12-2009

Identification and Quantification of Cotton Yield Monitor Errors

Jason Clay Head
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Jason Clay Head entitled "Identification and Quantification of Cotton Yield Monitor Errors." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

William E. Hart, Major Professor

We have read this thesis and recommend its acceptance:

John B. Wilkerson, Arnold M. Saxton

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Identification and Quantification of Cotton Yield Monitor Errors

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Jason Clay Head
December 2009

This Thesis is dedicated to the memory of my grandfather, John Conroy Head Sr., who instilled in me the value and reward of hard work. I will be forever grateful for the 20 plus years we farmed together.

ACKNOWLEDGEMENTS

I would like to express sincere appreciation to Dr. William E. Hart and Dr. John B. Wilkerson who served as co-major professors. Their guidance and support has been greatly appreciated as well as entrusting me with much independence during this study.

The guidance and advice of Dr. Arnold M. Saxton, who served as a committee member, is very much appreciated.

Gratitude is also expressed to Dr. Kevin Howard of Delta and Pine Land for the funding to complete this project.

I would again like to thank Dr. William E. Hart for giving me the opportunity to complete my Master's Degree by offering me a Graduate Teaching Assistantship. Dr. Hart taught me more than any textbook or class could have. I am extremely grateful to have been able to work with him.

Mr. Phillip Allen spent countless hours in the field, and on the road, with me during data collection. His assistance during this project was invaluable. Appreciation is also expressed for providing me with many opportunities to get out of the office and assist with field work.

Thanks are also extended to Dr. Stacy Worley for constantly challenging my work. His friendship, support and excellent ideas are greatly appreciated.

Mr. Craig Wagoner, Mr. David Smith, and Dr. Mike Buschermohle have been a pleasure to be around and to work with. Their friendship assistance has made my time at the University of Tennessee very enjoyable.

This project owes much of its success to the Milan Research and Education Center and its employees. Dr. Blake Brown, Mr. Darol Copley, Mr. Mark Coffman, Mr. Hunter Shelby, Mr. Chad Hicks, Mr. Jason Williams, and Mr. James McClure were very helpful and understanding during data collection. These gentlemen were truly a joy to work with and their sense of humor always kept things interesting.

Thanks are also expressed to Dr. Chris Main for allowing the use of the West Tennessee Research and Education Center's weighing boll buggy.

My Parents, Johnny and Anne Head, and my sister Susan, have provided me with so many opportunities and have been very supportive through all my endeavors. I am extremely grateful for the love and support they have provided me.

I would also like to thank my grandparents, aunts, uncles, cousins and friends for their love and support.

I owe extreme gratitude to my Wife, Julie, who has sacrificed so much during this project. Her unwavering love and support has been a blessing to me throughout my studies.

Finally and most importantly I would like to thank God for all the opportunities and blessings I have been given.

ABSTRACT

Cotton yield monitors are an important part of a precision agriculture program and are becoming widely used by cotton producers for making management decisions. Members of the cotton industry have shown interest in using cotton yield monitors for collecting data from production scale variety yield trials (experiments that test yield performance for numerous varieties). Weighing boll buggies are the current industry standard for measuring yield in variety trials. This process is time consuming and requires extra equipment and labor. The ability to use a yield monitor for measuring yield would streamline variety trial harvesting. Recommendations for the Ag Leader cotton yield monitor state that the monitor should be recalibrated when harvesting a new variety. This poses a problem for collecting yield data from a variety trial due to the numerous calibrations that would be required. The primary objective of this research is to evaluate and enhance monitor performance in order to use it for collecting variety trial data. This will be done using different calibration techniques and post-processing models developed using measured gin turnout and environmental variables.

Data were collected in 2007 and 2008 at the Milan Research and Education Center in Milan, TN. Monitor weights were compared to boll buggy weights to determine variation between these two yield estimation techniques. This measured variation is defined as Yield Prediction Error (YPE). Before calibration, yield explained 44% of the variation in YPE. After post-calibration, moisture and yield explained 48% of the variation in YPE. Post-processing models were developed using these types of relationships but were unsuccessful as they introduced more variation into the data set. The relationship of YPE to moisture suggests that boll buggy weights should be adjusted to a common moisture content. The relationship of YPE to yield suggests that improvements could be made to the monitor. Post-processing the data

using yield in the model was able to reduce the mean absolute error to 2.5% from 3.3% using only calibration C (recalibrating when weather or other events cause a multiple day stoppage in harvesting).

Tukey's mean separation test was used for both yield measurement techniques to determine differences in variety trial results. In both 2007 and 2008, the variety trial results returned the same differences for both yield estimation techniques. This dataset supports that with proper calibration, the yield monitor can be used to collect yield data for cotton variety trials.

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Chapter 1: Introduction

Cotton yield monitors are a fairly recent development and their popularity among producers is growing. Yield monitors are an important part of a precision agriculture program. The most common form of sensing technique used with these monitors is an optical sensor paired with a light emitter which measures the flow of cotton as it passes between these two devices. This technology is currently commercially available through Ag Leader. Another commercially available technique for measuring cotton flow available from John Deere uses microwave technology. Ag Leader’s system was selected for use in this research because it had been previously installed on the picker used in the research.

Generally monitor performance is compared to some standard type of yield measurement standard. Weighing mechanisms like truck scales or weighing boll buggies are typically used to measure yield when the area harvested is known. In this case, yield would be defined by the weight of cotton in the buggy per area harvested. This measurement can be compared to the yield monitor output to develop a measure of error based on a gravimetric measurement. The term Yield Prediction Error (YPE) will be used throughout the thesis to refer to this measure of monitor accuracy.

Researchers conducting field variety trials in cooperation with producers would like to use yield monitors for variety comparisons. The current industry standard yield measurement technique for production scale variety trials utilizes boll buggies equipped with load cells. Weighing buggies provide accurate measurements but require the use of extra time and labor because the picker must stop harvesting and unload after each plot. Utilization of a cotton yield monitor would increase efficiency of harvesting variety trials.

There is currently limited data on the impact of variety on yield monitor accuracy. Current recommendations for the Ag Leader cotton yield monitor indicate that the monitor should be recalibrated if a different variety is harvested (Wilkerson et. al. 2002). This research evaluates monitor performance in changing varietal and environmental conditions. Numerous variables were measured in order identify and quantify their relationship with YPE. These relationships were identified in order to develop a model that could be used to increase the accuracy of the monitor. Observed YPE was correlated to varietal and environmental variables to develop a post processing model to compensate for differences resulting from these variables. Performance is also evaluated in a variety trial situation to determine if the two techniques of measuring yield (weigh buggy and yield monitor) identified the same differences in yield.

Justification

The ultimate goal of precision agriculture is to minimize production input costs while maximizing productivity. Yield monitors are useful tools which provide valuable information about spatial productivity characteristics. All yield monitors require calibration which typically consists of weighing one or more loads. However when conditions or varieties change, calibrations must be performed to maintain monitor accuracy. During development and evaluation by Wilkerson et al. (2002), the cotton yield monitor gave promising results but variety was shown to have an effect on error. That being said, until further evaluations are performed in changing varieties, calibrations are necessary when harvesting a different variety.

The logistics of performing calibrations can be rather inconvenient and time consuming. Weighing boll buggies are expensive and are also rare in the sense that equipment manufacturers do not produce them in large quantities. Using portable truck scales are another possibility but they can be cumbersome to set up and use in the field. Alternatively, taking a single load to a gin to weigh it on platform scales would be extremely inefficient and would also result in errors due to cotton being blown out of the trailer in transit.

The principal sponsor of this research, Delta & Pine Land Company, is looking to the future of cotton harvesting. John Deere and Case IH have both developed cotton pickers that make modules as the cotton is harvested. One of these modules will be the smallest measurable unit of cotton available once these new implements become commonly used by producers resulting in heavy reliability on yield monitor data. As a result, the timing of this project is critical. Delta & Pine Land conducts much of its research in cooperation with producers and has experienced many of the same problems previously mentioned with calibrating yield monitors in varietal yield trials. This company is interested in determining whether their yield data for variety trials can be accurately measured using yield monitor data.

Objectives

This study proposes to minimize the need for calibration of cotton yield monitors when environmental conditions or varieties change by identifying and quantifying the factors causing inaccurate yield prediction. Seed cotton weights estimated by a yield monitor will be compared to the actual harvested weights measured by a weighing boll buggy. YPE will be calculated and compared to selected physical and biological factors. Ideally, there will be systematic errors which could be quantified to post process yield data, minimizing the need for repetitive and time consuming calibrations. Specific objectives of the study are:

1. Identify measurable environmental and varietal factors contributing to yield monitor prediction errors.
2. Develop a post-processing model to compensate for measurement errors between varieties. The goal is to develop an equation to improve yield estimates based on the

output from the yield monitor along with the environmental or physical factors identified under Objective 1.

3. Compare current industry standard method (weighing boll buggy) of measuring field plot yields to a cotton yield monitor.

Chapter 2: Review of Literature

Development

There are two basic designs of devices that have been developed for measuring the pneumatic flow of cotton. The earliest published work, Wilkerson et al. (1994), describes a system design that is based on optical sensors and light emitters. Cotton passing between these two devices affects the amount of light being detected by the sensors which allows for a measurement to be taken. This system was later patented and is now commercially available (Wilkerson et. al., 1999).

Mississippi State University developed a different type of mass flow sensor that also uses optical sensing but mounts on only one side of the pneumatic chute known as the Mississippi Cotton Yield monitor (MCYM) (Thomasson et. al., 1997 and 1999). This sensor consists of an emitter and a detector. The emitter discharges light onto the cotton stream and the detector measures the amount of light reflected off of the cotton as it passes through the chute. Tests were performed in Texas, Georgia, and Mississippi in 1999, 2000, and 2001 (Thomasson and Sui, 2003). In 1999 the monitors were tested with small amounts of cotton that was caught in mesh bags, weighed individually, and compared to the monitor output. In the next two years the tests were conducted on a load basis and the monitor output was compared to the actual weight of the load as determined by a weighing boll buggy. The monitors were improved after the 2000 season by adding features to limit the effects of stray light and temperature. The following season returned promising results with an average absolute YPE of 3.7% for one field and 4.9% for their second field. This type of monitor, after evaluation and improvements, demonstrated high accuracy coupled with easy installation.

Issues Associated with Optical Sensing

There are issues associated with optical sensing related to dust build-up and sensor mounting. Studies have been conducted to improve sensor mounting and physical features of the sensors. Dust is a concern when using optical sensors. It can accumulate on the optics of the sensor and affect performance. AirBox mounting technology was developed at Clemson University to keep the sensors clean. This has shown promise in early studies and appears to keep the sensors clean over several loads (Wolak et al. 1999). Khalilian et al. (1999) reported that the AirBox kept sensors clean for several loads on the two optical systems used in this study, Micro-Trak and Zycom. Resulting errors ranged from -2.4% to 2.4% for the Zycom System and -2.7 to 6.4% for the Micro-Trak Sensor.

Sassenrath-Cole et al. (1999) conducted a study using two optical yield monitors, Vision Systems and Zycom, to test the reliability and accuracy of these monitors. They determined that trash build-up and cotton caught in the duct were the main source of errors in their study. The sensors were cleaned once during the middle of the study and significantly increased the accuracy, however dust seemed to accumulate rapidly after they were cleaned and YPE quickly declined giving measurements similar to those prior to cleaning. Conclusions from this study suggest that continuous cleaning of the sensors will produce accurate results, but this is not practical in production scale harvesting.

Wilkerson et al. (2001) made improvements to their system to counter-act the problems of trash and dust build-up. The same physical design was maintained but the way the sensor data was read was modified. The most important feature added to the system was the process of continually setting a new baseline. The monitor determined the lowest flow detected for each one-second sampling period and set that as zero cotton flow. It is inevitable that over one sampling period there was at least one measurement for which no cotton was actually in the sensor's path. This allowed the system to account for the impact that dust and trash have for each individual sensor and eliminated the need for cleaning them. Evaluation of this improved system showed a mean absolute error of 4.9% for all loads. The sensors were never cleaned during this test. Additionally a laboratory test was conducted to examine the effects of moisture on accuracy. No correlation was found between monitor error and moisture content. Wilkerson et al. (2002) did find that errors differed by variety and recommended that when changing varieties a new calibration should be performed.

Thomasson and Sui (2000) made a similar change to a prototype they developed that had a changing baseline. The monitor became less sensitive to dust build-up after these changes were implemented and tested. The correlation between monitor output and seed-cotton weight was used to measure success in this study, and the improvements to the monitor resulted in a strong correlation (R^2=0.967) without cleaning the sensors during the test.

Sui and Thomasson (2002) studied the effects of temperature and ambient light on the MCYM. Each test was conducted under controlled laboratory conditions. Temperature was found to have an effect on the accuracy. As a result an internal temperature regulator was added to the system. It was also recommended that the monitor be allowed to warm up for 20 minutes before harvesting cotton, especially for calibration loads in order to allow internal temperature stabilization. Stray light was not found to have a significant effect on the monitor's performance.

Evaluating Accuracy of Cotton Yield Monitors

The University of Georgia conducted research from 1997 to 2001 comparing the performance of five different cotton yield monitors. Each year the same picker was equipped with two or three different monitors (depending on commercial availability). Monitors tested included Agri-Plan, Farmscam, Micro-trac, Ag Leader, and MCYM Monitor. Error was determined by comparing the monitor output to actual load weights determined by using a boll buggy and portable truck scales. Tests varied from year to year depending on conditions and availability of cotton, but the overall general procedure was consistent. The objective was to evaluate the monitors quantitatively (accuracy) and qualitatively (ease of use). They concluded that all the monitors had improved over the period of the experiment and were continuing to improve. Ag Leader had the most user friendly interface of all the models. Over the period of the study improvements made to the monitors did not improve accuracy although precision of some monitors did improve. In 1997-1999 there were numerous issues with calibration and failures in the monitors. Some YPEs were 50-100% due to dust buildup on sensors and sensor failure. In 2000 the Ag Leader, Farm Scan, and Agri-Plan had season mean absolute errors of 9.4, 9.9 and 8.6, respectively. Similar accuracies were seen in 2001 for the Ag Leader and MCYM. Improvements to the systems were beneficial to the operation and to the reliability of the monitors that improved precision. It was evident that quality performance by any monitor is directly dependent on proper calibration. (Vellidis et al. 2003)

Wallace, 1999 studied the performance of a yield monitor in small plot research. A monitor by Zycom Corporation using the system of optical emitters and detectors described by Gvili, (1998) was evaluated by capturing the cotton from each plot in bags, weighing them, and comparing the actual weight to monitor output. When a linear regression was performed on the data there was a very strong linear relationship between the monitor output and the weight of the cotton samples (R^2=0.99). This study concluded that the monitor was accurate enough to develop yield maps and may be used in the future as a tool for research.

Durrence et al. (1998) evaluated the Zycom and Micro-Trak yield monitoring systems performance in Georgia and identified needed improvements. This study battled problems with obtaining weights for calibration and comparison. There were problems identified in the load cells used for weighing the cotton after data was collected on one of the fields resulting in inaccurate weights. They also had difficulties harvesting due to weather conditions. Due to these issues some of the data was not considered in the analysis. Both systems under-predicted the weight of the cotton by an average of 22.4% and 22.8% for the Zycom and Micro-Trak systems, respectively. The need for physical improvements to increase ease of installation of both these systems was identified. The researchers determined that farmers would lack the tools and knowledge necessary to install both systems. The researchers also anticipated improvements to the software packages that were supplied with each monitor.

