EVALUATION OF AN EXPERIMENTAL MASS-FLOW SENSOR OF COTTON LINT AT THE GIN

Ruixiu Sui
USDA-ARS Crop Production Systems Research Unit
Stoneville, Mississippi
Richard Byler
USDA-ARS Cotton Ginning Research Unit
Stoneville, Mississippi

Abstract

As part of a system to optimize the cotton ginning process, a mass-flow sensor was evaluated at USDA-ARS Cotton Ginning Research Unit at Stoneville, Mississippi. The mass-flow sensor was developed and patented by Thomasson and Sui (2004). The optical and electronic components of the sensor were housed in a single aluminum unit with a mounting-magnet, which made it easy to install and maintain. To evaluate measurement of cotton lint mass-flow and the effect of cotton variety on the sensor, a test of the sensor with two cotton varieties was conducted using a micro-gin to compare lint mass-flow with sensor output. Results showed that the sensor output was very strongly correlated with the lint-mass which passed through the sensor ($r^2 = 0.98$), and the effect of cotton variety on the output of sensor was not significant ($F(1, 75) = 0.00$, $p = 0.9868$). This demonstrated that the mass-flow sensor can accurately measure the lint-flow in the gin and provide valuable information to the ginner.

Introduction

An automatic control system for cotton ginning process control has great potential in reducing labor costs, preserving fiber quality, and increasing operation efficiency at cotton gins. Real-time measurement of cotton flow at various stages of ginning is one of the most critical components in the control system.

Several optical cotton-flow measurement systems have been developed and tested in recent years on cotton harvesters. Wilkerson et al. (1994) developed an optical-attenuation-based sensor to measure cotton flow. This system was significantly modified and improved since Wilkerson et al. reported it in 1994 (Moody et al. 2000; Wilkerson et al., 2002) and the modified system was marketed beginning in 2000 as the AgLeader® (Ames, IA) Cotton Yield Monitor. Thomasson et al. (1999) reported the design and fabrication of two light sensing-bar devices for measuring the flow of pneumatically conveyed cotton. FarmScan (Perth, Western Australia), Micro-Trak® (Eagle Lake, MN), and Zycom/AGRIplan (Stow, MA) manufactured commercial optical cotton yield monitors using optical cotton-flow sensors since 1997. These cotton mass-flow sensors were evaluated with cotton harvesters under field conditions (Durrence et al., 1998; Roades et al., 2000; Sassenrath-Cole et al., 1999; Wolak et al., 1999; Vellidis et al., 2003). Studies involving these systems have shown that they can provide useful information in cotton-flow measurement, but issues remain to be dealt with concerning absolute accuracy, installation, and maintenance.

While being used to measure cotton flow on cotton harvesters, the optical mass-flow sensors have also been tested at gin. The light-sensing bar devices reported by Thomasson et al. (1999) were tested in collecting data in a seed-cotton unloading duct of a gin and a lint-cleaner-exhaust duct. Results indicated a strong correlation between output of the devices and the material flow (Thomasson et al., 1999; Whitelock and Thomson, 1998). Moody et al. (2000) tested the mass-flow sensor developed by Wilkerson et al. (1994) at a gin. The sensor was installed in a pneumatic seed-cotton conveying duct to measure the cotton flow with 59 loads. Data from the first 10 loads were used to calibrate a flow prediction model. Results showed that 48 of 49 total load weights were measured by the sensor to within ±10 percent of true values. They also found that moisture content (MC) of cotton had a detectable effect on measurement accuracy, but cotton variety had significant effect on the sensor performance. To detect the mass-flow rate of stripper-harvested cotton, Barker et al. (2000) evaluated several mass-flow sensors including a 12 inch light Beam-Array® system from Banner Engineering Corporation. They obtained very strong correlation (r^2=0.98) between the output signal of the light bar array and mass-flow rate of the cotton through the pipes. Gvilli (2001) tested a cotton flow sensor at a gin. The sensor-measured weight of the seed cotton conveyed through gin duct was compared with the scale-measured weight. He reported that measurement accuracies in the range of 5% were achieved.

