OPTICAL BASED SUGARCANE YIELD MONITORS

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ABSTRACT

Several different optical monitors were investigated to detect sugarcane yield on billet type sugarcane harvesters. The most researched approach, an under-conveyer design, gave good results with a zero intercept calibration line and an adjusted R-square value of 0.98. Weight wagon weights in the 0.6 to 1.6 metric ton range were estimated to within 7.5% on average and truck load out weights (21 to 23 metric tons) were estimated to 2.5% on average with new calibration loads inputted daily. Statistical analysis indicated that cane variety, speed of the combine, cutting distance, and lay of cane were not significant to weight prediction. In addition, the system was rugged and self-cleaned in the material flow.

INTRODUCTION

Yield monitors are an important part of farming operations. In sugarcane, these devices serve two purposes: 1) the geo-spatial recording and mapping of yields, and 2) the monitoring and controlling of truck load out weights. For research and nutrient management, the recording of yields is the most important parameter, but in production agriculture, the ability of the unit to estimate truck weights is the most important property. In addition, the widely varying harvest conditions around the world (rain or sunshine) have made the acceptance of a particular unit none existent. For this reason, an industry accepted method has not been invented yet. This paper discusses optical methods for detecting sugarcane yield and truck load out weights that may fulfill these conditions.

Literature Review:

Several monitors exist in literature. Cox et al. (1996) described a hydraulic pressure monitoring system with angular speed sensors to determine flow rate. The sensors produced a linear line output with R-square 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 cane 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 and with changes in crop maturity, crop variety, and moisture content. It was also thought that inconsistent readings would occur with the starting and stopping of the machine (a frequent occurrence when loading wagons).

Several weight plate systems have also been researched for sugarcane yield monitors. These systems typical require removing a section of the elevator floor and installing a load cell or weight plate. Various authors (Molin and Menegatti, 2004; Cerri and Magalhães, 2003, 2005; Cox, 2002; Cox et al., 1999, 2003; Pagnano and Magalhães, 2001; Benjamin et al., 2001; Benjamin, 2002) list results for these systems and many different systems have been tried including a system with tilt sensors, accelerometers, and Butterworth filters to aid in the weight predict. While most units tended to achieve 10 to 12% errors on 1 to 2 metric ton units (mapping scale), the unit produced by Cerri and Magalhães (2005) estimated 60 metric ton truck weights with 4.3% error on average. Still, one basic problem exists with these units. In some harvesting conditions, the mud, dirt, and grim tend to build up in the gap left between the plate and the elevator floor and cause loss of calibration and weighting ability over time (Benjamin et al., 2001; Benjamin, 2002). In addition, large portions of the flooring must be removed for installation.

A grain type impact sensor was also tested (Wendte et al., 2001) that utilized a torsion deflection plate at the outlet of the elevator to measured the impact force of billets spilling from the elevator outlet. In addition, a base cutter pressure sensor was also included to aid in the prediction capabilities. No research results exist for this unit.

Optical methods, although well documented in other crops have not been well documented in sugarcane. Thomasson and Sui (2004) describe an optical method for peanut harvesting that they state as potentially useable in sugarcane, but this system was never tested in this crop.

Other sensors and monitors tried in industry were Harvestmaster® (Juniper Systems, Utah) which produced a yield monitor that contained five ultrasonic sensors for sugarcane. No formal research results exist for this system and it is no longer available. Jaisaben Enterprises (2006) also mentions a yield monitor and has a graph available on-line which relates to pour rate. It is thought that this unit uses a modified hydraulic pressure monitoring technique initially described by Cox et al. (1996).

Procedure:

Several optic systems were designed with the main approach being an under-conveyer system (Figure 1) which had three optical eyes mounted in the elevator floor. A main advantage of this system is that the optic eyes self-clean in the material flow and the system can be installed in several hours on a machine in the field. The system determined weight by estimating the depth of material on the slats using a duty cycle type approach and transforming that depth information into weight using a calibration line (volume was assumed constant and pyramidal with depth since the elevator runs at a 51 degree inclination). Yield (mass flow rate) was determined by dividing the depth value by the total area covered by the combine during that period. An additional advantage of the duty cycle approach 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.

