeans were counted and recorded as a percent (by number).

Figure 8. Corn mechanical damage evaluation after being soaked in 0.1% FCF Green Dye for 5 minutes. Kernels on the right were classified as minor damage. Kernels on the left were classified as severe damage.
Data Analysis

The data analysis was done in two steps. The data recorded by the data acquisition computer were first analyzed with a Q-Basic (Quick Basic 4.50 1985-1988 Microsoft Corp, Redmond, WA) program to filter out poor torque data points (maximum or minimum torque values for the transducer, indicating poor electrical connection at the slip ring) and calculate maximum startup torque, average operating torque, standard deviation of the operating torque, and number of good operating torque values. Each of these torque values was important to illustrate what effects and requirements auger timing had on the unloading system. The results from the Q-Basic analyses were then entered into Excel (Microsoft Excel 2000, v9.0.4402 SR-1 Microsoft Corp, Redmond, WA) along with the flow rate, mechanical damage, and moisture content for each grain. Figure 10 is a sample graph of startup torque data, Figure 11 shows a sample graph of operating
torque data, and Figure 12 is a sample graph of operating torque data with a few data points pegged high and low that the Q-Basic program would remove from the analysis.

All the data were entered into SAS (SAS Institute, Inc., 2000) and an analysis of variance was carried out using PROC MIXED to determine if there were significant differences in auger timings. The design was a 3 x 2 factorial (3 levels of auger timing and 2 grain types) and the interaction between grain and timing was investigated. However, the mechanical damage evaluation technique was different for corn and soybeans so they could not be checked for interactions. Thus, two separate analyses were run for the grain to determine significant differences in grain quality among auger timings.
Figure 10. An example graph constructed from 2 seconds of startup torque data, sampled at a rate of 100 times per second when unloading augers were engaged. Data from the test run rep 1, using corn, and auger timing 3 (1C3).

Figure 11. An example graph constructed from 1 second of torque data sampled at a rate of 100 times per second when the unloading augers were operating at a steady state. Data from test run rep 1, using soybeans, and auger timing 2.
Figure 12. An example of 1 second of running torque with a few data points erroneously at maximum or minimum torque values for the transducer. The maximum and minimum torque values were not used in the analysis. Data from rep 4, with corn, and auger at timing 1.

Results And Discussion

Table 1 shows the values for flow rate, maximum startup torque, average operating torque, standard deviation of operating torque and moisture content, averaged over four replications for each timing treatment with corn. Table 2 shows the values for the same list of response variables averaged over the four replications for each timing treatment with soybeans. Data from each replication are shown in Appendix C-1.
Table 1. Flow rate, maximum startup torque, average operating torque, standard deviation of operating torque, and sample moisture content averaged over the four replications for each combine harvester unloading auger system timing treatment with corn. The standard error for each measurement is shown in parenthesis after the measured value.

<table>
<thead>
<tr>
<th>Timing</th>
<th>Flow Rate (L/s)</th>
<th>Max. Startup Torque (N·m)</th>
<th>Average Operating Torque (N·m)</th>
<th>Standard Deviation of Operating Torque (N·m)</th>
<th>Moisture Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>89.15 (0.493)</td>
<td>645 (16.72)</td>
<td>145 (4.46)</td>
<td>45 (5.49)</td>
<td>12.6 (0.172)</td>
</tr>
<tr>
<td>2</td>
<td>86.69 (0.493)</td>
<td>610 (16.72)</td>
<td>145 (4.46)</td>
<td>45 (5.49)</td>
<td>12.2 (0.172)</td>
</tr>
<tr>
<td>3</td>
<td>87.04 (0.493)</td>
<td>580 (16.72)</td>
<td>155 (4.46)</td>
<td>50 (5.49)</td>
<td>12.7 (0.172)</td>
</tr>
</tbody>
</table>

Table 2. Flow rate, maximum startup torque, average operating torque, standard deviation of operating torque, and sample moisture content averaged over the four replications for each combine harvester unloading auger system timing treatment with soybeans. The standard error for each measurement is shown in parenthesis after the measured value.

<table>
<thead>
<tr>
<th>Timing</th>
<th>Flow Rate (L/s)</th>
<th>Max. Startup Torque (N·m)</th>
<th>Average Operating Torque (N·m)</th>
<th>Standard Deviation of Operating Torque (N·m)</th>
<th>Moisture Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>81.75 (0.483)</td>
<td>595 (16.725)</td>
<td>155 (4.46)</td>
<td>65 (5.49)</td>
<td>9.90 (0.0172)</td>
</tr>
<tr>
<td>2</td>
<td>79.29 (0.483)</td>
<td>615 (16.725)</td>
<td>145 (4.46)</td>
<td>45 (5.49)</td>
<td>10.25 (0.0172)</td>
</tr>
<tr>
<td>3</td>
<td>79.29 (0.483)</td>
<td>540 (16.725)</td>
<td>150 (4.46)</td>
<td>45 (5.46)</td>
<td>9.98 (0.0172)</td>
</tr>
</tbody>
</table>

Results from the mechanical damage evaluation are shown in Table 3 and Table 4 for each combine harvester unloading auger timing treatment for corn and soybeans, respectively. Data from each replication is shown in appendix C-2.
Table 3. Percentages of corn mechanical damage fractions (severe damage, minor damage and broken corn) from each combine harvester unloading auger system timing treatment. Averaged over the two samples for each rep in each timing treatment.

<table>
<thead>
<tr>
<th>Timing</th>
<th>Severe Damage</th>
<th>Minor Damage</th>
<th>BC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Std. Error</td>
<td>Average</td>
</tr>
<tr>
<td>1*</td>
<td>Pre-Treatment</td>
<td>12.07%</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Post-Treatment</td>
<td>10.59%</td>
<td>1.98</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>0.471%</td>
<td>1.05</td>
</tr>
<tr>
<td>2</td>
<td>Pre-Treatment</td>
<td>12.65%</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>Post-Treatment</td>
<td>12.25%</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>-0.40%</td>
<td>0.91</td>
</tr>
<tr>
<td>3</td>
<td>Pre-Treatment</td>
<td>11.17%</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Post-Treatment</td>
<td>11.75%</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>0.58%</td>
<td>0.91</td>
</tr>
</tbody>
</table>

* data only available for three reps in this treatment

Table 4. Percentage of soybeans (by number) that were damaged but unbroken for each timing. Averaged over the two samples for each rep in each timing treatment.

