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INSTANTANEOUS ACCURACY OF COTTON YIELD MONITORS

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Abstract

One of the first questions potential yield monitor users ask is "What is the accuracy of the system?" The trick is to understand how accuracy is defined. Instantaneous accuracy is the accuracy of each yield data point which is difficult to measure. Load accuracy is the accuracy over a basket load of cotton. Field accuracy or field error is the accuracy over an entire field. Field accuracy is most commonly used by sales people when discussing a yield monitor because it is usually the smallest number of the three. This occurs because over an entire field, measurement errors average themselves out. In a study to evaluate the instantaneous accuracy of cotton yield monitors, we bagged and weighed cotton passing by three commercially available cotton yield monitors for 3, 5, and 7 second intervals which corresponded to 15.6, 26.0, and 36.4 ft of travel, respectively. We then compared the weights of the bagged cotton to the yield recorded by the yield monitors for that same interval. We found that instantaneous accuracy was not affected by yield or by the 3 harvest intervals we selected. Accuracy errors ranged from 0% (remarkable) to 40%. In general, most yield monitor readings were within 15% of the bagged weights.

Introduction

Precision farming is a catch-all term for techniques, technologies, and management strategies aimed at addressing within-field variability of parameters that affect crop growth. These parameters may include soil type, soil organic matter, plant nutrient levels, topography, water availability, and pest pressure. Now, technological breakthroughs in the miniaturization of computer technology, development of new sensors and detectors, and public access to GPS allow us to better address within-field variability with precision farming.

The most essential component of precision farming is the yield monitor – a sensor or group of sensors installed on harvesting equipment that dynamically measures spatial yield variability. Typically, yield measurements are combined with accurate location data, provided in the form of latitude and longitude by a GPS receiver with differential correction (DGPS), to create a yield map. Yield maps are extremely useful in providing a visual image which shows the variability of yield across a field. Yield maps can be viewed as both the entrance and the final exam for precision farming: as an entrance exam because yield maps can be used to determine if there is enough variability to justify the use of precision farming; as a final exam because they can subsequently be used to determine if the investment in precision farming was worthwhile.

Because cotton is entirely machine harvested in the United States, it lends itself well to the use of machine-mounted yield monitors. Currently there are four commercially available cotton yield monitors – Ag Leader®, AGRIplan®, FarmScan®, and Micro-Trak®. Perry et al., 1998; Searcy and Rhodes, 1998; Durrence et al., 1999; Khalilian et al., 1999, Sassenrath-Cole et al., 1999; Wolak et al., 1999, Perry et al., 2001; and Wilkerson et al., 2002 reported on one or more of these systems. The Mississippi Cotton Yield Monitor (MCYM) (Thomasson and Sui, 2000; Sui and Thomasson, 2001; 2003) is currently in beta testing and is expected to be commercially available in the near future. Vellidis et al. (2003) presented an in-field assessment of all five of these systems.

How Cotton Yield Monitors Work

All currently available cotton yield monitors use optical sensing techniques to measure yield. The sensors consist of 2 parts – a light emitting component and a light sensing component. In the Ag Leader®, AGRIplan®, FarmScan®, and Micro-Trak® systems, the 2 components are mounted on opposite sides of a cotton picker's delivery duct such that cotton passing between the emitter and receiver pair reduces transmitted light. The measured reduction in light is converted to pounds of cotton by a calibration formula unique to each yield monitor. In the MCYM sensor, both components are located in the same housing on one side of the duct. This sensor relies on light reflected by cotton passing through the duct.

Sensors may be installed on 2, 4 or 6 ducts. Cables from the sensors on the ducts lead to the cab of the picker where a user interface console is installed. The console receives and processes data from the sensors, displays yield information and stores the data for later use (Vellidis et al., 2003).

Yield Monitor Accuracy

One of the first questions potential cotton yield monitor users ask is “What is the accuracy of the system?” The issue is to understand how accuracy is defined. Field accuracy or field error is the accuracy over an entire field. Field accuracy is most commonly used by sales people when discussing a yield monitor because it is usually the smallest number of the three. This occurs because over an entire field, measurement errors average themselves out. Load accuracy or load error is the accuracy over a basket load of cotton. Instantaneous accuracy is the accuracy of each yield data point and is very difficult to measure.

Vellidis et al. (2003) reported on a plot test designed to investigate the instantaneous accuracies of the AGRIplan and Micro-Trak systems. Although they found high correlation between the yield monitor data and bagged cotton weights, yield monitor data consistently underestimated bagged yields by about 23%. They attributed these differences to a plot edge effect caused by yield monitoring systems’ data smoothing algorithms. This paper presents the results of recently completed tests designed to assess the instantaneous accuracy of three cotton yield monitoring systems.

Materials and Methods

Cotton is mechanically harvested when most of the cotton bolls are open and the leaves have fallen off the stalk. Most modern cotton pickers can simultaneously harvest 4 or more rows of cotton. A picking unit containing the equipment used to remove the cotton bolls from the stalks is dedicated to each row of cotton. As the harvester’s picking unit approaches a cotton stalk, the geometry of the unit and pressure plates force the plant into the picking zone and hold it so that the spindles which remove the cotton bolls from the stalks can come into contact with the lint. The lint, which also includes cotton seeds, is grabbed by the spindles, pulled off the stalk, and transported by a high velocity airstream through a delivery duct or chute into the collection basket of the cotton picker. Because there is very little mixing of the lint within the picking unit during harvest, yield sensors located on the delivery chutes can measure yield almost instantaneously without the complicating factor of convolution encountered by grain and peanut combines (Boydell et al., 1999; Vellidis et al., 2001).

