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# MISSISSIPPI YIELD MONITOR: PERFORMANCE IN ON-FARM TESTING

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## Abstract

A novel optical cotton yield monitor system has been under development at Mississippi State University since 1999, with laboratory and minimal field testing in that year. The system was field-tested more extensively in the 2000 harvest season. In 2001, the Mississippi cotton yield monitor was improved by adding temperature compensation and anti-stray-light features to the system. Five prototypes of the new version of the cotton yield monitor were fabricated. These prototypes were field-tested on three cotton pickers and two cotton strippers in five different locations across three States, Georgia, Texas, and Mississippi in 2001 season. More than 3,000 acres of cotton, with different varieties, and large yield variability, were harvested with the yield monitors from September to December of 2001. Results from the tests showed that the average absolute error of the system was 3.7% and 4.9% in two fields where system accuracy was evaluated load by load. All yield maps created with the data from the Mississippi cotton yield monitor realistically exhibited yield variations within fields, based on the expectations of experienced producers and consultants. The tests also indicated that the system was reliable, and easy to install, operate, and maintain.

## Introduction

The most important piece of information about a cotton crop, affecting all management decisions, is yield. Knowledge of a crop's yield at specific sites in a field (i.e., a yield map) is critical for the successful implementation of precision agriculture. Yield monitors that incorporate GPS data have been successfully implemented in grain crops, and they have been commercially available for several years. Development of yield monitors for non-grain crops such as cotton has been slow, partially because cotton is an inhomogeneous material. While cotton yield monitors have been commercially available for about four years, they have not been widely accepted in the marketplace, having had problems with installation, accuracy, and maintenance. As precision-agriculture technologies have become more and more widely adopted in cotton production, accurate, reliable, inexpensive and easy operating cotton yield monitors are greatly needed by cotton producers.

### Background

Wilkerson et al. (1994) developed a sensor to measure cotton flow in real time. The sensor performed well in preliminary laboratory tests. This system has been significantly modified since Wilkerson et al. reported it in 1994. Moody et al. (2000) presented the resulting design and accuracy tests of the modified system. The test results were promising, and the modified system was marketed by Ag Leader Technology, Inc. in 2000.

Thomasson et al. (1999) tested two experimental devices for measuring the flow of pneumatically conveyed cotton. The devices were installed on a cotton picker duct and a cotton gin duct. High correlations between sensor output and the weight of passing cotton were reported.

At present, four optically-based cotton yield monitor systems are commercially available. The manufactures are Ag Leader Technology, Inc. (Ames, IA); Farmscan, Corp. (Perth, Western Australia); Micro-Track Systems, Inc. (Eagle Lake, MN); and Zycom/Agriplan, Inc. (Stow, MA). These cotton yield monitors have been evaluated under field conditions (Durrence et. al., 1998; Gvili, 1998; Perry et. al., 2001; Roades et. al., 2000; Sassenrath-Cole et. al., 1999; Searcy and Roades, 1998; Wolak et. al., 1999). Results of these evaluations have varied from excellent to poor. In general, these yield monitors are able to provide some useful information, but they have often had problems with accuracy, reliability, installation, and maintenance.

The cotton-flow sensors in all commercially available cotton yield monitors 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. The light attenuation measurement is then converted by the data acquisition system to an amount of cotton passing the sensor cross-section. The light-emitter array functions as light source, and it consists of LEDs (light-emitting diodes) in some configuration. The light-detector array functions as light receiver, and it consists of photodiodes in some configuration. Each LED in a light-emitter array is lined up with a photodiode in the corresponding light-detector array.

Thomasson and Sui (2000) designed and fabricated a novel optical cotton-flow sensor to be used as part of a cotton yield monitor system at Mississippi State University. The sensor was tested in the laboratory and field in 1999, and more extensively in the field in 2000 (Sui et. al., 2000; Sui and Thomasson, 2001). The results from these tests were promising. In order to further improve the sensor's performance, two new features were added in 2001 (Sui and Thomasson, 2001): temperature compensation and an anti-stray-light feature. The sensor in the Mississippi cotton yield monitor includes energy sources and detectors mounted in one housing unit on the same wall of a picker duct, thus requiring only one port to be cut in the duct for sensor installation. All commercially available cotton yield monitors include one housing for detectors on one side of the duct and one housing for light sources on the opposite side of the duct. Thus, their installation requires two ports to be cut in a duct instead of one, and proper alignment of light sources and detectors. This creates difficulties in installation and possible misalignment over time due to vibration of the sensor; such is not the case with the Mississippi cotton yield monitor.