<table>
<thead>
<tr>
<th>Timing</th>
<th>Damaged but unbroken</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>1</td>
<td>Pre-Treatment</td>
</tr>
<tr>
<td></td>
<td>Post-Treatment</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
</tr>
<tr>
<td>2</td>
<td>Pre-Treatment</td>
</tr>
<tr>
<td></td>
<td>Post-Treatment</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
</tr>
<tr>
<td>3</td>
<td>Pre-Treatment</td>
</tr>
<tr>
<td></td>
<td>Post-Treatment</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
</tr>
</tbody>
</table>

Since this experiment used dried stored grain harvested the previous year, it is conceivable that this factor alone could have influenced any of the response
variables in the experiment. Hall and Johnson (1970) reported that corn below 20 to 24% moisture content will have an increase in damage. Hall (1974) said that soybeans below 13% are brittle and very susceptible to damage. If this is so then running the experiment with dried grains would then only amplify the amount of mechanical damage inflicted, resulting in a better resolution.

There was not a statistical difference in damage to either grain from timing to timing. While it can be criticized that the damage samples were quite small (100 grams) in relation to the amount of grain used for each replication (≈ 100 bushel) the standard errors are small compared to the means.

The statistical analyses showed almost no significant difference in mechanical damage between the pre- and post-treatment samples. The only difference that was significant was that the minor damage portion of the post-treatment samples in corn was less than pre-treatment samples! While the standard errors of the damage are low compared to the means, the amount of damage (means) is high, and the standard errors are about the same size as the differences among treatments. This comparable size of the differences and standard error of mechanical damage limited our ability to detect significant differences in mechanical damage among the unloading auger timing treatments.

The ISO Standard (ISO, 1999) was not followed exactly as it described for taking a flow rate measurement. The combine harvester's grain tank was filled using an auger separate of the combine harvester, not by means of its own loading system. The flow rate was recorded using soybeans and corn instead of wheat. This could be part of the reason why manufacturer's advertised flow rate
were not achieved. Also the unloading auger drive shaft speed did not match the manufacturer's specifications. The standard uses 30 seconds of diverted flow into a collection area for the flow rate calculation, while the time for diverted flow in our test varied between 22-24 seconds.

Mean differences between the three timings were estimated for each response variable, and Fishers protected LSD was used to determine if pairs of timings were significantly different. For each mean comparison an $\alpha = 0.1$ was used. The larger significance level was used due to a rather small sample size, as well as concern about making a Type 2 error (not detecting a difference when there is one).

There were no differences in grain quality between treatments for corn or soybeans. The only significant difference was in the minor damage in corn, after treatment (4.3%) lower than before treatment (5.6%). This should not happen unless the decrease in minor damage is a result of increase in severe or broken, but these parameters showed no significant difference.

From the SAS program output it was determined that there were not significant interactions between timing treatment and grain for maximum startup torque, average operating torque, and flow rate (Appendix D). Interactions were detected between grain and timing treatment with moisture content, number of operating torque values, and standard deviation of operating torques (Table 5).
Table 5. Response variables that showed significant interactions between grain and timing.

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Significant Interaction</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation of Operating Torque</td>
<td>Grain and Timing</td>
<td>0.0539</td>
</tr>
<tr>
<td>Number of Operating Torque Values</td>
<td>Grain and Timing</td>
<td>0.0028</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>Grain and Timing</td>
<td>0.0531</td>
</tr>
</tbody>
</table>

It was determined that the interaction effects for moisture content were not a relevant factor to the analysis since each grain type was stored at a different moisture content. The significant interaction of the number of operating torque values resulted due to several poor sets of data that had to have significant numbers of data points removed from the analysis for timing 3 in soybeans. Since there was also a significant difference between the standard deviation of operating torque for timings 1 and 3 we were somewhat skeptical about reaching a conclusion using the operating torque data for timing 3. However there were no statistical differences between the average operating torques (150 N·m) for any of the timings, and timing 2 for soybeans (similar to timing 3 for soybeans) also had a lower standard deviation of the operating torque (by 18 N·m). This gave us greater confidence that the data for timing 3 still accurately described the operating torque.
In soybeans alone auger timing 3 also had the smallest standard deviation of the operating torque (smallest variation from mean) 20.8 N·m (15.34 ft·lb) or about 30% less than timing 1. At timing 1 the end paddles of the cross augers are pushing grain towards the leading edge of the vertical auger as it pushes the grain up. As the ends of these augers come together, they are pinching the grain between them, possibly causing the higher peak torque at these times, and lower minimum torque at other times. This would result in a high variation in torque, leading to a high standard deviation of the operating torque. The end paddles of the cross augers in timing 3 do not push the bulk amount of grain to the vertical auger until the leading edge of the vertical auger is 90° past the cross auger. This would prevent the augers from pushing against each other as much, thereby reducing the peak torque, but also increasing the minimum torque leading to a lower standard deviation of the operating torque. Table 6 shows estimates of the difference from the statistical analysis.

Table 6. Significant differences that were in the same grain and showed a significant interaction.

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Test of Difference Between</th>
<th>Estimate from Difference of Least Square Means (standard error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation of the Operating Torque (N·m)</td>
<td>Soybeans Timing 1 and Soybeans Timing 2</td>
<td>0.0271</td>
</tr>
<tr>
<td></td>
<td>Soybeans Timing 1 and Soybeans Timing 3</td>
<td>0.0154</td>
</tr>
</tbody>
</table>

Significant differences were found in both grains for the maximum startup torque between timings 1 and 3 and timings 2 and 3. Timings 1 and 2 averaged
10% greater startup torque (615 N·m) than timing 3 (558 N·m). While this is significant it should be noted that maximum startup torque is only one value from each of the four repetitions, not an average. It is also not known how far the grain has moved through the unloading augers when the maximum torque values were recorded. It is possible that each of the three timings would result in the grain being in a different location in the unloading auger when the peak startup torque was recorded.

Roughly 0.5 second passed from the time torque started to increase (shaft starting to rotate) to when peak startup torque was recorded. This would mean the augers rotate about 5 times before peak startup torque is recorded, however this is assuming no slippage on the v-belt pulley or the chain.

Significant differences were found in the unloading auger flow rate between timings 1 and 2 and timings 1 and 3. Although these differences were significant, the estimates of the differences between the least square means were 2.4 L/s (0.068 bu/s) and 2.2L/s (0.063 bu/s) respectively. In other words there was less than a 2.4 L/s (0.068 bu/s) flow rate difference in the timings, or about 3% difference from highest flow rate recorded from timing 1. This led to the determination that auger timing did not have a practically significant effect on flow rate. Shown in table 7 are the estimates of the differences from the statistical analysis.
Table 7. Response variables for which statistical analyses indicated significant differences for both grain types.