Experimental Design

For the instantaneous accuracy test, we attempted to obtain (by purchasing or upgrading) the newest version of each of the four commercially available cotton yield monitoring systems. For various reasons, we were only able to obtain functional versions of the Ag Leader and AGRIplan systems. We also were loaned the latest version of the MCYM.

We equipped two ducts of a John Deere 9965 4-row cotton picker with sensors from each of the systems. Ag Leader and MCYM sensors were installed on ducts 1 and 3. AGRIplan sensors were installed on ducts 2 and 4 (fig. 1). The user interface consoles of all three systems were installed in the cab of the cotton picker. A single Trimble Ag132 DGPS receiver was used to provide a GPS signal to the three systems.

Sheet metal bagging mechanisms which allowed us to capture and bag the cotton flowing from each duct were designed, fabricated, and installed in the cotton picker (fig. 2). In the default or open position, the bagging mechanisms allowed cotton to flow throw them as if they were not there (fig. 3). When an internal, spring loaded metal flap was manually engaged (closed position), cotton was diverted downwards into a hanging, loosely woven bag (fig. 4). When the flap was disengaged, the spring rapidly returned the flap to the open position. The bagging mechanisms were manually controlled which required coordination between the operators to ensure that bagging began and ceased simultaneously at all the ducts. To achieve this, two lights was installed on the bagging mechanisms (fig. 2). When the lights were illuminated, bagging began. When the lights went out, bagging ceased. After a little practice, the bagger operators were able to synchronize their actions and respond to the light very quickly.

The intent of the study was to compare the yield monitor yields and bagged yields from the shortest possible harvest interval. Because most yield monitors record data at 1s intervals, in theory, 1s was the shortest possible interval available for comparison. In reality, this was impossible to achieve since the baggers were manually operated. After extensive time trials, we concluded that 3s was the shortest achievable sampling interval. For comparison purposes, we also added sampling intervals of 5s and 7s.

Measuring Instantaneous Accuracy

A 32 ac irrigated field in Colquitt Co., Georgia was selected for the study. The field was scouted prior to harvest and four 4-row strips of cotton which contained high, medium, and low yielding segments were identified and flagged. Each strip was 1000 to 1200 ft long. The authors have worked extensively in this field over a number of seasons and have a good understanding of the field’s inherent soil and yield variabilities.

Prior to beginning harvest, the sensors for the three yield monitors were cleaned and the systems were tested for operational readiness. The first two basket loads were weighed using a boll buggy and truck scales and were used to calibrate the Ag Leader and AGRIplan systems. Two additional basket loads were weighed to provide a check to ensure the calibration of each system remained acceptable. Then the remainder of the field was harvested leaving only the 4 strips for the instantaneous accuracy experiment. All three yield monitors were operational throughout this phase of the harvest.

Because the field was relatively high yielding, priority was given to centering at least one sampling area or plot in an obviously low yielding segment of each strip. The other plots within each strip were delineated relative to the position of the low yielding plot. The plots were delineated with flags and in no way segregated from the surrounding cotton. Five replicates of each harvest interval were randomly established within the four strips with the exception that at least one 3, 5, and 7s plot was located within a low-yielding segment. A total of 16 plots were harvested.

Harvest speed of the cotton picker was measured at 3.55 mph or 5.2 ft/s. Harvest intervals of 3, 5, and 7s correspond to travel distances of 15.6 ft, 26.0 ft, and 36.4 ft, respectively. To avoid the edge effects associated with the initiation or termination of cotton flowing past the yield monitor sensors described by Vellidis et al. (2003) , we added 100 ft buffers to either side of the plots.

We harvested the plots using the following sequence: We stopped the picker 100 ft from the plot at which point we hung empty bags from the baggers and began logging data. We then began harvesting the buffer. As the picking units reached the flag delineating the beginning of the plot, a team member in the picker cab switched on the bagging light and the baggers were set to the closed position at which point all incoming cotton was diverted to the bags. Once the picking units reached the flag delineating the end of the plot, the bagging light was switched off and we stopped bagging but continued to harvest and collect data for another 100 ft. At this point we stopped the picker, ended data collection, and tagged and removed the bags from the baggers. We estimated that the elapsed time between when the picking units reached the edge of the plot and bagging began to be approximately the same as the time required for the first bolls from the plot to reach the bagging mechanism. Before continuing on to the next plot, empty bags were hung on the baggers and appropriate steps were taken to segregate the most recently collected yield monitor data set from the next data set. The plots were all harvested in the same direction (from north to south) to minimize complications with stray light entering the ducts and interfering with sensor readings.

Immediately following harvest, the bags were weighed to within a 10th of a pound using a calibrated scale with a digital display. The GPS coordinates (latitude and longitude) of the plot boundaries were recorded using the same Trimble Ag132 DGPS receiver. The yield monitor sensors were inspected prior to the beginning of the experiment and were observed to be free of trash and excessive dust build-up. At this point, the sensors had been used over approximately 30 ac since being installed. The sensors were not wiped clean because we wanted to quantify yield monitor performance under harvest conditions.

Yield monitor data were assigned to the plots by matching the manually collected GPS coordinates for the start and end of each plot to GPS coordinates in the yield monitor data files. Because the yield monitors were not entirely synchronized with the boundaries of the plots, on occasion 4, 6, or 8 rather than 3, 5, or 7 yield monitor data points fell within the bounds of the manually collected GPS coordinates. If this occurred, we began with the datum closest to the end of the plot and worked backwards to accumulate the appropriate number of data points. Yield monitor "weights" were determined by multiplying yield monitor "yields" by the area covered in 1 second. Bagged "yields" were determined by dividing bagged "weight" by the area covered in 1 second.