Laboratory and Field Tests:

Initial test were performed on a 1.5 m circular table with 5 cm high slats rotating at 20 RPM to identify components that could survive the scouring of the material while sensing sugarcane billets. Of several different systems tested on the table, a fiber optic system composed of a glass fiber optical cable (Model BT13S, Banner Engineering Corp., Minneapolis, MN) and a diffuse optical sensor (Model SM312, Banner Engineering Corp., Minneapolis, MN) were chosen for the project. Readings were collected and transformed into useful data using two single chip computers (Model BasicAtomPro, Basic X Micro Inc., Murrieta, CA) and GPS (Model 16 HVS, Garmin Corp., Olathe, KS). Results were recorded either through the serial port of a laptop computer (using the HyperTerminal - Microsoft Corp., Redmond, WA), or serial display and SD card. After laboratory testing, the components were mounted in several combines in Figure 2 and field tested at several locations around the U.S. including the USDA-ARS Sugarcane Research Unit (SRU) in Houma, Louisiana, Bain Farms, Bunkie, Louisiana (in cooperation with Ouachita Fertilizer, Co.), White Star Farms, New Iberia Louisiana (in cooperation with Ouachita Fertilizer, Co.) and the U.S. Sugar Corporation in Clewiston, Florida. All data collected at the Houma and Clewiston locations was under green-cane conditions, while the cane at Bain Farms and White Star was both green and burned.

In Clewiston, estimated weights were plotted against actual weights to determine a calibration equation and yields were mapped and compared against photos. At Clewiston and Bunkie the durability of the system was accessed by allowing the system to remain in operation for extended periods of time. At New Iberia, truck load weights were estimated and compared using mill weights. In Houma, testing consisted of comparing sensor readings with external "weigh wagon" weights (Johnson and Richard, 2005) which were certified to within 0.5% of weight.

Variable effects were also investigated at the SRU and included three commercial varieties (HoCP 96-540, L 99-226, L 99-233) and basic seedlings, five travel distances (3, 18, 76, 146, 176 m), three speeds (3.2, 4.8, and 6.4 KPH), and two directions of cut (against or with cane lodging - some cane was slightly lodged in one direction from hurricanes, weather, and natural falling effects). These effects were also 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):

$$\text{Duty cycle} = b_0 + A*b_1 + B*b_2 + C*b_3 + D*b_4 + E*b_5$$

where: b_0 = intercept
$b_1 – b_5$ = slopes
A = weight wagon weight (metric tons)
B = combine travel distance during reading (m)
C = cut direction (1 – with / 2 – against)
D = combine speed (grouped into 3 levels)
E = cane variety (grouped into 4 levels)

Eq. 1

For prediction, the equation was reversed since weigh wagon load is being estimated by the raw sensor readings and other significance variables (Eq. 2). This model was used in the PROC REG procedure in SAS® to determine the calibration equation.

$$\text{Weight (metric tons)} = b_0 + A*b_1 + B*b_2 + C*b_3 + D*b_4 + E*b_5$$

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 (kph)
E = cane variety (1 through 4)

Percent error was used to determine how well the weight estimates matched actual values. Average percent error was used to calculate the mean of these points.

Yield maps were constructed by importing the raw data files into Farmworks® and smoothing with either 4.6 or 7.6 m blocks (smoothing involved a median function which reduced the effects of overly high or low numbers - in sugarcane mapping this step can be crucial as artificially high and low yield numbers are created by the stopping and starting of the combine during wagon filling).

RESULTS

Laboratory tests (Figure 3) indicate that the sensors could see billets on the slats and also indicated a linear relationship between the sensor readings and the weight of the billets with an R-square of 0.88. Since the laboratory system ran horizontal and the elevator on the machines runs at much stepper angles (approx. 51 degrees), it was anticipated that the weight estimates on the combine would be better than in the laboratory test.

Wear tests on the fiber optics for several weeks with continuous running indicated very few problems. In one case, though, a small dimple appeared on the glass tip of the fiber optic end and filled with soil. It was thought that the fiber may have chipped during this test. The end was fixed by screwing it further into the floor and grinding off flush with the floor. Subsequent tests did not reveal any problems.

Field tests at the SRU research farm indicated that all variables (cane 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-square fit of 0.98 and an F-value of 506 (Pr < 0.0001). Table 2 list the parameters estimates for the linear line regression and yielded an adjusted R^2 of 0.976. The intercept, although included, was not significant at the 5% level (Pr = 0.0647) and is not needed in the equation for accurate prediction of weight. Tests at Clewiston, Florida, also resulted in a similar linear calibration line with an R-square of 0.97.

A plot of the actual weights versus predicted weights (using the parameters from Table 2) for the Houma test is shown in Figure 4. This data had an average error of 9.5% for the predicted values and a standard deviation of 9.2%. A plot of the individual errors is shown in Figure 5. Note that these values reduce in magnitude as the weight increases. This decrease in error with increasing load is common for sugarcane yield monitors that measure the load on each slat and then total. When erroneous numbers were removed from the data set (point created from combining distances less than 3 m) the individual weigh wagon yields indicated an average error of 7.5% with a standard deviation of 6.3%.

Another use for a yield monitor is to estimate the load out weights of trucks. Data for this test (New Iberia Test) is shown in Tables 3 and 4 and indicates a 2.0% accuracy per day on truck load out weights near 21 metric tons and maintained a 2.5% overall accuracy (standard deviation = 2.55) for several weeks when calibration loads were added daily. This result is very good for a monitor that has an empirical volume to mass relationship.

