

# Cotton-harvester-flow simulator for testing cotton yield monitors

Ruixiu Sui<sup>1</sup>, J. Alex Thomasson<sup>2</sup>, S. D. Filip To<sup>3</sup>

(1. Agricultural Engineer, USDA-ARS Cotton Ginning Research Unit, Stoneville, MS 38776, USA;

2. Professor, Biological and Agricultural Engineering Department, Texas A&M University, College Station, TX 77843, USA;

3. Associate Professor, Agricultural and Biological Engineering Department, Mississippi State University, Mississippi State, MS 39762, USA)

**Abstract:** An experimental system was developed to simulate the pneumatic flow arrangement found in picker-type cotton harvesters. The simulation system was designed and constructed for testing a prototype cotton yield monitor developed at Mississippi State University. The simulation system was constructed to approximate the pneumatic cotton flow system of a cotton picker, and was capable of operating with varying cotton flow rates. The simulator was tested with different cotton flow rates, and the relationship between feeder rate and amount of conveyed seed cotton was found to be consistent. Further, the simulator was used to conduct tests with the novel optical cotton yield monitor, which proved accurate at measuring the amount of seed cotton flowing through the simulator. Finally, some differences between laboratory testing and field-testing were noted: seed cotton becomes fluffed and twisted when recycled through the simulator, and seed cotton stored in the laboratory tends to be of lower moisture content than cotton during harvest. These differences should be considered when using a laboratory simulator to test cotton yield monitors.

**Keywords:** cotton yield monitor, precision agriculture, sensor, cotton harvester

**DOI:** 10.3965/j.issn.1934-6344.2010.01.0-0

**Citation:** Ruixiu Sui, J. Alex Thomasson, S. D. Filip To. Cotton-harvester-flow simulator for testing cotton yield monitors. Int J Agric & Biol Eng, 2010; 3(1): —.

## 1 Introduction

Precision agriculture technologies have been used to optimize farm profit and minimize environmental impact by adjusting production inputs based on the needs of individual areas within fields. Crop yield is a very important factor in optimizing farm profit. An accurate

yield monitoring system is able to measure the magnitude and variability of crop yield within a field. Yield data can be related to other field data for computing optimal inputs for profit and thereby making a prescription for each specific location within a field. Grain yield monitors have proven reasonably accurate and have been successfully marketed to many producers around the country. Cotton yield monitors, on the other hand, have been slow in development and commercialization.

Several cotton yield monitor systems have been researched and tested in recent years. Wilkerson et al. developed an optical-attenuation-based sensor to measure cotton flow<sup>[1]</sup>. This system has been significantly modified and improved since Wilkerson et al. reported it in 1994<sup>[2,3]</sup>, and the modified system was marketed beginning in 2000 as the AgLeader<sup>®</sup> (Ames, IA) Cotton Yield Monitor. Thomasson et al. reported the design and fabrication of two optical-attenuation-based

**Received date:** 2009-12-01 **Accepted date:** 2010-03-25

**Biographies:** **Ruixiu Sui**, Ph.D., Agricultural Engineer, USDA-ARS, Cotton Ginning Research Unit, P.O. Box 256, 111 Experiment Station Rd., Stoneville, MS 38776, USA, Email: [ruixiu.sui@ars.usda.gov](mailto:ruixiu.sui@ars.usda.gov); **J. Alex Thomasson**, Ph.D., Professor, Biological and Agricultural Engineering Department, Texas A&M University, 2117 TAMU, College Station, TX 77843-2117, USA, Email: [thomasson@tamu.edu](mailto:thomasson@tamu.edu); **S.D. Filip To**, Ph.D., Associate Professor, Agricultural and Biological Engineering Department, Mississippi State University, Box 9632, 130 Creelman St., Mississippi State University, MS 39762, USA, Email: [fto@abe.msstate.edu](mailto:fto@abe.msstate.edu)

experimental devices for measuring the flow of pneumatically conveyed cotton<sup>[4]</sup>. FarmScan (Perth, Western Australia), Micro-Trak<sup>®</sup> (Eagle Lake, MN), and Zycom/AGRIplan (Stow, MA) have commercialized optical cotton yield monitors since 1997. These cotton yield monitors have been evaluated under field conditions<sup>[5-12]</sup>. Studies involving these systems have shown that they can provide useful information, particularly on variability, but issues remain to be dealt with concerning absolute accuracy, installation, and maintenance.

