Production Scale Single-pass Corn Stover Large Square Baling Systems

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Abstract
A single-pass combine baler was operated in Central Iowa for the harvest of 2012 in a production scale setting. The combine’s performance was monitored with a telemetry data logger. The combine was able to harvest 2227 bushels (62.4 tons) of grain per hour on average and 18.8 tons of stover per hour on average. A complete quality analysis system was evaluated for the single-pass combine through the harvest of 2012. On board baler scales were tested showing a less than 1% difference in average weight between calibrated platform scales and the baler scales. Also, a microwave moisture meter was evaluated on a separate baler which showed between the 10% and 29% moisture level an $R^2$ value of 87%.

Keywords
Corn Stover, Single-pass baling, Microwave moisture sensing, baler scales, Gazeeka

Disciplines
Agriculture | Bioresource and Agricultural Engineering

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Introduction

There has been much research into the productivity and throughput of a single-pass baling combine as the cellulosic ethanol supply chain has been researched and developed. There are two options for baling behind a combine round and square bales. The most commercially ready option currently is the AGCO Challenger Single-pass baler and combine. The first units that were supplied to a custom harvester have allowed for new research to take place, looking at performance of the combine in a completely commercial setting (Jensen 2011). At Iowa State University Webster (2010) (2012) and at University of Wisconsin Shinners (2012) (2009) have analyzed the productivity and performance of a single-pass combine compared to a conventional combine in both fuel and harvested throughput. This has been looked at for a forage type system with blower and spout and for a baler. Currently, there are commercially produced single-pass square baler and combines in use. A prototype single-pass round baler is also being tested (Keene, et al. 2013).

There has been very little research on what the complete system would look like from a quality analysis standpoint. The advantage of single-pass is that the ash content of the corn stover or feedstock is known; typically 3-5% depending on the timing of harvest and weather conditions. What is not known and can play a major factor in the storability of the bales is moisture content. To ensure the proper density of the bale is being achieved, the overall bale weight is also needed. Baler scales have been available in the market place for some time. The individual developing companies have tested these scales for development and accuracy, though most of the test results have not been publicly available.

The current state of the art for rapid moisture analysis is to use an electro conductivity probe, which in corn stover has been not very reliable or accurate. The best practice currently for moisture analysis has been to take a core sample and oven dry the sample which extends the time period for returning the data to the producer over 24 to 36 hours. At Iowa State University research has shown that to get the metrics of ash and moisture this is the least expensive and easiest method. There are currently two companies that are producing a baler microwave moisture tester: DSE test solutions (2013) and Vomax Industries (2013). Each company has claimed to show fair accuracy of the meter, independently testing them by sending samples to outside laboratories. An analysis has not been thoroughly conducted by any independent research and made publicly available. Digman and Shinners looked at the feasibility of the Vomax Gazeeka moisture meter for forages but did not test the sensor and was dismissed in the research conducted because it didn’t provide enough information for the focus area of the research (2013).

Materials and Methods

Data Logging

The moisture meter, scales, and combine/baler were all logged using the CyCAN data logger from Iowa State University. The data logger recorded both CAN bus and serial data. Over the CAN bus the logger was able to record the baler scale message through the Challenger baler virtual terminal. This message was updated each time a bale dropped from the tail board of the baler. Along with the scale weight message, the virtual terminal message was logged to capture failure event messages and other pertinent information from the baler.

In addition to the data captured by the CAN channel on the data logger, two separate serial channels on the logger were used to capture data from a GPS hockey puck antenna and from the Gazeeka moisture meter. The GPS was communicated over a RS 232 connection and was filtered for specific messages in the NMEA string. The Gazeeka moisture meter was also connected via RS 232 port through a special port installed in the monitor of the display. A message from the Gazeeka meter was broadcasted every time the bale incrementally moved forward past the sensor.

Equipment

An AGCO Challenger Single-pass combine and baler (Figure 1) were used for the testing in the fall of 2012. The combine and baler were from the Feedstox custom harvesting company. The combine was outfitted with a prototype high take rate corn header from AGCO Corporation. The baler was a Challenger LB34 single-pass baler was outfitted with on-board scales which were connected to the baler bus. The baler was powered hydraulically by the combine. This was different from past years in which the baler was power by an engine separate of the combine. The baler ISOBUS connected into the combine ISOBUS which allowed the baler to be controlled from the cab of the combine.
Scale calibration occurred at the Feedstox facility prior to delivery of the combine and baler to central Iowa. The calibration procedure was completed using the virtual terminal in the combine. By accessing the scale control screen in the baler controller, a live weight read out was displayed. When a known weight was placed on the baler tailboard the difference in the weight was noted. The known weight was then entered into the baler scale control screen and an automatic offset was calculated by the controller.

The Gazeeka moisture meter was installed on a separate baler, in Figure 2, in order to capture a comprehensive comparative dataset taken via core samples. The moisture meter was attached to the rear of an LB34 XD Challenger baler. A serial cable was attached to the display screen of the moisture meter by Vomax Instrumentation and then connected by serial cable into the CyCAN logger.

