

FIBER OPTIC YIELD MONITOR FOR A SUGARCANE HARVESTER

R. R. Price, R. M. Johnson, R. P. Viator, J. Larsen, A. Peters

ABSTRACT. A fiber optic yield monitoring system was developed for a sugarcane chopper harvester that utilized a duty-cycle type approach with three fiber optic sensors mounted in the elevator floor to estimate sugarcane yield. Field testing of the monitor demonstrated that there was a zero intercept linear relationship between the optical sensor response and the actual sugarcane yields with an R^2 value of 0.98. The average observed prediction error on 0.5 to 1.6 Mg estimates was 7.5%; however, the magnitude of the error decreased as the harvested area (tonnage) increased, with an estimated error of 0.03% for 57.8 Mg loads. Factor testing indicated that the duty cycle reading was not affected by sugarcane variety, harvester speed, harvested distance, or direction of cut (lay of the sugarcane). Field testing across several locations in the U.S. totaled more than 557 h of operation and indicated that the system was robust, maintenance free, and self-cleaning, but some obstruction of the fiber optic sensors did occur in wet, muddy soils. These obstructions were minimized by relocating the fiber optics closer to the bottom of the elevator and leaving holes on each side of the sensors to enhance cleaning and scouring. This monitoring system compares well with all previously tested methods and is very durable and easy to install.

Keywords. GPS, Mapping, Precision agriculture, Sugarcane, Yield monitor.

Yield mapping is the first step in developing precision farming management and strategies (Erickson, 2006; Jhoty and Autre, 2003). With these maps, a producer can determine yield variations within a particular field (Johnson and Richard, 2005a) and the effects of different management practices on those yields. In addition, the maps can be used to generate accurate profit/loss maps for revenue (Lund et al., 2001) and prescription maps for spraying. Although several yield monitors exist in the literature, those tested in Louisiana are subject to limitations in accuracy and environmental effects caused by sensor blockage in the wet, high clay content soils. To overcome these limitations, a fiber optic system was designed with self-cleaning sensors and improved accuracies. This article describes the development, testing, and durability of this yield monitoring system for sugarcane.

LITERATURE REVIEW

Several attempts have been made to produce a yield monitor on a sugarcane chopper harvester. Cox et al. (1996) described a hydraulic pressure monitoring system with angular speed sensors to determine flow rate. The sensors were placed in the chopper and elevator systems and produced a

linear line output with R^2 values equal to 0.96 and 0.95 for the chopper and elevator systems, respectively. When the monitor was used to map several fields, an average error of approximately 10% was observed in the predicted sugarcane yields. One concern with this system was that the calibration equation would change due to external factors, such as wear in the snapping bars on the chopper drum (which occurs frequently in harvesters), changes in crop maturity or crop variety, and moisture content. It was also thought that inconsistent readings would occur with the starting and stopping of the harvester, a frequent occurrence when loading field transport wagons.

Molin and Menegatti (2004), Magalhães and Cerri (2007), Cox et al. (1999, 2003), Pagnano and Magalhães (2001), Benjamin et al. (2001), and Benjamin (2002) tested a weight scale system placed in the elevator floor of the harvester. Benjamin et al. (2001, 2002) indicated that for a simple weight scale system (no additional tilt, accelerometer, or slat speed sensors) the sensor predicted the actual weight of the harvested sugarcane with an R^2 of 0.90 and an average percent error rate of 11.05%. Statistical analysis of the system indicated that different sugarcane varieties had an effect on yield, but that sugarcane maturity, distance traveled during readings, and the flow rate (induced by two different travel speeds of the chopper harvester) did not affect yield, as indicated by the scale readings. Individual percentage errors ranged from 0% to 33% and in 14 out of the 118 tests were above 20%. Molin and Menegatti (2004) reported an average error of -3.5% to 8.3% (5% to 13% when converted to absolute values) on several different methods used to estimate weight of harvested sugarcane as compared to actual weights obtained from a weight scale. These methods ranged from inclusion and exclusion of slat speed, tilt sensor data, and different processing algorithms. All tests were evaluated on 13.6 to 22.7 Mg truck loads. Standard deviations ranged from 4% to 10%. Magalhães and Cerri (2007) indicated a 0.96% average error on the combination of eleven 60 Mg weight

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loads. When these values were converted to absolute value error numbers, the average error was 4.3%.

Some problems were observed with the weight scale plates. Over time, soil, sediment, and debris can accumulate in the gap between the weight scale and the elevator floor, causing locking of the weight plate to the elevator floor. In addition, extensive changes are needed to mount the systems on a harvester, such as removing a large portion of the elevator floor and lowering the return chains to accommodate the load cell and frame components.

Wendte et al. (2001) described a monitor that utilized a torsion deflection plate at the outlet of the chopper harvester's elevator that measured the force and impact of the 0.15 to 0.2 m sections of sugarcane stalks (billets) that spill from the elevator outlet, similar to the yield monitor force plates used on small grain harvesters. A base cutter pressure sensor was also included in this system to aid in the prediction capabilities. Currently, no research results exist for this system, so the accuracy and precision of the system cannot be evaluated.