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Test of Difference Between</th>
<th>P &gt;</th>
<th>Estimate from Difference of Least Square Means (standard error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Startup Torque (N·m)</td>
<td>Timing 1 and Timing 3</td>
<td>0.0503</td>
<td>60.7750 (28.9692)</td>
</tr>
<tr>
<td></td>
<td>Timing 2 and Timing 3</td>
<td>0.0726</td>
<td>55.2375 (28.9692)</td>
</tr>
<tr>
<td>Flow Rate (L/s)</td>
<td>Timing 1 and Timing 2</td>
<td>0.0140</td>
<td>2.3892 (0.8725)</td>
</tr>
<tr>
<td></td>
<td>Timing 1 and Timing 3</td>
<td>0.0171</td>
<td>2.2165 (0.8383)</td>
</tr>
<tr>
<td>Moisture Content (% w.b.)</td>
<td>Corn and Soybeans</td>
<td>&lt;.0001</td>
<td>2.4500 (0.1409)</td>
</tr>
</tbody>
</table>

Conclusions

There were significant effects of auger timing on grain flow rate, torque and mechanical damage. For both corn and soybeans auger timing 3 (90° out of time) appeared to be the best overall setting. Specific conclusions were:

1. The manufacturer's suggested setting (timing 1) proved to be the best setting for the flow rate, however the difference was less than 2.5 L/s (0.07 bu/s) or about a 3% difference over timing 2 and timing 3.

2. Timings 1 and 2 averaged 10% greater startup torque (615 N·m) than timing 3 (558 N·m).

3. The average operating torque (150 N·m) did not significantly differ among any of the timing and grain combinations.

4. For soybeans timing 3 also had the lowest standard deviation in torque, 20 N·m (about 30%) less than timing 1. It should also be noted that timing 2 had a standard deviation of operating torque that was 18 N·m less than...
40

timing 1. There was no significant difference in the standard deviation of operating torque for corn.

5. There was an interaction of grain type with timing level for standard deviation of operating torque, number of operating torque values and moisture content.

6. We were unable to detect any differences in mechanical damage to corn or soybeans as a result of unloading auger timing.

Recommendations for Further Research

Several areas are suggested for further research. The three timings used in this study were chosen as a place to begin to evaluate the effects of unloading auger timing. Timing 3, with the horizontal cross augers timed 90° behind the vertical auger, seemed to have the best all around performance in this study. It would be interesting to see how the performance of the unloading auger system changes when the cross augers are timed 90° ahead of the vertical auger and 45° before and after the vertical auger. It would also be interesting to have a comparison to this study using grain at harvest level moisture contents.
References

Al-Mosawi, A.A. 1983. Corn kernel damage in harvesting and on farm handling system. Masters Thesis. University of Nebraska Lincoln


Chowdhury, M.H. and W.F. Buchele. 1975. Colorimetric determination of grain damage. ASAE Paper No. 75-1538, ASAE, St. Joseph, MI 49085


Appendix A

Program for the TFX-11 data acquisition computer used for collecting torque data, shaft speed (RPM), and to operate the directional control valve for the grain diverter.

// Program LexnTest.TFB for collection of unloading system torque and speed data using the onset TFX-11 computer.
pclr 0,1,2
pset 3,4,5,6,7,16,17,18,19,20,21,22,23

INIT: INPUT "The year is (20??) "? (5)
INPUT "The month is (1 to 12)" ?(4)
INPUT "The day is (1 to 31)" ?(3)
INPUT "The hour is (0 to 23)" ?(2)
INPUT "The minute is (0 to 59)" ?(1)
STIME //set TFX-11 clock
RTIME //read TFX-11 clock time
PRINT "The current time is ":? (1),":",? (0)," on ":? (4),":",? (3),":",? (5),":".
PRINT INPUT "Is this correct(0) for no, or(1) for yes."A
IF A=0 //go back to get correct date/time if answer is no.
GOTO INIT
ENDIF

PRINT PRINT "Prepare combine and system to start the test."
PRINT "Click button to start the unloading auger and the data collection start switch simultaneously when ready to begin"
PRINT "data collection and take samples."

S1: A1= PIN(1) //check to see if data collection start switch has been clicked.
   IF A1 <>2 // if it hasn't
      GOTO S1 //go back and check again.
   ENDIF //if it has, go on
   RTIME //read start time
   STORE STR("\34,\11,\10","\34,\11,\10")
   RATE 1 //leave timing speed at 100 counts per second.
   SLEEP 0 //start timing
   SLEEP 450 //delay 4.5 seconds
   SLEEP 0
   FOR I=1 to 201 //collect 201 torque values in Nm at 0.01 second intervals
      SLEEP 1
      T! = 0.029524*FLOAT(CHAN(0))-46.6734
      STORE STR(#7.1F,T!,\13,\10) //store startup torque data
   NEXT I
   PRINT T!
Program for the TFX-11 data acquisition computer – continued

F!=0.
TIM=PERIOD (40,40) //measure time to get 40 teeth on drive shaft sprocket (about 0.1s)
IF TIM = 0
GOTO S2
ENDIF
F!= 393216000./FLOAT(TIM) //convert time to shaft speed in rpm.
S2: STORE STR(#8.2F,F!,\13,\10) //store startup speed data
PRINT F!
SLEEP 0 //restart timing
SLEEP 600 //wait 6 seconds for flow to stabilize
PSET 2 //activate relay (solenoid) to extend pneumatic cylinder (start grain collection)
SLEEP 1150 //wait 11.5 seconds
SLEEP 0
FOR I=1 to 101 //collect 101 torque values (in Nm) at 0.01 second intervals
SLEEP 1
T!=0.029524*FLOAT(CHAN(0))-46.6734
STORE STR (#7.1F,T!,\13,\10) //store normal torque data
NEXT I
F!=0.
TIM= PERIOD (400,300) //measure time for 400 teeth on drive shaft sprocket to pass sensor (about 1s)
IF TIM=0
GOTO S3
ENDIF
F!= 3932160000./FLOAT (TIM)
S3: STORE STR(#8.2F,F!,\13,\10)
SLEEP 1150 //wait another 11.5 seconds
PCLR 2 //shut off relay (solenoid) so cylinder retracts
//(ends grain collection of about 30 seconds.)
STOP
Appendix B

The timing and grain treatment combinations were randomized and applied during the experiment in the order shown below.

<table>
<thead>
<tr>
<th>Replication</th>
<th>Grain</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CORN</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>CORN</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>CORN</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>CORN</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>CORN</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>CORN</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>CORN</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>CORN</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>CORN</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>CORN</td>
<td>2</td>
</tr>
<tr>
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</tr>
<tr>
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<td>CORN</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>SOYBEANS</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>SOYBEANS</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>SOYBEANS</td>
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<tr>
<td>2</td>
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<td>2</td>
</tr>
<tr>
<td>4</td>
<td>SOYBEANS</td>
<td>2</td>
</tr>
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</table>
Appendix C-1

Performance data was collected as described in the procedures. The maximum startup torque, average operating torque, standard deviation of the operating torque, number of operating torque values, flow rate, and moisture content for each treatment are given.