The cotton-flow sensors in commercially available cotton yield monitors mentioned above use optical detectors. The sensors are all 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 cotton picker's pneumatic ducts. The sensors measure light attenuation caused by cotton particles passing through the ducts.

Thomasson and Sui also reported on an optical-reflectance-based mass-flow sensor as a cotton yield monitor<sup>[13-16]</sup>. Their sensor is an optical-reflectance-based sensor, which includes light source and detectors mounted in one housing unit on the same wall of a cotton picker's 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.

At the Department of Agricultural and Biological Engineering at Mississippi State University, a cotton yield monitor system was developed using the optical-reflectance-based cotton-flow sensor<sup>[13-16]</sup>. Many tests are required in cotton yield monitor development. In a given cotton producing area, there is only a short harvest season each year when a cotton yield monitor can be tested. If problems occur during field experiments (which is a common occurrence), time is spent to overcome the problems while harvesting continues. It can be the case that experiments must be put on hold until the following year. Thus, field-testing is the limiting factor in cotton yield monitor development.

The objective of this study was to develop and test a cotton-harvester-flow simulator to speed up the development of cotton yield monitor systems. Its design and testing are presented, and the differences between laboratory testing and field testing of cotton yield monitors are discussed in this article.

## 2 Materials and methods

The basic design of the cotton-harvester-flow simulator is shown in Figure 1. The simulator was designed to resemble as closely as possible the design of the pneumatic section on an actual cotton picker. It consists mainly of an air blower, cotton feeder, cotton harvester duct, flow rate controller, cotton hopper, receiving duct with an air separator, receiving container, and a digital scale.

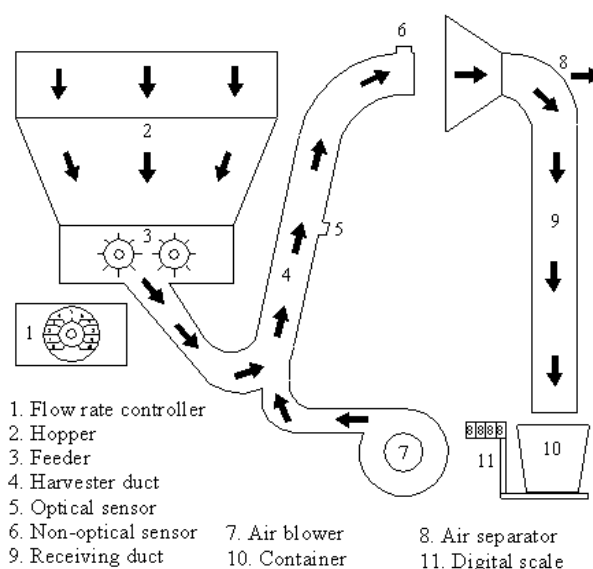


Figure 1 Structure of the cotton-harvester-flow simulator

A 7.5-HP motor operating at 3515 RPM was used to drive a centrifugal fan (Sterling Blower, Model 6, Forest, VA) that was the source of conveying air for the cotton. The air exiting the fan was connected to the cotton picker duct in the same fashion as is done on an actual cotton picker; i.e., air is introduced into the duct ahead of the seed cotton source, and induced suction pulls the seed cotton into the air flow.