Optical methods, although well documented in other crops (Thomasson et al., 2006, 1999; Thomasson and Sui, 2000, 2004; Wilkerson et al., 2001, 2002; Moody et al., 2000), have not been utilized on sugarcane harvesters, even though they have the advantage of inexpensive and relatively uncomplicated components. Thomasson and Sui (2004) described an optical method used in peanut yield monitoring that could potentially be used for sugarcane. This system used an optical array bolted on the side of a peanut harvester's blower tube. Yield was determined by the breaking of the light curtain as material flowed through the tube. The reported R^2 value for the system was 0.90. This system was never formally tested on a sugarcane harvester and may have problems with the soil and debris associated with poor harvesting conditions.

MATERIALS AND METHODS

YIELD MONITOR DESIGN

A yield monitor was designed and constructed that used optical sensors mounted in the floor of a sugarcane harvester conveyor (fig. 1). The optical sensors were mounted with their faces flush to the inside surface of the floor so that normal scouring of the floor surface would keep the sensors clean. The system determined weight by estimating the depth of material on the slats using a duty cycle type approach and transforming that information into weight using a calibration line (volume was assumed constant, as a triangular prism

shape is formed by the billets on the slats from the step elevator slope during operation). Yield (mass flow rate) was determined by dividing the depth value by the total area covered by the chopper harvester during that period. An advantage of the duty cycle calculation is that a separate speed sensor is not needed on the elevator chain, and the method works correctly regardless of the speed of the slats. However, when using this method, the software must also recognize the open slat condition or the system will misread the number of slats, but volume estimates will be the same.

LABORATORY STUDY

Different components were tested in the laboratory to determine their durability and ability to sense sugarcane billets on the slats. These tests were performed on a 1.5 m circular table with 50 mm high slats rotating at 20 rpm. Three different sensor systems were tested and included a diffuse optical sensor (fig. 2a), a photo-resistor sensor (fig. 2b), and a fiber optic sensor (fig. 2c). The diffuse optical sensor was constructed of an optical sensor (model QS18VP6DB, Banner Engineering Corp., Minneapolis, Minn.) mounted in a weld-on-sprocket hub (model X10018R, Shoup Manufacturing Co., Kankakee, Ill.) with a sapphire lens and stainless steel cap (embedded with epoxy). The photo-resistor sensor was constructed of a 3 mm glass rod mounted in a 22 mm bolt with a cadmium sulfide (CdS) photo-resistor in the back (model 276-1657, Radio Shack, Fort Worth, Tex.). A 55 W, 12 VDC automotive light mounted approximately 0.3 m above the sensor was used to illuminate the sensor when it was installed in the table floor. The fiber optic system was a glass fiber optic cable (model BT13S, Banner Engineering Corp., Minneapolis, Minn.) mated with a diffuse optical sensor (model SM312, Banner Engineering Corp.). Sensing distance for the fiber optic system was approximately 6 mm. Readings from the diffuse optical sensor and the fiber optic sensor were collected by counting discrete digital data, while information from the photo-resistor sensor was collected as analog data using a capacitor in series between the polling transistor pin and the sensor and measuring the discharge time). Data collection was performed using a single-chip computer (BasicAtomPro, Basic X Micro, Inc., Murrieta, Cal.) and recording into a laptop computer (Compaq Presario, Hewlett-Packard, Palo Alto, Cal.).

FIELD TESTING

Fiber optic systems were tested in the field by mounting three fiber optic pairs at equal distances across the conveyor floor (fig. 3) and using 7.9 mm nuts (fig. 4). Signals from the

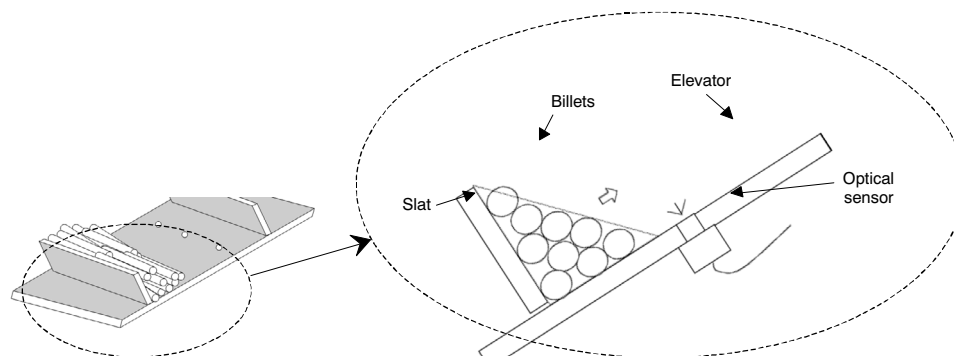


Figure 1. Method to detect billets from the elevator floor using optical sensors.

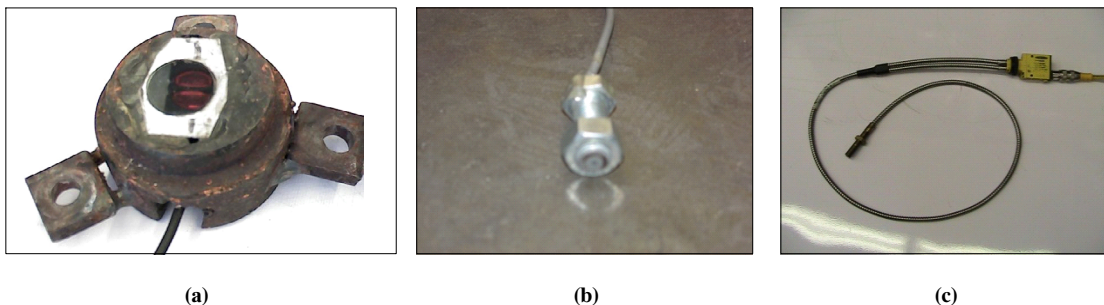


Figure 2. Different optical sensors tested in the laboratory: (a) optical sensor mounted in a hardened case with sapphire lens, (b) optical sensor mounted in bolt, and (c) glass fiber optic sensor.