### Objective

The objectives of the work were to:

1. Evaluate field accuracy of the Mississippi cotton yield monitor
2. Test the Mississippi cotton yield monitor's reliability and ease of use

## Materials and Methods

### System Description

The Mississippi cotton yield monitor consists mainly of optical sensors and a data acquisition box. Each sensor includes energy sources and detectors mounted in one housing unit on the same wall of a picker duct, thus requiring only one port to be cut in the duct. Specific measures to reduce temperature and stray-light effects on sensor performance have been used in the design of the sensor. Sensors detect the cotton flow in the picker duct and provide an output signal to the data acquisition box, which is placed in the picker's cab. The data acquisition box processes and records sensor outputs in real time based on preset algorithms. Yield information is displayed on a screen and stored in a PCMCIA memory card. A Trimble AgGPS 132 receiver has been employed for use with the monitor. The GSA sentence and RMC sentence from the receiver are used to provide PDOP (position dilution of precision), location, and speed data. Location data are differentially-corrected with the signal from the nearest U.S. Coast Guard beacon station. The system's data acquisition box directly reads data from the DGPS receiver. Five prototypes of the Mississippi cotton yield monitor were fabricated for field testing.

### System Installation

The two sensors (typical configuration) of the cotton yield monitor were installed on the middle section of two ducts of a picker. In the stripper, two sensors were mounted at strategic locations on the collective "chute." Only one 3-in. diameter hole was cut in the duct or chute for each sensor installation. In a picker, the hole was made at the bottom of the duct. In the stripper, the hole was cut at the back side of the chute.

The data acquisition box was affixed on the wall inside the harvester's cab. Each sensor was connected to the data acquisition box through a 25-ft long cable. The Antenna of the DGPS receiver was mounted on the top of the cab, and the receiver's output was connected to the data acquisition box so that location information could be collected.

### Test Procedures

The five Mississippi cotton yield monitor prototypes were tested separately in different places across southern Georgia, the Delta region of Mississippi, and western Texas. Three monitors were tested in cotton pickers, and two in cotton strippers.

For measurement to be as accurate as possible early in the harvest day, it was recommended that the yield monitor be turned on 20 minutes before harvesting to allow the system to "warm-up." Sensors were cleaned once per day during the harvester's routine maintenance, usually early in the morning before picking.

The first prototype Mississippi cotton yield monitor was tested in southern Georgia. About 125 acres in three fields were harvested with a four-row-picker (John Deere Model 9965) from November to December, 2001. The second and third prototypes were evaluated in the Mississippi Delta. One of them was installed in a four row picker (John Deere Model 9965). About 1200 acres of cotton in five fields were harvested with that unit. The other unit was tested with another John Deere four-row picker, and 1500 acres over 18 fields were harvested. The harvesting period in this location was from

September to December of 2001. The fourth prototype was tested in a cotton stripper in South Georgia. About 100 acres had been harvested at the time of this writing. The fifth prototype was installed in another cotton stripper in Lubbock, Texas. About 100 acres of experimental cotton plots and fields were harvested in December of 2001.

In order to investigate the accuracy of the system, the performance of the first prototype was tested on a per-basket-load basis. Three fields were harvested: experimental field, commercial field 1, and commercial field 2. The experimental field included about 41 acres of some 90 experimental plots with more than 20 different cotton varieties. The basket-load was weighed with a boll buggy equipped with a load cell weighing system. Commercial field 1 included about 37 acres, while commercial field 2 included about 47 acres. A high degree of yield variability was present in commercial field 1. The plants ranged in height from roughly 2 to 5 ft. Commercial field 2 was generally a low yielding field. In both commercial fields, cotton basket weight was measured with five truck scales (Model PT300, Intercomp) on which a boll buggy was placed. After the cotton in the picker's basket was dumped into the boll buggy, weight values shown on the five scales were recorded and summed to obtain a total weight for the basket. After emptying the basket, the scales were set to zero. A computer file was created within the data acquisition box to store yield monitor sensor output data corresponding to each basket load, so that predicted cotton weight could be calculated. Seventeen loads were weighed in commercial field 1. One load's data file was not considered in the analysis due to the fact that the morning "warm-up" time required by the system had not been met. Thus, in commercial field 1, data from 16 loads were used in the analysis. Sixteen loads were weighed in commercial field 2, and all associated data files were included in the analysis. Two commercial cotton yield monitor systems were also evaluated in the same picker along with the prototype Mississippi cotton yield monitor. While results for the other two systems may be reported later by the cotton yield monitor evaluation team at the University of Georgia, only the results with the Mississippi yield monitor are presented here.