All of the cotton-flow sensors mentioned above used optical detectors. The sensors were based on the same principle and are similar in configuration and operation. Each sensor unit has two parts, a light-emitter array and a light-detector array mounted opposite each other on a pneumatic duct. The sensors measure light attenuation caused by cotton particles passing through the duct. Thus, their installation requires two ports to be cut in the duct and proper alignment of the light-emitter array and a light-detector array. This creates difficulties in installation and possible misalignment over time due to vibration of the sensor; such is not the case with the mass-flow sensor developed by Thomasson and Sui (2000).

Thomasson and Sui (2000) and Sui and Thomasson (2002) reported on an optical-reflectance-based mass-flow sensor. Their sensor included light source and detectors mounted in one housing unit on the same wall of a pneumatic duct, thus requiring only one port to be cut in the duct. Such a configuration minimizes the difficulty of installation and maintenance and removes any requirement for alignment of sensor parts. This mass-flow sensor has been used as a cotton yield monitor and has been field tested since 1999 (Ge et al., 2008; Sui et al., 2004; Thomasson and Sui, 2003; Vellidis et al., 2003). Test results indicated the sensor was reliable and easy to install, operate, and maintain. However, this sensor has not been tested and used to measure cotton flow at a gin.

Mass-flow sensors used on cotton harvesters would need to be adapted for use in cotton gins because of the different operating environment and different demands. The flow rate in a cotton gin is considerably higher than on a harvester. When the cotton enters the gin it is similar to what was harvested in the field, but after processing the cotton changes and after ginning the fiber in the air stream is considerably different.

Objectives of this study were to 1) evaluate the functionality and accuracy of a custom made mass-flow sensor in measuring lint-flow at gins and 2) test the effect of cotton variety on performance of the mass-flow sensor.

Materials and Methods

Mass-Flow Sensor Description

A mass-flow sensor patented by Thomasson and Sui (2004) was used in this study. The sensor includes optical and electronic components. All the components are housed in a single aluminum unit with a mounting-magnet which makes it easy to install and maintain (Fig. 1). The sensor is 12cm long and 11.5cm in diameter with a 4.5m long cable. The sensor is designed to detect mass-flow by sensing the reflectance properties of the measured material as the material passes the sensor. The sensor has an anti-stray-light feature. Therefore, ambient light fluctuations did not affect its performance (Thomasson and Sui, 2004). Furthermore, the mass-flow sensor includes a built-in temperature control so that the sensor's internal temperature is controlled, which improves accuracy and stability of the sensor when used under varying temperatures.

Figure 1. Mass-flow sensor for gins.

Sensor Installation and Data Acquisition

A bracket was built for installation of the mass-flow sensor (Fig. 2). The bracket was made of sheet metal with a 76mm diameter hole and a 30mm high x 115mm diameter circular holder at center. One 76 mm diameter hole was cut on the conveying duct after the gin stand and before the first lint cleaner for installing the sensor. The bracket was mounted on the duct aligning up its central hole with the hole cut on the duct. The mass-flow sensor was placed into the circular holder with its window toward the duct. The senor was firmly fixed onto the duct through magnetic force from the three magnets on the sensor and by fastening two side screws on the holder (Fig. 3).

Figure 2 Bracket on gin duct.

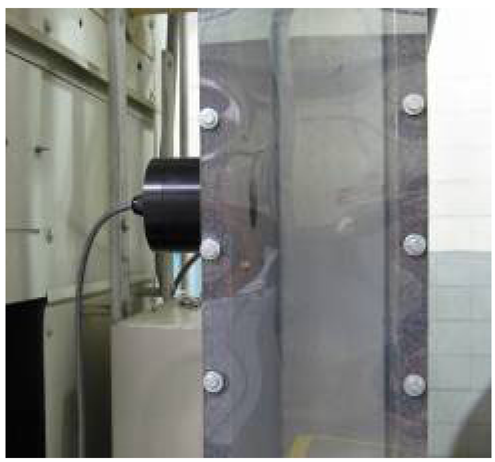

Figure 3. The mass-flow sensor installed on a duct behind gin stand to measure lint-flow at Cotton Ginning Research Unit in Stoneville, MS.

The mass-flow sensor was connected to a single board computer (SBC) based data acquisition unit reported by Sui and Thomasson (2006). The unit included a 206-MHz, 32-bit CPU and an 8-channel 12-bit analog–to-digital converter (ADC). The analog signal from the mass-flow sensor was input to the ADC and then collected by the SBC. Sensor data were displayed on a screen and stored in a memory card. Embedded Visual Basic was used as the programming language for the data acquisition unit.