Figure 3. Fiber optic yield monitor system mounted on underside of combine elevator.



Figure 4. Fiber optic mounting for improved scouring.

optical sensors were read with a computer box containing two single-chip computers (BasicAtomPro, Basic X Micro Murrieta, Cal.) arranged to read the GPS (model 16-HVS, Garmin Corp., Olathe, Kans.) and sensor readings simultaneously. A flowchart of the program to determine duty cycle is shown in figure 5. Readings were output every 3 s and recorded either on an SD card, LCD screen, or laptop computer (using a standard terminal program). Later versions included full functions of a yield monitor with calibration, yield output, and totalizing. Red wavelength sensors (660 nm) were used in all

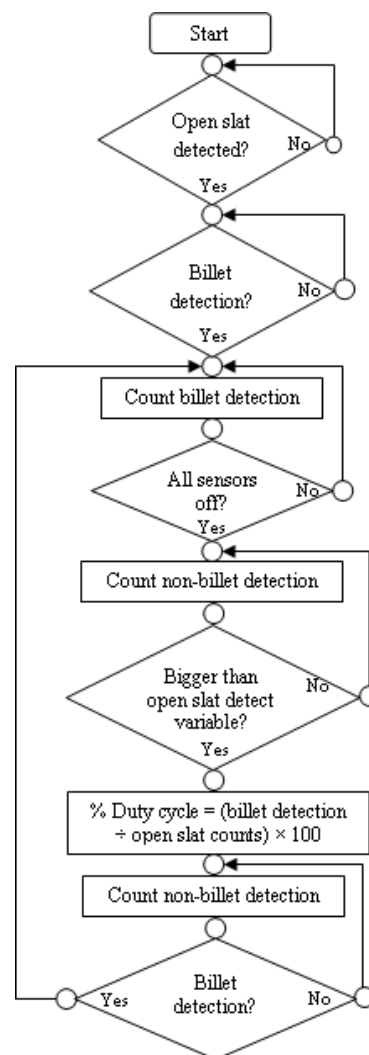


Figure 5. Flowchart of program used to detect billets with a duty cycle procedure.

tests since technicians could quickly diagnose operation of the system by looking for the red light transmission. Installation times were several hours and only required minor changes to the elevator floor.

Three monitors were tested at locations around the U.S. including the USDA-ARS Sugarcane Research Unit's (SRU) Ardoyne Research Farm at Schriever, Louisiana; Bain Farms at Bunkie, Louisiana (in cooperation with Ouachita Fertilizer Company); and the U.S. Sugar Corporation (USSC) at Cle-

wiston, Florida. All data collected at the SRU and USSC locations was under green-cane conditions, while the standing sugarcane at Bain Farms was harvested both green and after being burned. In Clewiston, yields estimated with the monitor were compared to actual yields for an entire field. At Clewiston and Bunkie, the durability of the system was assessed by allowing the system to remain in operation for one harvesting season (six months).

At the SRU location, testing consisted of comparing sensor readings for the sugarcane billets during harvesting to the weights of the same harvested billets as determined by a weigh wagon (Johnson and Richard, 2005b). The weigh wagon consist of a single-axle, high-dump billet wagon containing three electronic load sensors (Cameco Industries, Thibodaux, La.) mounted on the spindles at the end of the axles and on the wagon's tongue. The weigh wagon was certified to be within 0.5% of weight. In addition to weight testing, the variable effects on the system were investigated and included three commercial varieties (HoCP 96-540, L 99-226, and L 99-233) and basic seedlings, five harvest distances (3, 18, 76, 146, and 176 m), three ground speeds (3.2, 4.8, and 6.4 km h⁻¹), and two directions of cut, as some of the sugarcane was lodged in one direction along the row. Direction of cut included with the direction of lodged sugarcane, denoted as a 1 in the analysis, while cutting against the lodged sugar was denoted as a 0 in analysis. During all tests, the elevator was allowed to completely clean out before and after each test.

These variables were analyzed to indicate their effect on the raw sensor readings using the PROC GLM procedure in SAS and type III sum of squares. The following model (eq. 1) was used in this analysis (weigh wagon weight is considered a standard or independent variable to indicate its effect on the duty cycle reading):

$$\text{Duty cycle} = b_0 + Ab_1 + Bb_2 + Cb_3 + Db_4 + Eb_5 \quad (1)$$

where

- b_0 = intercept
- $b_1 - b_5$ = slopes
- A = weight wagon weight (Mg)
- B = combine travel distance during reading (m)
- C = cut direction (1 = with, 2 = against)
- D = combine speed (grouped into 3 levels)
- E = cane variety (each variety assigned a random number from 1 to 4).