Results

To verify that the three yield monitor systems were working properly prior to harvesting the test plots, each was operated as the field (minus the four aforementioned strips) was harvested. Weights for each harvested load were recorded for the Ag Leader and AGRIplan systems. The MCYM did not provide weight values on the user interface, therefore, these values were extracted from the resulting data files. Truck scales and a boll buggy were employed to determine the true weights of four of the first five harvested loads (Table 1). These four weight comparisons indicated the systems were working satisfactorily. The total weight harvested (from gin module weights) was 88960 lbs over 30 acres for an average yield of 2965 lb/ac. From Table 2, we see that the yield monitor systems each had acceptable total yield values. It should be noted that the MCYM was calibrated using total field weight whereas the Ag Leader and AGRIplan systems used only the first two loads for calibration.

Figures 5 - 7 show the yield maps from the data of the three yield monitors with the yield values divided over four categories representing equal numbers of data points in each category. The Ag Leader and AGRIplan yield maps tend to better characterize the known high and low yielding areas in the field as compared to the MCYM map. The white strips in the three maps are where the instantaneous accuracy test was conducted.

The results of the instantaneous tests are given in Tables 3 and 4 and Figures 8 and 9. The MCYM data was not included after the system developers pointed out that their system records one data point in every 1.278 seconds, rather than once per second like the other two systems.

From Table 3 and Figures 10 and 11, it appears that plot weights from both the Ag Leader and AGRIplan systems corresponded quite well to plot bagged weights, with each having r^2 values of 0.90. However, in Table 4 and Figures 12 and 13, one can see that the yield monitor "yields" did not correspond to bagged "yields" as closely, with r^2 values of 0.77 and 0.78.

To aid in determining if instantaneous accuracy was influenced by plot length, harvested weight, or yield level, Figures 14 - 16 present the instantaneous test results in terms of these three values versus yield error. In Figure 14, it appears that the harvest interval length (plot length) had no major affect on instantaneous accuracy. In Figures 15 and 16, the yield errors of both systems seem to diminish slightly as bagged weight/yield increased, with the lowest yielding plots (in the shaded rows of Tables 3 and 4) having some of the highest yield errors. However, this is simply an observation and statistical tests must be performed before any effects/patterns can be ruled out.

Conclusions

The three yield monitoring systems tested in this study proved to be quite accurate at the field and load scales, with most errors less than 10%. The yield maps produced from the data collected by each system reflected known features in the test field. However, the Ag Leader and AGRIplan systems appeared to better characterize known high and low yielding areas.

As anticipated, testing the instantaneous accuracy of these systems proved to be quite a challenge. Because of a data collection interval different from that assumed during the experiment's design, the MCYM system was not included in the instantaneous testing phase of this project. For the Ag Leader and AGRIplan systems, we found that instantaneous accuracy was not affected by yield or by the 3 harvest intervals we selected. Accuracy errors ranged from 0% (remarkable) to over 40%. In general, most yield monitor readings were within 15% of the bagged weights. Additional statistical tests will need to be performed on these data sets to "officially" rule out any effects.

Acknowledgments

We wish to thank our grower partners – Louie Perry and Tony Laster who allowed us to conduct our research on their farm. Rodney Hill and Andrew Knowlton designed and fabricated the bagging mechanisms and they and Dewayne Dales, Terrell Whitley, and Gene Hart assisted with the harvest. Their contributions were essential to the success of the project. Finally, we wish to thank Cotton, Inc. and the Georgia Research Alliance for funding this project.

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Table 1. Load weights from four of sixteen harvested loads.

Load	Area (ac)	Scale Weight (lb)	Ag Leader		AGRIplan		MCYM	
			Weight (lb)	Error (%)	Weight (lb)	Error (%)	Weight (lb)	Error (%)
1	1.78	5195	5152	-0.83	4845	-6.74	5512	6.10
2	1.23	3325	3389	1.92	3440	3.46	3916	17.77
3	1.52	3940	4007	1.70	3863	-1.95	4274	8.48
5	1.85	4925	4994	1.40	5410	9.85	5870	19.19

Table 2. Total weights for the sixteen harvested field loads.

System	Total Weight (lbs)	Error (%)	Avg Yield (lb/ac)
From Modules	88960	n/a	2965
Ag Leader	81986	-7.84	2709
AGRIplan	84517	-4.99	2785
MCYM	88811	-0.17	2736

Table 3. Bagged and yield monitor weights for 16 test plots. Low yielding areas shaded.

Plot	Plot Size in terms of Time (s) and (Distance (ft))	Bagged Weight (lb)	Ag Leader		AGRIplan	
			Weight (lb)	Error (%)	Weight (lb)	Error (%)
1	5 (26.0)	22.7	20.3	-10.4	23.0	1.5
2	3 (15.6)	12.4	13.6	10.0	14.0	13.3
3	7 (36.4)	12.1	12.6	4.5	15.8	31.0
4	3 (15.6)	12.3	12.3	0.3	12.2	-0.5
5	3 (15.6)	11.8	12.5	6.3	12.6	7.1
6	3 (15.6)	12.2	13.3	9.4	10.4	-14.5
7	5 (26.0)	9.7	13.6	40.6	11.0	13.8
8	7 (36.4)	22.2	26.6	20.0	19.6	-11.6
9	3 (15.6)	11.4	12.5	10.0	14.7	29.4
10	5 (26.0)	21.8	21.2	-2.6	23.3	7.1
11	3 (15.6)	6.3	8.7	39.0	4.2	-32.9
12	7 (36.4)	26.6	25.4	-4.4	28.2	6.2
13	5 (26.0)	22.3	20.3	-8.8	26.5	19.0
14	7 (36.4)	21.3	18.7	-12.0	28.7	35.0
15	7 (36.4)	28.9	25.2	-12.7	32.6	12.9
16	5 (26.0)	18.6	18.0	-3.0	18.6	0.2

Table 4. Bagged and yield monitor yields for 16 test plots. Low yielding areas shaded.