Maps produced by the monitor are shown in Figures 6, 7, and 8. Figure 6 is for the New Iberia location where the large variances in yield are clearly evident in different areas of the field. These yield maps could be used as a basis for variable rate applications of inputs and/or detection of low yielding areas of a field. If low yielding areas are identified, the problem causing the low yield may be corrected. Figure 7 is for the Houma, Louisiana, location where the harvested area was a variety plot. The left side of the field contained square test blocks with different cane varieties, while the right side of the field had full field rows of different varieties. These features are evident in the map. Figure 8 is for the Clewiston Florida location where the monitor was used to map a 30 hectare 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% skips (areas with more than 1 m gaps between plants), while the right side of the field had very few skips (Fig. 9). These photos were taken 1 month after harvest.

In terms of durability, the monitor at U.S. Sugar ran for more than 500 hours of operation with no breakdowns or adjustments of the sensor array. The sensor array was then (fiber optic ends, optical sensors, etc.) left on the machine for a majority of the next fall cutting season and saw more than 2000 hours of operation. After this time, the sensors were scouring normally with the elevator floor and still functional. Also, 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 hours with no breakdowns or maintenance, but 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 of lost was 1.2% over the 57 hrs of operation. On several fields the problem was extreme, although enough data was collected to make a yield estimate for that field. For this reason, a different mounting method was devised and this method relocated the fibers closer to the bottom of the elevator and left holes on each side to enhance cleaning and scouring. This method seemed to solve some of the obstruction problems.

CONCLUSIONS

Several optical yield monitors were created for sugarcane harvesters. The most researched approach was a monitor with three optical sensors placed in the elevator floor and a duty cycle type analysis to predict cane yield. Using this method, no elevator speed sensors were needed and the optical sensors self-cleaned in the material flow of the elevator. Testing resulted in a zero intercept linear line with an adjusted R-square of 0.98. Factor testing indicated that the duty cycle reading was not influenced by cane variety, distance travelled, combine speed, or direction of cut. Average weigh wagon yield error was 7.5% with a standard deviation of 6.3% on mapping size units (1.6 metric ton loads) and the load out weights of trucks (21 to 23 metric tons) were estimated with 2.5% error on average and a standard deviation of 2.55. Fields mapped with the system matched actual variances in the field well and the sensor and monitor performed adequately well to predict sugarcane truck load out weights. The system was operating for more than 557 hours with no breakdowns or servicing required (although some fibers did have to be replaced in later test). Some obstruction of the sensors did occur in muddy Louisiana fields, but the newer mounting system and several program changes have been made to help prevent this problem. The results of the monitor compare well or better to other monitors in the literature and also have the advantage of being easy to mount and self-cleaning.

RECOMMENDATIONS

More testing is needed to determine if the truck load error will stay constant or drift over large periods of time (several weeks to months) if the unit is not recalibrated. In the New Iberia test, the software was setup to recalibrate every time the driver put in a new truck load out weight, and he put in much more data than we originally thought he would. More testing is needed to determine how often calibration is necessary to achieve a certain error, and at what value a one time calibrated unit will achieve after several months or years.

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REFERENCES

Benjamin, C.E., M.P. Mailander, and R.R. Price. 2001. Sugar Cane Yield Monitoring System. ASAE Paper No. 011189. St. Joseph, Mich.: ASABE.

Benjamin, C.E. 2002. Sugar cane yield monitoring system. MS Thesis. Baton Rouge, Louisiana: Louisiana State University, Department of Biological and Agricultural Engineering.

Cerri, D.G. and P.G. Magalhães. 2003. Applying Sugar Cane Precision Agriculture in Brazil. ASAE Paper No. 031041. St. Joseph, Mich.: ASABE.

Cerri, D.G. and P.G. Magalhães. 2005. Sugar Cane Yield Monitor. ASAE Paper No. 051154. St. Joseph, Mich.: ASABE.

Cox G., Harris H, Pax R and Dick R. 1996. Monitoring cane yield by measuring mass flow rate through the harvester. p. 152-157. Proc. of Aust. Soc. of Sugar Cane Technol.

Cox, G. J., H.D. Harris, D.R. Cox, D.M. Bakker, R.A. Pax, and S.R. Zillman. 1999. Mass Flow Rate Sensor for Sugar Cane Harvesters. Australian Patent No. 744047.

Cox, G. J. 2002. A Yield Mapping System For Sugar Cane Chopper Harvesters. PhD Thesis. University of Southern Queensland, Australia.

Cox, G. J., D.R. Cox, S.R. Zillman, R. Simon, R.A. Pax, D.M. Bakker, M. Derk, and H.D. Harris. 2003. Mass Flow Rate Sensor for Sugar Cane Harvester. U.S. Patent No. 6508049.