This study was repeated the following year to evaluate improvements in each of the systems tested. Both companies made physical improvements to make installation easier and less time consuming. One change made in the test procedure from the previous year was that the sensor windows were wiped clean after every load. The accuracies in yield prediction improved over the previous year with the average YPE by field ranging from 3-8% and 11-16% for the Zycom and the Micro-Trak systems, respectively. Improvements in yield prediction could not be completely attributed to the system improvements since better calibration practices and improved harvest conditions were thought to decrease YPE. The Zycom had a lower YPE and also defined spatial trends in yield maps with more detail (Durrence et. al. 1999)

Searcy (1998) tested two systems: a Zycom system and an experimental system developed at the Texas Agriculture Experiment Station (TAES). This test was designed to examine the yield accuracy (lbs. per acre) on a very small scale. This test differed from previous tests by evaluating the accuracy of yield estimation on a very small scale rather than comparing load weights. Yield was estimated by hand picking a small area immediately adjacent to the area to be picked or stripped. The Zycom system, mounted on a picker, displayed high YPE at small scale levels but displayed low YPE when measuring the total amount of cotton harvested. The TAES system was mounted on a cotton stripper and displayed low YPE at the small scale level. This system utilized load cells on a supported basket that weighed the cotton continuously throughout harvest. Another significant observation was the difficulty in confirming yield map accuracy at small scale levels for any yield monitoring system.

Roades et al. (2000) performed a similar test using Micro-Trak and the TAES system on stripper type harvesters. Accuracy and consistency as related to YPE were the focus of the study for the Micro-Trak system, where as the main focus of the TAES monitor was accuracy and robustness of the experimental system. The instantaneous accuracy was tested using the same procedure, hand picking cotton to estimate yield, as in the previous study by Searcy (1998). It was not possible to install the Micro-Trak sensors on the ducts that transferred the cleaned cotton. The sensors were placed on the main duct that transferred cotton along with the stalks and other trash. The TAES system was used by two different operators that managed the system differently by initiating logging at different times before they began harvesting. This resulted in different accuracies for each operator resulting in the need for improvements to the system that would automatically begin logging data. Neither system gave desirable results on a small scale basis but showed general trends in yield across the field.

Rains et al. (2002) conducted research on monitor performance over different cotton varieties. Twenty-nine varieties in a single field were harvested and yield measured using two yield monitors: Ag Leader and Farmscan. Monitor errors were determined by comparing weights from the yield monitor to weights from a weighing boll buggy. Tests incurred several difficulties, so much so that data from the Farmscan monitor was not utilized in analysis. The Farmscan monitor had many technical difficulties which caused loss of data and collection of incorrect data. These researchers concluded that quality factors (e.g., micronaire and fiber strength) do not have an effect on monitor error. A slight linear correlation was observed between the percent gin turnout and weight measured by the monitor (R^2=0.12). Seed mass was proposed as a possible source of error in changing varieties.

Three cotton yield monitors were tested to determine instantaneous accuracy by Perry et al. (2004). The Ag Leader®, AGRIplan®, and the MCYM were mounted on a picker that had been retro-fitted with bagging mechanisms that could be manually operated to collect cotton samples for short periods of time. Areas of low, medium, and high yield levels were identified and flagged for the test plots. These areas were harvested and cotton was collected in the bags for 3, 5, and 7 seconds. The spatial position was also recorded in order to compare the actual weight in the bags to the measured weight by the monitor. The MCYM was not used in this test due to the fact that it uses a different time logging interval. YPEs in the tests were not statistically impacted by yield or by the length of collection. The author also states that additional statistical analysis should be conducted to further rule out any effects, although no specific potential effects were detailed in the manuscript.

Perry and Vellidis (2008) conducted a study that was intended to evaluate the Ag Leader and John Deere cotton yield monitors simultaneously. Accuracy and ease of use were the two issues addressed by this study. John Deere's system was not installed on the picker used in the study until very late in the season. This did not allow an adequate amount of data to be collected to assess the John Deere cotton yield monitor. The Ag Leader system was calibrated using four loads ranging from 3700 lbs. to 5500 lbs. Cotton modules were tracked as individual regions and the weights from the monitor were compared to the weight of the module measured at the gin. The average error after the first five weeks of harvest was -11.7%. Additional check weights were obtained using a boll buggy on portable truck scales. Average error calculated using these weights was -12.4%. The monitor was recalibrated for the remainder of the season and average error was 5.7% when measuring module weights at the gin. An average error of 2.1% resulted from measuring weights with the portable truck scales. It was also noted that the monitor errors were consistent although the error values were high (mean YPE = -12.4%).

Cotton Yield Monitors in Research Situations

Few studies have evaluated the ability to use cotton yield monitors for collecting data from production scale or on-farm research. Little documentation is available on the ability of cotton yield monitors to accurately predict yield in changing varieties (Robertson et al., 2006). As described previously, numerous studies have evaluated accuracy of monitors for producers to develop yield maps and make management decisions, but few studies have directly addressed the use of cotton yield monitors in varietal tests.

Robertson et al. (2006) studied an optical sensing yield monitor by Agriplan and a microwave sensing method by John Deere. This study evaluated production scale plots with eight to ten variety strips planted the length of the field. Monitor weight correlated well with boll buggy weight in eight of the twelve varieties tested ($R^2 \geq 0.90$). However one variety had an R^2 value of 0.71. There was a large amount of difference in the slopes of these regression lines that would not allow for accurate determination of differences in yield. Line slopes varied from 0.99 to 1.4 in regression analysis of monitor weight versus boll buggy weight. Both monitors performed similarly in terms of accuracy and these data do not show a large difference in accuracy between the two systems. This study recommended that yield monitors should not be used for data collection on replicated variety trials.

Stewart et al. (2008) conducted a similar study to evaluate monitor performance in replicated variety trials. Ag Leader yield monitor and weighing boll buggy data were collected in 2007 from seven on-farm variety trials containing a total of 29 different varieties. Five of the twenty-nine varieties harvested occurred in four of the variety trials and were analyzed in detail. When considering all of the data, a very strong correlation (R^2 = 0.94) existed between yield monitor output and boll buggy weight, but the slope was 0.825 (a slope of one would represent zero error). Analyses were performed comparing yield performance of the varieties. Rank by lint yield for the varieties did not change, however statistical differences were identified with the boll buggy that were not identified with the yield monitor. When the locations were analyzed individually the rank by lint yield varied at one location. This study determined that boll buggies should be the only method of measuring yield in variety trials unless a correction factor for varieties can be determined.

Summary

The majority of the yield monitors discussed in the previous sections consist of two optical devices, an emitter and a detector, that measure the volumetric flow rate of cotton in the pneumatic ducts. An exception is the Texas Agriculture Experiment Station system which consists of modified basket supports equipped with load cells to continuously weigh the cotton in the basket. Optical sensing is the most common method used by many of the commercially available systems today. Another exception is John Deere's monitor which uses microwave technology to measure the cotton flow in each of the ducts. However, no substantial literature has been published evaluating John Deere's yield monitor. Current YPEs of optically based systems like the one used in this study average less than ±5 %. These systems are also capable of making very accurate yield maps that can be used in management decisions.

Few studies have evaluated the usefulness of the cotton yield monitor in variety trials. Two studies that do so recommend that the yield monitor should not be used to collect data from varieties trials. One researcher goes further to say that yield monitors should not be used unless a correction factor can be developed (Stewart et. al., 2008). Hence, an in depth study is needed to further evaluate the performance of cotton yield monitors and measure variables that may be related to monitor errors. Ag Leader is the most commonly used yield monitor that has several published evaluations of its accuracy. John Deere’s monitor is also very common but only one publication has evaluated it and public knowledge about its performance is limited.

Chapter 3: Materials and Methods

Data were collected during 2007 and 2008 at the Milan Research and Education Center (REC) in Milan, TN. All procedures were conducted with production scale equipment (i.e., no plot planters or plot pickers) in order to closely simulate on-farm production scale research. Due to the numerous cotton research projects already taking place at the REC, and the ability of all variables necessary for this study to be measured at harvest, there was no problem in obtaining an adequate amount of cotton for this study. The collection of yield data across several production scale experimental trials not only provided a sufficient quantity of data, but the various production management practices included in these experiments also provided a range of yield and cotton quality conditions that was more representative of the range of typical production situations. The differences in management practices did not impact this research since the independent variables of interest were quantified at the time of harvest.

Phase I: Planting

A John Deere 8-row vacuum no-till planter was used to plant cotton in 40 inch rows. Fields were planted using no-till practices and all varieties were Roundup® resistant. All the varieties within a field were selected from the same maturity group for practical production purposes.

2007

Approximately 130 acres of cotton at the Milan REC were used for this study in 2007 (Appendix A). Cotton acreage was distributed across five fields named 202, 203, 206, A-5, and S4. Fields 202 and 203 were subdivided and were planted with two cotton varieties. Fields A-5, S4, and 206 were planted in a single variety. Cotton was planted in contiguous blocks rather than strips that are more typical of variety trials.

Six Delta & Pine Land varieties (DP 143 B2RF, DP 164 B2RF, DP 432 RR, DP 444 BG/RR, DP 445 BG/RR, and DP 555 BG/RR) and one Stoneville variety, ST 5599 BR, were selected for testing. These varieties were selected to represent a range of maturity levels, seed sizes, and other characteristics that could influence yield monitor results.

2008

Approximately 160 acres of cotton were planted in six fields named 201, 202, A5, S1LS, S2LS, and S3LS (Appendix B). Varieties planted were DP 117 B2RF, DP 143 B2RF, DP 432 RR, DP 434 RR, DP 444 BG/RR, DP 445 BG/RR, DP 455 BG/RR, DP 555 BG/RR, PHY 370 WR, and ST 5599 BG/RR. Field 202 was divided into sections per constraints of the REC's additional studies. The center 40 acres of the field were planted with the assistance of Real-Time Kinematic (RTK) GPS guidance allowing all of one of the varieties to be planted at one time. The three varieties planted in eight row strips in this portion were DP432, DP434, and DP444. The two blocks on the north western side were planted with DP117 and Phytogen 370. The south-eastern side was planted with two varieties in eight row strips by splitting the planter which means that four hoppers were filled with DP 455 and the other four hoppers were filled with DP 445, which created eight-row strips. This same technique was utilized in field S2LS. S3LS and S1LS were planted with single varieties, DP432 and DP143 respectively. Field A5 was irrigated and contained a production scale test by another researcher that allowed a second variety to be planted in the border areas, hence the odd geometry of the variety layout.

Phase II: Harvest

Cotton was harvested in the fall using a John Deere Model 9976 four-row picker equipped with an Ag Leader Insight yield monitor (firmware 4.5.0.0) and CAN-bus sensors (detector PN# 4000615 and emitter PN#4000924)(firmware 1.5.0.0). The sensors on each chute were cleaned at the beginning of each harvest season and were not cleaned again during the season (Figure 1). Cleaning the sensors during the season could positively or negatively impact monitor performance. Each load was weighed for comparison in a Crust Buster weighing boll buggy equipped with scales having ±5 pound resolution (Figure 2). The crew was very careful to measure weights before the buggy was moved and to always keep the buggy on a level area.

Figure 1. Dust accumulation was cleaned from the sensors at the beginning of the harvest season.

The buggy was tested throughout the season by placing weights on it when loaded and not loaded. It performed very well in these tests. Monitor weights and buggy weights were recorded to determine a percent error. Recall that this difference in yield measurement is referred to as Yield Prediction Error (YPE) in this thesis. The first three representative loads harvested at the start of the 2007 season were used to calibrate the yield monitor. This same calibration was used on all loads harvested during the 2007 and 2008 seasons.

During harvest composite samples weighing approximately five pounds were collected to determine moisture content and gin samples weighing approximately ten pounds were

Figure 2. Cotton being unloaded from picker basket to boll buggy to obtain weight and to collect samples.

collected for gin analysis. Care was taken to include material from multiple locations in the boll buggy so that the composite samples were representative of the entire buggy load. Harvesting was stratified throughout a harvest date in order to capture potential diurnal effects on environmental variables. Moisture samples were sealed in plastic bags and taken back to the laboratory where the oven-dry moisture content (dry basis(db)) was determined. Samples were dried according to the *Standard Procedures for Foreign Matter and Moisture Analytical Tests Used in Cotton Ginning Research* (Shepheard, 1972). Gin samples were placed in canvas bags and sent to Delta & Pine Land's® micro-gin in Scott, MS to determine gin turnout percentage as well as quality characteristics (i.e., micron, strength, color, etc.) as determined by the High Volume Instrument (HVI).

Figure 3. Composite sample are collected from multiple sampling points throughout the boll buggy.

Post Calibrations

The Ag Leader Insight monitor allows the user to apply different calibrations to their data after harvest has been completed. This process is simple and was utilized to assess how different calibrations affected the accuracy of the monitor. In 2007 no post calibration techniques were applied (Calibration 07). In 2008, three post calibration techniques were implemented on the dataset. These methods were determined after looking at the data and noticing trends in error related to yield as well as using current company recommended calibration procedures. Calibration A (yield range technique) used a high yield, low yield and average yield load from the 2008 season. Calibration B (first loads technique) used the first three representative loads harvested of the 2008 season. The term "representative loads" refers to loads that consist of a down and back picker pass. Loads that contained shorter rows and required several picker passes and turn-arounds were not used for calibration. These two techniques used one calibration to calibrate the entire season. Calibration C (individual harvest periods technique) consisted of three individual calibrations. The 2008 season consisted of three harvest periods that were interrupted by rain events. Each of these harvest periods were calibrated individually by using the first three representative loads harvested in that particular harvest period.

Phase III: Statistical Analysis.

The data were analyzed statistically using SAS software, version 9.2. A Pearson Correlation test was used determine if there was a correlation between YPE (dependent variable) and the independent variables. Any significant correlations could indicate potential systematic errors. All independent, continuous variables measured are listed below and more in depth descriptions can be found in Appendix C:

- Moisture at harvest (dry basis)
- Micronaire (MIC)
- Spinning Consistency Index (SCI)
- Upper Half Mean fiber Length (UHML)
- Short Fiber Index (SFI)
- Elongation (Elg)
- Yellowness (b+)
- Trash area (TrArea)
- Yield
- Time of day
- Fiber Maturity (MAT)
- Lint turnout
- Uniformity (UI)
- Fiber strength (STR)
- Reflectance (Rd)
- Trash count (TrCnt)
- Area harvested
- Buggy weight

The r-squared variable selection test was also used in the analysis. This considered all variables in all possible combinations to develop a model that would explain the most variability in the data. This method helped to identify models that were used to post process the data. Another model selection method was used, called the stepwise variable selection technique. It is important to note that these variable selection techniques are only for identifying models. The models were verified by running a regression analysis in SAS. The comparison of the two methods of yield measurement was analyzed using mixed model analysis of variance (MANOVA). Tukey's mean separation was used to analyze the mean yield as predicted by the yield monitor and as measured by the weighing boll buggy. Essentially the two methods were compared to determine if the yield monitor would predict the same differences in yield that were measured by the weighing boll buggy. The experimental design used for this analysis was a Completely Randomized Design (CRD). This is the ultimate test for the yield monitor in the sense that mean separations by yield are what researchers are trying to identify when conducting a varietal trial. Tukey's was also used to test for differences in YPE by variety.

Chapter 4: 2007 Results

The extremes of the 2007 growing season resulted in cotton yields unrepresentative of the typical production in the fields observed (544 lbs of lint per acre average yield across all varieties in dry land production). This was one of the driest years on record with 20 days during the season exceeding 100 degrees F. There were 9 inches of total rainfall during the first 120 days of the growing season. Figure 4 presents the cumulative precipitation through the growing season. There were 59 consecutive days during the growing season that received a total of 1 inch of precipitation. Table 1 highlights the cotton performance by variety.