Plot	Plot Size in terms of Time (s) and (Distance (ft))	Bagged Yield (lb/ac)	Ag Leader		AGRIplan	
			Yield (lb/ac)	Error (%)	Yield (lb/ac)	Error (%)
1	5 (26.0)	3164	2839	-10.3	3207	1.4
2	3 (15.6)	2876	3172	10.3	3260	13.3
3	7 (36.4)	1203	1258	4.6	1574	30.9
4	3 (15.6)	2853	2864	0.4	2842	-0.4
5	3 (15.6)	2736	2918	6.6	2930	7.1
6	3 (15.6)	2830	3096	9.4	2429	-14.2
7	5 (26.0)	1350	1905	41.1	1530	13.3
8	7 (36.4)	2210	2652	20.0	1951	-11.7
9	3 (15.6)	2643	2918	10.4	3419	29.3
10	5 (26.0)	3038	2960	-2.6	3258	7.2
11	3 (15.6)	1457	2017	38.5	974	-33.1
12	7 (36.4)	2649	2537	-4.2	2817	6.4
13	5 (26.0)	3108	2829	-9.0	3705	19.2
14	7 (36.4)	2120	1868	-11.9	2858	34.8
15	7 (36.4)	2879	2514	-12.7	3252	13.0
16	5 (26.0)	2591	2511	-3.1	2598	0.3

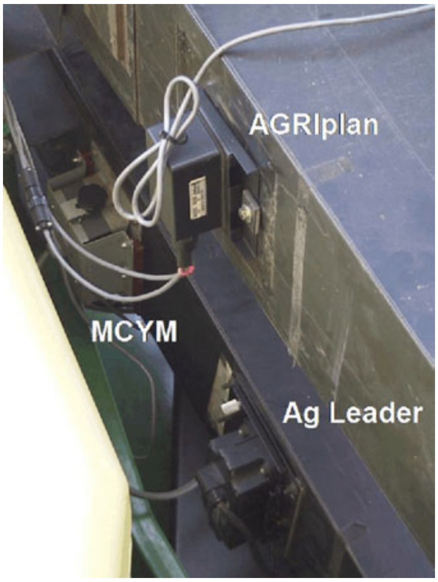

Figure 1. AGRIplan sensor on duct 4 and MCYM and Ag Leader sensors on duct 3.

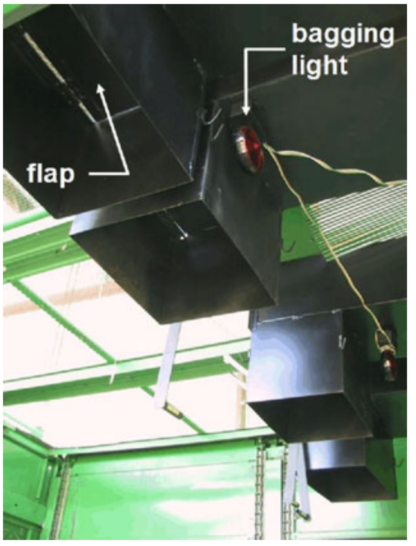

Figure 2. Bagging mechanisms installed on each of the four ducts.

Figure 3. Baggers in the open position with cotton flowing through.

Figure 4. Baggers in the closed position with cotton flowing into bags.

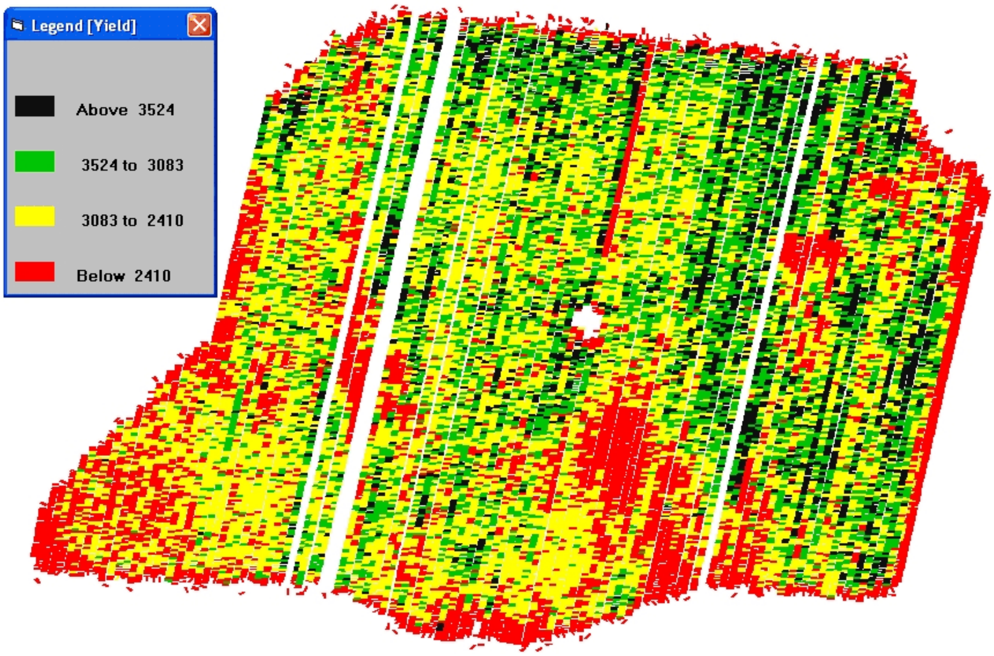

Figure 5. Yield map from data collected by AGRIplan yield monitor.