<u>Test Procedures</u>

To evaluate performance of the sensor in measuring lint-flow at the gin and test the effect of cotton variety on the performance of the sensor, a test was conducted at the Micro-Gin of the USDA-ARS Cotton Ginning Research Unit (CGRU) at Stoneville, Mississippi on July 19 and 20, 2010. The sensor and data acquisition unit was turned on 30 minutes before the test to allow the sensor to warm up. Two varieties of cotton, FiberMax 960 and PhytoGen 485, were used in the test. Thirty-nine seed-cotton samples, with a weight range from around 4.5kg to 58.5kg of each variety, were randomly selected and ginned with the sensor measuring the mass flow. The seed-cotton samples were divided into 13 levels based on their weight, with around 4.5 kg increments. As the cotton being ginned and the lint being conveyed through the duct passed the sensor, the data output from the sensor was recorded with the data acquisition unit (Sui and Thomasson, 2006). Seed-cotton samples were weighed using a digital scale before being ginned and the lint weights were determined after the flow data were collected. One saw-type lint cleaner was used and there was no drying process involved in the ginning process. Three sub-samples of lint were collected from each sample for tests of Advance Fiber Information System (AFIS), High Volume Instrument (HVI), and MC. All lint samples were analyzed at the USDA-ARS CGRU at Stoneville, MS, and the USDA-ARS SRRC (Southern Regional Research Center) at New Orleans, LA, to determine the effect of fiber quality on performance of the sensor. Fiber quality parameters including trash content, neps, and short fiber content (SFC) were measured with AFIS and HVI tests. MC was determined with conventional oven method (Shepherd, 1972).

Data Analysis

The output from the mass-flow sensor was accumulated over the ginning time with each sample. Linear regression was then used to determine the correlation between the lint weight and the summation of sensor output. Lint weights were predicted using the regression functions and compared with the scaled lint weights of the samples. Lint weight residuals were calculated by subtracting the predicted weights from the scaled weights. To validate the regression functions, graphical residual analysis was conducted. Signal-to-weight ratio (STWR) was calculated by dividing the summation of sensor output by the lint weight. One-way ANOVA and a Tukey post-hoc test were conducted with SAS to compare the effect of the cotton variety on the STWR. Variety differences in fiber quality; including micronaire, SFC, and trash content were also analyzed using ANOVA test. Additionally PROC MEANS procedure was used to calculate the mean, standard deviation, standard error, maximum, and minimum of the fiber quality data, turnout, and the STWR.

Results and Discussion

Sensor Performance

The mass-flow sensor performed well during the test. After the 30-minute warm-up, the sensor showed a stable output baseline when there was no cotton passing through the sensor. As the cotton passed the sensor, output of the sensor varied with the change of cotton mass flow (Fig. 4). Magnitude fluctuation of the sensor output was about 0.5 volt with the ginning rate in the test. Fig. 5a shows the correlation between lint-flow weight and the sensor output with variety FiberMax 960 and PhytoGen 485. Fig. 5b is a plot of the lint-flow weight versus the sensor output using combined data of the two varieties. Both Fig. 5a and 5b indicated that the lint weight measured by the sensor was very strongly correlated with summation of the sensor output (r^2=0.98). Lint weights calculated using the regression function shown in Fig. 5b was plotted against the scaled weights (Fig. 6). Fig. 7 shows a plot of lint weight residuals versus the scaled lint weights of samples. In general, the residuals appear to behave randomly, suggesting that the models fit the data well. However, it was observed that lint weight was over-predicted with the samples weighing less than 5kg. This could possibly be caused by time delay while manually feeding the overflowed seed-cotton into the gin stand, because the delay introduced a significantly higher STWR with smaller samples.