In order to evaluate long-term reliability and ease of use in cotton pickers and strippers, the Mississippi yield monitor's performance was tested in Mississippi by considering ease of installation, ease of operation, and problems encountered in a commercial operation.

**Yield Maps**

Yield maps were created in Arcview for all the picker-harvested fields in Georgia and Mississippi. The data from the two prototype yield monitors in the Mississippi Delta were "pre-calibrated" with three consecutive loads harvested in the first of the day. These basket loads were weighed by emptying the cotton into a cotton wagon that had been placed on a set of four scales (Model PT300DW, Intercomp). To calculate a coefficient for calibration, the actual cotton weight was divided by the corresponding integrated sensor output. On the picker-harvested fields in Georgia, the total weight in the field was used to calibrate, or post-correct, the data prior to making yield maps. Ultimately, the data obtained from Mississippi, and from the stripper-harvested fields in Georgia and Texas, will be post-corrected with total gin weight on a per-field basis.

**Calibration**

A cotton yield monitor system's accuracy system is directly dependent on the calibration method. Based on the authors' experience, it is believed that cotton yield monitors should be calibrated in each field to maintain high accuracy. In an actual production situation, however, producers are usually unwilling to devote much time to calibration, which is generally done by weighing the first three to five loads in a field. This is especially true when small fields are involved. Most producers will calibrate the system once at the beginning of the harvesting season. For the load-by-load accuracy evaluation, the method used to calibrate the Mississippi cotton yield monitor was based on post-correction with known field weights. This method uses the total field weight as measured at the gin, and the integrated sensor output for the field, to calculate a ratio of cotton weight to sensor output, which is known as the calibration coefficient. Yield at each field location can be calculated with the calibration coefficient. This calibration method is the most accurate one for developing yield maps, and it is also practical for management decisions based on yield data. On the other hand, some producers like to see a measure of yield in real time. This requirement can be satisfied by using an estimated calibration coefficient derived from a few basket-load weights at the beginning of the season. This would allow the producer to have a display of estimated yield in real time, although a real-time estimate would be significantly less accurate than the value after post-correction.

## Results

Tables 1 and 2 include the results of field tests in South Georgia. The average absolute error was 3.7% in commercial field 1, and it was 4.9% in commercial field 2. Figures 1 and 2 depict the relationships between the weight predicted by the Mississippi yield monitor and the scale weight in commercial fields 1 and 2, respectively. In both fields the predicted weight was very strongly correlated with the scale weight, with $R^2$ values of 0.97 and 0.96 for commercial fields 1 and 2, respectively. Figure 3 is the yield map of commercial field 1. It is apparent from figure 3 that yield in commercial field 1 varied greatly, with an average of 1734 lb/ac (seed cotton). The yield map of commercial field 2 is shown as figure 4. Commercial field 2 had an average yield of 1627 lb/ac seed cotton.

The average yield of the experimental field was 2182 lb/ac. Ninety loads were harvested in that field. The load by load information from the experimental field, and the comparison of the Mississippi yield monitor with commercial yield monitors, may be reported later by the cotton yield monitor evaluation team at the University of Georgia. Figure 5 is the yield map of the experimental field. The map related well to known yield variations caused by different experimental treatments and different varieties grown in the field.

During a two-month harvesting season with two Mississippi cotton yield monitor systems, more than 2700 acres of cotton were harvested in 23 fields in the Mississippi Delta. Cotton yield maps of all fields harvested were created with the data from the yield monitors. All maps realistically exhibited the yield variations within the field, according to the producer's expectations regarding information such as soil type, soil moisture, soil fertility, etc. The producers and a related consulting agency have drawn useful information from the yield maps for guiding future production management. Figure 6 is an example of the yield maps in Mississippi Delta. During the harvesting season, the Mississippi yield monitor worked continuously at least 8 hours per working day, and the system performed well, with very high reliability. The only problem that occurred was a loose cable connection in the second monitor set. This was caused by the daily opening of the data acquisition box for retrieving data from a data card. The problem was solved by making a slot in one side of the data acquisition box so that the data card could be removed without opening the box.