<table>
<thead>
<tr>
<th>Rep</th>
<th>Grain</th>
<th>Timing</th>
<th>Max. Startup Torque (N·m)</th>
<th>Avg. Operating Torque (N·m)</th>
<th>Std. Dev. of Operating Torque (N·m)</th>
<th>Flow Rate (L/s)</th>
<th>Moisture Content %</th>
<th>No. Of Operating Torque Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Corn</td>
<td>1</td>
<td>585</td>
<td>145</td>
<td>43</td>
<td>87.4</td>
<td>12.4</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Corn</td>
<td>1</td>
<td>680</td>
<td>130</td>
<td>39</td>
<td>87.6</td>
<td>12.9</td>
<td>98</td>
</tr>
<tr>
<td>3</td>
<td>Corn</td>
<td>1</td>
<td>575</td>
<td>150</td>
<td>45</td>
<td>88.3</td>
<td>12.9</td>
<td>101</td>
</tr>
<tr>
<td>4</td>
<td>Corn</td>
<td>1</td>
<td>735</td>
<td>150</td>
<td>47</td>
<td>93.8</td>
<td>12.2</td>
<td>70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rep</th>
<th>Grain</th>
<th>Timing</th>
<th>Max. Startup Torque (N·m)</th>
<th>Avg. Operating Torque (N·m)</th>
<th>Std. Dev. of Operating Torque (N·m)</th>
<th>Flow Rate (L/s)</th>
<th>Moisture Content %</th>
<th>No. Of Operating Torque Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soybeans</td>
<td>3</td>
<td>550</td>
<td>155</td>
<td>47</td>
<td>77.7</td>
<td>9.8</td>
<td>64</td>
</tr>
<tr>
<td>2</td>
<td>Soybeans</td>
<td>3</td>
<td>485</td>
<td>135</td>
<td>45</td>
<td>77.6</td>
<td>10.2</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>Soybeans</td>
<td>3</td>
<td>570</td>
<td>160</td>
<td>36</td>
<td>80.5</td>
<td>10.1</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>Soybeans</td>
<td>3</td>
<td>550</td>
<td>155</td>
<td>47</td>
<td>81.3</td>
<td>9.8</td>
<td>16</td>
</tr>
</tbody>
</table>
Appendix C-2

Differences in percentages of corn mechanical damage fractions (severe damage, minor damage and broken corn) from each combine harvester unloading auger system timing treatment. Values shown are averages over the two samples for each rep. Calculated by subtracting the pre-treatment damage percentage of from the post-treatment damage percentage.

<table>
<thead>
<tr>
<th>Timing</th>
<th>Rep</th>
<th>Severe Damage</th>
<th>Minor Damage</th>
<th>BC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>-0.31%</td>
<td>-2.30%</td>
<td>0.70%</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1.61%</td>
<td>-1.73%</td>
<td>-0.10%</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>0.11%</td>
<td>-2.42%</td>
<td>-0.05%</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>no data</td>
<td>no data</td>
<td>no data</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>-0.27%</td>
<td>-3.16%</td>
<td>0.14%</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>-0.25%</td>
<td>2.45%</td>
<td>0.19%</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>-0.41%</td>
<td>-0.21%</td>
<td>-0.27%</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>-0.66%</td>
<td>-1.26%</td>
<td>0.19%</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1.07%</td>
<td>0.34%</td>
<td>-0.25%</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>4.35%</td>
<td>-2.20%</td>
<td>-0.05%</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>-2.34%</td>
<td>0.38%</td>
<td>0.20%</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>-0.77%</td>
<td>-2.50%</td>
<td>0.19%</td>
</tr>
</tbody>
</table>

Differences in percentage of soybeans (by number) that were damaged but unbroken for each timing and replication. Values shown are averages over the two samples for each rep. Calculated by subtracting the number of enlarged beans in the pre-treatment sample from the post-treatment sample.

<table>
<thead>
<tr>
<th>Timing</th>
<th>Rep</th>
<th>Damaged but unbroken (# out of 100 whole beans)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
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<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>7.5</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>-6.5</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>-6</td>
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<tr>
<td>3</td>
<td>1</td>
<td>-2.5</td>
</tr>
<tr>
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<td>3.25</td>
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<td>3</td>
<td>2.25</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>-1.5</td>
</tr>
</tbody>
</table>
Appendix D

This appendix includes the glossary of terms, programs and output from the SAS system (The SAS System for Windows, v8.00. SAS Institute Inc. Cary, NC) for each response variable used in the analysis.

Glossary of Terms

Appendix D-1 shows the program used for the comparisons of torque, flow rate and moisture content.

Appendix D-2 shows the output from the comparisons of torque, flow rate and moisture content.

Appendix D-3 shows the program used for the comparisons of mechanical damage with corn.

Appendix D-4 shows the output from the comparisons of mechanical damage with corn.

Appendix D-5 shows the program used for the comparisons of mechanical damage with soybeans.

Appendix D-6 shows the output from the comparison of mechanical damage with soybeans.
Glossary of Terms

Abbreviations were used for the statistical analysis program. The abbreviations, their definitions and the units for the quantities are shown below.

- **maxstart**: Maximum startup torque in N·m
- **avgrun**: Average operating torque in N·m
- **sdrun**: Standard Deviation of operating torque in N·m
- **flow**: Flow rate of the unloading system in bushels per second
- **mc**: Moisture content of the grain in percent wet basis
- **numop**: Number of operating torque values used in the analysis
- **befaft**: Indicates whether the sample was taken from before or after the grain was run through unloading system (1 = before and 2 = after)
- **severe**: Percentage of corn with severe damage
- **minor**: Percentage of corn with minor damage
- **bcfm**: Percentage of corn that was considered as broken
- **damage**: Percentage (number out of 100) of soybeans that were damaged but unbroken
- **timing**: Unloading auger position (1-3)
- **rep**: Replication (1-4)
Appendix D-1

data performance;
  input rep grain $ timing maxstart avgrun sdrun flow mc numop;
datalines;

1  Corn  1  583.5  144.1  43.8  2.480  12.4  100
2  Corn  1  679.4  131.1  39.2  2.487  12.9  98
3  Corn  1  574.5  151.7  45.4  2.505  12.9  101
4  Corn  1  735.1  149.4  46.8  2.661  12.2  70
1  Corn  2  690.2  156.9  44.1  12.3  82
3  Corn  2  559.9  149.2  58.1  2.480  11.5  62
4  Corn  2  593.9  132.5  38.8  2.459  12.1  90
1  Corn  3  608.5  138.0  41.2  2.477  12.9  100
2  Corn  3  584.4  201.0  50.9  2.484  12.4  78
3  Corn  3  620.8  155.1  44.1  2.515  12.9  98
4  Corn  3  497.0  137.5  67.4  2.432  12.6  70