All non-numeric class variables (cut direction and sugarcane variety) were assigned a random number with equal spacing to represent the variable in the equation. The equation is reversed for prediction, since weigh wagon load is estimated by the raw sensor readings and other significance variables (eq. 2) (although in the final analysis the only significant variable for weight prediction is raw sensor reading, and all other variables are taken out of the equation). This model was used in the PROC REG procedure in SAS to determine the actual calibration equation:

$$\text{Weight (Mg)} = b_0 + Ab_1 + Bb_2 + Cb_3 + Db_4 + Eb_5 \quad (2)$$

where

- b_0 = intercept
- $b_1 - b_5$ = coefficients
- A = totaled raw sensor readings for that period
- B = combine travel distance (m)

C = cut direction (1 = with, 2 = against)

D = combine speed (km h⁻¹)

E = cane variety (1 through 4).

Percent error was used to determine how well the weight estimates matched actual values and was calculated as the absolute value of the difference between predicted and actual values (eq. 3):

% Error =

$$\text{ABS} \left[\frac{\text{Predicted weight} - \text{Actual weight}}{\text{Actual weight}} \right] \times 100 \quad (3)$$

Yield maps were constructed by importing the raw data files into Farm Works software (division of Trimble, Hamilton, Ind.) and smoothing with either 4.6 or 7.6 m blocks. Smoothing involved a median function that reduced the effects of overly high or low numbers. This step can be crucial in sugarcane mapping, as artificially high and low yield numbers are created by the stopping and starting of the harvester during wagon filling.

RESULTS

LABORATORY TESTS

The diffuse optical sensor was found to be large and needed a 50 mm or larger hole in the conveyer floor to allow mounting (this hole would be detrimental to the floor if the sensors were removed). In addition, testing of the sensors on the rotating table indicated that the optical faces had to be level and flush to create a good scouring surface, and manufacture of the sensor faces had to be precise. For these reasons, the epoxy-encapsulated diffuse sensor was discontinued from testing.

The glass-bolt-rod sensor was better for quick and easy mounting, with only a large nut welded to the bottom of the floor. In addition, the tip diameter of the bolt could be reduced to 7.5 mm to fit between the slots in the floor. This sensor was tested for its ability to sense the billets on the slats (fig. 6), which proved successful, and it was even able to indicate spaces between billets and different stacked densities (noted as varying signal levels as the billets traveled over the sensor). This system was also tested for its weight prediction ability, which was performed by pouring known amounts of billets on the slats and recording the cumulative output from the sensor. In this test, the billets were only allowed to be counted once, and each test was repeated three times. The results (fig. 7) indicate a linear relationship between the sensor readings and the weight of the billets with an R^2 of 0.88. Since the laboratory system ran horizontally and the elevator on a harvester runs at much steeper angles (approx. 51°), it was anticipated that the weight estimates with the harvester should be better than in the laboratory tests since the volume of billets on the slats may be better maintained.

Although the laboratory results were good for the photo-resistor sensor, the sensor had no means to reject ambient light for field use, and the fiber optic sensor was chosen for the field studies. The glass fiber optic sensor allowed light readings to be transmitted to and from the conveyer floor with a very small hole in the floor (<7 mm), and the industrial optical sensors provided their own light sources with good ambient light rejection. Response times of the optical sensor was

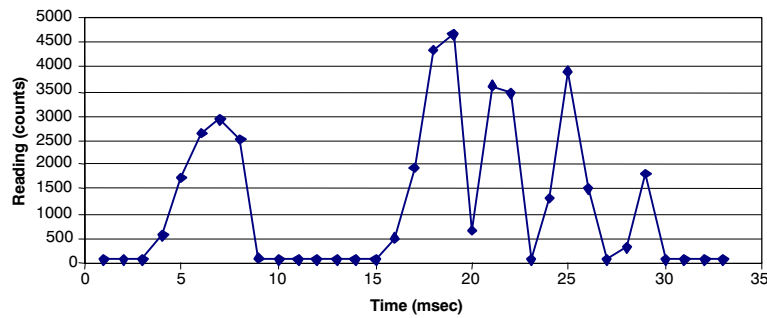


Figure 6. Output for one slat of billets with the photo-resistor sensor (output recorded in 1 μ sec time counts, taken for a capacitor across the photo-resistor pin and transistor to degrade to zero).

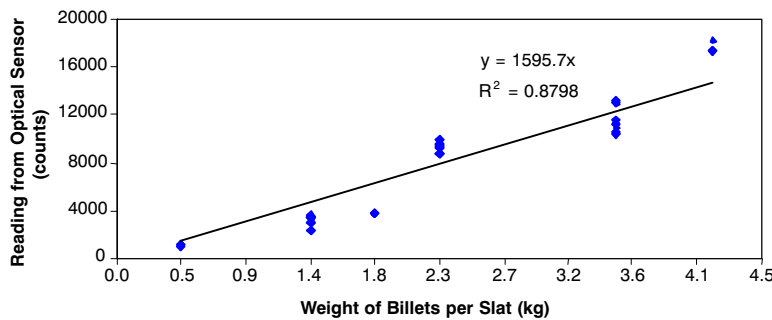


Figure 7. Sensor readings versus weight of billet mass on each slat.

1 ms. At normal conveyor speeds (8 m s^{-1}), the system can detect objects down to 1.8 mm in width.