A moisture meter is able to be universally installed to any baler using the generic brackets and instructions provided with the unit. Calibrations to the moisture meter occurred at the beginning of the season after installation of the unit on the baler. The calibration was completed using a test material that produced a stable and known moisture. The Gazeeka meter came with the following selectable calibration curves: grass hay, cereal hay, oat mix, legume hay, and general. The general calibration was selected as corn stover had not been tested prior to fall of 2012 and no known curve was available.

Figure 1: Feedstox Harvesting team's single-pass combine and baler.
To check the weight and take core samples from individual bales using two different systems. To check the baler scales a commercially institutionalized system was used as shown in Figure 4. The single-pass bales were weighed in the DuPont harvest system using a telehandler and platform scale on a trailer. At each field the platform scale was calibrated by taking a known weight, carried on the trailer from field to field, and testing the scale for accuracy. Once the scale was calibrated then the bales were removed from the stack and nine bales from each stack were weighed and core sampled in order to determine the wet and dry weights (Figures 4 and 5).
recalibrated with a 1000 lb calibration weight and from the stack 12 bales were removed and weighed and cored for ash and moisture content. For testing the Gazeeka moisture meter a tractor mounted in-field 3 pt corer was used.

The in-field unit (Figure 3) worked closely with an experimental team that encountered highly variable conditions to fully test the moisture meter. In these tests a higher concentration of bales were sampled within a field versus the commercial sampled fields. This also allowed for a point-by-point comparison of the bales from the moisture meter to the core sample. A GPS tag was assigned to each individual bale that could then be tracked back to the location of the bale in the field and then compared to the points that the moisture meter produced from the analysis.

Figure 3: A tractor outfitted with a three point coring rig. The tractor above is beginning to weigh a bale and will then use the corer (extended up) to take a sample of the bale.
Core samples taken from bales were put into aluminum foil pans and sealed until the conclusion of the work day. The samples were then transported back to the BioCentury Research Farm and stored in a walk-in cooler until space was available to dry the samples. Samples were then weighed in prior to being put into the drying oven. The drying oven was set to a temperature of 95 degrees Celsius with an overall drying time of 24 hours.

Research Ground

Through a cooperative agreement with DuPont Cellulosic Ethanol, nine growers in a 30 mile radius around the Nevada, IA plant were selected to have the single-pass combine on their farms. Growers were responsible for hauling grain away from the field. Along with the combine and baler, two grain carts and tractors and one stacker were made available to move corn away from the combine and stack bales at the road edge. Bales stacked at the field edge were removed at a later date and entered into the DuPont storage system.
Data Processing

Single-pass Baling

The data collected from the single-pass combine and baler on the data loggers was collected periodically from the data cards over the harvest season. The data collected included the combine performance data and scale data read from CAN messages on the combine. The data from the Gazeeka moisture meter was logged to the data card over the serial connection to the logger. This data was in a data string format.

To convert the data into specific engineering units a lookup table was created using a mixture of publicly and privately available CAN PGN’s and serial messages. The files containing these messages were batch converted into files containing engineering units, GPS location, and time stamp. These files were also converted into comma separated value (.csv) files. The data within these files was then uploaded to SMS Advanced for further processing.

Baler Scales

Data from the baler scales was collected using the CyCAN data loggers. This data was processed similarly to the performance data of the combine discussed previously. The message was decoded from the CAN message string and a complete dataset of bale weights from the baler scales was completed. This was then compared to the known weights of the bales sampled in each field for the quality analysis performed on a commercial basis. These were listed in a database containing all quality data including moisture and ash content of each individual bale weighed.

The weights of the individually weighed bales and the weights of the known bales were compared using Minitab statistical program. Due to the smaller sample size of the individually weighed bales an average weight was only calculated. The larger sample size of the scales on the baler allowed for a histogram to be created which showed if there was a large amount of variation and outliers in the scale weights. There was no method, however, to individually connect the truck scale weights to the baler scale weights.
The data collected from the Gazeeka moisture meter was loaded into the SMS Advanced program. The lab data for each individual bale was also loaded into the same profile as shown in Figure 6. To compare the two methods of moisture detection, the lab results were overlaid on a map showing the display point values of the Gazeeka meter. The lab results were treated as the gold standard for the moisture. The Gazeeka moisture values were then averaged on a per bale basis as the sensor logged a reading every time motion was detected in front of the sensor. To determine the average of the 5-10 sample points in each bale, the points were queried in SMS Advanced which produced average moisture as shown in Figure 7. The average and the lab data were then recorded in an Excel spreadsheet and transferred to the Minitab Statistical program which analyzed the dataset.
Results