Detailed information about the tests on stripper harvesters was not available at the time of this writing. However, the systems in the strippers had performed well, with no operating problems observed so far. One map of field variability was created with data from a stripper-harvested field in South Georgia, but no calibration data were available, so the map could not be related to yield. On the other hand, the variability map was in line with expectations of the producer's consultant.

## Summary and Conclusions

Mississippi State University has been developing a novel cotton yield monitor system since 1999. Five prototypes of the Mississippi cotton yield monitor were field-tested in Georgia, Texas, and Mississippi in the 2001 season. Three of them were tested in cotton pickers, and the other two were tested in cotton strippers. In the picker test in Georgia, the yield monitor's accuracy was evaluated load by load in three fields, with results from two of those fields reported herein. Average absolute error of the system was less than 5% in both fields. Tests of system reliability on pickers in Mississippi indicated that the system was reliable and easy to operate. All yield maps created with the system realistically exhibited yield variations within fields. The systems tested in strippers performed well and reliably also. Overall, the Mississippi cotton yield monitor demonstrated ease of installation and operation, and high accuracy and reliability.

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Table 1. Results of the test in commercial field 1 on the picker in Georgia, November 19-20, 2001.

| **Load No.** | **Scale (lb)** | **Monitor (lb)** | **Error (%)** |
|---|---|---|---|
| 1 | 4890 | 5196 | +6.3 |
| 2 | 4605 | 4575 | -0.7 |
| 3 | 4315 | 4102 | -4.9 |
| 4 | 3705 | 3575 | -3.5 |
| 5 | 3380 | 3103 | -8.2 |
| 6 | 3455 | 3434 | -0.6 |
| 7 | 3325 | 3310 | -0.5 |
| 8 | 3785 | 3587 | -5.2 |
| 9 | 3800 | 3690 | -2.9 |
| 10 | 3890 | 3797 | -2.4 |
| 11 | 3535 | 3439 | -2.7 |
| 12 | 3970 | 3957 | -0.3 |
| 13 | 3765 | 3960 | +5.2 |
| 14 | 4445 | Improper warmup | N/A |
| 15 | 1585 | 1610 | +1.6 |
| 16 | 5620 | 6265 | +11.5 |
| 17 | 880 | 904 | +2.8 |

Average absolute error: 3.7%.

Table 2. Results of the test in commercial field 2 on the picker in Georgia, November 27-29, 2001.

| Load No. | Scale (lb) | Monitor (lb) | Error (%) |
|---|---|---|---|
| 1 | 5700 | 5469 | -4.1 |
| 2 | 3700 | 3854 | +4.2 |
| 3 | 5570 | 5581 | +0.2 |
| 4 | 5565 | 5944 | +6.8 |
| 5 | 5945 | 6195 | +4.2 |
| 6 | 6070 | 6220 | +2.5 |
| 7 | 6400 | 6432 | +0.5 |
| 8 | 4305 | 4217 | -2.0 |
| 9 | 4125 | 3704 | -0.2 |
| 10 | 4710 | 4192 | -1.0 |
| 11 | 5585 | 5431 | -2.8 |
| 12 | 4045 | 4180 | +3.3 |
| 13 | 4235 | 3917 | -7.5 |
| 14 | 4425 | 4555 | +2.9 |
| 15 | 4365 | 4793 | +9.8 |
| 16 | 1005 | 1064 | +5.8 |

Average absolute error: 4.9%.

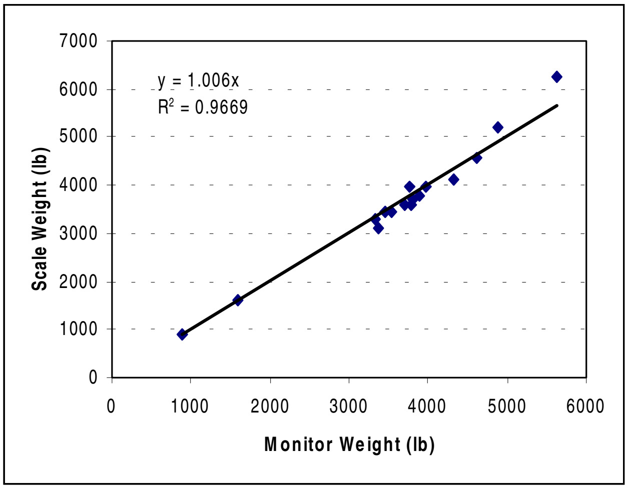


Figure 1. Correlation between the monitor weight and scale weight in commercial field 1.