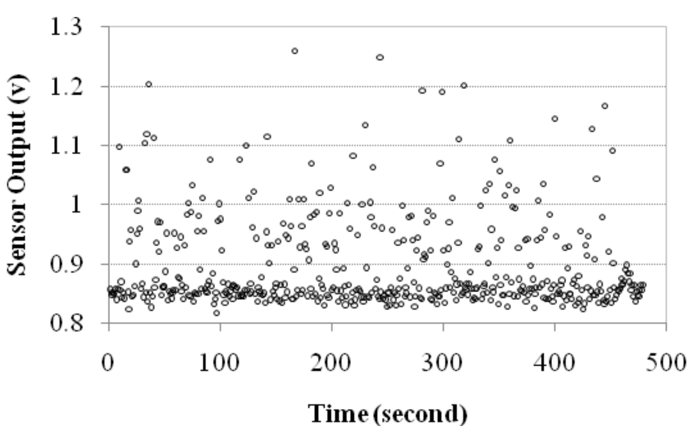

Figure 4. An example of mass-flow sensor output as cotton passed through the sensor.

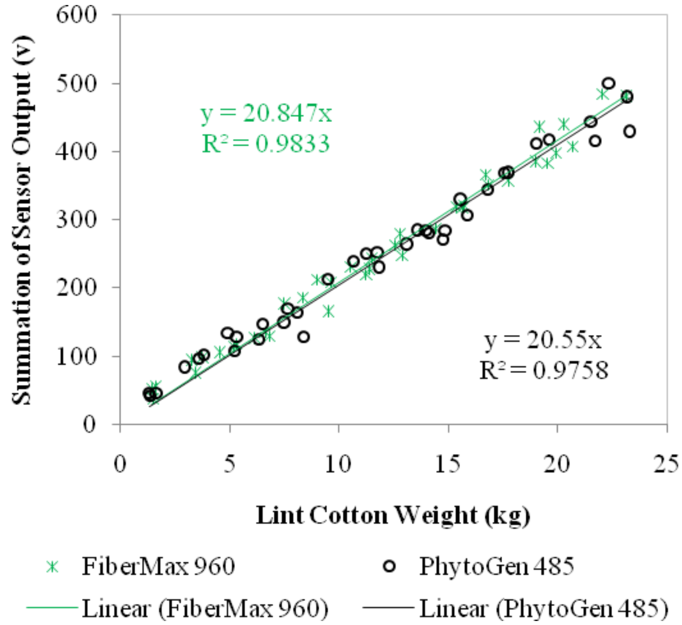

Figure 5a. Correlation of sensor output versus mass flow weight with the variety FiberMax 960 and PhytoGen 485.

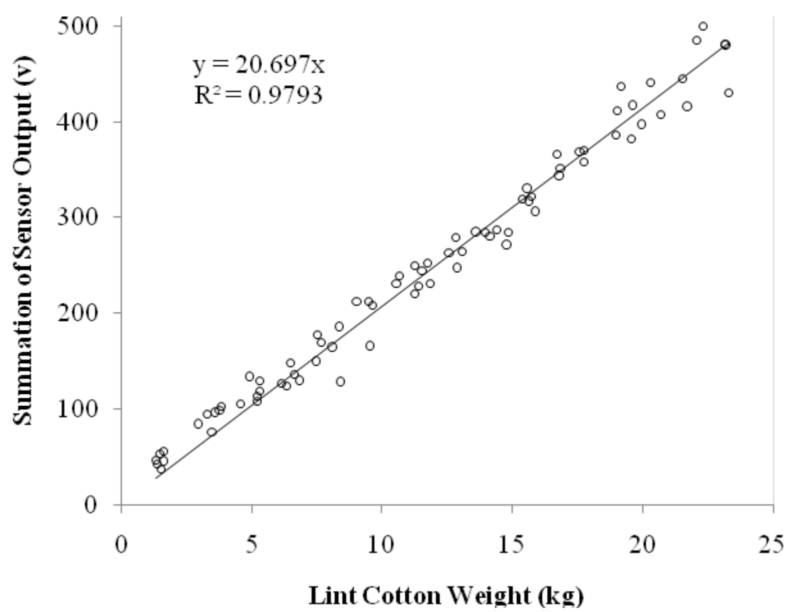

Figure 5b. Correlation of sensor output versus mass flow weight using the combined data of the two varieties.