At first, it was conjectured that a sapphire lens (Part No. 031759, Edmund Industrial Optics, Barrington, N.J.) would be needed to protect the surface of the glass optic fibers, but testing indicated that the sapphire lens caused too much internal reflection in the fiber, and a bare glass fiber was mounted directly in the conveyor floor. Laboratory tests with this system indicated that the fiber optic ends wore clean with the elevator floor, were very durable, and could see 8 to 13 mm into the billet stack. Wear tests were performed for several weeks with continuous running, and very few problems were detected. Harvesting in Louisiana is routinely done in rainy and/or muddy conditions to ensure a steady flow of sugarcane to the mill. Hence, the system was checked for operation in the rain to see if the light beams would transmit through water. This test was performed by applying billets to the rotating table and adding water to create a film. Two wavelengths were tested using a 660 nm sensor (model SM312FV, Banner Engineering Corp., Minneapolis, Minn.) and an 880 nm sensor (model SM312F, Banner Engineering Corp.). These tests indicated that the red beam would not transmit through the water film but that the infrared sensor would. Even though the red sensor did not transmit, it was noted that the water film was quickly erased by the slats and the sensor system started working again. These results indicate that red wavelength sensors may have problems working in rain but should quickly return to normal operation when the rain stops.

FIELD TESTS

Field tests at the SRU indicated that all variables (sugarcane variety, speed, distance, and direction of cut) did not significantly affect the duty cycle reading, except for weigh wagon weight (table 1). The model had an overall R^2 fit of 0.98 and an F-value of 506 ($\text{Pr} < 0.0001$). Table 2 list the pa-

rameter estimates for the linear line regression, which yielded an adjusted R^2 of 0.976. The intercept, although included, was not significant at the 5% level ($\text{Pr} = 0.0647$) and is not needed in the equation for accurate prediction of sugarcane weight. A plot of the actual weights versus predicted weights (using the parameters from table 2) is shown in figure 8. Average error for the predicted weights was 9.5% with a standard deviation of 9.2%. A plot of the individual errors is shown in figure 9 (note that these values reduce in magnitude as the weight increases). These values compare well to the other yield monitoring systems tested over mapping size units, which had R^2 values of 0.95 to 0.96 for the hydraulic pressure monitoring system (Cox et al., 1996) and 0.97 for the weight scale (Benjamin et al., 2001). Average errors for these systems were 10% and 11%, respectively.

In production use, the monitor may indicate improved results. First, unusually high yield numbers (448 Mg ha^{-1} or

Table 1. SAS analysis for under-conveyor yield monitor; type III sum of squares.

Parameter	F-value	Probability
Weigh wagon weight	289.86	<0.0001
Travel distance during reading	0.12	0.7321
Cut direction	1.61	0.2104
Harvester ground speed	0.03	0.8734
Sugarcane variety	0.44	0.5083

Table 2. SAS PROC REG analysis of significant variables.

Variable	DOF ^[a]	Parameter Estimate (Mg)	Standard Error	t Value	Pr > t
Intercept	1	0.03712	0.01971	1.88	0.0647
Sensor reading	1	0.00004482	9.117995E-7	49.15	<0.0001

^[a] Degrees of freedom.

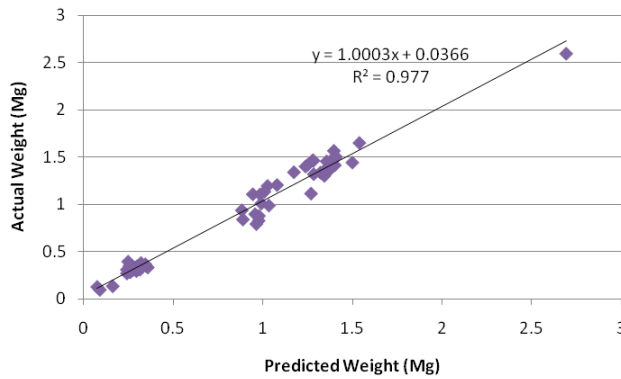


Figure 8. Chart of predicted weight versus actual weight for SAS results.

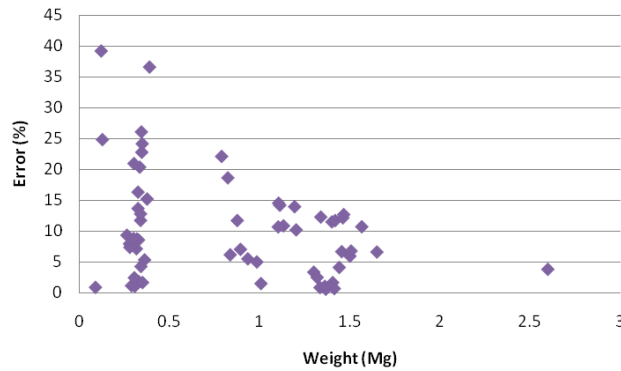


Figure 9. Reduction in error as measured weight increases.

higher) were created by the frequent starting and stopping of the machine on test plot borders. These numbers were single values created at the end of a run and had especially large effects on short runs (3 m) that had very few numbers to offset the single large number. Second, the calibration equation would be formed from truck loads delivered to the mill rather than from smaller individual wagon loads. The calibration equation would benefit from the reduction of weight errors (fig. 9). Using these theories, a new data set was constructed filtering out the high readings with distances less than 3 m and using a zero intercept linear calibration equation formed for the equivalent of three large truck loads (152 Mg) of sugarcane. Using this procedure, the individual weigh wagon yields were computed (table 3) and indicated a new average error of 7.5% with a standard deviation of 6.3%. On production units, a farmer could expect these results on mapping units in the 1.5 to 2.5 Mg size. These values are better than those of the hydraulic pressure monitoring system, which had a 10% error, and the weight scale (Benjamin et al., 2001), which had an 11% error.