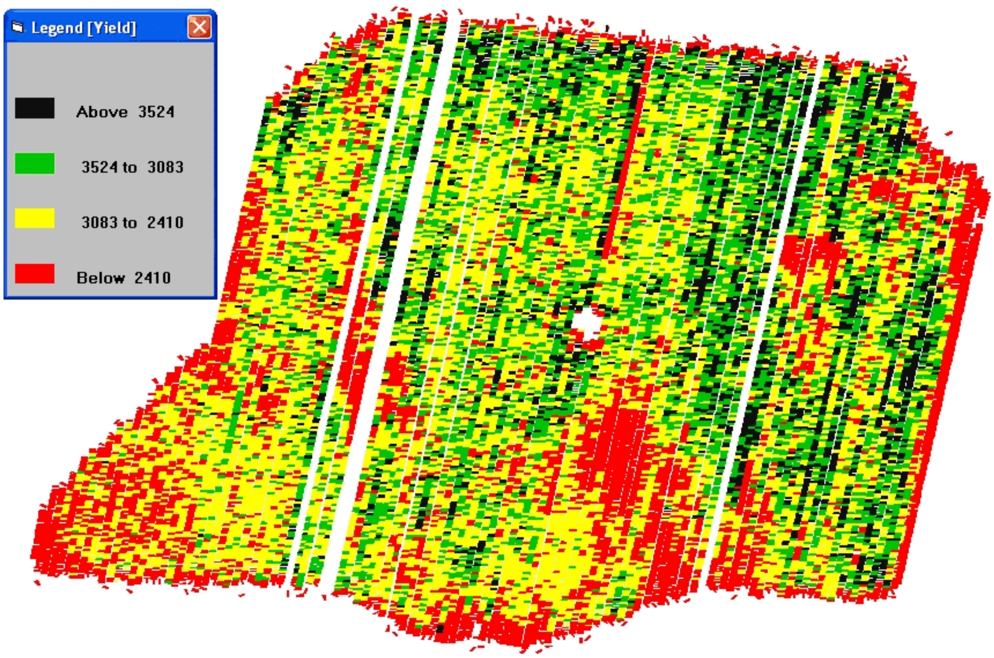

Figure 6. Yield map from data collected by AGRIplan yield monitor.

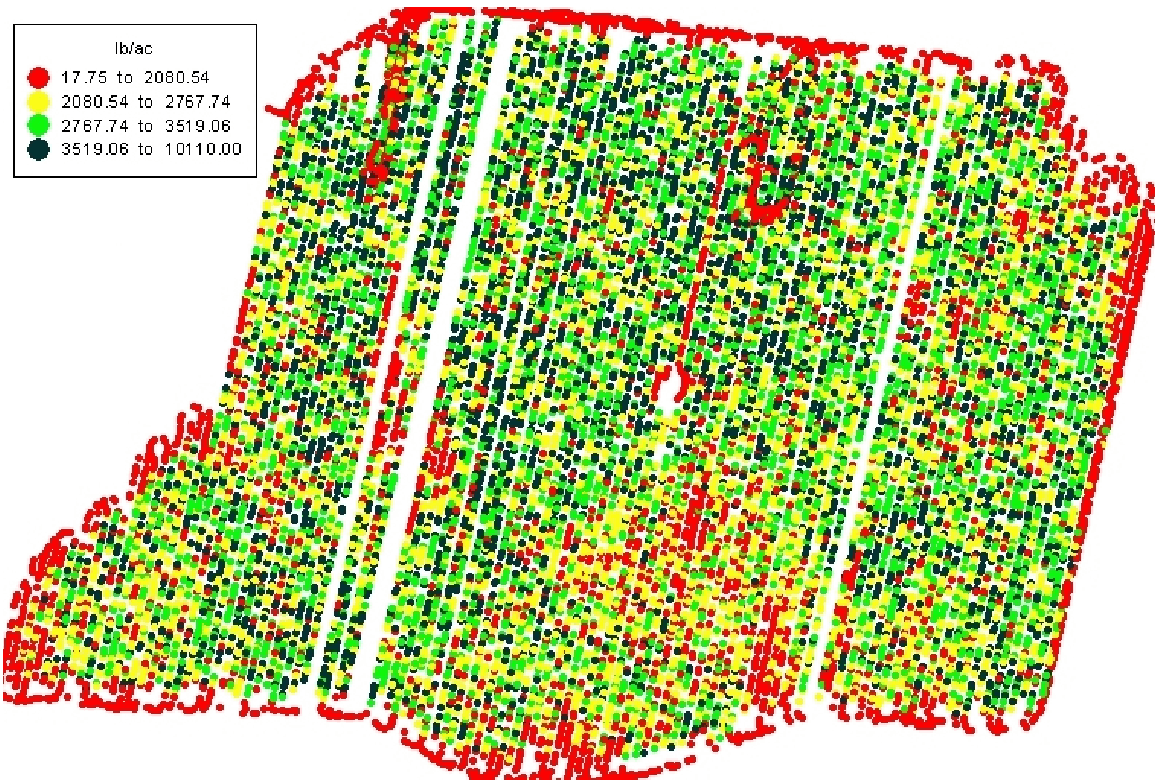

Figure 7. Yield map from data collected by MCYM yield monitor.