Jaisaben Enterprises. 2006. Jaisaben Enterprises and AgGuide Pty Ltd Join Forces to Develop Exciting Yield Monitor. Available at http: www.jaisaben.com. Accessed 11 December 2006.

Johnson, R.M. and Richard Jr., E.P. 2005. Precision Agriculture Research in Louisiana Sugarcane. Sugar J. 67(11):6-7.

Molin, J.P. and L.A. Menegatti. 2004. Field-testing of a sugar cane yield monitor in Brazil. ASAE Meeting Paper No. 041099. St. Joseph, Mich.: ASABE.

Moody, F. H., J. B. Wilkerson, W. E. Hart, J. E. Goodwin, and P. A. Funk. 2000. Non-intrusive flow rate sensor for harvester and gin application. In Proc. Belt wide Cotton Conf., 410-415. Memphis, Tenn.: Nat. Cotton Council Am.

Pagnano, N.B., and P.S. Magalhães. 2001. Sugarcane yield measurement. p.839-3. In: BLACKMORE, S. and GRENIER, G. (ed.) 3rd European Conference on Precision Agriculture, June, 18-20, 2001. Montpellier: AgroMontpellier-ENITAdeBordeaux.

Thomasson, A.J., and R. Sui. 2004. Optical Peanut Yield Monitor: Development and Testing. ASABE Presentation Paper No. 041095. St. Joseph, Mich.: ASABE.

Wendte, K.W., A. Skotnikov, and K.K. Thomas. 2001. Sugar Cane Yield Monitor. U.S. Patent No. 6272819.

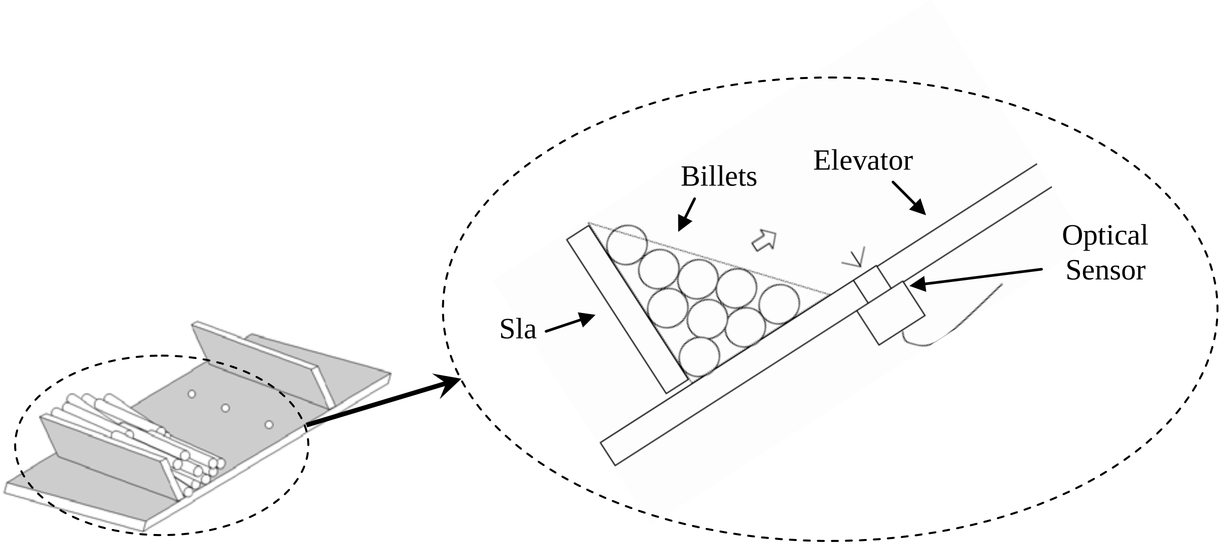

Figure 1: Method to detect billets under the elevator floor using several optical sensors.

(A)

(B)

Figure 2: Yield monitor system consisting of optical sensor box (A) and fiber optic cables (B).