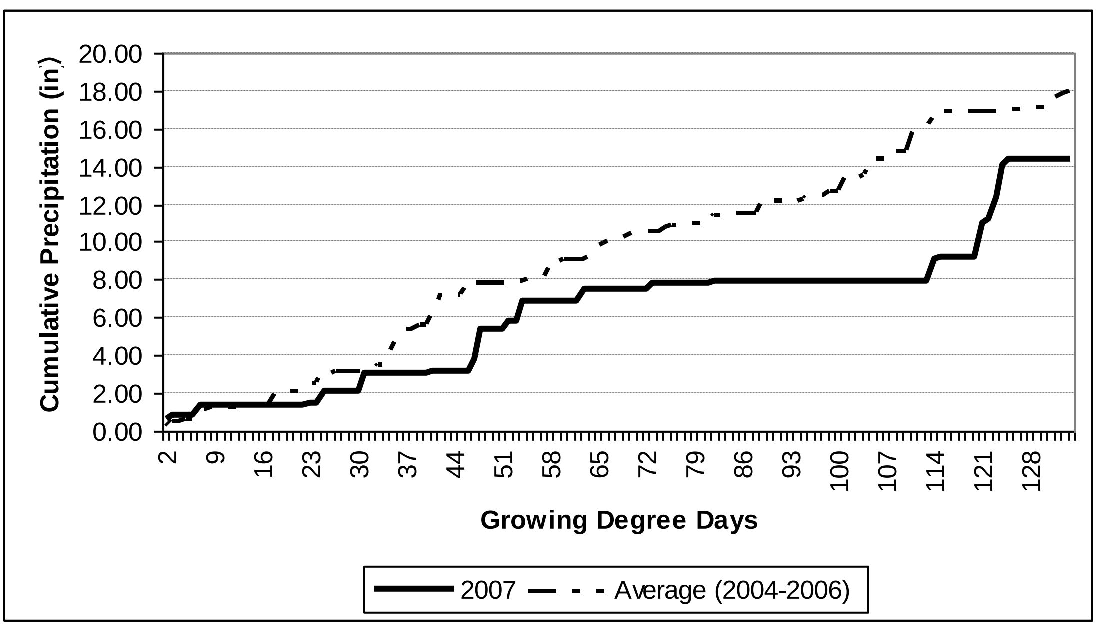

Figure 4. Cumulative precipitation between planting and harvest during 2007.

Table 1. Summary of yield and gin characteristics of varieties included in study.

Variety	n[1]	Lint Yield	n[2]	Mic	Mat	TO	UHML	Short Fiber Index	Fiber Strength	SCI	Elg	Rd	b	Tr CNT	Tr AREA	UI
		Lbs. / acre				%	in.		g/tex		%			trash / gram	%	%
DP143 B2RF	9	449.1	7	4.4	0.87	36.0	1.025	14.39	23.0	89	5.1	73.7	8.5	37.7	0.45	79.3
DP164 B2RF	4	459.6	4	3.3	0.84	30.5	1.084	13.2	22.5	103	5.0	71.8	9.6	40.5	0.39	80.2
DP432 RR	11	662.0	9	3.3	0.84	33.9	1.088	11.71	25.1	117	5.7	67.8	10.1	47.9	0.54	81.9
DP444 BG/RR	7	648.9	6	3.0	0.84	35.0	1.078	12.25	24.3	117	5.3	70.9	9.7	58.7	0.69	81.6
DP445 BG/RR	5	598.8	5	3.5	0.84	34.3	1.089	11.59	26.9	123	6.1	72.3	10.0	40.2	0.37	81.7
DP555 BG/RR	8	366.0	5	3.9	0.86	33.8	1.063	14.19	22.7	91	5.1	71.8	8.8	46.2	0.56	79.1
ST 5599BR[3]	28	1083.4	13	4.4	0.87	36.11	1.079	11.52	27.5	119	5.3	76.2	8.2	41	0.56	82.2

[1] Number of loads harvested
[2] Number of gin samples collected. (Samples were not collected from every load)
[3] ST 5599BR was irrigated
Reference Appendix C for list of gin characteristics and explanations.

Defoliation was a problem in varieties DP 555 and DP 143 (Figure 5). Six inches of rain after the defoliant had been applied promoted re-growth. Much of this green plant matter made its way into the basket during harvest. This green plant matter was included in the moisture samples and elevated the measured moisture content.

Figure 5. Leaf re-growth after application of defoliant on DP 555 at harvest.

Statistical Analysis

The data from field A5 (Stoneville variety) was not included in analyses. This field produced higher quality cotton at much higher yields than other fields since it was irrigated. The average YPE for this variety was -15.33%, whereas YPE from all other varieties in other fields was below ±4%. Including the irrigated field in the statistical analyses would have confounded the results since the yield levels were drastically different between A5 and the other fields. This study would have benefitted from an additional variety being planted in irrigation so that the variation due to irrigation could have been accounted for and would have allowed an individual comparison of those two varieties. The poor yields and ideal harvest season reduced the amount of variation seen in YPE. No obvious systematic errors were observed as the observed YPE was within ±4% which is comparable to other research findings when calibrated properly (Figure 6). Of all variables analyzed in a regression analysis with YPE, time of day explained the most

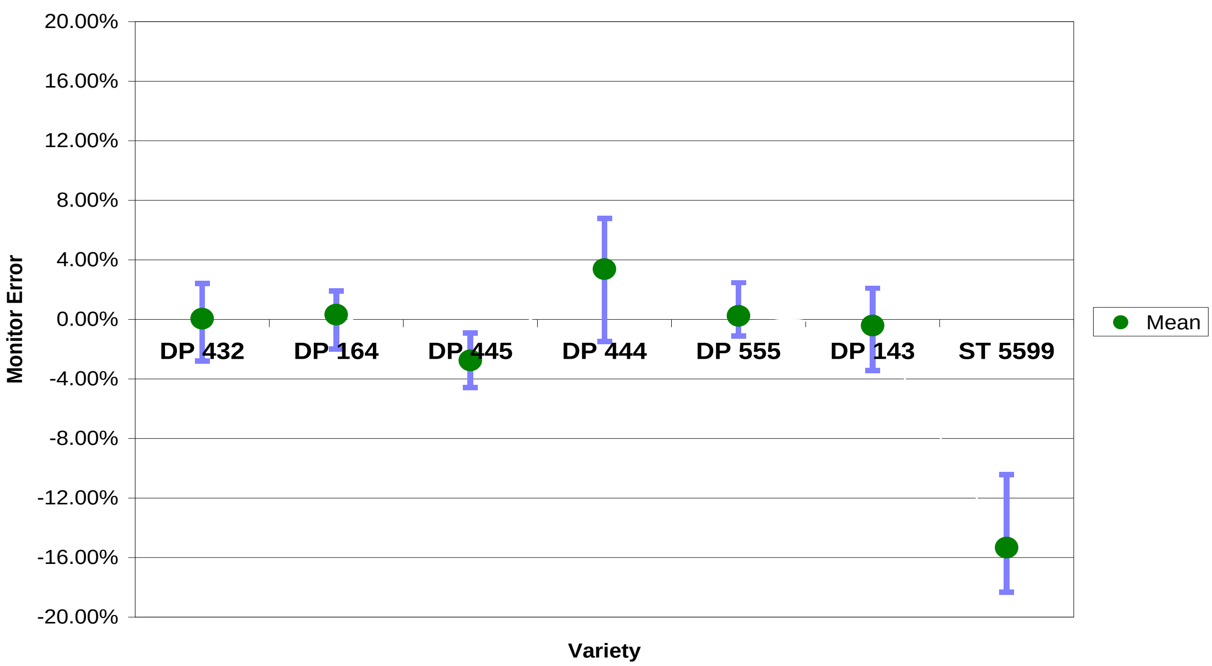

Figure 6. Range of errors by variety displayed with the mean error for 2007.

variation in YPE, 21% (R^2=0.211). Logically time of day would track with moisture content. Moisture most likely showed no correlation with time of day due to the falsely elevated moisture content levels resulting from green leaves in field 202. Moisture could have had an effect on error but was masked by this effect. Models with two variables also showed poor performance. The best two-variable model contained fiber maturity and color and explained 40 % of the variation in YPE. Maturity and color continued to appear in the models and more variation was explained as additional variables were added to the models. Variation in YPE was very low and it was difficult to find correlations. No post-processing models were developed from the 2007 data as a result of the low variation and/or excellent performance of the monitor. Figure 7 shows recorded monitor weight output versus buggy weights. The line displayed was forced to have an intercept of zero. The equation for the line is y=0.9994x and the R^2 value is 0.996 (line with a slope of one would represent an YPE of zero).

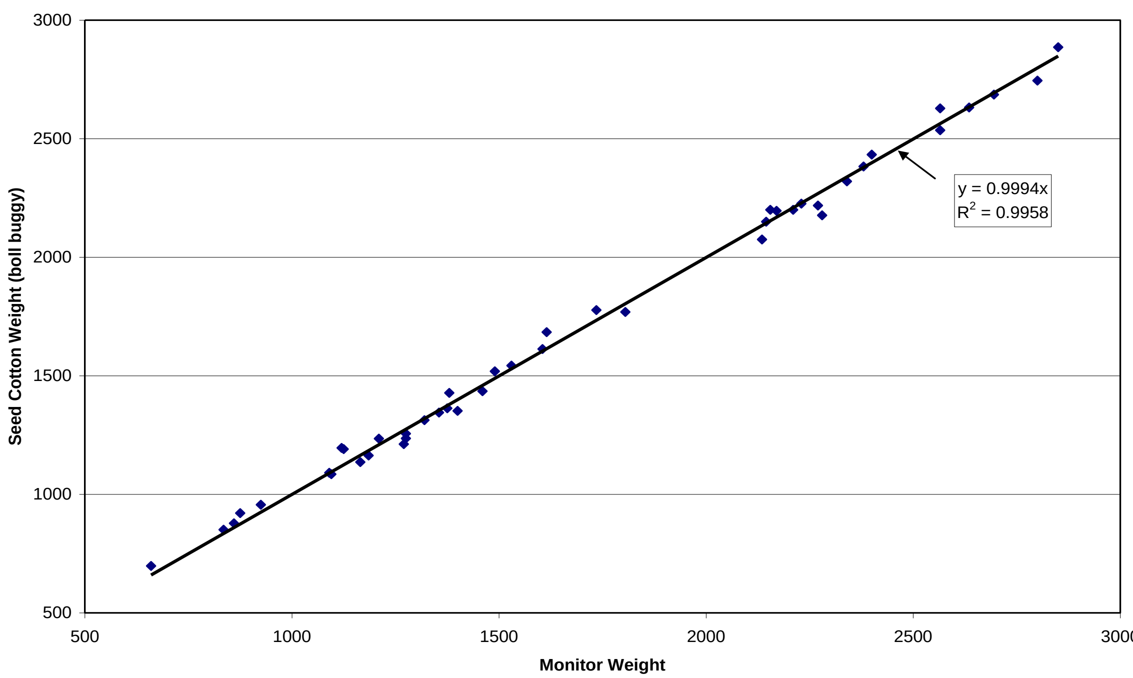

Figure 7. Monitor weight versus buggy weight for 2007.

Tukey's mean separation determined that there were differences in yield by variety in both methods of yield measurement (p<0.0001). Both methods of measurement delineated the same mean separation differences by variety (Figure 8).

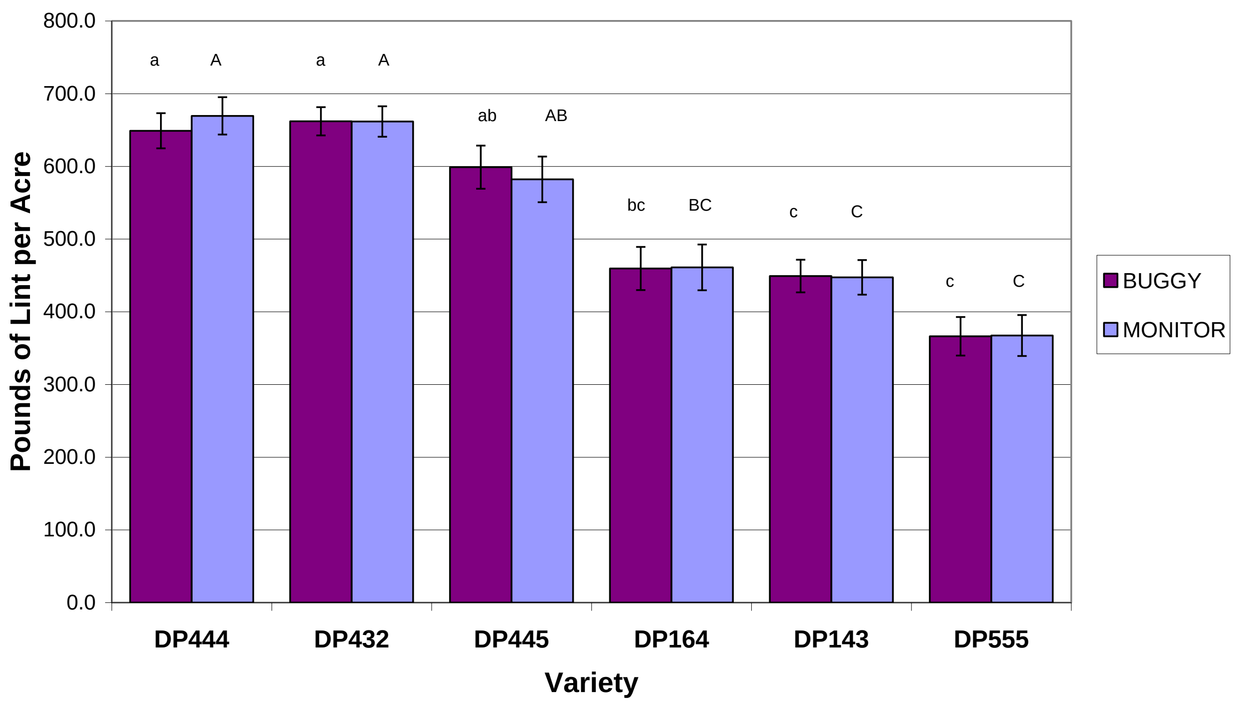

Figure 8. Tukey's mean separation test for average pounds of lint by variety. Varieties with the same letter do not differ significantly (p<0.0001).

Chapter 5: 2008 Results

The 2008 season was more typical of a West Tennessee growing season and harvest season. Figure 9 displays a timeline of the harvest season that indicates rain events, harvest periods and fields harvested during each period. There were three periods in which harvest took place over consecutive days. The first consisted of harvest in field 202. The second harvest period finished field 202, field 201 and all fields in the south tract (S1LS, S2LS, & S3LS). The long break between the second and third harvest was a result of mechanical failure on the cotton picker and subjected the cotton to two rain events. During the third harvest period field A5 was harvested. These periods are important in considering post-calibration techniques.

The 2008 season produced a slightly above average cotton crop at the Milan REC. Average yield for the entire station was 995 lbs. of lint per acre or 2.1 bales per acre. Average gin turnout was 37.7%. Table 2 summarizes yield and gin turnout data by variety.