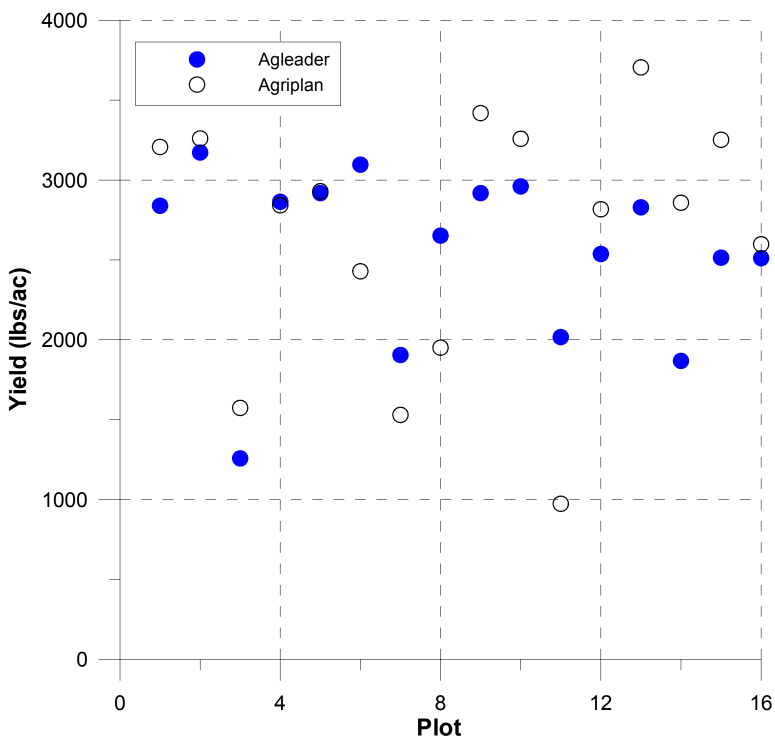

Figure 8. Yield determined by Ag Leader and AGRIplan yield monitor system for each instantaneous test plot.

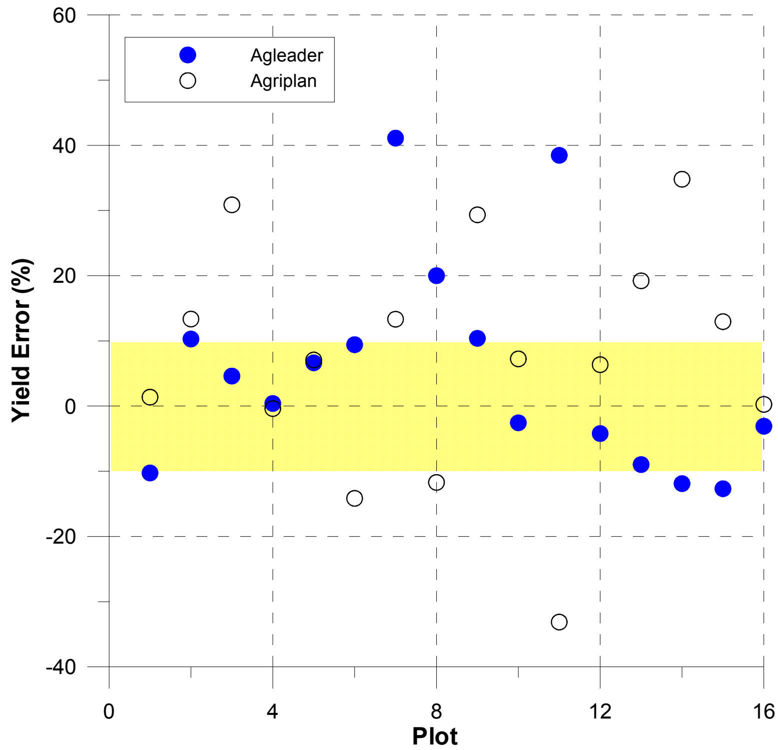

Figure 9. Error in yield determined by Ag Leader and AGRIplan yield monitor system for each instantaneous test plot.

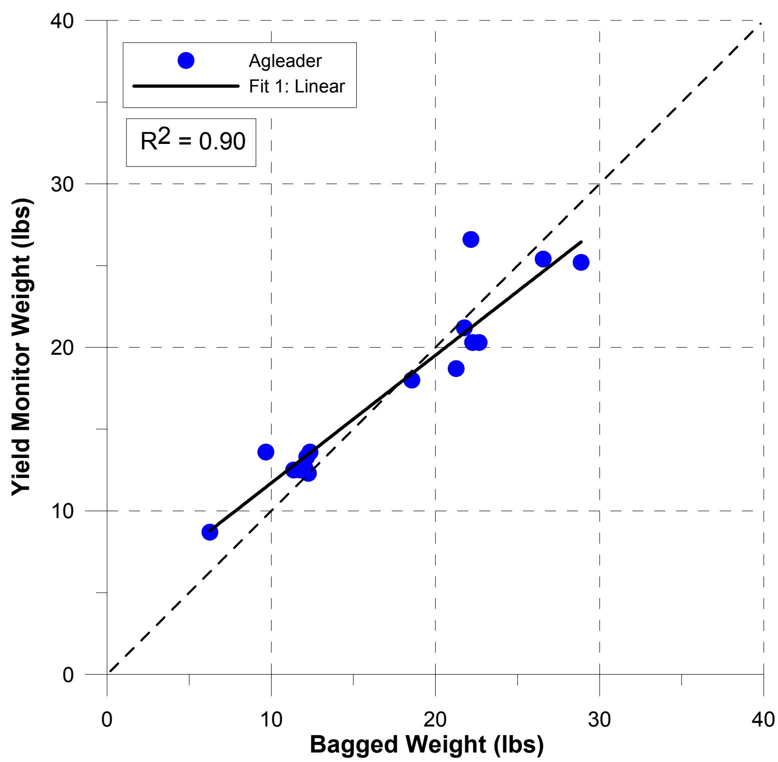

Figure 10. Comparison of Ag Leader weight to weight from bagged cotton in test plots. The diagonal dashed line represents 1:1 agreement.