Seed cotton was placed in the hopper, which channeled the cotton into the feeder that supplied cotton to the picker duct. The feeder consisted of two "star rollers", or cylinders with paddles, that rotated in opposite

directions in such a manner as to feed cotton down to the air-flow pick-up point. A Dayton<sup>®</sup> (Dayton, TX), 0.5-HP, variable-speed motor was employed to drive the feeder by way of a chain and sprockets. This gear motor has a maximum speed of 34 RPM, and its speed is controlled by turning a knob on the motor's controller that adjusts the voltage applied to the motor. The gear motor's knob and nominal speed adjustment points were used to determine the speed of the feeder, and thus control the cotton flow rate. Ten locations around the control knob representing different flow rates were marked for later use in yield monitor testing.

The receiving duct collected the cotton from the air stream, much as a picker basket would act on a cotton picker. The cotton then fell down into a receiving container. A digital scale was placed under the receiving container to weigh the cotton received. The air separator functioned to remove the seed cotton from the air stream while preventing the cotton from rebounding back toward the picker duct. The simulator was built such that ducts of both John Deere and Case-IH cotton pickers could be installed. A small laboratory was devoted to the simulator, and a 609-mm fan was installed in the laboratory window for ventilation.

The simulator was tested to calibrate the cotton flow rate. Feeding speed was set by turning the feeder motor's speed-control knob to a certain point, seed cotton was fed through the simulator, and the cotton flow continued for 30, 60, 90, 120, 150, or 180 seconds. This test was replicated 4–5 times for each time period. For each replication, the amount of conveyed cotton was weighed. The cotton flow rate for each replication was calculated by dividing the weight of the conveyed cotton by the time period of the test. Various flow rates were calibrated in this manner.

The optical-reflectance-based mass-flow sensor of Thomasson and Sui<sup>[13]</sup> has been tested with this cotton-harvester-flow simulator. One 133 by 51-mm slot was cut at the bottom of the duct, near the midpoint of its length, but above the duct's expansion joint (Figure 1). The sensor was attached to the duct such that its sensing surface protruded slightly into the duct through the slot. There were two sensing channels

(channel -1 and channel-2) in the optical sensor. Channel-1 measured reflectance at visible band and channel-2 did at NIR band. As seed cotton being conveyed through the duct passed the sensor, data output from the two channels was recorded with the yield monitor's data acquisition system. After data were collected, the seed cotton samples were weighed. Linear regression was then used to determine the correlation between the seed cotton weight and recorded sensor output.

## 3 Results and discussion

### 3.1 Cotton flow rate test

Figures 2, 3, and 4 depict some flow rate calibration results. The results were obtained with nominal feeder speed settings of 3, 4, and 4.5, respectively. Strong correlations ( $R^2 = 0.92, 0.96, 0.95$ ) between running time and conveyed cotton weight were observed for all three feeder speed settings. At the feeder speed setting of 3, the simulator could convey 3.90 kg of seed cotton per minute. It could convey 8.40 kg and 9.48 kg per minute with the feeder speed settings of 4 and 4.5, respectively.

In general, the simulator performed well during tests. It served the purpose of approximating the pneumatic cotton flow system of a cotton picker, was capable of operating with varying cotton flow rates, and facilitated laboratory testing of cotton yield monitors. However, some problems remain to be solved. When the feeding speed setting was equal to or higher than 5, cotton would sometimes clog at the picker duct entrance. A higher capacity centrifugal fan was needed for higher cotton flow rates. It was also observed that the cotton used in the tests was twisted and changed in shape (i.e., "fluffed up") after being passing through the simulator more than once. This physical change may influence the consistency of the feeding rate and the sensor's response. The density of twisted cotton may have been significantly higher than that of fluffed cotton. It was noted even under the same feeder speed setting the feeding rate varied significantly in a few runs of the test (Table 1). For example, feeding rate with time duration of 60-second was 18.34% higher than the average feeding rate of all time durations at feeder speed setting of 3.

Feeding rate variation decreased 77% as the feeder speed setting changed from 3 to 4.