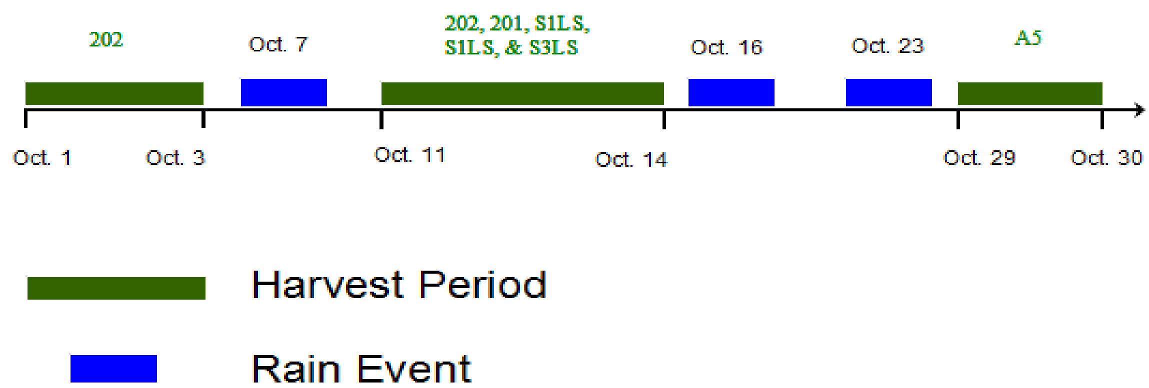

Figure 9. Timeline for 2008 harvest indicating fields harvested during each period.

Table 2. Summary of yield and gin characteristics of varieties included in study.

Variety	n[1]	Lint Yield	n[2]	Mic	Mat	Turnout	UHML	Short Fiber Index	Fiber Strength	SCI	Elg	Rd	b	Tr CNT	Tr AREA	UI
		Lbs. / acre				%	in.		g/tex		%				%	%
DP143 B2RF	4	1113.2	3	3.5	0.84	33.5	1.182	10.55	29.3	130	6.3	79.9	7.2	32.7	0.61	80.0
DP444 BG/RR	12	991.2	10	4.1	0.85	37.6	1.103	9.83	30.1	132	6.8	81.5	7.5	16.5	0.22	82.1
DP445 BG/RR	20	996.6	17	4.1	0.86	38.3	1.118	10.03	30.7	133	6.5	79.2	8.2	23.5	0.34	81.7
DP117 B2RF	7	855.6	7	4.1	0.86	36.4	1.116	10.06	32.0	134	6.3	78.3	7.4	46.6	0.73	81.3
DP432 RR	13	880.2	12	4.3	0.86	37.0	1.103	9.65	30.0	134	7.0	79.6	8.1	25.3	0.37	83.1
DP455 BG/RR	10	960.9	10	4.1	0.85	37.0	1.144	9.35	31.2	143	6.9	79.9	7.8	30.0	0.42	83.2
DP434 RR	5	896.7	5	4.4	0.86	39.1	1.117	10.32	29.3	128	6.6	81.6	7.5	13.4	0.21	81.8
PHY 370 WR	6	925.0	6	4.6	0.87	38.4	1.078	9.92	30.6	127	6.7	78.1	8.1	26.8	0.36	82.0
[3]ST5599 BR	15	1291.7	7	4.5	0.87	38.3	1.075	11.35	29.5	118	6.1	78.9	7.2	35.1	0.47	80.7
[3]DP555 BG/RR	10	1119.8	9	4.4	0.86	38.6	1.077	11.82	28.5	113	6.2	80.8	6.0	26.1	0.29	80.0

[3] Represents the only varieties grown under irrigation
[1] Number of loads harvested
[2] Number of gin samples collected. (Samples were not collected from every load)
Reference Appendix C for list of gin characteristics and explanations.

Post Calibrations

The average absolute yield monitor error for the entire season was 7.2 % before any post calibrations. Calibration data from 2007 was used while harvesting the 2008 crop and this calibration is named calibration 07. Yield showed the greatest relationship with YPE and when verified with a linear regression analysis, yield explained 44% (R^2 = 0.4375) of the variation in YPE (Figure 10). This correlation between yield level and YPE prompted the investigation into the recalibration techniques discussed previously. A summary of those recalibration techniques are given in Table 3. Recall that calibration A uses three loads with different yield levels, calibration B uses the first three loads harvested and calibration C calibrates each harvest period individually.

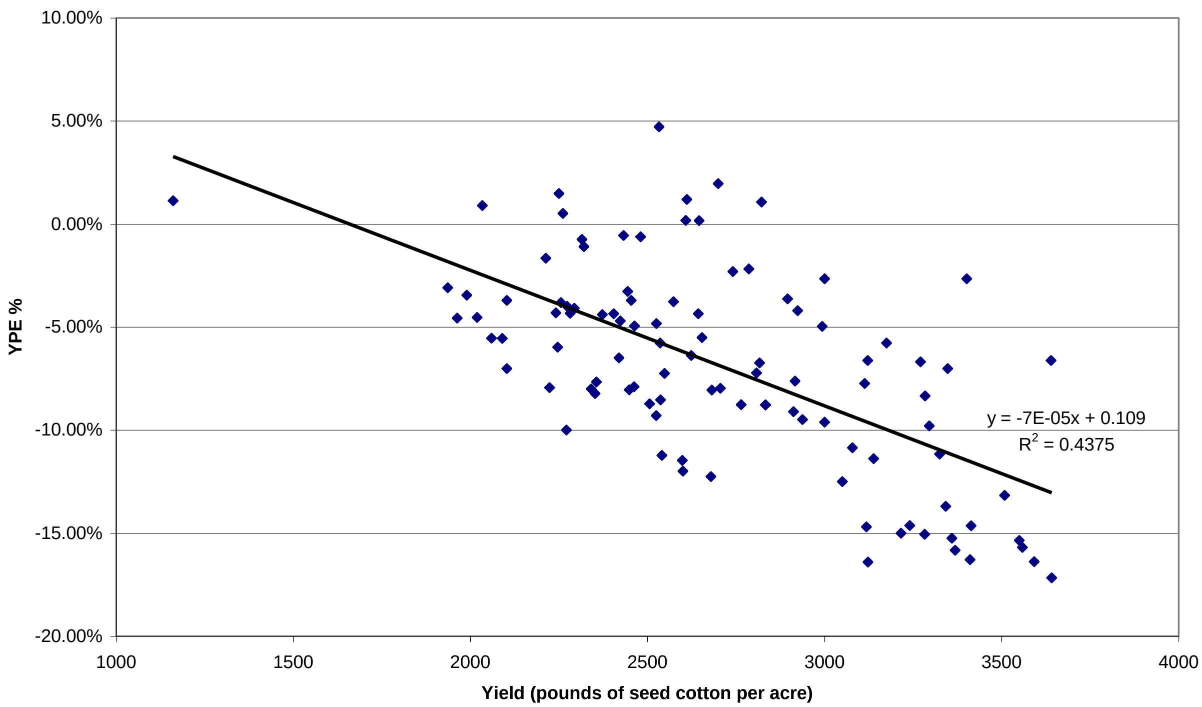

Figure 10. Relationship of yield and YPE

Table 3. Summary of errors in calibration techniques on the 2008 dataset.

Calibration Technique	Error Summary
Calibration 07	YPE = -6.91% Variance = 0.24% Mean Absolute Error = 7.17% Root Mean Squared Error = 8.46%
Calibration A. Yield Range Technique	YPE = 1.31% Variance = 0.32% Mean Absolute Error = 4.78% Root Mean Squared Error = 5.73%
Calibration B. First Loads Technique	YPE = 3.82% Variance = 0.35% Mean Absolute Error = 5.94% Root Mean Squared Error = 6.24%
Calibration C. Individual Harvest Period Technique	YPE = -0.13% Variance = 0.21% Mean Absolute Error = 3.77% Root Mean Squared Error = 4.55%

Figures 11 through 18 provide a summary of error by variety and the relationship between monitor weight and buggy weight for the three calibration techniques. A graph was prepared for each calibration that includes the mean YPE and bars that show the range of YPE. Figure 11 displays a summary of YPEs using calibration 07. The monitor was not calibrated when harvesting started on variety DP 445 due the relative agreement between the monitor and buggy weights as compared in the field at the beginning of the 2008 harvest. Calibration 07 was used during harvest for the entire 2008 season. As the season progressed the monitor began to underestimate yields using the 2007 calibration (Figure 11). Figure 12 shows the predicted weight vs. the actual weight and include a line (y=x) that represents YPE of 0.0% for the 2007 calibration. The slope of this line is 0.93 and the R^2 value is 0.96 which represents a very strong relationship.

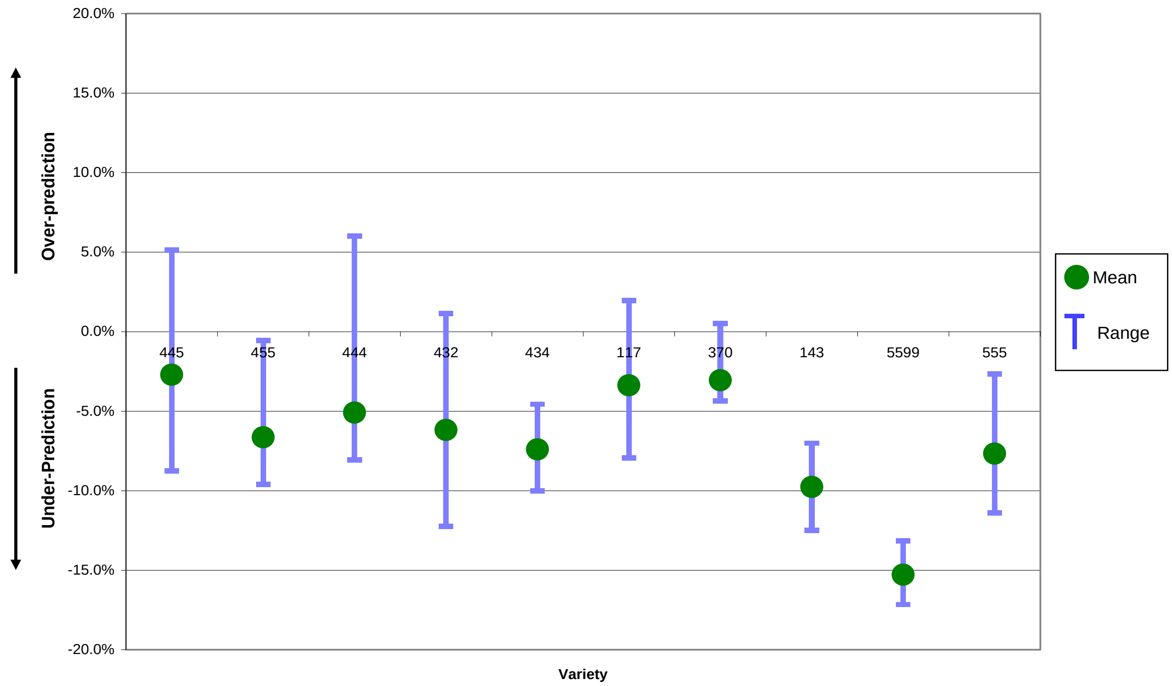

Figure 11. Summary of YPE by variety using calibration 07 on the 2008 data.

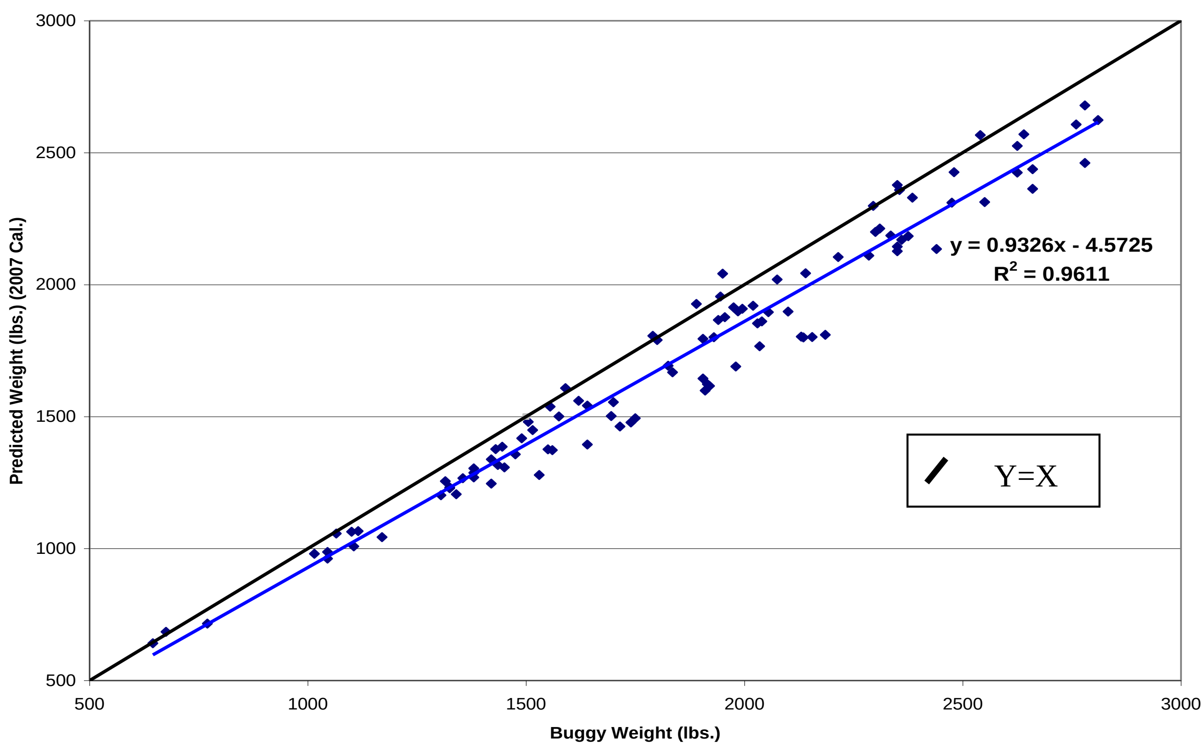

Figure 12. Weight measured by buggy vs. weight predicted by monitor using the calibration 07 on the 2008 data.

To investigate how different calibrations affected monitor accuracy the different calibrations were implemented and summarized. Figure 13 displays YPEs summarized by variety using calibration A. This calibration used three representative loads selected on varying ranges of yields in an attempt to eliminate the relationship between error and yield level. It was not possible to use loads from the same variety for this calibration. The high yielding (3672 lbs. seed cotton/ac.) load from this calibration came from field A-5 and was variety ST 5599. This mid range yielding load (2644 lbs. seed cotton/ac.) came from field S2LS and was variety DP 444. The low yielding load (1944 lbs. seed cotton/ac.) came from field 202 and was variety DP 445. This calibration reduced the YPE but did not reduce the variation in YPE across varieties. Figure 14 displays the relationship between calibration A and buggy weight. The slope of the line is 1.03 with an R^2 of 0.96, as compared to a slope of 0.93 and R^2 of 0.96 for calibration 07.