1  Soybeans  1  576.9  159.4  85.5  2.293  9.7  77
2  Soybeans  1  654.3  159.6  80.3  2.323  9.7  88
3  Soybeans  1  598.1  170.2  50.8  2.299  10.2  100
4  Soybeans  1  550.9  141.2  41.4  2.362  10  101
1  Soybeans  2  523.5  146.0  43.4  2.245  10.7  101
2  Soybeans  2  617.0  155.1  44.5  2.271  9.8  88
3  Soybeans  2  659.1  139.2  46.4  2.253  10.3  101
4  Soybeans  2  670.9  139.7  48.9  2.241  10.2  64
1  Soybeans  3  548.0  153.2  46.6  2.205  9.8  64
2  Soybeans  3  484.3  133.8  45.3  2.201  10.2  23
3  Soybeans  3  572.6  161.2  36.4  2.285  10.1  16
4  Soybeans  3  550.9  156.9  46.5  2.308  9.8  16

proc print data=performance;
run;

proc mixed data=performance;
  class grain timing;
  model maxstart=grain timing grain*timing;
  lsmeans grain timing/diff;
run;

proc mixed data=performance;
  class grain timing;
  model avgrun=grain timing grain*timing;
  lsmeans grain timing/diff;
run;
SAS program – continued

proc mixed data=performance;
   class grain timing;
   model sdrun=grain timing grain*timing;
   lsmeans grain*timing/diff;
run;

proc mixed data=performance;
   class grain timing;
   model flow=grain timing grain*timing;
   lsmeans grain timing/diff;
run;

proc mixed data=performance;
   class grain timing;
   model mc=grain timing grain*timing;
   lsmeans grain*timing/diff;
run;

proc mixed data=performance;
   class grain timing;
   model numop=grain timing grain*timing;
   lsmeans grain*timing/diff;
run;
Appendix D-2

The Mixed Procedure

Model Information

Data Set WORK.PERFORMANCE
Dependent Variable maxstart
Covariance Structure Diagonal
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Residual

Class Level Information

Class Levels Values
grain 2 Corn Soybeans
timing 3 1 2 3

Dimensions

Covariance Parameters 1
Columns in X 12
Columns in Z 0
Subjects 1
Max Obs Per Subject 24
Observations Used 24
Observations Not Used 0
Total Observations 24

Covariance Parameter Estimates

Cov Parm Estimate
Residual 3356.85

Fit Statistics

-2 Res Log Likelihood 205.5
AIC (smaller is better) 207.5
AICC (smaller is better) 207.8
BIC (smaller is better) 208.4

The Mixed Procedure

Type 3 Tests of Fixed Effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Num</th>
<th>Den</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>grain</td>
<td>1</td>
<td>18</td>
<td>1.23</td>
<td>0.2823</td>
</tr>
<tr>
<td>timing</td>
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<td>18</td>
<td>2.69</td>
<td>0.0949</td>
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<td>grain•timing</td>
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Least Squares Means

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<th>Effect</th>
<th>grain</th>
<th>timing</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>DF</th>
<th>t Value</th>
<th>Pr &gt;</th>
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<td>16.7254</td>
<td>18</td>
<td>34.91</td>
<td>&lt;.0001</td>
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<td>30.22</td>
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<tr>
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<td>20.4843</td>
<td>18</td>
<td>29.95</td>
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<td></td>
<td>558.31</td>
<td>20.4843</td>
<td>18</td>
<td>27.26</td>
<td>&lt;.0001</td>
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The SAS System 14:02 Friday, October 4, 2002
Differences of Least Squares Means

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<th>Timing</th>
<th>_Grain</th>
<th>_Timing</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>DF</th>
<th>t Value</th>
<th>Pr &gt;</th>
<th>t</th>
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</thead>
<tbody>
<tr>
<td>Grain</td>
<td>Corn</td>
<td>Soybeans</td>
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<td>26.2167</td>
<td>23.6532</td>
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<td>3</td>
<td></td>
<td></td>
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<td>28.9692</td>
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<td>0.0503</td>
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<tr>
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<td>3</td>
<td></td>
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<td>28.9692</td>
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</table>
The SAS System 14:02 Friday, October 4, 2002 10

The Mixed Procedure

Model Information

Data Set WORK.PERFORMANCE
Dependent Variable avgrun
Covariance Structure Diagonal
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Residual

Class Level Information

Class Levels Values
grain 2 Corn Soybeans
timing 3 1 2 3

Dimensions

Covariance Parameters 1
Columns in X 12
Columns in Z 0
Subjects 1
Max Obs Per Subject 24
Observations Used 24
Observations Not Used 0
Total Observations 24

Covariance Parameter Estimates

Cov Parm Estimate
Residual 238.76

Fit Statistics

-2 Res Log Likelihood 158.0
AIC (smaller is better) 160.0
AICC (smaller is better) 160.2
BIC (smaller is better) 160.8

Type 3 Tests of Fixed Effects

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<th>Den DF</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
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<td>18</td>
<td>0.06</td>
<td>0.8117</td>
</tr>
<tr>
<td>timing</td>
<td>2</td>
<td>18</td>
<td>0.60</td>
<td>0.5610</td>
</tr>
<tr>
<td>grain*timing</td>
<td>2</td>
<td>18</td>
<td>0.94</td>
<td>0.4077</td>
</tr>
</tbody>
</table>
### Least Squares Means

| Effect | grain   | timing | Estimate | Standard Error | DF  | t Value | Pr > |t| |
|--------|---------|--------|----------|----------------|-----|---------|------|---|
| grain  | Corn    |        | 149.77   | 4.4606         | 18  | 33.58   | <.0001|   |
| grain  | Soybeans|        | 151.29   | 4.4606         | 18  | 33.92   | <.0001|   |
| timing | 1       |        | 150.84   | 5.4631         | 18  | 27.61   | <.0001|   |
| timing | 2       |        | 146.16   | 5.4631         | 18  | 26.75   | <.0001|   |
| timing | 3       |        | 154.59   | 5.4631         | 18  | 28.30   | <.0001|   |

### Differences of Least Squares Means

| Effect | grain   | timing | _grain | _timing | Estimate | Standard Error | DF  | t Value | Pr > |t| |
|--------|---------|--------|--------|---------|----------|----------------|-----|---------|------|---|
| grain  | Corn    | Soybeans| _grain | _timing | -1.5250  | 6.3083         | 18  | -0.24   | 0.8117|   |
| timing | 1       | 2      |        |         | 4.6750   | 7.7260         | 18  | 0.61    | 0.5527|   |
| timing | 1       | 3      |        |         | -3.7500  | 7.7260         | 18  | -0.49   | 0.6333|   |
| timing | 2       | 3      |        |         | -8.4250  | 7.7260         | 18  | -1.09   | 0.2899|   |
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The Mixed Procedure