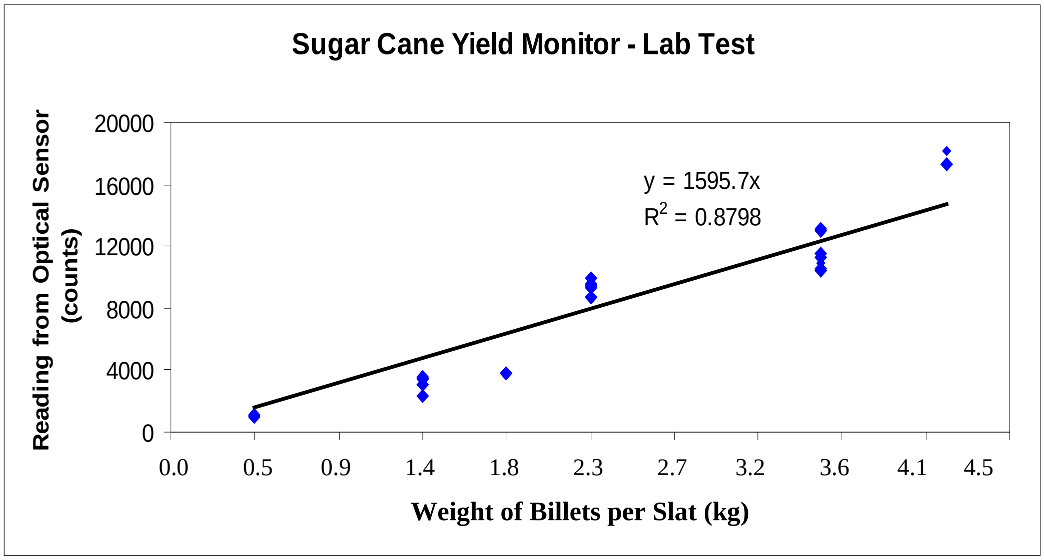

Figure 3: Sensor readings versus weight of billet mass on each slat.

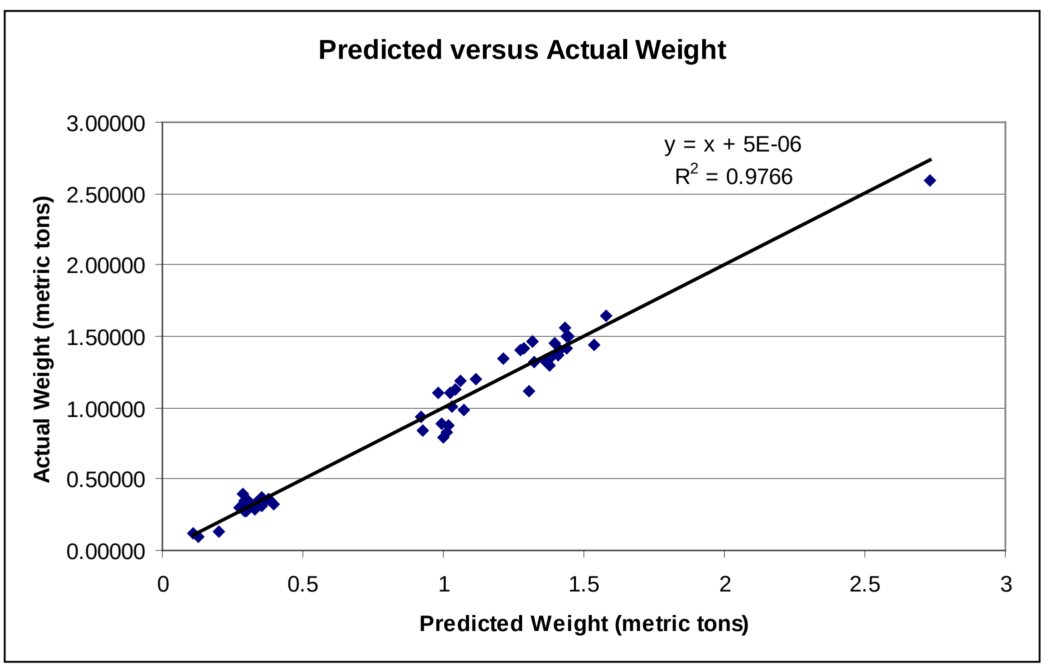

Figure 4: Chart of predicted weight versus actual weight for SAS® results.