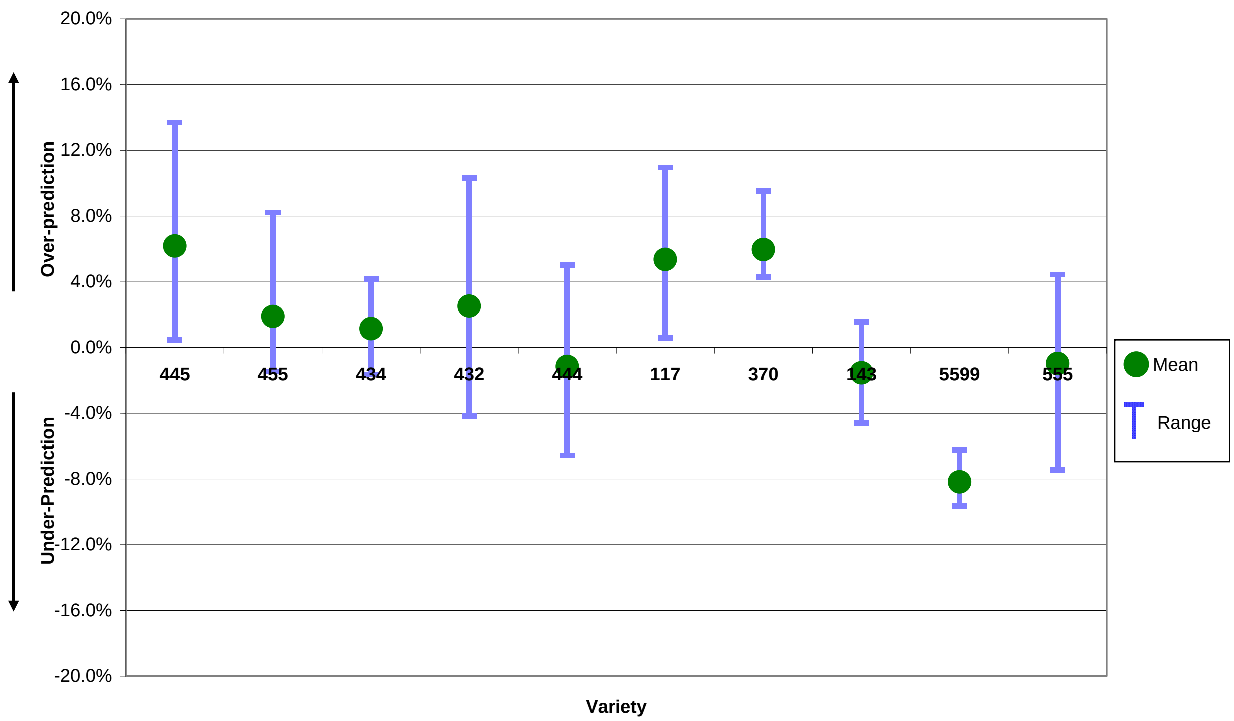

Figure 13. YPE by variety for calibration A. Bars represent the range of YPE.

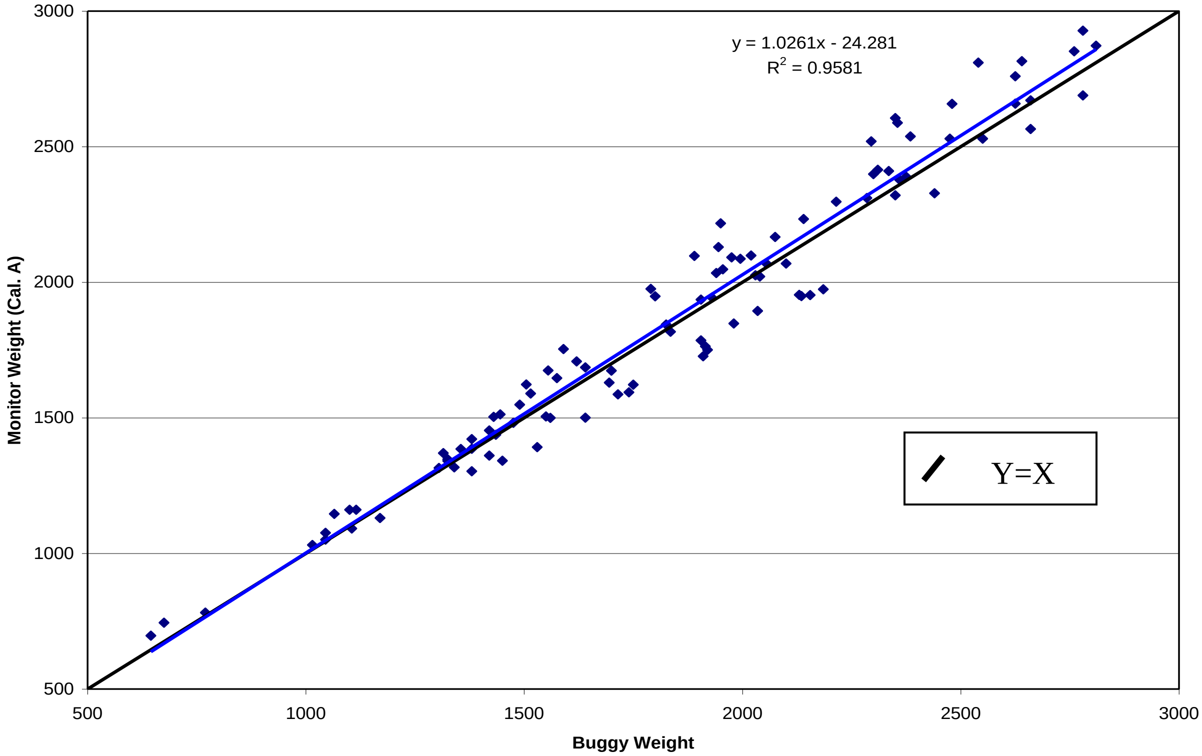

Figure 14. Buggy Weight versus monitor weight using calibration A.

The application of calibration B is summarized in Figure 15. This calibration represents a calibration that would typically be used by a producer. The first three representative loads harvested were used to calibrate the entire season. This calibration used loads from variety DP 455 in field 202 and yields of these loads were 2565, 2501, and 2525 lbs. seed cotton/ ac. Calibration B tended to over predict yield for most varieties and had a higher average absolute error than Calibration A. Calibration B did not reduce variation in YPE. Figure 16 illustrates that again the slope was the only thing that changed after performing the post calibration (slope= 1.05, R^2=0.96). The regression fit was not improved and the residuals were not markedly reduced.

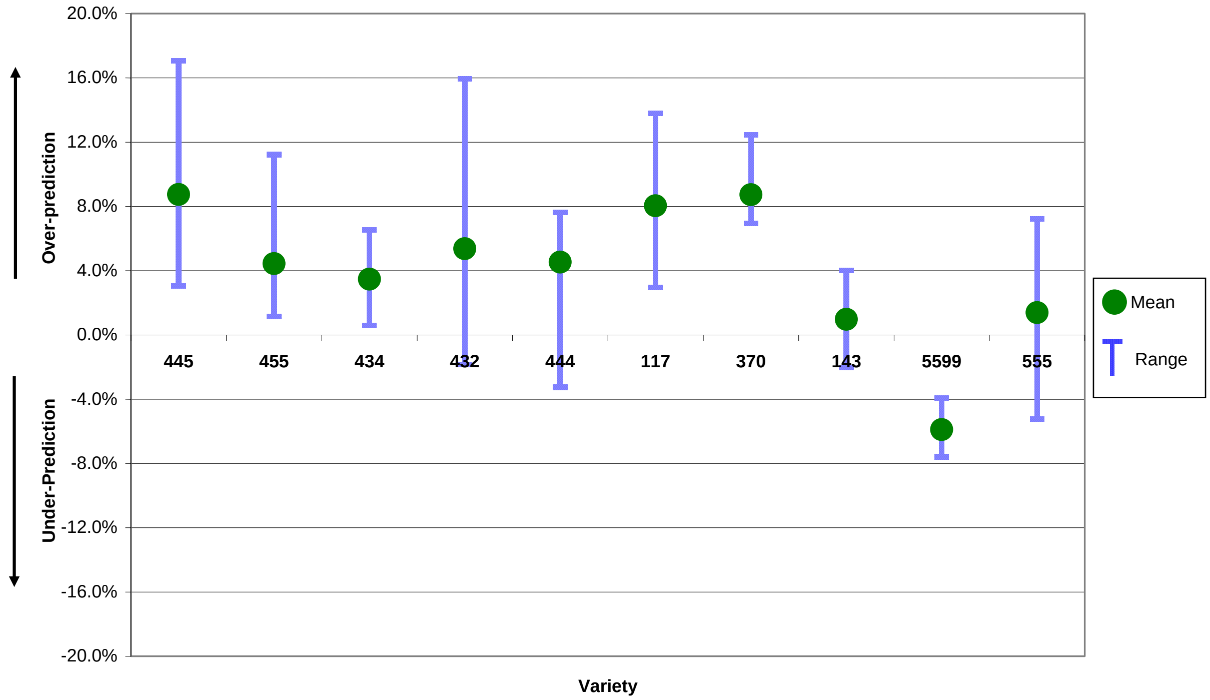

Figure 15. YPE by variety for calibration B. Bars represent the range of YPE.

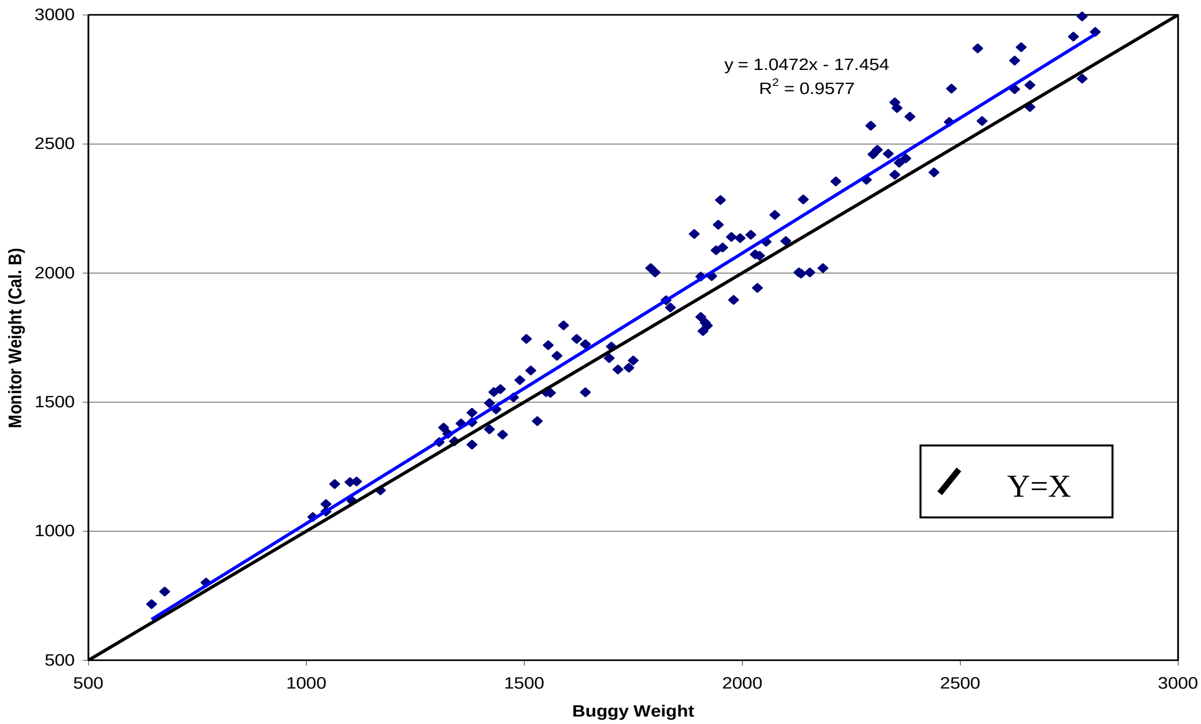

Figure 16. Buggy Weight versus monitor weight using calibration B.

Calibration C consists of an individual calibration for each harvest period. The first three representative loads from one variety were used to calibrate each harvest period individually. The first harvest period used the same loads as calibration B. The second harvest period used loads from field S3LS and variety DP 432 with yields of 2411, 2121, and 2920 lbs. seed cotton/ac. The third harvest period used loads from field A-5 and variety ST 5599 and yields of 3509, 3549, and 3524 lbs. seed cotton/ac. Figure 17 displays YPE by variety for calibration C. This calibration method provides the lowest average absolute mean error (3.8%) of all calibration techniques analyzed. Calibration C was used for all remaining analyses. As seen in Figure 18 this calibration produces a slightly better fit with an R^2 of 0.97 as compared to R^2 of 0.96 in calibration A and B. The slope of the line fitting the data is 0.96. A summary of the slopes and R^2 values is presented in Table 4.

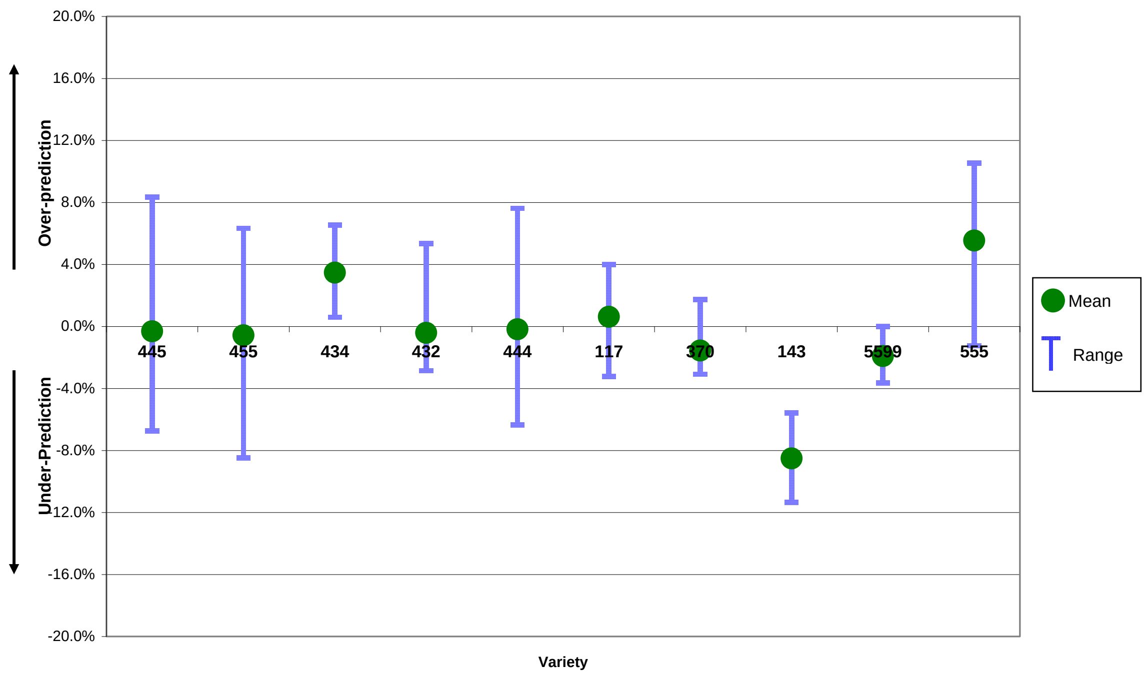

Figure 17. YPE by variety for calibration C. Bars represent range of YPE.