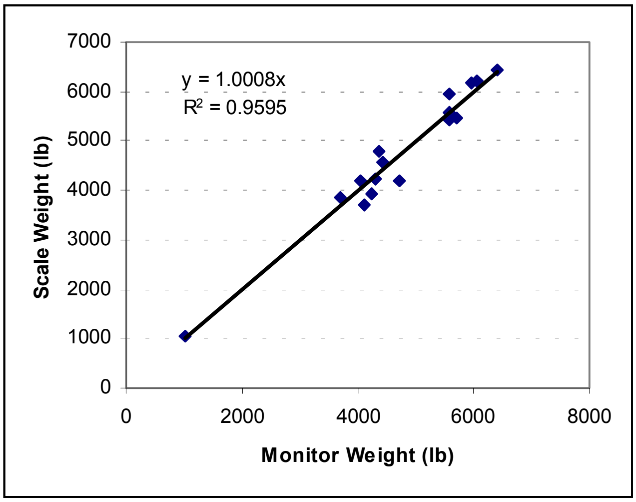


Figure 2. Correlation between monitor weight and scale weight in commercial field 2.

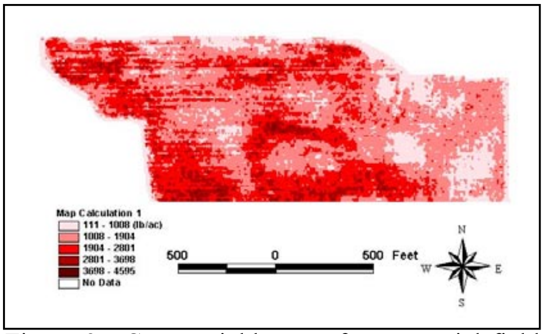


Figure 3. Cotton yield map of commercial field 1. The 37-ac field had an average yield of 1734 lb/ac.

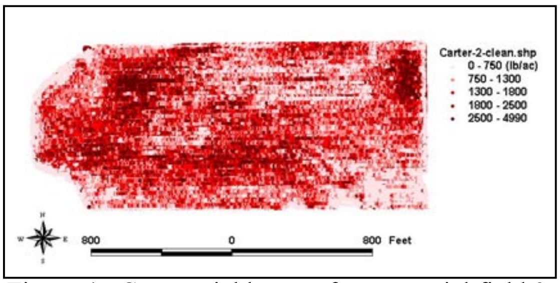


Figure 4. Cotton yield map of commercial field 2. This 47-ac field had an average yield of 1627 lb/ac.

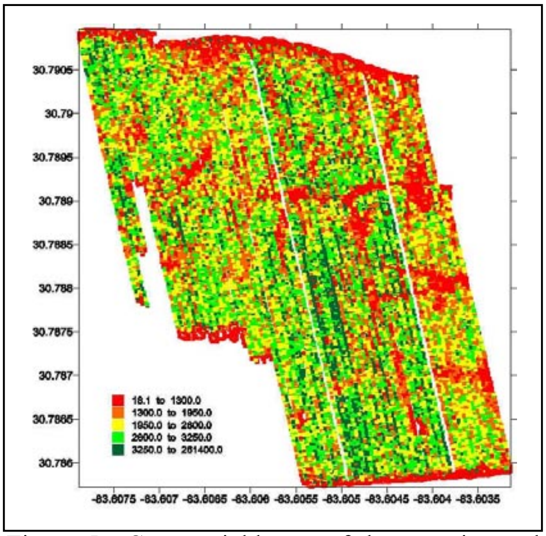


Figure 5. Cotton yield map of the experimental field in South Georgia. This 41-ac field had and average yield of 2182 lb/ac.

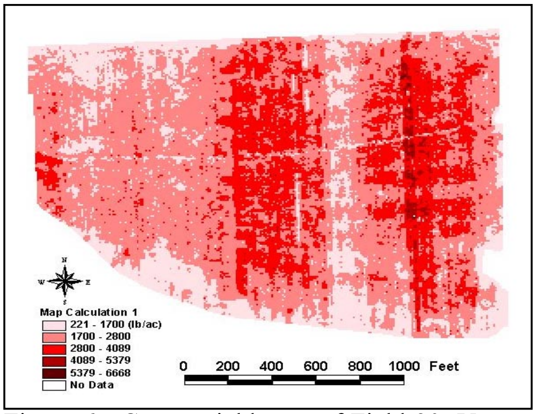


Figure 6. Cotton yield map of Field-30, Vance, Mississippi. This 66-ac field had an average yield of 2305 lb/ac.