Model Information

Data Set WORK.PERFORMANCE
Dependent Variable sdrun
Covariance Structure Diagonal
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Residual

Class Level Information

Class Levels Values
grain 2 Corn Soybeans
timing 3 1 2 3

Dimensions

Covariance Parameters 1
Columns in X 12
Columns in Z 0
Subjects 1
Max Obs Per Subject 24
Observations Used 24
Observations Not Used 0
Total Observations 24

Covariance Parameter Estimates

Cov Parm Estimate
Residual 120.75

Fit Statistics

-2 Res Log Likelihood 145.7
AIC (smaller is better) 147.7
AICC (smaller is better) 147.9
BIC (smaller is better) 148.6

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The Mixed Procedure

Type 3 Tests of Fixed Effects

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<td>18</td>
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Least Squares Means

| Effect | grain | timing | Estimate | Standard Error | DF | t Value | Pr > |t| |
|--------|-------|--------|----------|----------------|----|---------|------|---|
| grain  | Corn  |        | 46.7250  | 3.1722         | 18 | 14.73   | <.0001|
| grain  | Soybeans |     | 51.3333  | 3.1722         | 18 | 16.18   | <.0001|
| timing | 1     |        | 54.1500  | 3.8851         | 18 | 13.94   | <.0001|
| timing | 2     |        | 45.6175  | 3.8851         | 18 | 11.75   | <.0001|
| timing | 3     |        | 47.3000  | 3.8851         | 18 | 12.17   | <.0001|
SAS output – continued

Differences of Least Squares Means

| Effect | grain | timing | _grain | _timing | Estimate | Standard Error | DF | t Value | Pr > |t| |
|--------|-------|--------|--------|---------|----------|----------------|----|---------|------|---|
| grain  | Corn  | Soybeans | _grain | _timing | -4.6081 | 4.4861          | 18 | -1.03   | 0.3179 |
| timing | 1     | 2      | 8.5125 | 5.4944  | 1.55    | 0.1387         |    | 1.25   | 0.2285 |
| timing | 2     | 3      | 6.8500 | 5.4944  | 1.25    | 0.2285         |    | -0.30  | 0.7657 |
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The Mixed Procedure

Model Information

Data Set WORK.PERFORMANCE
Dependent Variable flow
Covariance Structure Diagonal
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Residual

Class Level Information

Class Levels Values
grain 2 Corn Soybeans
timing 3 1 2 3

Dimensions

Covariance Parameters 1
Columns in X 12
Columns in Z 0
Subjects 1
Max Obs Per Subject 24
Observations Used 23
Observations Not Used 1
Total Observations 24

Covariance Parameter Estimates

Cov Parm Estimate
Residual 0.002263

Fit Statistics

-2 Res Log Likelihood -47.3
AIC (smaller is better) -45.3
AICC (smaller is better) -45.0
BIC (smaller is better) -44.4

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The Mixed Procedure

Type 3 Tests of Fixed Effects

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<th>Pr &gt; F</th>
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grain     | 1      | 17     | 119.02  | <.0001 |
timing    | 2      | 17     | 4.90    | 0.0209 |
grain*timing | 2  | 17     | 0.06    | 0.9426 |

Least Squares Means

| Effect   | grain | timing | Estimate | Standard Error | DF  | t Value | Pr > |t|
|----------|-------|--------|----------|----------------|-----|---------|------|
grain     | Corn  |        | 2.4915   | 0.01448        | 17  | 172.11  | <.0001 |
grain     | Soybeans |    | 2.2738   | 0.01373        | 17  | 165.56  | <.0001 |
timing    | 1     |        | 2.4263   | 0.01682        | 17  | 144.24  | <.0001 |
timing    | 2     |        | 2.3584   | 0.01817        | 17  | 129.81  | <.0001 |
timing    | 3     |        | 2.3634   | 0.01682        | 17  | 140.51  | <.0001 |
### Differences of Least Squares Means

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The Mixed Procedure

Model Information

Data Set WORK.PERFORMANCE
Dependent Variable mc
Covariance Structure Diagonal
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Residual

Class Level Information

Class Levels Values
grain 2 Corn Soybeans
timing 3 1 2 3

Dimensions

Covariance Parameters 1
Columns in X 12
Columns in Z 0
Subjects 1
Max Obs Per Subject 24
Observations Used 24
Observations Not Used 0
Total Observations 24

Covariance Parameter Estimates

Cov Parm Estimate
Residual 0.1192

Fit Statistics

-2 Res Log Likelihood 21.1
AIC (smaller is better) 23.1
AICC (smaller is better) 23.4
BIC (smaller is better) 24.0

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The Mixed Procedure

Type 3 Tests of Fixed Effects

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Least Squares Means

| Effect | Grain | Timing | Estimate | Standard Error | DF | t Value | Pr > |t| |
|--------|-------|--------|----------|----------------|----|---------|------|---|
| grain  | Corn  |        | 12.4917  | 0.09965       | 18 | 125.35  | <.0001|
| grain  | Soybeans | | 10.0417  | 0.09965     | 18 | 100.77  | <.0001|
| timing |       | 1      | 11.2500  | 0.1220        | 18 | 92.18   | <.0001|
| timing |       | 2      | 11.2125  | 0.1220        | 18 | 91.87   | <.0001|
| timing |       | 3      | 11.3175  | 0.1220        | 18 | 92.89   | <.0001|
### Differences of Least Squares Means

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The Mixed Procedure

Model Information

Data Set
Dependent Variable
Covariance Structure
Estimation Method
Residual Variance Method
Fixed Effects SE Method
Degrees of Freedom Method
WORK.PERFORMANCE
numop
Diagonal
REML
Profile
Model-Based
Residual

Class Level Information

Class Levels Values
grain 2 Corn Soybeans
timing 3 1 2 3

Dimensions

Covariance Parameters
Columns in X
Columns in Z
Subjects
Max Obs Per Subject
Observations Used
Observations Not Used
Total Observations
12
0
1
24
24
0
24

Covariance Parameter Estimates

Cov Parm  Estimate
Residual  279.51

Fit Statistics

-2 Res Log Likelihood  160.8
AIC (smaller is better)  162.8
AICC (smaller is better)  163.0
BIC (smaller is better)  163.7

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The Mixed Procedure

Type 3 Tests of Fixed Effects

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Least Squares Means

| Effect    | grain| timing | Estimate | Standard Error | DF | t Value | Pr > |t| |
|-----------|------|--------|----------|----------------|----|---------|------|---|
| grain     | Corn |        | 87.5000  | 4.8263         | 18 | 18.13   | .0001|
| grain     | Soybeans |    | 69.9167  | 4.8263         | 18 | 14.49   | .0001|
| timing    | 1    |        | 91.8750  | 5.9109         | 18 | 15.94   | .0001|
| timing    | 2    |        | 86.1250  | 5.9109         | 18 | 14.57   | .0001|
| timing    | 3    |        | 58.1250  | 5.9109         | 18 | 9.83    | .0001|
Differences of Least Squares Means