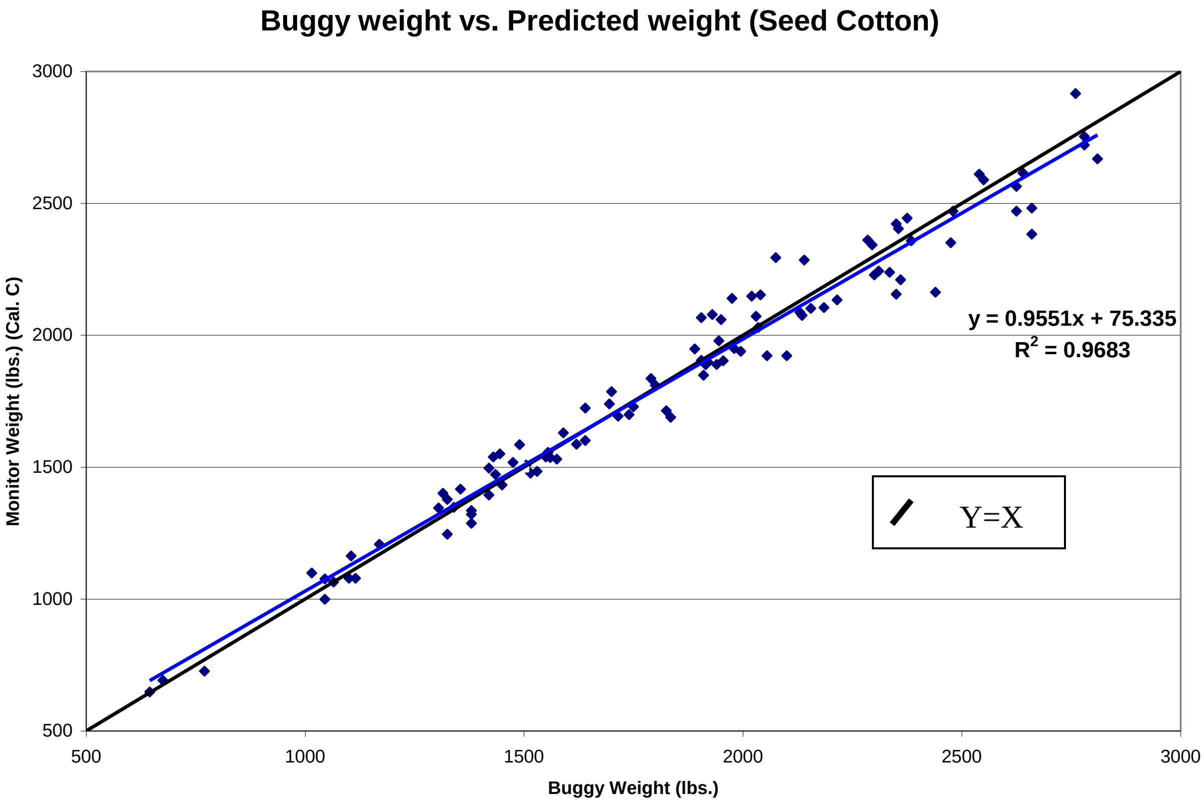

Figure 18. Weight measured by the buggy vs. weight predicted by the monitor using calibration C.

Table 4. Summary of slopes and R^2 values for regression of monitor versus buggy for the four different calibration techniques.

Calibration Method	Slope	R^2 values
Calibration 07	0.933	0.961
Calibration A	1.026	0.958
Calibration B	1.047	0.958
Calibration C	0.955	0.968

As previously discussed, the 2008 harvest season was divided into three harvest periods. It should be noted that there may have been differences between the harvest periods (e.g., environmental conditions or measurement equipment) that could have caused differences in the measured data. If such differences exist, only calibration C would correct for these effects.

Representative data points were selected from each harvest period, and all four calibrations were applied to this data subset. Results are presented in Figure 19. With the exception of calibration C, the highest predicted yield resulted from calibration B and the lowest predicted yield from the 2007 calibration. However, the predicted yield using calibration C starts in the first harvest period being the highest predicted yield and then drops to the second lowest predicted yield during the second harvest period. In the third harvest period it returns to the highest predicted yield but not by the same magnitude. This illustrates the potential to reduce YPE by using harvest period specific calibrations.

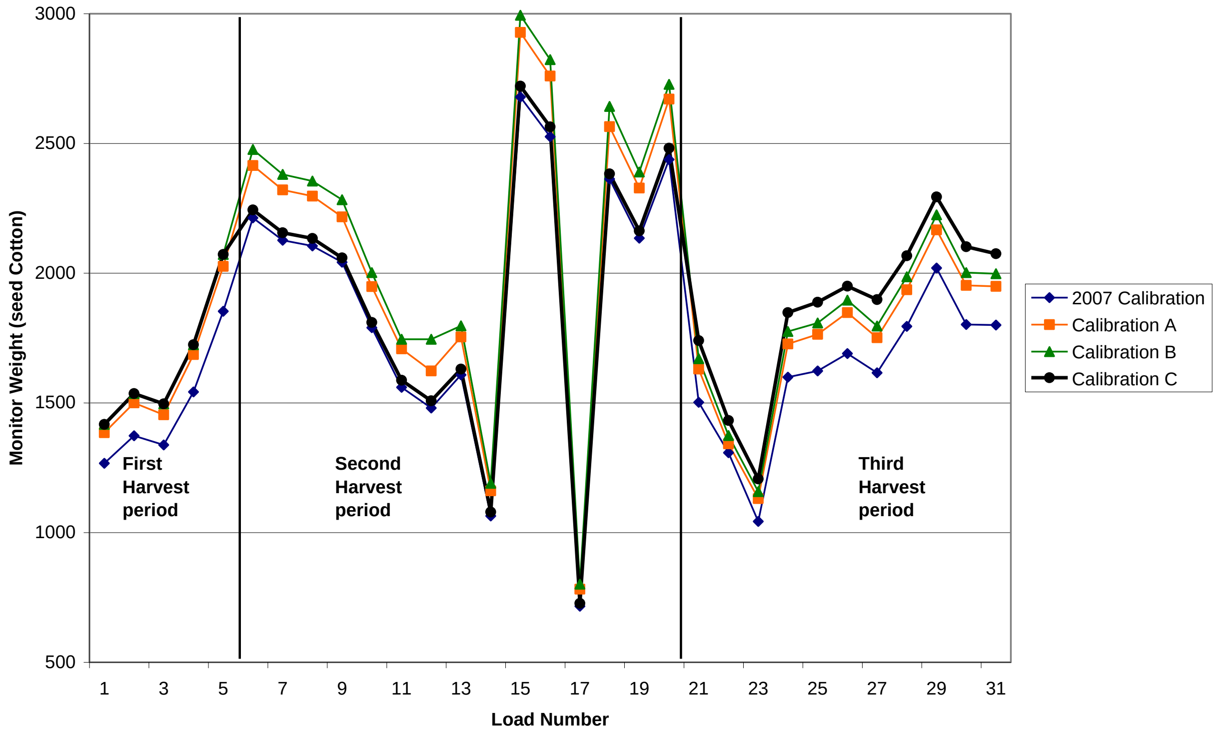

Figure 19. When performing calibrations the monitor simply shifts the data points. Note that the different calibrations maintain the same rank unless a different calibration is applied.

Post Processing

Post processing models were developed and analyzed in an attempt to further reduce YPE. A Pearson Correlation was run to identify possible relationships between YPE and other variables. A summary of that analysis is given in Table 5. Table 6 provides a summary all the models from the stepwise selection consisting of independent variables that passed the significance test for inclusion. The variables in each model and the corresponding R^2 values are presented. Field moisture content and yield were two variables identified that had statistical correlation with YPE. A multiple regression analysis was performed to verify the model and revealed a statistically significant relationship ($p < 0.0001$) between YPE and yield plus moisture. These variables together were able to explain 48% (R^2=0.48) of the variation in YPE. The coefficients for this model were determined and the following equations were used to correct the monitor prediction weights:

YPE=.19913-(.9126*Moisture Content)-(.00004297*Seed Cotton Yield)

Corrected Weight=Predicted Weight-(predicted weight*YPE)

Table 5. Pearson Correlation results. YPE compared to variables. Variables with correlations that showed slopes not significantly different from zero are not reported.

	Acres	moisture	yield	sci	mic	mat	ui	sfi	rd	b
YPE	0.3	0.37	-0.62	0.34	-0.37	-0.38	0.24	-0.31	-0.25	0.3

Table 6. Models providing highest correlation with YPE.

Models	**R^2**
Moisture	28%
Moisture + Yield	48%
Moisture + Yield + SFI	57%
Moisture + Yield + SFI + Reflectance	60%
Moisture + Yield + SFI + Reflectance + Elongation	63%

Figure 20 is similar to previous figures illustrating how the monitor data relates to the buggy weight, but the data has been post-processed using the model that adjusts for yield and moisture. Unfortunately, the model tends to introduce more noise into the data. This method results in a slope of 0.91 and an R^2 value of 0.93 which is less accurate than the 2007 calibration (slope of 0.93 and R^2 of 0.96). Similarly adding additional variables, reflectance and elongation, to the model introduced noise as did the model using only yield and moisture and was not suitable for post-processing.

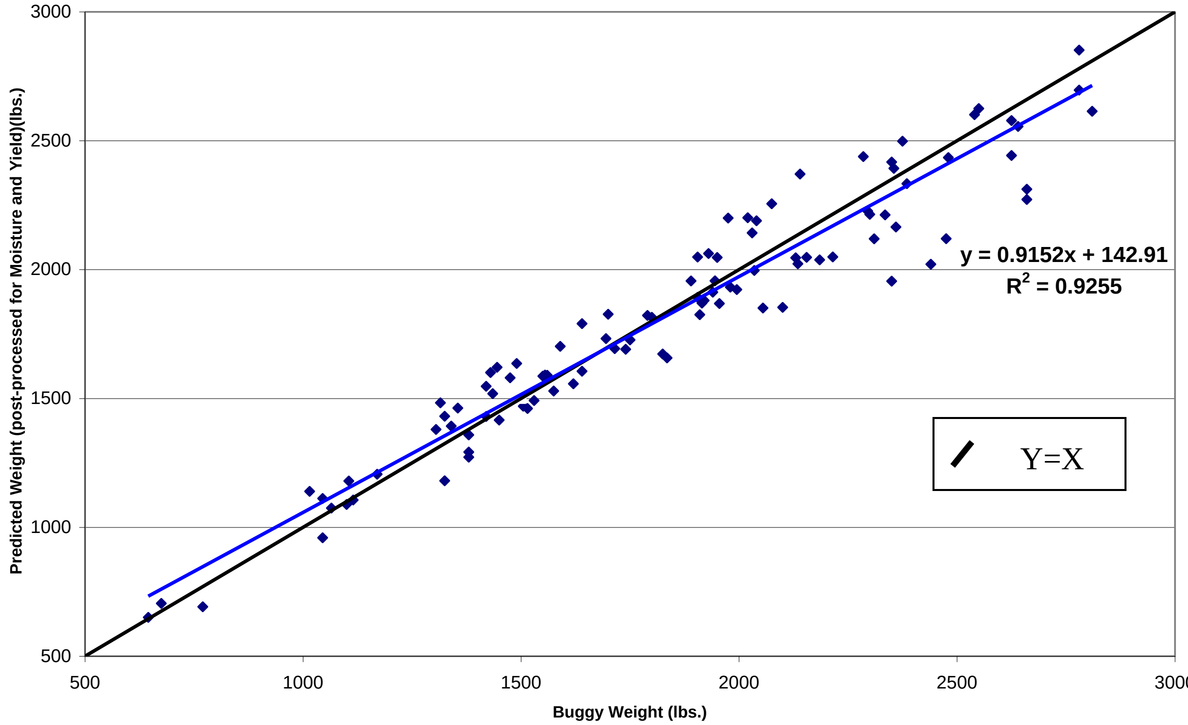

Figure 20. Weight measured by the buggy vs. weight predicted by the monitor using calibration C post processed using moisture and yield.

Moisture Effect on YPE

With moisture correlating to YPE, it was hypothesized that moisture does not affect the the monitor prediction but has an effect on the actual weight measured by the buggy. Figure 21 shows the all buggy weights adjusted to a common moisture content (10% dry basis) versus predicted weight (calibration C). This procedure improves slope to 0.97 and gives an R^2 value of 0.98 which is a stronger relationship than in calibration C. Table 7 summarizes errors for adjusted moisture content and compares them to calibration C. Note that adjusting for moisture increases the YPE mean absolute error and root mean squared error. It is important to note that YPE is a signed value and is not as important here as mean absolute error (i.e. YPEs of -100.0% and 100.0% would result in average YPE of 0.0%).

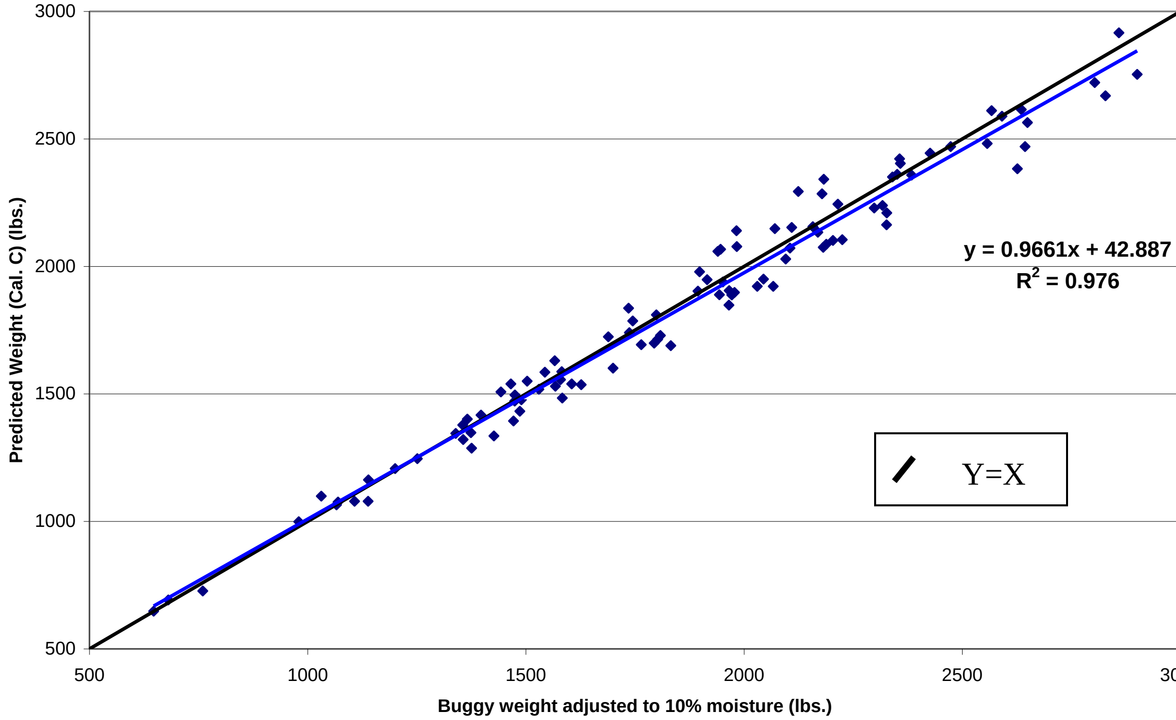

Figure 21.Weight measured by the buggy adjusted to 10% moisture content (db) vs. weight predicted by the monitor using calibration C.

Table 7. **Summary of errors in calibration C and calibration C compared to buggy weight adjusted to 10% moisture(db)**.

Calibration Technique	Error Summary
Calibration C	YPE=-0.13% Variance = .21% Mean Absolute Error = 3.77% Root Mean Squared Error = 4.55%
Calibration C and buggy weight adjusted for moisture	YPE=-0.92% Variance = .15% Mean Absolute Error = 3.31% Root Mean Squared Error = 3.94%

The same post processing techniques were utilized on the moisture corrected data to determine if YPE and variability in YPE could be further reduced, with the exception of moisture content as an independent variable. The stepwise regression used the YPE (dependent variable) calculated from Calibration C and the buggy weight adjusted to 10% moisture content. Stepwise regression was performed again and produced models with the same variables. The moisture adjusted yield explained 27% of the variation in YPE and moisture adjusted yield (10% moisture (db)) with SFI model explained 36%. These models were implemented as before to try to correct the error left in Calibration C at 10% moisture (db). The following equations were used:

YPE=(Seed Cotton Yield at 10% moisture * -0.0000419)+0.10544

YPE=(Seed Cotton Yield at 10% moisture * -0.00005773)+(SFI*0.01573)+0.01316

Corrected Weight=Predicted Weight-(predicted weight*YPE)

These two models explained a very small portion of the variability in the data but when they were implemented they further improved the regressed fit. Simply adjusting for yield reduced the mean absolute monitor error to 2.6% and produced a slope of 0.99 and R^2 of 0.982 when graphed versus buggy weight at 10% moisture (db) (Figure 22). When adjusting for yield and SFI the slope changes slightly (1.01) and the R^2 value (0.985) basically stays the same (Figure 23). Adjusting the buggy weight to 10% moisture (db) and post-processing the monitor output based on yield gives the most accurate results (Table 8). No other variables met the significance level for entry into the model when removing moisture and yield from stepwise regression variable list.