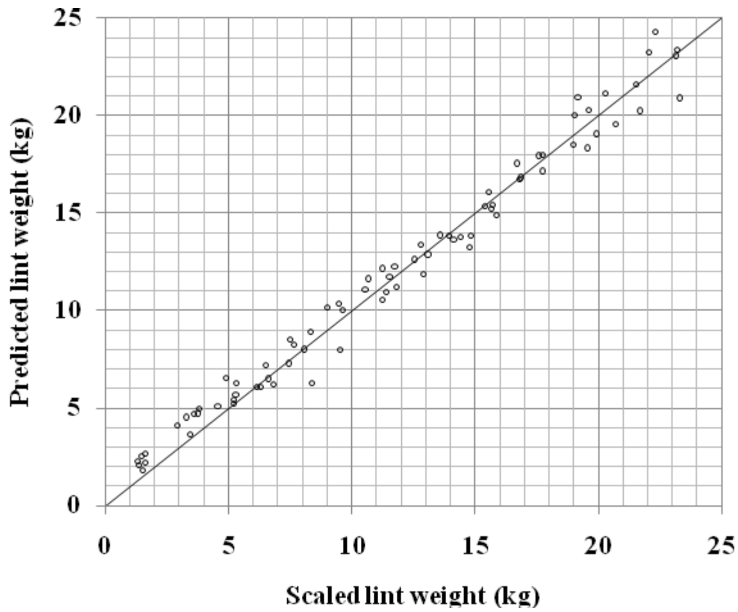

Fig. 6 Scaled lint weight versus predicted lint weight.

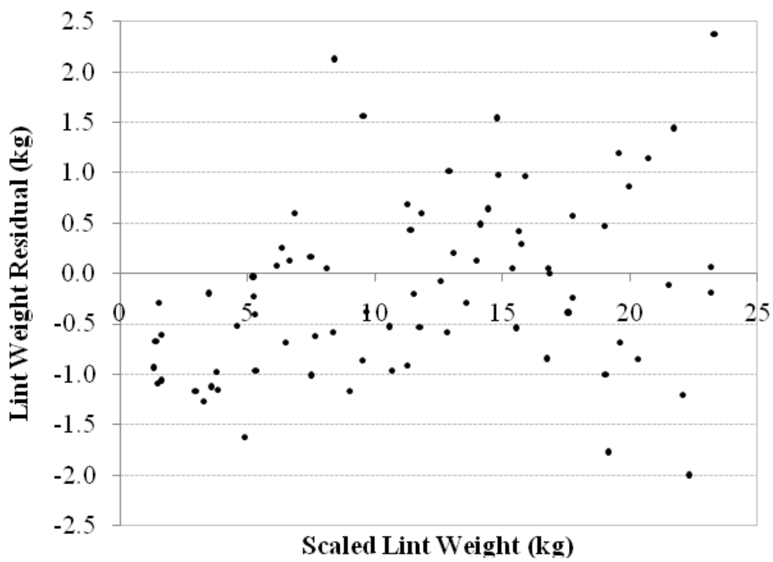

Figure 7. Plot of lint weight residuals

The sensor's optical window remained fairly clean up to completion of the test. The method used in sensor installation worked effectively and efficiently. No maintenance for the sensor was required during the test. However, one issue was observed that a cotton tag was occasionally created inside the duct at the screw heads that were used in mounting the bracket. It was possible that the tag could be viewed by the sensor making the sensor generate a "false" output signal. This issue can be solved by wielding the bracket onto the duct instead of mounting it by using screws.

Fiber Quality and Turnout

Table 1 shows major fiber quality factors of the cotton used in the test. A one-way ANOVA test revealed that SFC in the samples differed significantly as a function of the variety ($F (1, 76) = 81.63$, $p < 0.0001$). FiberMax samples had higher SFC ($M = 9.28$, $SD = 0.58$) than PhytoGen samples ($M = 8.03$, $SD = 0.64$). The one-way ANOVA tests also indicated that the effect of variety on both the trash content (F (1, 76) = 71.54, $p < 0.0001$) and nep content (F (1, 76) = 6.25, $p = 0.0146$) was significant. There was more trash (M = 166.33, SD = 36.02) and neps (M = 230.82, SD = 24.04) in PhytoGen samples than the trash (M = 102.31, SD = 30.61) and neps (M = 215.46, SD = 29.91) in the FiberMax samples. MC of the PhytoGen samples was a little higher (M = 6.19, SD = 0.34) than that of the FiberMax samples (M = 6.02, SD = 0.32), but the ANOVA test showed the difference was statistically significant (F (1, 76) = 5.25, $p = 0.0214$). Means of the micronaire value were 4.24 (SD = 0.24) with the FiberMax samples and 4.18 (SD = 0.11) with the PhytoGen samples. They were not significantly different (F (1, 76) = 1.89, $p = 0.1737$). Turnout of the FiberMax variety (M = 0.37, SD = 0.01) was one percent higher than the PhytoGen variety (M = 0.36, SD = 0.02). However, the difference was statistically significant as well (F (1, 76) = 5.54, $p = 0.0212$).