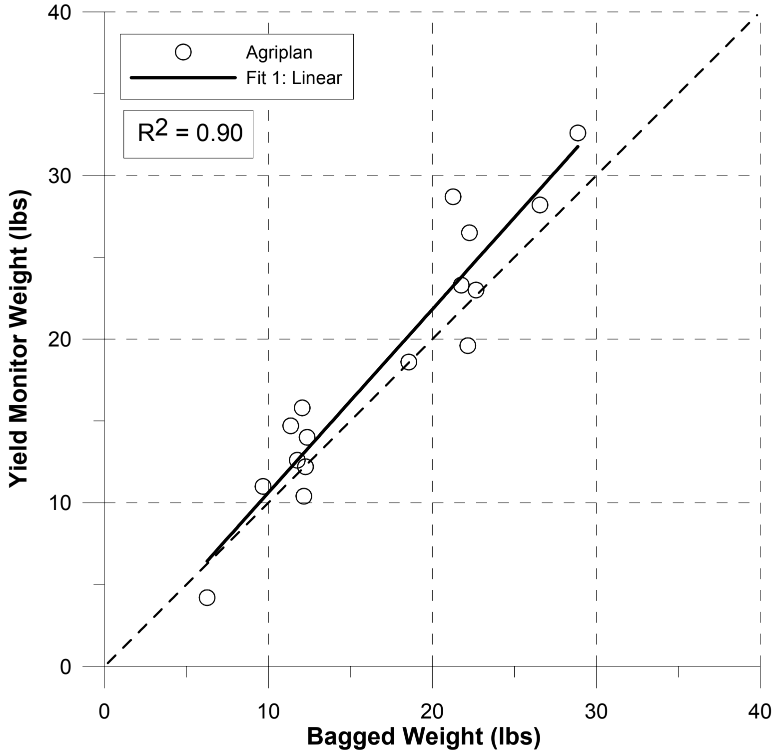

Figure 11. Comparison of AGRIplan weight to weight from bagged cotton in test plots.

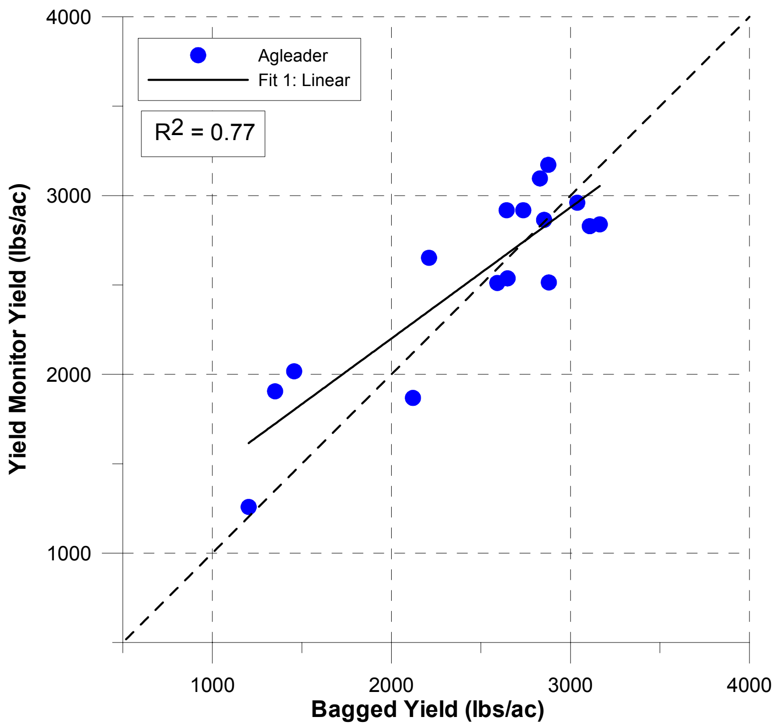

Figure 12. Comparison of Ag Leader yield to yield calculated from bagged cotton in test plots.

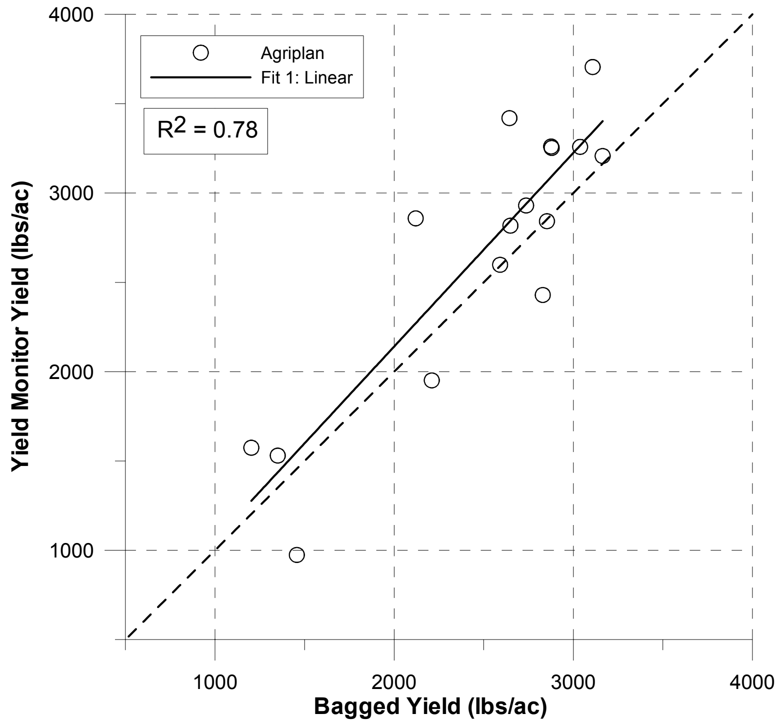

Figure 13. Comparison of AGRIplan yield to yield calculated from bagged cotton in test plots.