Table 8. Summary of slopes and R^2 values for regression of monitor versus buggy at 10% moisture (db) for the calibration C and post-processing.

Calibration Method compared with buggy at 10% moisture (db)	Slope	R^2 values
Calibration C Post-Processed for yield and moisture (buggy not adjusted)	0.915	0.925
Calibration C	0.966	0.976
Calibration C Post-Processed for yield	0.994	0.982
Calibration C Post-Processed for yield and SFI	1.007	0.985

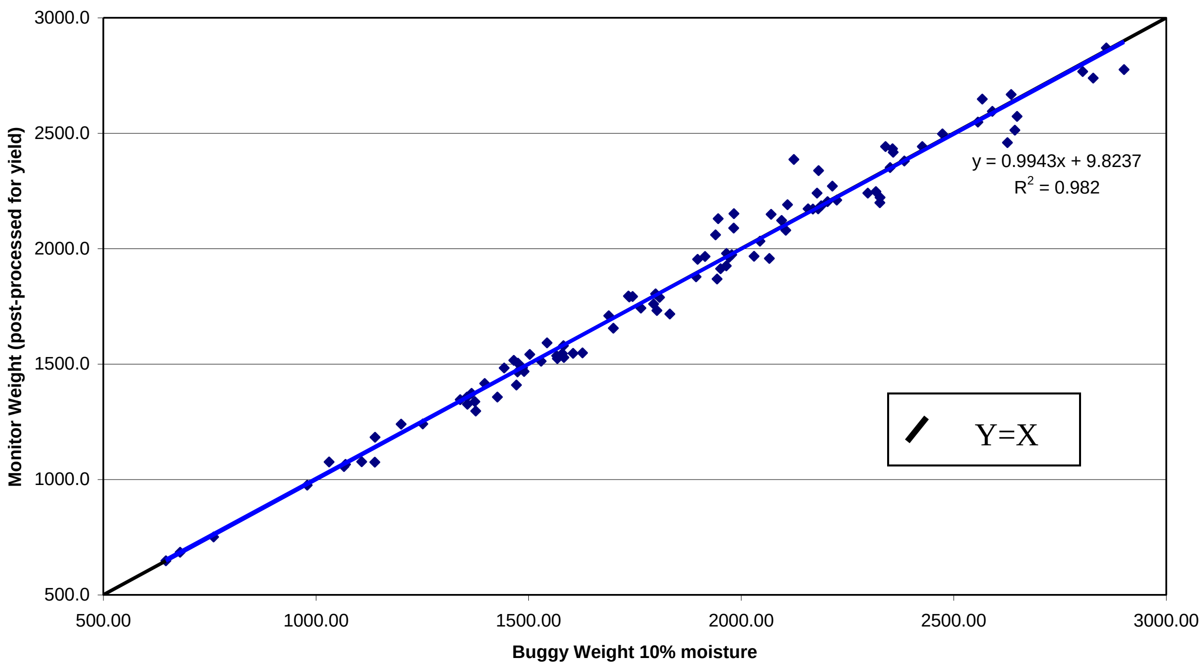

Figure 22. Calibration C adjusted with yield compared to Buggy weight at 10% moisture (db).

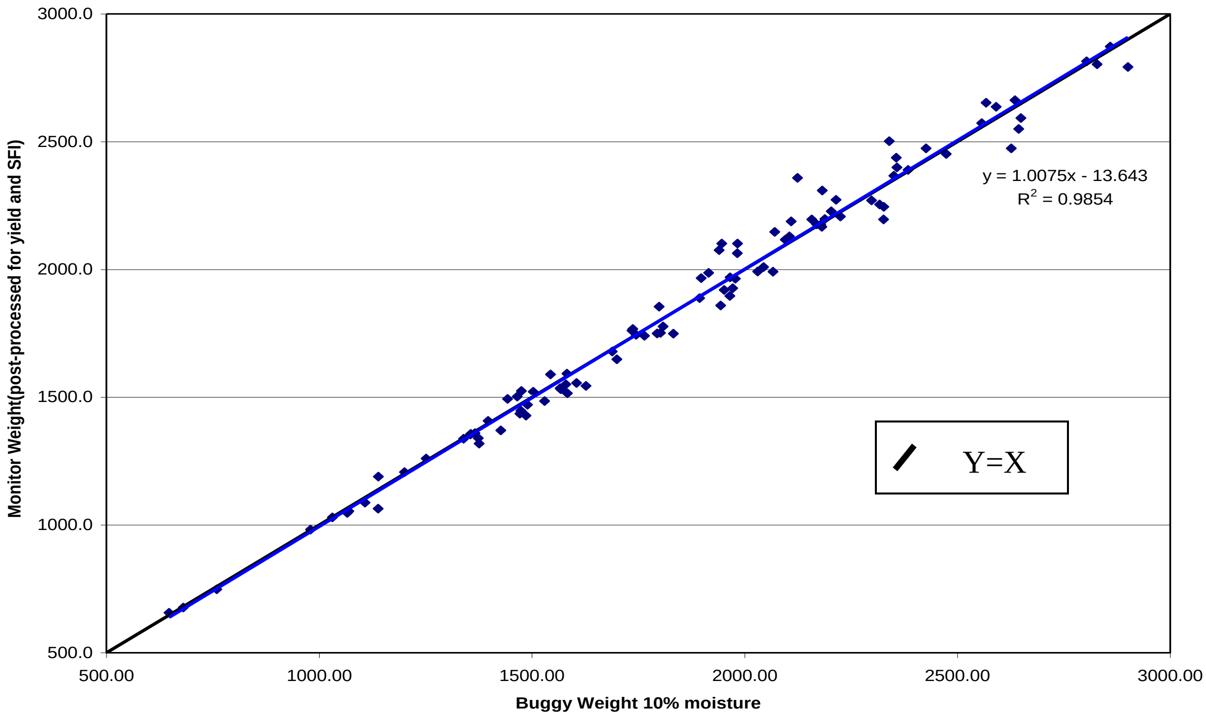

Figure 23. Calibration C adjusted with yield and SFI compared to Buggy weight at 10% moisture (db).

Variety Trial Comparison

Figure 24 compares the two techniques of measuring lint yield by variety (calculated using the gin turnout values from gin sample data) using the calibration C and the buggy yield not adjusted for moisture. Figure 25 shows a comparison of these two measurement techniques with the buggy yield adjusted to 10% moisture. As shown in Figure 25, Tukey's mean separation (α=0.05) found identical differences in yield ($P<.0001$) in both the weighing buggy at 10% moisture and the third calibration of the yield monitor. Note the buggy's mean separation groupings changed while the monitor mean separation groupings do not. This implies that moisture content variations and the resulting impact on the buggy weights are the source for the difference in mean separation analysis between the buggy weight and monitor predictions rather than monitor prediction error. This implication is also supported by the difference in the physics of the two measurement techniques. The weighing boll buggy measurement inherently includes the weight associated with varying moisture content in the seed cotton while the optical basis of the yield monitor does not. In that sense the yield monitor may provide a more direct and accurate characterization of the actual lint yield.

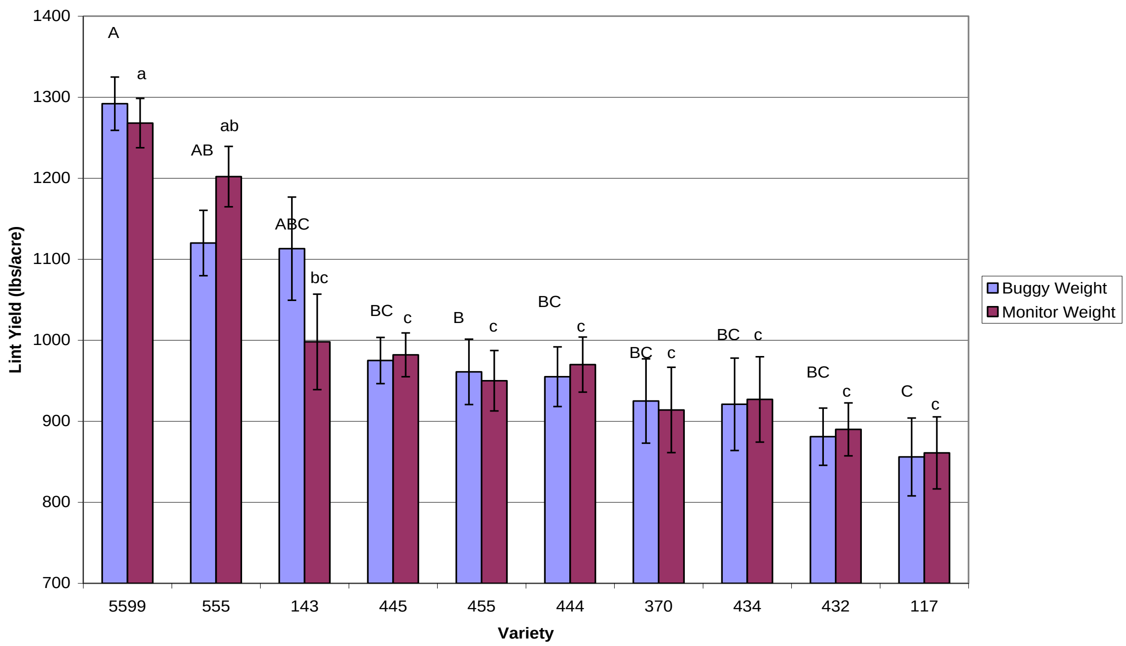

Figure 24. Comparison of two yield measurement techniques for yield trial results utilizing calibration C. Varieties with the same letter grouping do not differ significantly (p<0.0001).

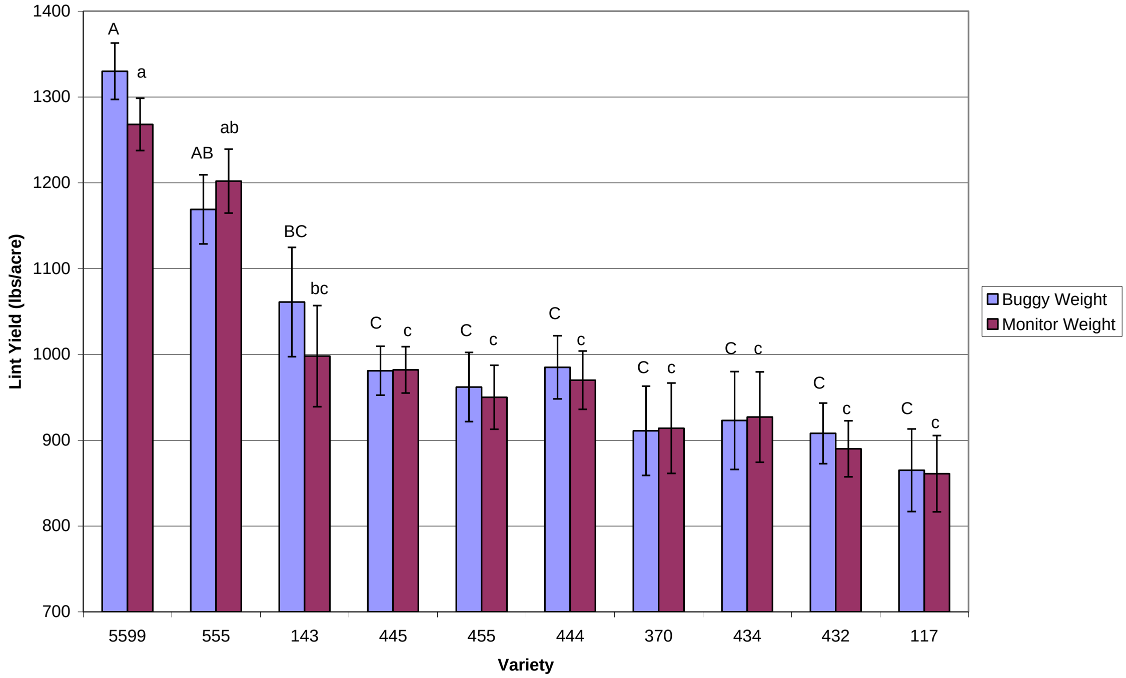

Figure 25. Comparison of two yield measurement techniques for yield trial results utilizing calibration C and with buggy weight adjusted to 10% moisture content (db). Varieties with the same letter grouping do not differ significantly (p<0.0001).

Figure 26 displays the same information as the two previous graphs for yield comparison based on moisture adjusted yield data that includes the application of post processing. It is important to note that the mean separation classes are identical whether post processing is applied or not. This may suggest that post processing is not necessary to properly classify differences between varieties. However, improved accuracy in the predicted lint yield may increase confidence in the classification or possibly enable the detection of smaller differences between varieties through reduction in measurement variability. Figure 27 displays differences in YPE by variety. YPE in variety DP 555 is significantly different from the other varieties and illustrates that there is still room for improvement in the system. This variety was in field A5 with variety ST 5599 and yield was 170 lbs. lint/acre less than the Stoneville variety. These two varieties were in a separate harvest period and therefore used the same calibration (ST 5599 was used for calibration loads). This difference in yield may have been too high for the post processing to completely correct.

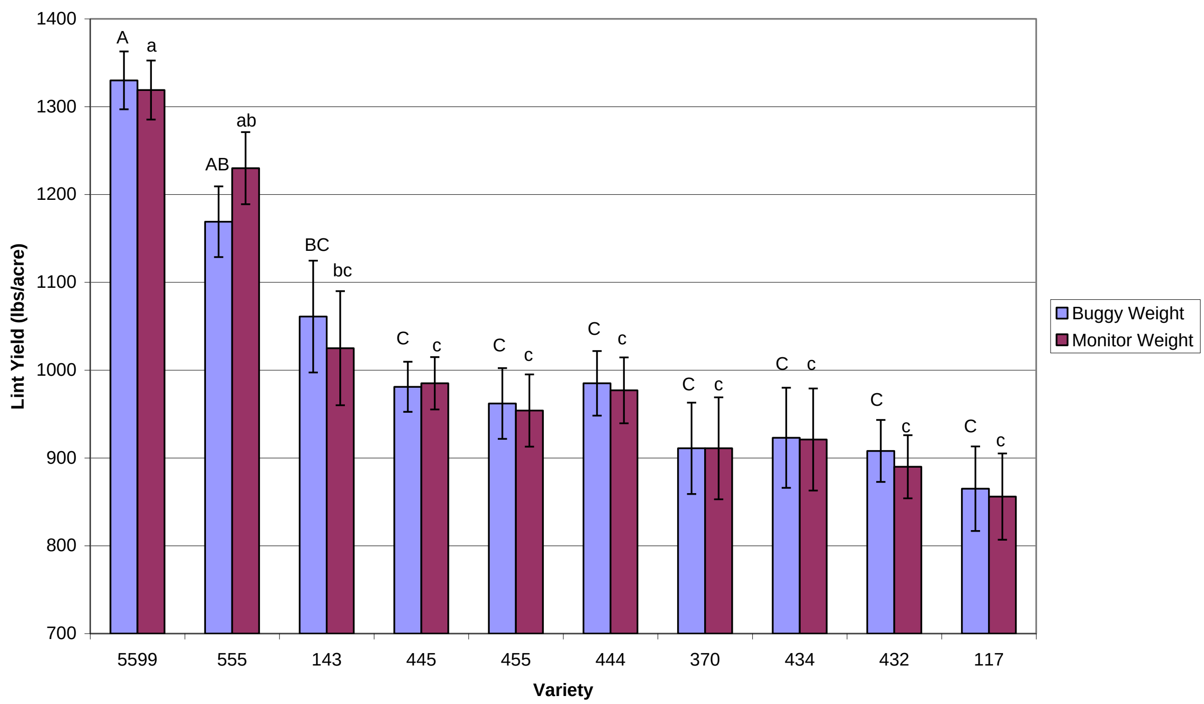

Figure 26. Comparison of two yield measurement techniques for yield trial results utilizing calibration C post processed for yield compared with buggy at 10% moisture content (db). Varieties with the same letter grouping do not differ significantly ($p<0.0001$).