Single-pass Baling

In the seven fields analyzed in the commercial scale harvest, three of the seven fields analyzed were at or above the average throughput of a conventional AGCO combine tested in the 2011 harvest, which was 85 tons of material per hour. This mainly consisted of grain with a small amount of stover which was mainly cob and husks. The increase in productivity was attributed to the improvements in the current combine learned from previous harvesting and from improvements in the design of the high take rate corn head that allowed for higher flow rate of crop into the combine. Two of the remaining four fields were within 10% of throughput of the combine from 2011 which further strengthens the argument that a stepwise improvement in the combine and corn head improved the throughput. The two remaining fields that were analyzed were both affected by the drought in Central Iowa in the summer of 2011 and had been knocked down by wind over the growing season. In both situations the challenges with picking up the downed corn would have affected any combine that was harvesting the corn. The other challenge with measuring combine throughput solely on productivity was that if there wasn’t enough grain or stover in the field it would become mechanically impossible to travel fast enough and harvest the grain.
Three fields were compared for differences in the weights between the scales on the trailers versus the scales on the balers. The data from the baler scales was laid out in a histogram, Figure 9. Shown in the histogram, the weights of the bales did show a wide range of weights. On a bale by bale basis the individual weights of the bales could be off. However, in most cases as shown in Table 1, the field averages for all of the bales were within 1% of the field average individually weighed bales using the calibrated platform scales. The histogram showed that in the fields analyzed that two of the fields showed a tight grouping of weights. This was indicated by the accuracy of the scales in comparison to the platform scale weights taken of the random sampling of bales at the field edge. In the remaining field there was a larger error compared to the randomly sampled bales but there was also a larger spread in the histogram indicating that the variation in weight was higher in the field. The source of the error could have been from randomly sampling bales from the lower end of the weight scale causing the error.

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Table 1. A summarized comparison of the average weight determined by the scale on the baler in comparison to the platform scale used by ISU for commercial bale sampling for DuPont Cellulosic Ethanol.

<table>
<thead>
<tr>
<th>Field ID #</th>
<th>Scale Weight (lbs)</th>
<th>ISU Commercial Scale Weight (lbs)</th>
<th>ISU Lab Moisture (%)</th>
<th>Weight % Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>207</td>
<td>1583</td>
<td>1586</td>
<td>40.8</td>
<td>1</td>
</tr>
<tr>
<td>185</td>
<td>1801</td>
<td>1757</td>
<td>40.7</td>
<td>3</td>
</tr>
<tr>
<td>158</td>
<td>1615</td>
<td>1610</td>
<td>35.7</td>
<td>1</td>
</tr>
</tbody>
</table>
The standard deviation of the bale weights further confirms the histogram. In F0158 the standard deviation was 141 lbs; for F0185 the standard deviation was 210 lbs; for F0207 the deviation was 130 lbs. The narrow deviation indicated that the scales were accurate in the dynamic conditions exposed to them. The wider deviation seen in F0185 could have been caused by a selection of higher weight bales, thus causing the difference in weights between the baler scales and the platform scales.

**Gazeeka Moisture Meter**

Analysis of the moisture meter showed a close relationship of the meter’s readings compared to the lab results. An $R^2$ value of 86.7% was determined from the analysis. The natural variability of the harvested fields produced moisture ranges from 7.5% to 40% in individual bales; average field to field moisture range was 10% to 29.5%. The moisture meter had a programmed maximum of 28.9% moisture. The high correlation of the analyzed moisture contents to the core samples taken from the bales was highly encouraging as most biological materials are hard to capture such a relationship.

Figure 9: A histogram depicting the three fields of bales analyzed in the 2012 harvest. Over 500 bales were analyzed.
Figure 10: As shown in the scatter plot above the correlation in moisture between the Gazeeka Microwave moisture meter and the lab samples was highly correlated up to a moisture content of about 30%. The 30% level was a preprogramed level from the manufacturer.

Figure 11: A wide range of varying moisture levels was tested as shown above. The fields harvested naturally had varying moisture levels depending upon the time of the year harvest and any rainfall events that occurred.
Discussion

In the single-pass harvesting platform the use of baler scales and of a microwave moisture meter, such as the Gazeeka meter, offers a complete package for quality analysis of harvested biomass. Regardless of the material being harvested the moisture and weight will help the harvest crews make decisions on harvesting the material that day and how to handle that material as it starts into the supply chain. Vertically integrated supply chains can use this information to determine how the biomass is moved about the supply chain into storage or into the plant. Since the ash content in a single-pass corn stover bale is known to be between 3-5% an estimate based upon the timing of the harvest and moisture content of the material can be used to estimate whether the sample would be closer to 3% or 5% ash based upon the amount of residual nutrients remaining in the stover. Beyond single-pass harvesting in general the sensors are very good at determining moisture content of material. Both tools should be able to transfer over to a multi-pass baler with no issues for crews to use in that area.

The single-pass combine has the capability to take exceptionally high take rates of corn stover. In comparison to previous year's data a stepwise improvement in design of the combine and header has allowed for improvement of the throughput of the combine at maximum capacity. As further refinements of the machine are made further stepwise improvements should be expected.

Conclusion

The AGCO single-pass combine improved its throughput capacity in high take rate corn harvesting. On average the combine harvested about 2200 bushels (62 ton) of grain per hour and 18 tons of stover per hour. The combine was outfitted by baler scales which proved in the three fields selected for analysis to be within 1-3% of the platform scales used commercially for the 2012 harvest. The Gazeeka sensor, which was intensively tested, proved to be as accurate as well, having an R² of 87% when compared to a core sample moisture.

Acknowledgements

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References