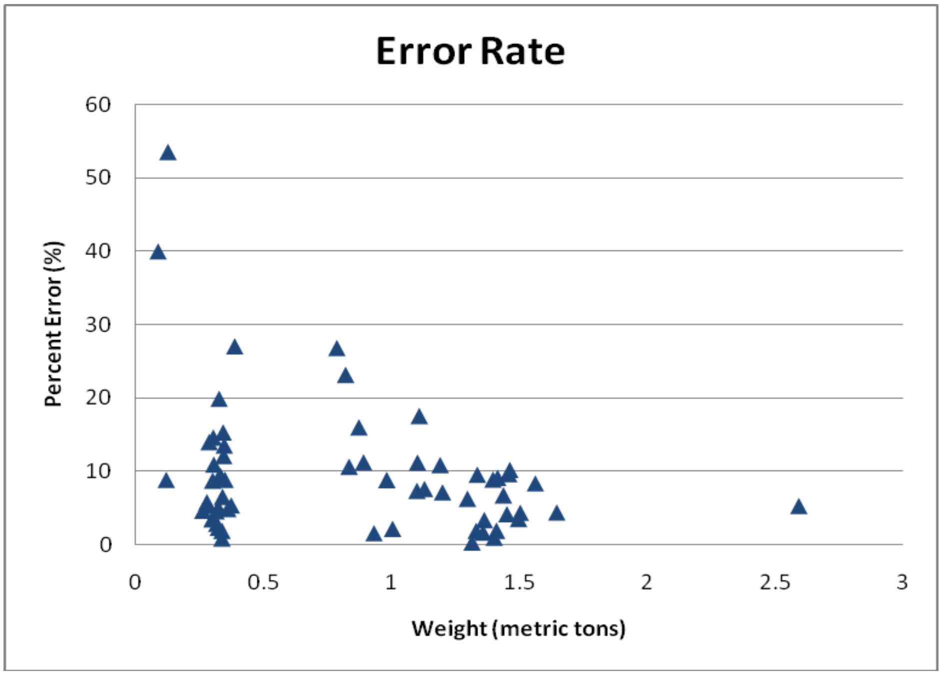

Figure 5: Reduction in error as measured weight increases.

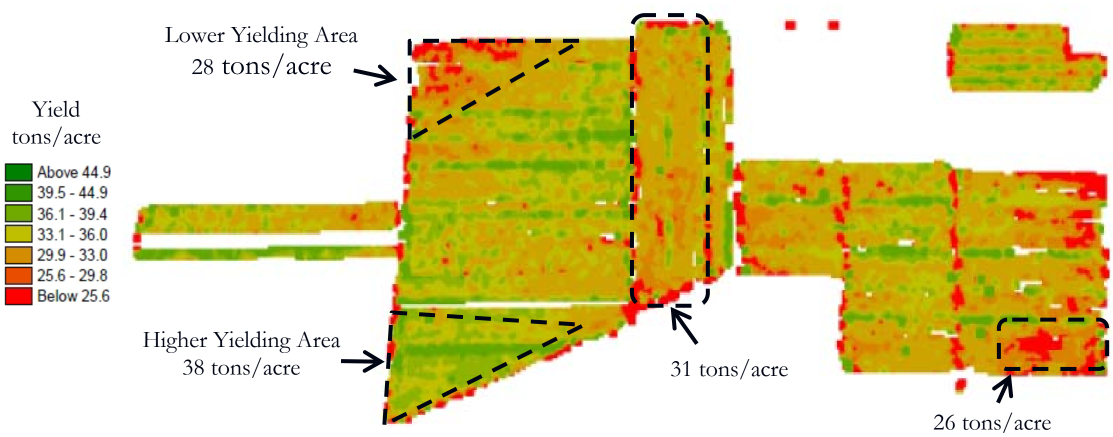

Figure 6: Map of field (smoothed with 20 foot blocks in Farmworks®).