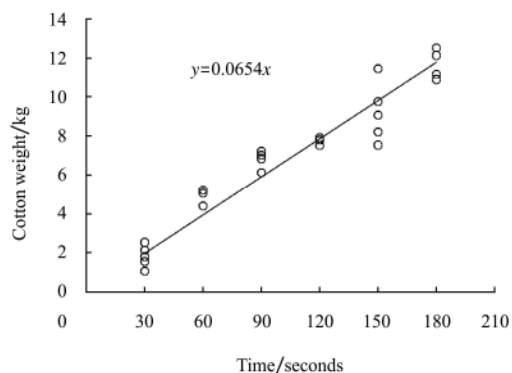


Figure 2 Conveyed cotton weight versus running time with a feeder speed setting of 3

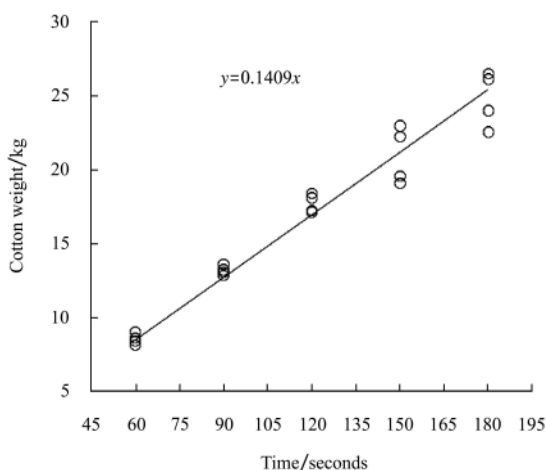


Figure 3 Conveyed cotton weight versus running time with a feeder speed setting of 4

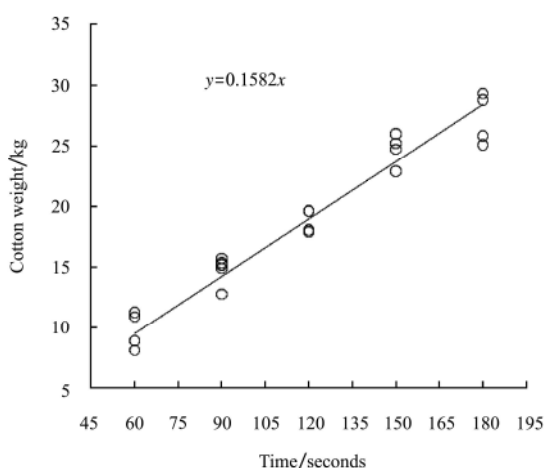


Figure 4 Conveyed cotton weight versus running time with a feeder speed setting of 4.5

The physical change factor should also be considered when testing cotton yield monitors with a cotton-harvester-flow simulator. Recycling the cotton

more than twice is not recommended. Further, stored cotton is typically used to test a cotton yield monitor in the lab. The moisture content of stored cotton is normally lower than that of cotton in the field. That results in the optical sensor having less dirt built-up on the window during laboratory testing compared to use in field. This phenomenon should be considered when calibrating or when testing the dirt tolerance of a cotton flow sensor.

Table 1 Variation of a feeding rate with a feeder speed setting from its average across time durations

Time duration/s	Setting #3 /%	Setting #4 /%	Setting #4.5 /%
60	18.34	-0.45	2.09
90	8.04	2.58	2.72
120	-7.39	3.47	-2.16
150	-12.01	-2.07	2.81
180	-6.98	-3.54	-5.45

### 3.2 Cotton-flow sensor test

Figures 5, 6, and 7 represented testing results of the optical cotton flow sensor. Output signals of the sensor were very strongly correlated with the weight of cotton that passed across the sensor. In Figure 5, the output signal was the sum of the signals from channel-1 and channel-2 of the sensor. It showed that the sum of the output signal was very strongly correlated to conveyed cotton weight with a  $R^2$  of 0.99. The output signal in Figure 6 was the sum of the signal from channel-1 only. The output signal in Figure 7 was the sum of the signal from channel-2 only. Signals from both individual channels had a very high linear correlation with conveyed cotton weight ( $R^2=0.99$ ). This demonstrated that