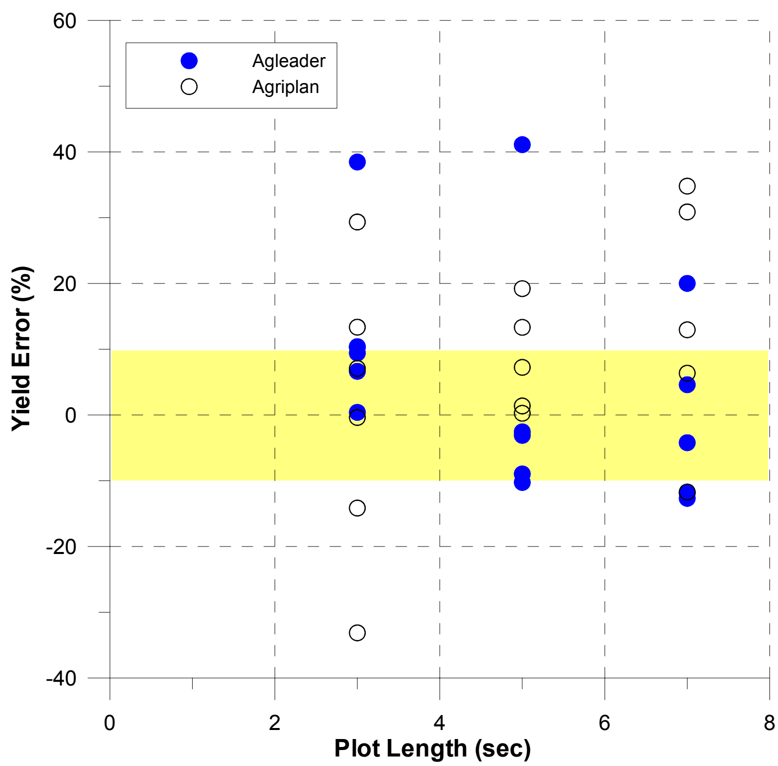

Figure 14. Comparison of plot length to yield monitor yield error. Yellow band represents +/- 10 % error.

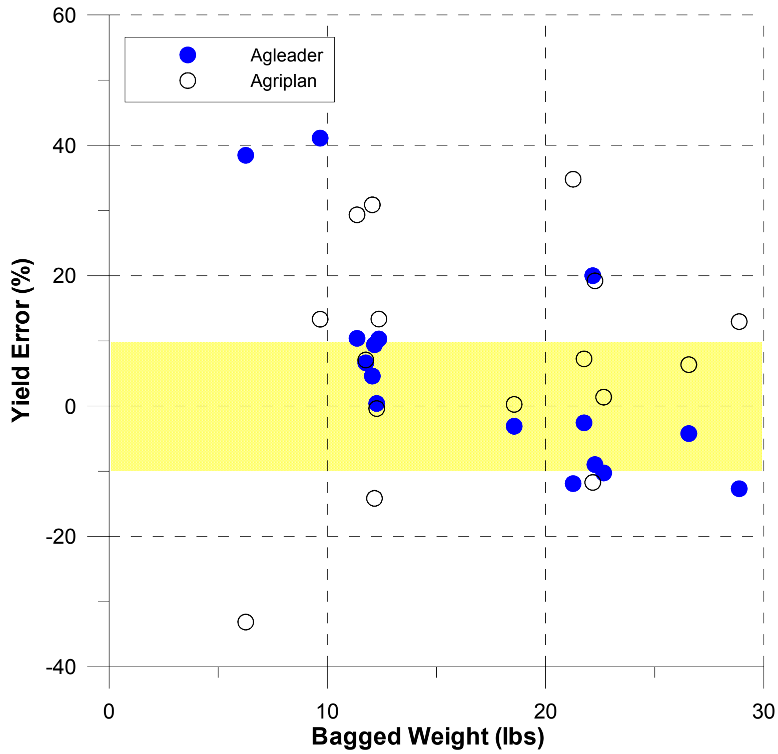

Figure 15. Comparison of bagged weight to yield monitor yield error.

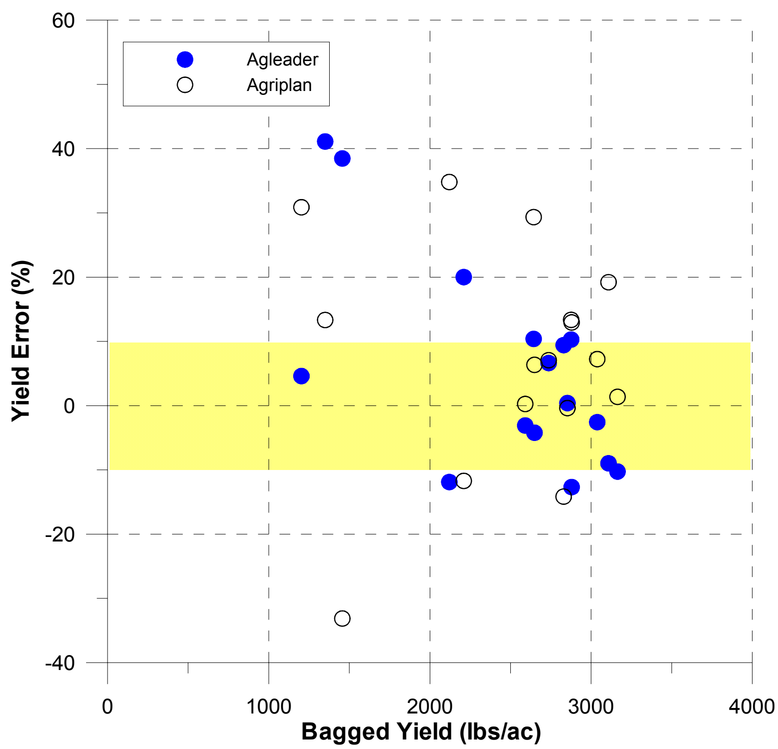

Figure 16. Comparison of yield from bagged weight to yield monitor yield error.