Another use for a yield monitor is to estimate the load out weights of trucks. Although this attribute was not tested, some conclusions can be made about how well the monitor might perform in this application. Magalhães and Cerri (2007) indicated an average error of 4.3% on truck weights greater than 60 Mg. For this monitor, the total amount harvested during a test was 57.8 Mg. Using the SAS-generated parameter estimates (table 2), the percent error for this amount was 0.03%. Still, this is for a single test point and does not indicate the variances that might occur with multiple load tests. A plot of average yield error (grouped by distance

Table 3. Plot weights from test field at the Sugarcane Research Unit's Research Farm in Schriever, Louisiana (November 2008).

Yield (Mg ha ⁻¹)		Distance of Run (m)	Percent Error (%)
Predicted	Actual		
73.5	86.4	18.3	15.0
75.4	103.2	18.3	26.9
78.7	94.1	18.3	16.3
80.4	93.4	18.3	13.9
81.5	98.3	18.3	17.1
83.9	94.8	18.3	11.4
85.5	92.7	18.3	7.8
87.1	105.9	18.3	17.8
87.6	97.6	18.3	10.2
89.0	107.3	18.3	17.1
90.8	106.6	18.3	14.8
92.0	89.2	18.3	3.1
92.4	96.4	18.3	4.2
94.1	85.7	18.3	9.8
96.2	115.7	18.3	16.9
96.5	111.5	18.3	13.5
98.4	104.5	18.3	5.9
99.7	108.0	18.3	7.7
102.8	101.8	18.3	1.1
103.3	101.1	18.3	2.2
103.5	100.4	18.3	3.1
104.2	100.4	18.3	3.8
106.1	104.5	18.3	1.5
106.9	105.2	18.3	1.6
100.0	94.7	76.8	5.6
86.2	87.3	76.8	1.3
96.4	97.9	76.8	1.6
97.9	81.3	76.8	20.4
97.9	97.6	76.8	0.4
98.8	102.4	76.8	3.5
101.8	107.2	76.8	5.0
102.1	95.1	76.8	7.3
105.4	106.9	76.8	1.4
105.7	103.7	76.8	1.9
107.1	99.6	76.8	7.6
108.0	103.4	76.8	4.4
109.7	102.7	76.8	6.8
111.7	105.4	76.8	6.0
111.7	109.7	76.8	1.8
113.2	99.9	76.8	13.4
119.4	106.4	76.8	12.3
121.3	120.6	76.8	0.5
40.3	35.9	146.3	12.2
41.7	42.4	146.3	1.8
41.7	42.3	146.3	1.5
46.0	43.5	146.3	5.8
46.3	44.0	146.3	5.3
46.9	46.2	146.3	1.6
60.5	60.1	146.3	0.7
62.5	57.8	146.3	8.1
104.3	106.9	167.6	2.4
		Average	7.5
		SD	6.3

traveled) also showed that the error decreases exponentially (fig. 10) and is described by equation 4:

$$\text{Average error}(\%) = -3.1115 \times \ln(\text{harvest distance, m}) + 19.188 \quad (4)$$

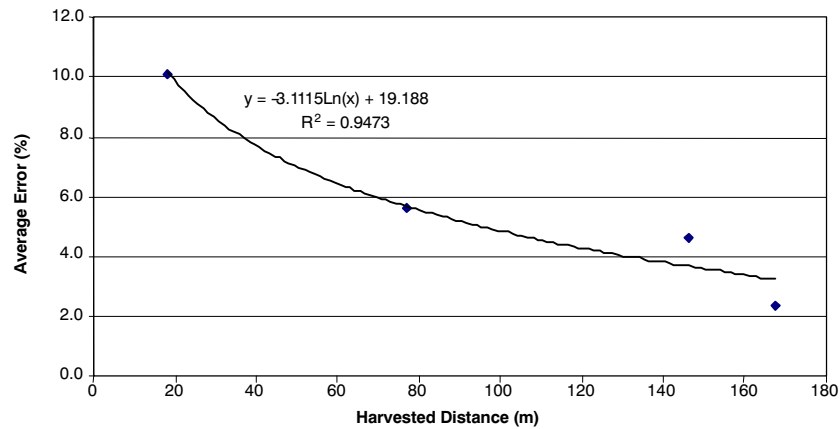


Figure 10. Error estimate in weight prediction as harvested length increases.

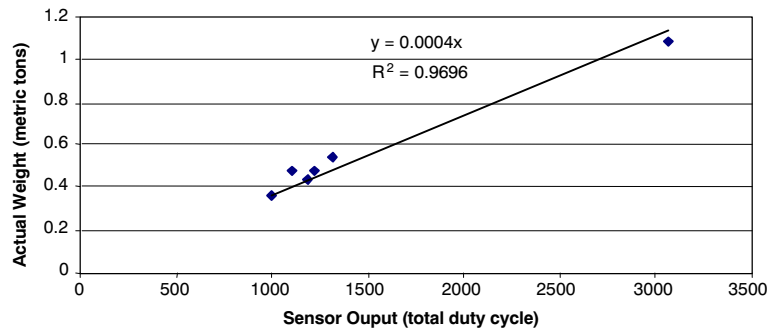


Figure 11. Calibration curve for U.S. Sugar fields.