Table 1. Summary of fiber quality parameters of cotton varieties used in the test and the effect of the variety on STWR. Means with the same letter are not significantly different at the 0.05 level.

Variety	Data Type	Micronaire	SFC(w) %	Trash cnt/g	Neps cnt/g	MC %	Turnout %	STWR v/kg
FiberMax 960	N	39	39	39	39	39	39	39
	Mean	4.24[a]	9.28[a]	102.3[a]	215.46[a]	6.02[a]	37.00 [a]	22.17[a]
	SD	0.24	0.58	30.61	29.91	0.32	1.00	3.74
	Max	4.99	10.70	145	358	6.95	39.70	36.49
	Min	3.80	8.40	31	175	5.30	34.86	17.43
PhytoGen 485	N	39	39	39	39	39	39	38
	Mean	4.18[a]	8.03[b]	166.33[b]	230.82[b]	6.19[b]	36.00 [b]	22.19[a]
	SD	0.11	0.64	36.02	24.04	0.34	2.00	3.82
	Max	4.41	9.90	233	283	7.00	40.95	35.00
	Min	3.94	7.10	39	185	5.35	30.53	15.34

Effect on Sensor Output

A one-way ANOVA test revealed that STWR did not differ significantly as a function of cotton variety (F (1, 75) = 0.00, $p = 0.9868$). Tukey post-hoc comparison of the two varieties indicated that STWR of the sensor with FiberMax samples (M = 22.17, SD = 3.74) was not significantly different from that with PhytoGen samples (M = 22.19, SD = 3.82) (Table 1). Results showed that effect of the cotton variety on the sensor's performance was not significant, although fiber quality of the cotton differed significantly between the varieties.

Moisture and trash content of the cotton could be two key factors which may negatively affect the sensor performance, because either of them can change spectral characteristics of the cotton reflectance. However, in this study the results indicated that the variation of moisture and trash content in the samples did not significantly affect the sensor output. While both moisture and trash content of the FiberMax samples were significantly different from that of the PhytoGen samples, sensor's STWR with the PhytoGen samples (22.19v/kg) did not significantly differed from that with the FiberMax samples (22.17v/kg).

This study showed that the mass-flow sensor functioned well in measuring lint flow at gin. However, it is worth pointing out that quality of the cotton processed at gins has a greater range than that of the cotton used in this study. Maximum tolerance of the sensor to the variation of cotton quality including MC and trash content will be further evaluated in future.

Conclusions

An experimental mass-flow sensor was built and evaluated with two different varieties of cotton in determining lint flow at a gin. The mass-flow sensor was installed on a conveying duct between the gin stand and the first lint cleaner. Tests were conducted in comparing the lint flow with the output of the sensor. Lint-mass flow weight showed a very strong correlation with the sensor output ($r^2 = 0.98$). Fiber quality of two cotton varieties used in the test was analyzed using AFIS and HVI tests. The results indicated that the SFC, trash content, and MC differed significantly. Statistic analysis of sensor output with the fiber quality data was conducted to determine the effect of cotton variety on sensor performance. Sensor output did not differ as a function of the varieties. The sensor was easy to install and maintain. It has the potential to be used for the control of cotton ginning process.

Acknowledgements

The authors would like to extend their appreciation to the staff of USDA-ARS CGRU at Stoneville, MS and Dr. Chris Delhom of USDA-ARS SRRC at New Orleans, LA for their assistance in this study.

Disclaimer

Mention of a commercial product is solely for the purpose of providing specific information and should not be construed as a product endorsement by the authors or the institutions with which the authors are affiliated.

References

Barker, G.L., M.G. Pelletier, J.W. Laird, and A.D. Brashears. 2000. Evaluation of mass flow sensors for stripper harvested cotton. P. 1574-1577. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. Natl. Cotton Counc. Am., Memphis, TN.