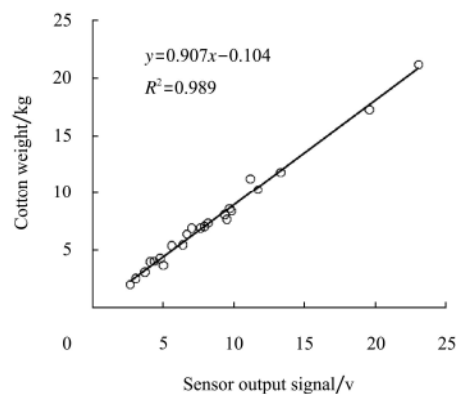


Figure 5 Relationship between cotton weight and the sum of the signals from channels-1 and channel-2 of the sensor

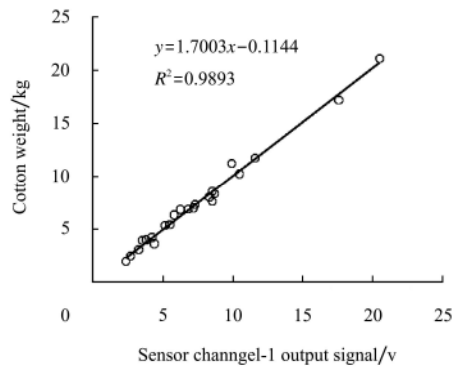


Figure 6 Relationship between cotton weight and the sum of the signal from channel-1 only

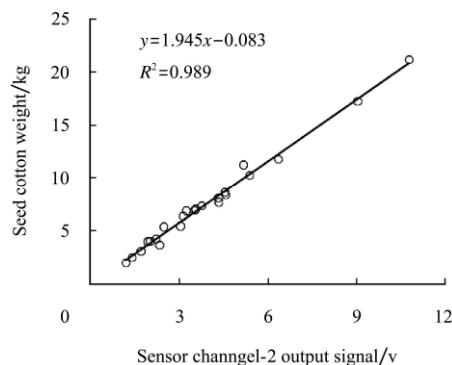


Figure 7 Relationship between cotton weight and the sum of the signal from only channel-2 only

accurate measurements could be obtained by using only one channel of the sensor. Testing results proved that this sensor had great potential as a cotton yield monitor.

#### 4 Conclusions

A cotton-harvester-flow simulator was developed. It consisted chiefly of a centrifugal fan, hopper, cotton feeder, and a cotton picker duct. Ducts of both John Deere and Case-IH cotton pickers fit in the simulator. Adjusting the feeder speed controlled the cotton flow rate, which was calibrated at several feeder speeds. The relationship between the feeder speed setting and the amount of conveyed seed cotton was found to be consistent. A novel optical-reflectance-based mass-flow sensor for cotton yield monitor, developed at Mississippi State University, was evaluated with the simulator. A very strong correlation ( $R^2=0.99$ ) was found between conveyed seed cotton weight and sensor output. During testing of the simulator, it was discovered that a physical change in seed cotton occurs if the cotton is used repeatedly. This change could affect sensor response,

and should therefore be taken into account. Also, stored cotton usually has lower moisture content than field cotton. This moisture difference should be considered when a cotton yield monitor is being calibrated or is being evaluated for dirt-tolerance.

#### Acknowledgements

The authors extend their appreciation to Mr. Daniel Chesser, Mr. Jeff Doler, and Mr. Wade Givens (former Research Associates at Agricultural and Biological Engineering Department of Mississippi State University) for their excellent work in building and testing of this cotton-harvester-flow simulator. This work was conducted when the Drs. Sui and Thomasson were on the faculty at Mississippi State University.

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