Solving this equation at the 2% level indicated that the scale reaches this error at 906 m. Using the average harvest rate of 100 Mg ha⁻¹ and 1.5 m row width, equation 4 yields 16.3 Mg at this error rate. Since most trucks are loaded at weights far greater than this value, the monitor should perform well. In addition, equation 4 agrees well with the standard error rate that indicates a maximum error of 19.2% at the 99% confidence interval (3 times the 6.3% standard deviation) as the harvested distance approaches zero.

Tests at USSC resulted in the calibration line shown in figure 11 and a linear line with an R² of 0.97. Using this equation, the yield monitor indicated an overall tonnage of 121 Mg ha⁻¹ for a 30 ha field. The reported estimated value from the mill was 128 Mg ha⁻¹ for a five-section field containing the two sections in this study, yielding an estimated 7% error.

Maps produced by the monitor are shown in figures 12 and 13. Figure 12 is for the SRU's Louisiana location, where the harvested area contained a randomized complete block study containing three different varieties. This is most evident on the left side of the field, where the rectangular plots with different sugarcane varieties are apparent. On the far right side of the field, several full-field rows of one variety are visible. Figure 13 is for the USSC's Florida location, where the monitor was used to map a 30 ha field. Skips in the map were caused by the yield monitor only being present on one harvester in a four-harvester group. This field revealed a large variance between the left and right sides of the field, and when investigated, the left side of the field had a much lower stand density, containing 40% of the area with more than 1 m gaps between stools of sugarcane, while the right side of the

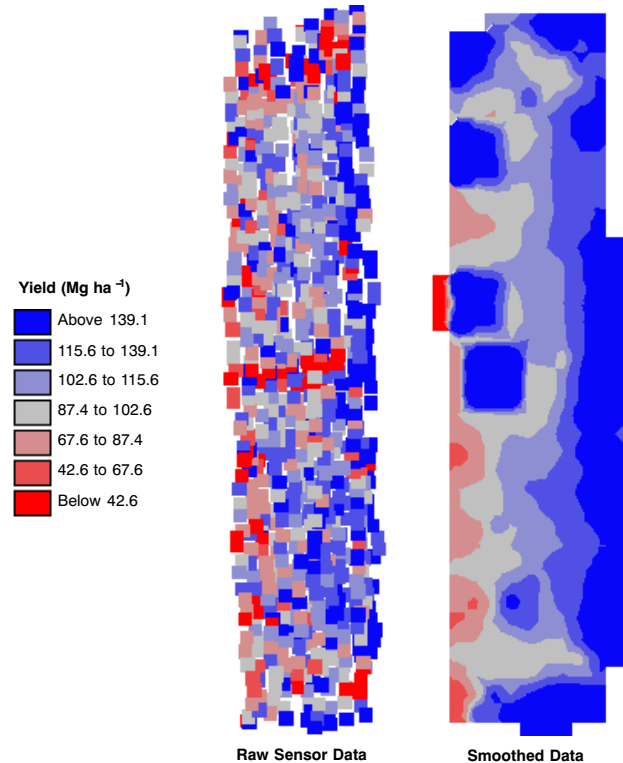


Figure 12. Yield map of test field at the Sugarcane Research Unit created from monitor data (4.6 m smooth blocks, Farmworks). The left side shows test blocks of different varieties, while the right side shows full row lengths of different varieties.