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The Mixed Procedure

Model Information

Data Set WORK.PERFORMANCE
Dependent Variable sdrun
Covariance Structure Diagonal
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Residual

Class Level Information

Class Levels Values
grain 2 Corn Soybeans
timing 3 1 2 3

Dimensions

Covariance Parameters 1
Columns in X 12
Columns in Z 0
Subjects 1
Max Obs Per Subject 24
Observations Used 24
Observations Not Used 0
Total Observations 24

Covariance Parameter Estimates

Cov Parm Estimate
Residual 120.75

Fit Statistics

-2 Res Log Likelihood 145.7
AIC (smaller is better) 147.7
AICC (smaller is better) 147.9
BIC (smaller is better) 148.6

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The Mixed Procedure

Type 3 Tests of Fixed Effects

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Least Squares Means

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The SAS System 14:02 Friday, October 4, 2002 22

The Mixed Procedure

Model Information

Data Set WORK.PERFORMANCE
Dependent Variable me
Covariance Structure Diagonal
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Residual

Class Level Information

Class Levels Values
grain 2 Corn Soybeans
timing 3 1 2 3

Dimensions

Covariance Parameters 1
Columns in X 12
Columns in Z 0
Subjects 1
Max Obs Per Subject 24
Observations Used 24
Observations Not Used 0
Total Observations 24

Covariance Parameter Estimates

Cov Parm Estimate
Residual 0.1192

Fit Statistics

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AICC (smaller is better) 23.4
BIC (smaller is better) 24.0

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The Mixed Procedure

Type 3 Tests of Fixed Effects

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Least Squares Means

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| grain*timing | Corn 1 | 12.4000 | 0.1726 | 18 | 73.00 | <.0001 |
| grain*timing | Corn 2 | 12.1750 | 0.1726 | 18 | 70.54 | <.0001 |
| grain*timing | Corn 3 | 12.7000 | 0.1726 | 18 | 73.58 | <.0001 |
| grain*timing | Soybeans 1 | 9.9000 | 0.1726 | 18 | 57.36 | <.0001 |
| grain*timing | Soybeans 2 | 10.2500 | 0.1726 | 18 | 59.38 | <.0001 |
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### Differences of Least Squares Means

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The SAS System  14:02 Friday, October 4, 2002  24

The Mixed Procedure

Model Information

Data Set WORK.PERFORMANCE
Dependent Variable numop
Covariance Structure Diagonal
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Residual

Class Level Information

Class Levels Values
grain 2 Corn Soybeans
timing 3 1 2 3

Dimensions

Covariance Parameters 1
Columns in X 12
Columns in Z 0
Subjects 1
Max Obs Per Subject 24
Observations Used 24
Observations Not Used 0
Total Observations 24

Covariance Parameter Estimates

Cov Parm Estimate
Residual 279.51

Fit Statistics

-2 Res Log Likelihood 160.8
AIC (smaller is better) 162.8
AICC (smaller is better) 163.0
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The Mixed Procedure

Type 3 Tests of Fixed Effects

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Appendix D-3

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1 1 2 13.514 5.692 .698
1 2 1 10.358 7.592 .099
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2 4 1 12.891 3.349 .4
2 4 2 12.213 2.093 .586
3 1 1 10.623 4.721 .249
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3 4 2 10.439 2.606 .469
;
proc mixed data=corndamage;
class timing rep befaft;
model severe= timing befaft timing*befaft/ddfm=satterth;
random rep(timing);
run;

proc mixed data=corndamage;
class timing rep befaft;
model minor= timing befaft timing*befaft/ddfm=satterth;
random rep(timing);
lsmeans timing befaft/diff;
run;

proc mixed data=corndamage;
class timing rep befaft;
model bcfm= timing befaft timing*befaft/ddfm=satterth;
random rep(timing);
run;
Appendix D-4

The Mixed Procedure

Model Information

Data Set WORK.CORNDAMAGE
Dependent Variable severe
Covariance Structure Variance Components
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Satterthwaite

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</tr>
<tr>
<td>3</td>
<td>1</td>
<td>82.77528638</td>
<td>0.00019165</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>82.77013437</td>
<td>0.00000000</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>82.77011103</td>
<td>0.00000000</td>
</tr>
</tbody>
</table>

Convergence criteria met.
SAS output - continued

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The Mixed Procedure

Covariance Parameter Estimates

<table>
<thead>
<tr>
<th>Cov Parm</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>rep(timing)</td>
<td>4.8233</td>
</tr>
<tr>
<td>Residual</td>
<td>1.8773</td>
</tr>
</tbody>
</table>

Fit Statistics

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-2 Res Log Likelihood</td>
<td>82.8</td>
</tr>
<tr>
<td>AIC (smaller is better)</td>
<td>86.8</td>
</tr>
<tr>
<td>AICC (smaller is better)</td>
<td>87.6</td>
</tr>
<tr>
<td>BIC (smaller is better)</td>
<td>87.7</td>
</tr>
</tbody>
</table>

Type 3 Tests of Fixed Effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Num DF</th>
<th>Den DF</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>timing</td>
<td>2</td>
<td>7.2</td>
<td>0.57</td>
<td>0.5885</td>
</tr>
<tr>
<td>befaft</td>
<td>1</td>
<td>6.48</td>
<td>0.00</td>
<td>0.9560</td>
</tr>
<tr>
<td>timing*befaft</td>
<td>2</td>
<td>6.46</td>
<td>0.26</td>
<td>0.7762</td>
</tr>
</tbody>
</table>
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The Mixed Procedure

Model Information

Data Set WORK.CORNDAMAGE
Dependent Variable minor
Covariance Structure Variance Components
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Satterthwaite

Class Level Information

Class Levels Values

timing 3 1 2 3
rep 4 1 2 3 4
befaft 2 1 2

Dimensions

Covariance Parameters 2
Columns in X 12
Columns in Z 12
Subjects 1
Max Obs Per Subject 24
Observations Used 23
Observations Not Used 1
Total Observations 24

Iteration History

Iteration Evaluations -2 Res Log Like Criterion
0 1 86.64089576
1 2 80.08214858 0.00000002
2 1 80.08214798 0.00000000

Convergence criteria met.
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The Mixed Procedure

Covariance Parameter Estimates

Cov Parm    Estimate
rep(timing)  4.4472
Residual     1.5082

Fit Statistics

-2 Res Log Likelihood  80.1
AIC (smaller is better)  84.1
AICC (smaller is better) 84.9
BIC (smaller is better)  85.1