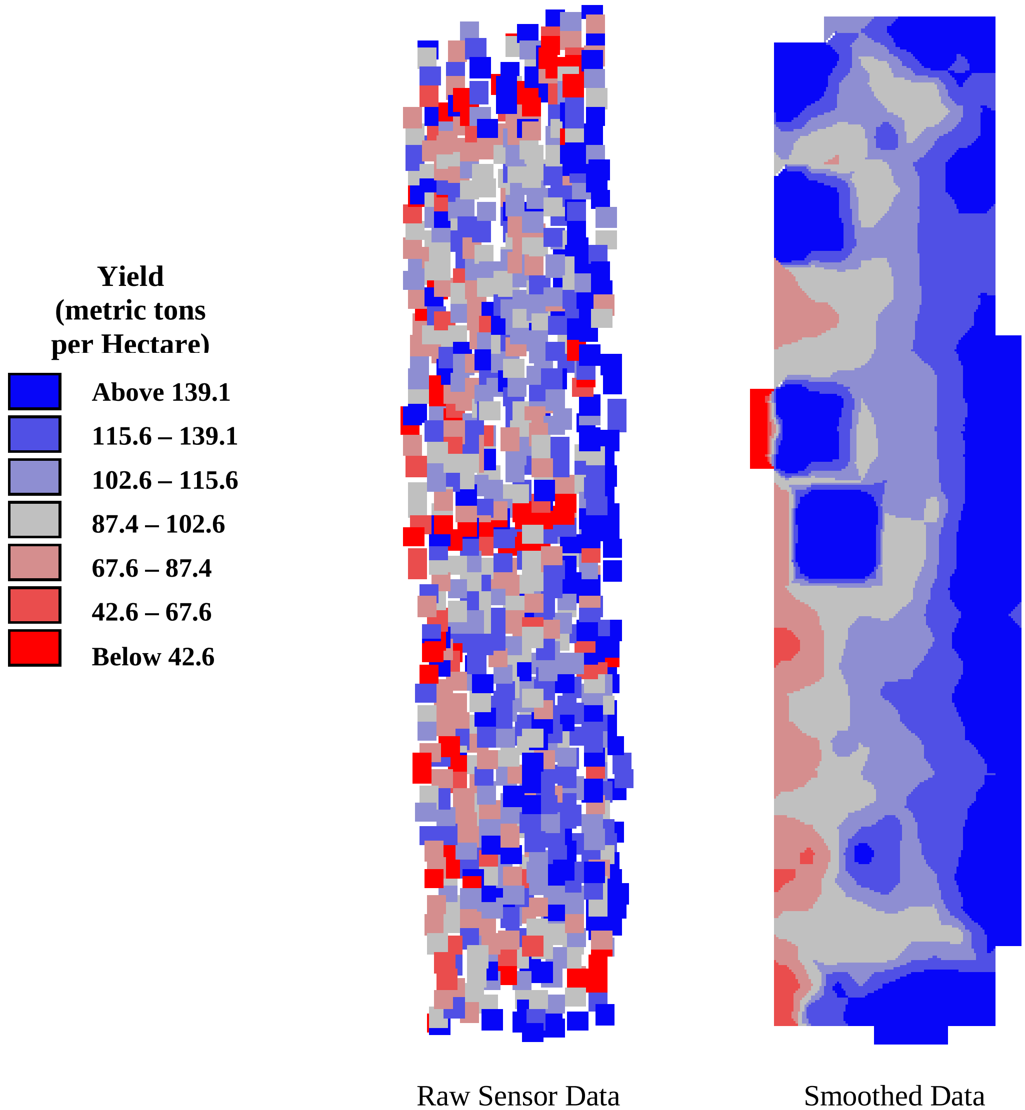

Figure 7: Yield map of test field created from monitor data (4.6 m smooth blocks, Farmworks®). The left side shows test blocks of different varieties, while the right side shows full row lengths of different varieties.

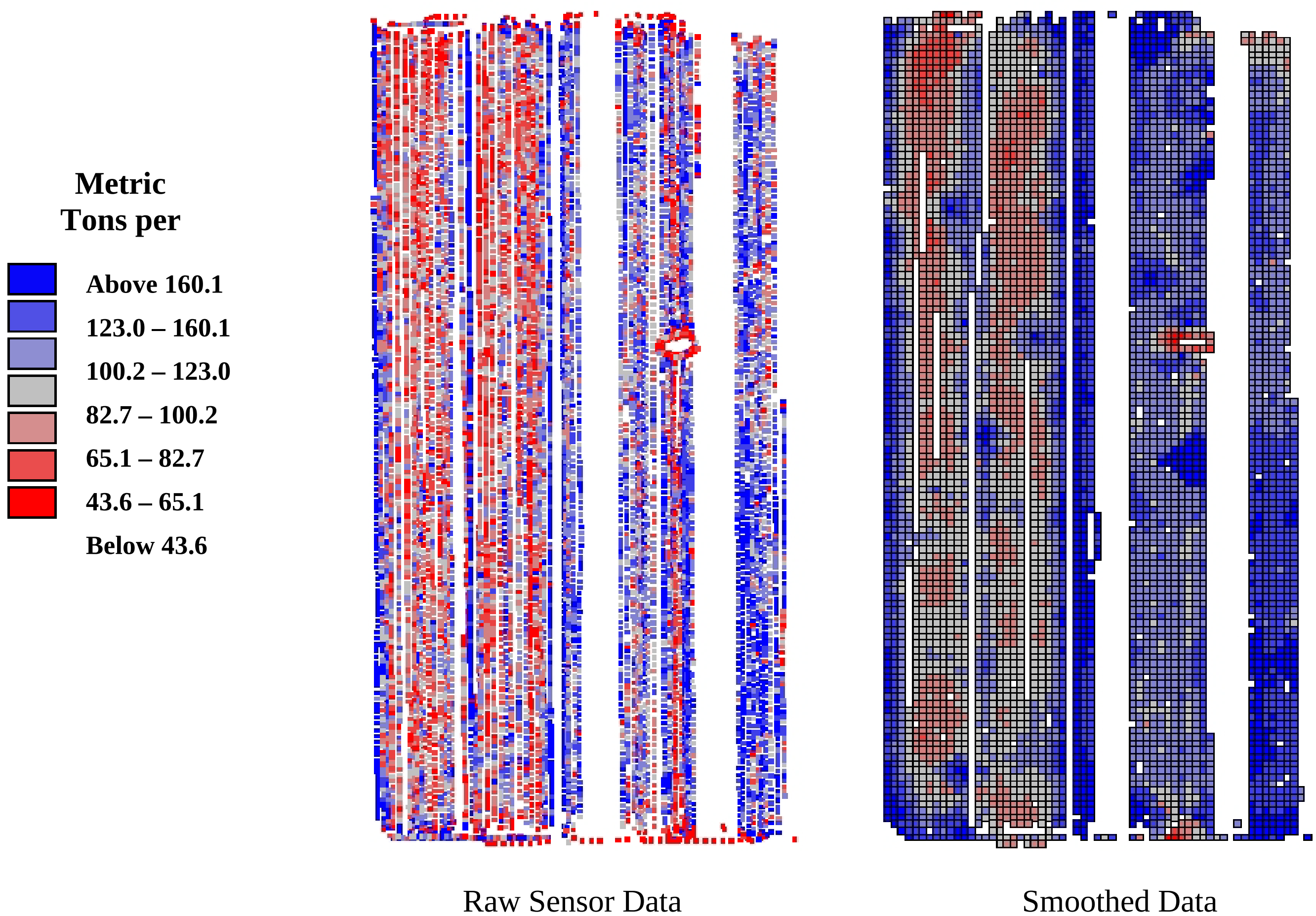

Figure 8: 30 hectare field mapped at U.S. Sugar (smoothed map used 7.6 m square blocks).