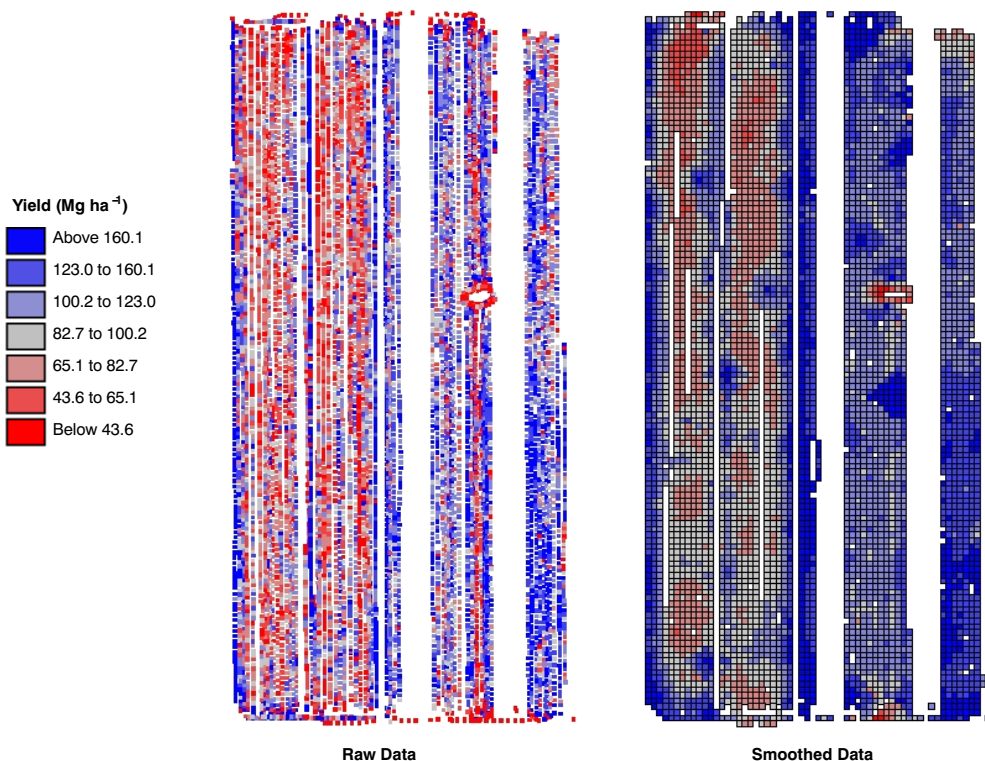


Figure 13. 30 ha field mapped at U.S. Sugar (smoothed map used 7.6 m square blocks).

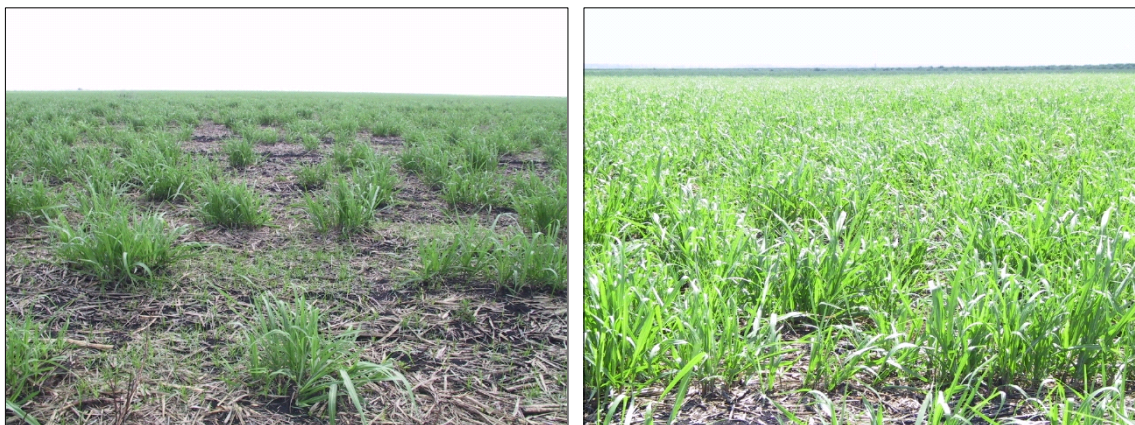


Figure 14. Left and right sides of field showing higher gap counts (40%) and lower yielding areas versus no gap counts and higher yielding areas.

field had very few gaps (fig. 14). These photos were taken one month after harvest.

In terms of durability, the monitor at USSC was used for more than 500 h of harvesting operation with no breakdowns or adjustments of the sensor array. The sensor array (fiber optic ends, optical sensors, etc.) was then left on the machine for a majority of the next fall cutting season and saw more than 2000 h of operation. After this time, the sensors were scouring normally with the elevator floor and still functional. In addition, no damage had occurred to the fiber optic cables located on the back of the elevator, which was a concern since the return slats can bring back debris. The Louisiana monitor was operated for 57 h with no breakdowns or maintenance, but it did have some problems with obstruction of the fiber optic sensors at certain times during the season due to mud. Total yield monitor recording time lost was 1.2% (39 min)

over the 57 h of operation. On several fields, obstruction of the sensor was a problem, although enough data were collected to make a yield estimate for that field. For this reason, a different mounting method was devised. This method relocated the fiber optics closer to the bottom of the elevator and left holes on each side to enhance cleaning and scouring. Repositioning the fiber optics seemed to solve the obstruction problems, but results are still preliminary as there were not enough rainy days during the remainder of the 2008 harvesting season to fully evaluate the new positioning.

CONCLUSIONS

A sugarcane yield monitor was designed for a mechanical chopper harvester using three optical sensors placed in the

elevator floor and a duty cycle type approach to predict sugarcane yield. Field testing resulted in a zero intercept linear line with an adjusted R^2 of 0.97. Factor testing indicated that the duty cycle reading was not influenced by sugarcane variety, distance traveled, combine speed, or direction of cut. Average yield error was 7.5% with a standard deviation of 6.3% based on actual field weight comparisons, and error decreased as larger weights were totaled. For this reason, estimates of large truck load-out weights (15.3 Mg or more) should average 2% or less in error. In this test, the totaled amount harvested (57.8 Mg) was estimated with 0.03% error. Fields mapped with the fiber optic monitoring system matched actual variances recorded with the actual weights of harvested sugarcane under various field conditions. The system appeared durable, operating more than 557 h with no breakdowns or servicing required. Some obstruction of the sensors occurred in muddy Louisiana fields; however, by relocating the fiber optics closer to the bottom of the elevator and leaving holes on each side of the sensors to enhance cleaning and scouring, this problem may be prevented. The results achieved with this monitor are as good as or better than those of other monitors reported in the literature, and the sensors have the advantages of being easy to mount, almost completely self-cleaning, and can easily be made pressure washdown rated (IP69K) if desired.

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