Type 3 Tests of Fixed Effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Num DF</th>
<th>Den DF</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>timing</td>
<td>2</td>
<td>8.99</td>
<td>0.99</td>
<td>0.9143</td>
</tr>
<tr>
<td>befaft</td>
<td>1</td>
<td>8.21</td>
<td>6.00</td>
<td>0.0392</td>
</tr>
<tr>
<td>timing*befaft</td>
<td>2</td>
<td>8.2</td>
<td>0.96</td>
<td>0.4224</td>
</tr>
</tbody>
</table>

Least Squares Means

| Effect    | timing | befaft | Estimate | Standard Error | DF  | t Value | Pr > |t| |
|------------|--------|--------|----------|----------------|-----|---------|-------|
| timing     | 1      |        | 5.1950   | 1.1641         | 9.42| 4.46    | 0.0014|
|            | 2      |        | 5.1324   | 1.1403         | 8.77| 4.50    | 0.0016|
|            | 3      |        | 5.5694   | 1.1403         | 8.77| 4.01    | 0.0012|
| befaft     | 1      |        | 5.6087   | 0.7216         | 12.1| 7.77    | <.0001|
|            | 2      |        | 4.3224   | 0.7045         | 11.3| 6.14    | <.0001|

Differences of Least Squares Means

| Effect    | timing | befaft | _timing | _befaft | Estimate | Standard Error | DF  | t Value | Pr > |t| |
|------------|--------|--------|---------|---------|----------|----------------|-----|---------|-------|
| timing     | 1      | 2      | 0.06259 | 1.6296  | 9.1      | 0.04           | 0.9702|
|            | 1      | 3      | 0.6256  | 1.6296  | 9.1      | 0.38           | 0.7099|
|            | 2      | 3      | 0.5630  | 1.6127  | 8.77     | 0.35           | 0.7352|
| befaft     | 1      | 2      | 1.2863  | 0.5251  | 8.21     | 2.45           | 0.0392|
The Mixed Procedure

Model Information

Data Set WORK.CORN DAMAGE
Dependent Variable bcfm
Covariance Structure Variance Components
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Satterthwaite

Class Level Information

Class Levels Values
timing 3 1 2 3
rep 4 1 2 3 4
befaft 2 1 2

Dimensions

Covariance Parameters 2
Columns in X 12
Columns in Z 12
Subjects 1
Max Obs Per Subject 24
Observations Used 23
Observations Not Used 1
Total Observations 24

Iteration History

Iteration Evaluations -2 Res Log Like Criterion
0 1 42.55375155
1 3 28.78806307 0.43649505
2 2 28.62317353 0.09456034
3 1 28.47920409 0.00815660
4 1 28.46721858 0.00008495
5 1 28.46709979 0.00000001
6 1 28.46709978 0.00000000

Convergence criteria met.
SAS output - continued

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The Mixed Procedure

Covariance Parameter Estimates

<table>
<thead>
<tr>
<th>Cov Parm</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>rep(timing)</td>
<td>0.3842</td>
</tr>
<tr>
<td>Residual</td>
<td>0.04244</td>
</tr>
</tbody>
</table>

Fit Statistics

-2 Res Log Likelihood 28.5
AIC (smaller is better) 32.5
AICC (smaller is better) 33.3
BIC (smaller is better) 33.4

Type 3 Tests of Fixed Effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Num DF</th>
<th>Den DF</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>timing</td>
<td>2</td>
<td>9.09</td>
<td>1.74</td>
<td>0.2292</td>
</tr>
<tr>
<td>befaft</td>
<td>1</td>
<td>8.17</td>
<td>0.99</td>
<td>0.3489</td>
</tr>
<tr>
<td>timing*befaft</td>
<td>2</td>
<td>8.16</td>
<td>0.26</td>
<td>0.7743</td>
</tr>
</tbody>
</table>
Appendix D-5

data soydamage;
  input timing rep befaft damage;
datalines;
1  1  1  16.75
1  1  2  17.0
1  2  1  19.75
1  2  2  20.75
1  3  1  21.75
1  3  2  21.75
1  4  1  20.75
1  4  2  20.0
2  1  1  19.25
2  1  2  19.5
2  2  1  16.75
2  2  2  24.25
2  3  1  23.5
2  3  2  17.0
2  4  1  25.0
2  4  2  19.0
3  1  1  22.25
3  1  2  19.75
3  2  1  15.75
3  2  2  19.0
3  3  1  15.75
3  3  2  18.0
3  4  1  18.75
3  4  2  17.25
;

proc mixed data=soydamage;
  class timing befaft;
  model damage=timing befaft timing*befaft/ddf=satterth;
  random rep(timing);
  lsmeans timing befaft;
run;
Appendix D-6

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The Mixed Procedure

Model Information

Data Set WORK.SOYDAMAGE
Dependent Variable damage
Covariance Structure Variance Components
Estimation Method REML
Residual Variance Method Profile
Fixed Effects SE Method Model-Based
Degrees of Freedom Method Satterthwaite

Class Level Information

Class Levels Values
timing 3 1 2 3
befaft 2 1 2

Dimensions
Covariance Parameters 2
Columns in X 12
Columns in Z 3
Subjects 1
Max Obs Per Subject 24
Observations Used 22
Observations Not Used 2
Total Observations 24

Iteration History

Iteration Evaluations -2 Res Log Like Criterion
0 1 80.38361296
1 3 80.37111051 0.00000109
2 1 80.37108264 0.00000000

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm Estimate
timing*v 0.05677
Residual 5.3994

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The Mixed Procedure

Fit Statistics

-2 Res Log Likelihood 80.4
AIC (smaller is better) 84.4
AICC (smaller is better) 85.3
BIC (smaller is better) 82.6

Type 3 Tests of Fixed Effects

Effect Num DF Den DF F Value Pr > F
timing 2 1 1.26 0.5329
befaft 1 14.5 0.43 0.5215
timing•befaft 2 14.5 0.29 0.7547
### Least Squares Means

| Effect | timing | befaft | Estimate | Standard Error | DF | t Value | Pr > |t| |
|--------|--------|--------|----------|----------------|----|---------|-------|---|
| timing | 1      |        | 19.5271  | 0.9980        | 1  | 19.57   | 0.0325 |
| timing | 2      |        | 19.8882  | 1.0272        | 1  | 19.36   | 0.0329 |
| timing | 3      |        | 17.6587  | 1.0896        | 1  | 16.21   | 0.0392 |
| befaft | 1      |        | 18.6957  | 0.8136        | 1.04| 22.98   | 0.0250 |
| befaft | 2      |        | 19.3536  | 0.7477        | 1  | 25.88   | 0.0246 |