Durrence, J.S., C.D. Perry, G. Vellidis, D.L. Thomas, and C.K. Kvien. 1998. Evaluation of commercially available cotton yield monitors in Georgia field conditions, ASAE Paper No. 983106. ASABE, St. Joseph, MI.

Ge, Y., J.A. Thomasson, R. Sui, C.L. Morgan, S.W. Searcy, and C.B. Parnell. 2008. Spatial variation of fiber quality and associated loan rate in a dryland cotton field. *Precision Agric* (2008) 9:181-194.

Gvilli, M. 2001. Cotton flow monitoring system for gins. P. 1410-1412. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. Natl. Cotton Counc. Am., Memphis, TN.

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. P. 410-415. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. Natl. Cotton Counc. Am., Memphis, TN.

Roades, J.P., A.D. Beck, and S.W. Searcy. 2000. Cotton yield mapping: Texas experiences in 1999. P. 404-408. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. Natl. Cotton Counc. Am., Memphis, TN.

Sassenrath-Cole, G.F., S.J. Thomson, J.R. Williford, K.B. Hood, J.A. Thomasson, J. Williams, and D. Woodard. 1999. Field testing of cotton yield monitors. P. 364-366. *In* Proc. Beltwide Cotton Conf., Orlando, FL. 3-7 Jan. Natl. Cotton Counc. Am., Memphis, TN.

Shepherd, J.V. 1972. Standard procedures for foreign matter and moisture analytical tests used in cotton ginning research. USDA Agricultural Handbook No. 422.

Sui, R., and J.A. Thomasson. 2002. Test of temperature and stray-light effects on mass-flow sensor for cotton yield monitor. Applied Engineering in Agriculture. 18(4): 127-132.

Sui, R., and J.A. Thomasson. 2006. Ground-Based Sensing System for Cotton Nitrogen Status Determination. *Transaction of the ASABE.* Vol. 49(6):1983-1991.

Sui, R., J.A. Thomasson, R. Mehrle, M. Dale, C.D. Perry, and G. Rains. 2004. Mississippi Cotton Yield Monitor: Beta test for Commercialization. *Computers and Electronics in Agriculture.* Vol. 42(3):149-160. Elsevier Science B. V.

Thomasson, J.A., D.A. Pennington, H.C. Pringle, E.P. Columbus, S.J. Thomson, and R.K. Byler. 1999. Cotton mass flow measurement: experiments with two optical devices. Applied Engineering in Agriculture. 15(1): 11-17.

Thomasson, J.A., and R. Sui. 2000. Advanced optical cotton yield monitor. P. 408-410. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. Natl. Cotton Counc. Am., Memphis, TN.

Thomasson, J.A. and R. Sui. 2003. Mississippi Cotton Yield Monitor: Three Years of Field Test Results. *Applied Engineering in Agriculture*. Vol. 19(6): 631-636.

Thomasson, J.A., and R. Sui. 2004. Optical-Reflectance-Based Mass-Flow Sensor. US Patent No.: 6,809,821

Vellidis, G., C.D. Perry, G.C. Rains, D.L. Thomas, N. Wells, and C.K. Kvien. 2003. Simultaneous assessment of cotton yield monitors. Applied Engineering in Agriculture. Vol. 19(3): 259-272.

Wilkerson, J.B., J.S. Kirby, W.E. Hart, and A.R. Womac. 1994. Real-time cotton flow sensor, ASAE Paper No. 941054. ASABE, St. Joseph, MI.

Wilkerson, J.B., F.H. Moody, and W.E. Hart. 2002. Implementation and field evaluation of a cotton yield monitor. Applied Engineering in Agriculture. 18(2): 153-159.

Whitelock, D.P. and S.J. Thomson. 1998. Estimating lint cleaner waste flow-rate. P. 1071-1075. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. Natl. Cotton Counc. Am., Memphis, TN.

Wolak, F.J., A. Khalilian, R.B. Dodd, Y.J. Han, M. Keshlkin, R.M. Lippert, and W. Hair. 1999. Cotton yield monitor evaluation, South Carolina-Year 2. P. 361-364. *In* Proc. Beltwide Cotton Conf., Orlando, FL. 3-7 Jan. Natl. Cotton Counc. Am., Memphis, TN.