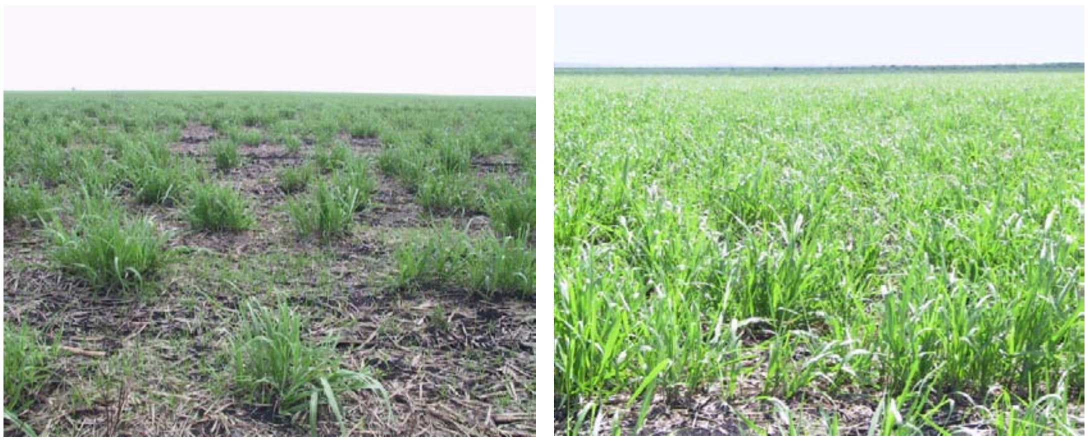

Figure 9: Left and right sides of field showing higher skip counts (40%) and lower yielding areas versus no skips and higher yielding areas.

Table 1: SAS® Analysis for Under-Conveyor Yield Monitor
Type III Sum of Squares

Parameter	F-value	Probability
Weight wagon weight	289.86	< 0.0001
Travel distance during reading	0.12	0.7321
Cut direction	1.61	0.2104
Combine speed	0.03	0.8734
Cane variety	0.44	0.5083

Table 2: SAS® PROC REG analysis of significant variables

Variable	Degree of Freedom	Parameter Estimate (metric tons)	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	<.0001

Table 3: Percent Error for Truck Load Out Weights
Same Day Calibration*

Raw Sensor Reading	Actual Weight (lbs)	Estimated Weight (lbs)	Error (%)
411000	43200	42000.09	2.78
460000	46222	47007.4	1.70
437000	45420	44657.03	1.68
475000	47560	48540.25	2.06
		Aver. Error	2.05
		St. dev.	0.51

* Weight = 0.10219 * Raw Sensor Reading

Table 4: Percent Error for Truck Load out Weights
One Week Operation with New Calibration Loads added Daily

Date	Actual Weight	Estimated Weight	Error (%)
11/9/2009	44380	45756.67	3.10
11/9/2009	46980	45394.72	3.37
11/9/2009	45840	48119.58	4.97
11/9/2009	49300	43175.13	12.42
11/10/2009	49080	48819.5	0.53
11/10/2009	46100	44392.45	3.70
11/10/2009	46900	46748.94	0.32
11/10/2009	46420	45578.87	1.81
11/10/2009	46480	46850.31	0.80
11/10/2009	45100	44559.46	1.20
11/10/2009	48040	50727.44	5.59
11/10/2009	47960	45719.53	4.67
11/10/2009	50020	49127.42	1.78
11/10/2009	44300	42580.2	3.88
11/10/2009	46900	49215.67	4.94
11/11/2009	47000	47499.8	1.06
11/11/2009	44860	45616.29	1.69
11/11/2009	44380	44283.93	0.22
11/11/2009	45080	43707.78	3.04
11/11/2009	46420	47269.5	1.83
11/11/2009	49220	51283	4.19
11/11/2009	51200	51842.86	1.26
11/11/2009	51084	51578.6	0.97
11/11/2009	45260	45000.90	0.57
11/11/2009	45380	45658.79	0.61
11/13/2009	44660	45242.46	1.30
11/13/2009	46320	46532.50	0.46
11/15/2009	46140	45929.4	0.46
		Average	2.53
		Stdev	2.55