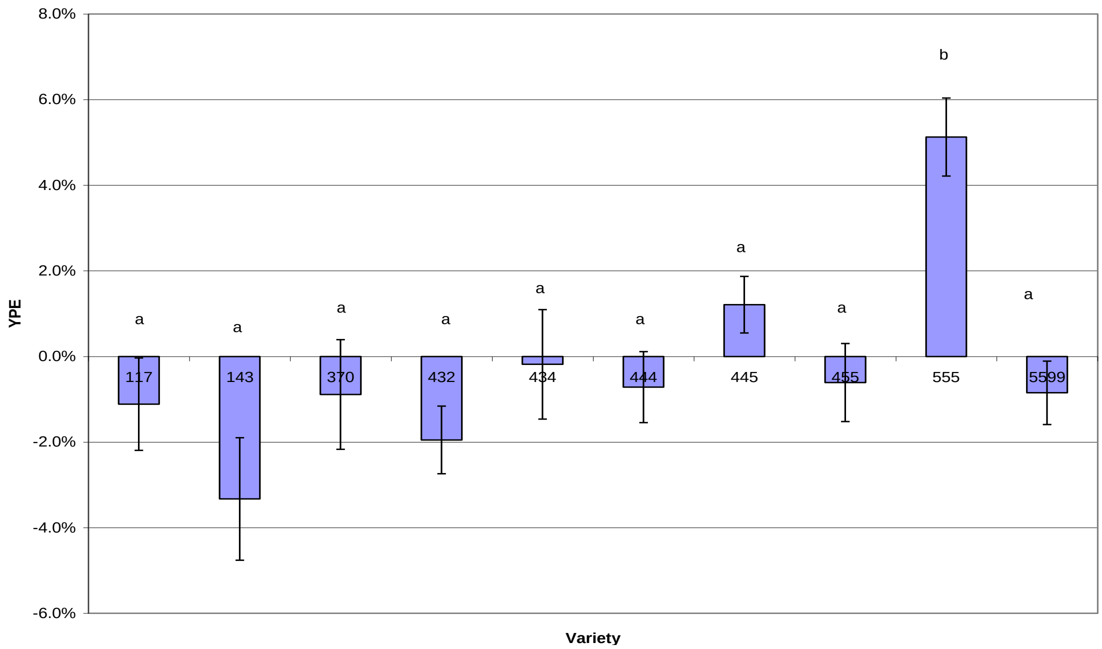

Figure 27. YPE by variety using Tukey's mean separation. Values with different letter groupings are significantly different ($p < 0.0001$).

Chapter 6: Discussion and Conclusions

An Ag Leader cotton yield monitor was evaluated for performance in changing varietal and environmental conditions. The monitor was installed on a John Deere 9976 four row cotton picker. Monitor yield prediction was compared to weighing boll buggy yield measurement in 2007 and 2008. In 2007 and 2008 the yield monitor showed strong correlations (R^2 0.996 and 0.982 respectively) to the boll buggy measurement and both had slopes very close to one (0.999 and 0.966 respectively) when re-calibrating for each harvest period.

Moisture and yield were identified as having a statistically significant relationship to YPE. Moisture and yield explained 48% of the variation in YPE after calibration C (calibrating each harvest period individually) was implemented. Moisture however did not affect the monitor but affects the gravimetric weight of the cotton measured with the boll buggy. Moisture content should be measured to determine an accurate weight if boll buggies continue to be used for variety trials. Yield was used to post-process the output from the monitor and was successful in further reducing the mean absolute error from 3.3% (calibration C compared to monitor at 10% moisture) to 2.5%.

Proper calibration is an extremely important process in insuring the accuracy of measurement systems, and the yield monitor is no exception. The monitor should be calibrated when harvest is interrupted for consecutive days due to rain, equipment failure, or waiting for the crop to mature. The ability to post calibrate would make this feasible in the sense that weights could be obtained at any point during the harvest or from the gin. The new cotton module building pickers would allow for the calibration weights to be obtained from the gin as well.

In 2007 and 2008 researchers would have arrived at the same conclusion for yield trial results with the monitor as they would have with the boll buggy by simply using the proper calibration techniques (i.e. calibration C). Even though the post processing model is successful in reducing the error it may not be necessary since this data returned the same conclusion as calibration C for the yield trial test. This is very important when considering the new module building pickers which would create experimental units too large for practical purposes. It would be possible to use these modules to calibrate and use the same calibration technique described by calibration C if they are well identified and weighed at the gin. The following bullet list summarizes key findings:

- Yield was determined to have a statistically significant relationship with YPE ($p<0.0001$, $R^2 = 0.4375$) before any post calibrations were implemented.
- Moisture also affected YPE and adjusting buggy weights to a common moisture content reduced mean absolute error from 3.7% to 3.3%. This does not seem to affect the monitor but affects the gravimetric weight of the cotton, which is being used for comparison.
- A post-processing model was developed using yield and was able to further reduce mean absolute error to 2.6%.
- In 2007 and 2008 the yield monitor would have given the same conclusion as the boll buggy for a variety yield trial with the proper calibration (calibration C).

It is important to remember that this study is measuring monitor performance by comparing it to the industry standard of using weighing boll buggies for yield trials. As with any measurement tool there is always some degree of uncertainty. It is very possible that the remaining average absolute errors (less than 3.5% both years) are as much related to the buggy as the yield monitor. These errors will also introduce some error into the calibration but they would most likely be systematic and would not affect variability in weights but skew them in one direction or another. Data from 2007 and 2008 suggest that the monitor can be used to collect data from varietal trials when an intensive calibration technique similar to calibration C is implemented. This is appealing to researchers conducting yield trials because it will greatly increase their efficiency and perhaps allow them to conduct more trials in the future. This also allows for the new module building pickers to be used for varietal trials.

Recommendations

During post processing attempts it was discovered that yield explained 44% (R^2=0.4375) variation in Relative Monitor Error. It may be possible to make adjustments to the system to improve the system's accuracy at higher yields and in turn higher cotton flow rates. Flow rate is a function of yield and speed. Possibly to increase accuracy in yield trials speed could be reduced to reduce flow rate and improve monitor performance. In 2007 yields were so low that the monitor was likely counting one or two cotton bolls at a time. In 2008 as yields increased that stream of cotton likely gets too thick for the monitor to maintain the same accuracy at lower yields.

Future studies should analyze the impact of picker speed on accuracy within a variety with a constant yield. Additionally, this study was not able to address the impact of yield within a variety. It could be argued that the impact of yield is confounded by the impact of variety. Therefore, work should be done to vary yield within a variety by varying plant population density and fertilization rates. This would control the impact of variety while comparing yield and flow rate to YPE.

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APPENDICES

Appendix A: 2007 Field Layout Maps

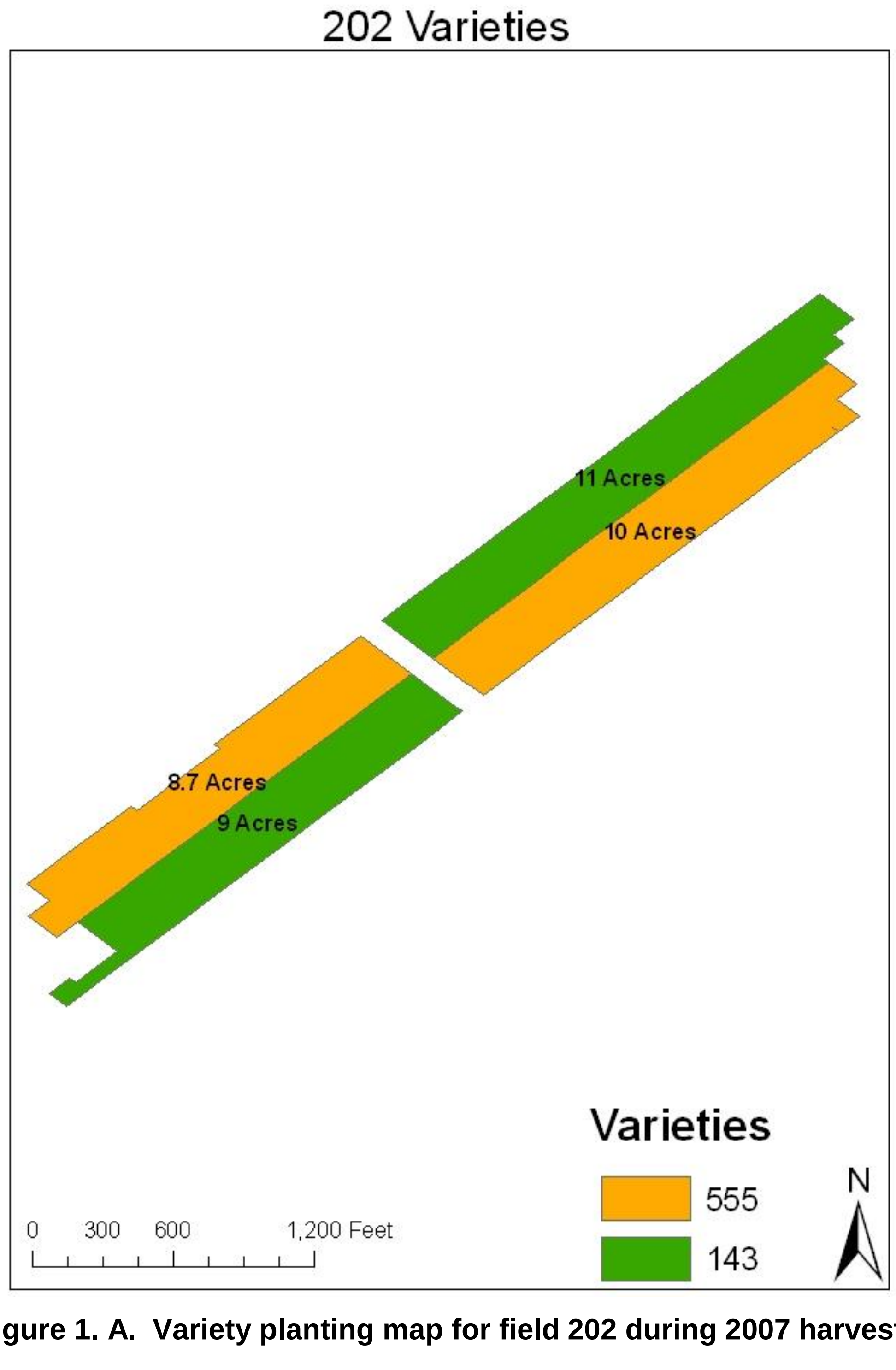

Figure 1. A. Variety planting map for field 202 during 2007 harvest.

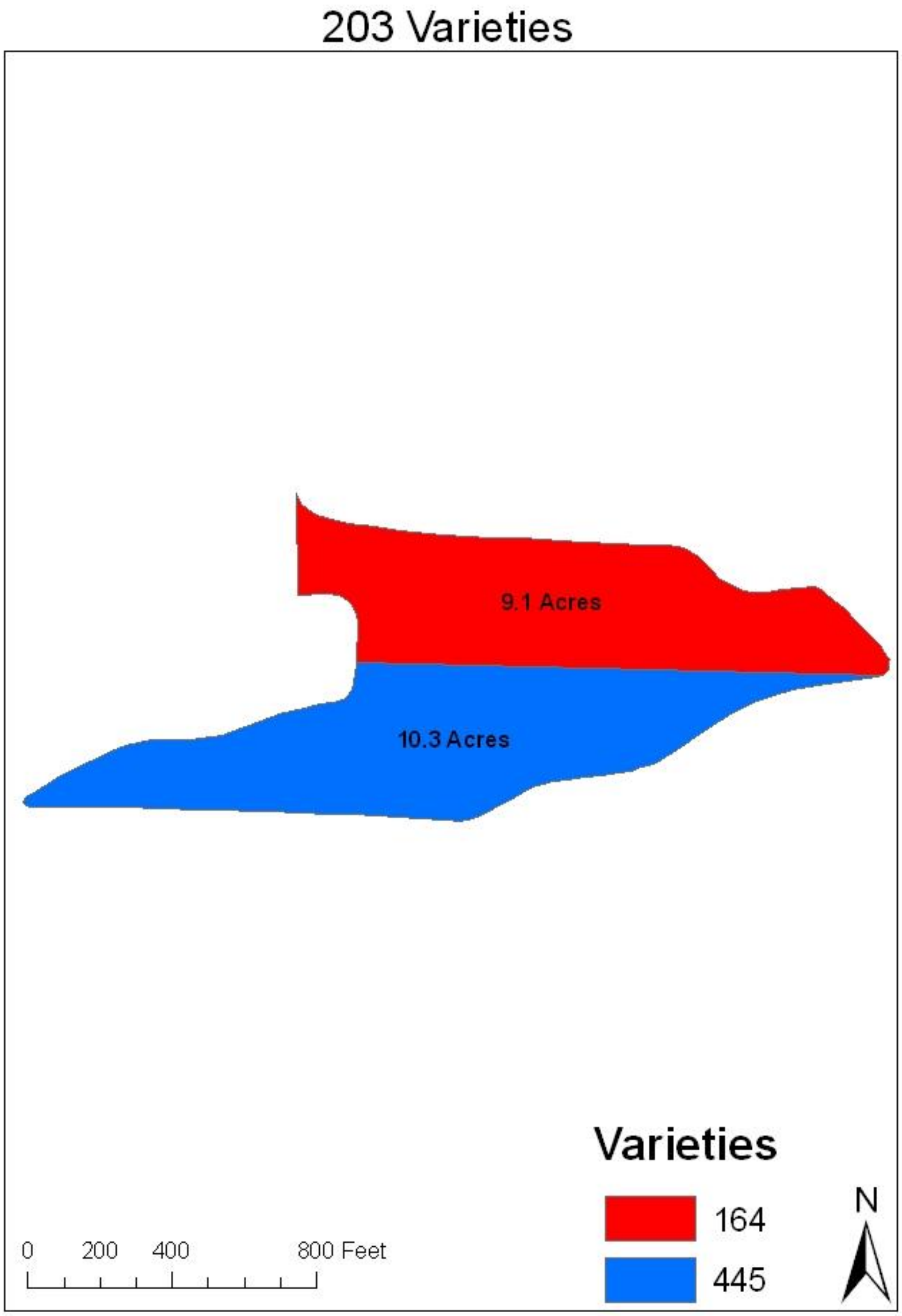

Figure 2. A. Variety planting map for field 203 during 2007 harvest season.

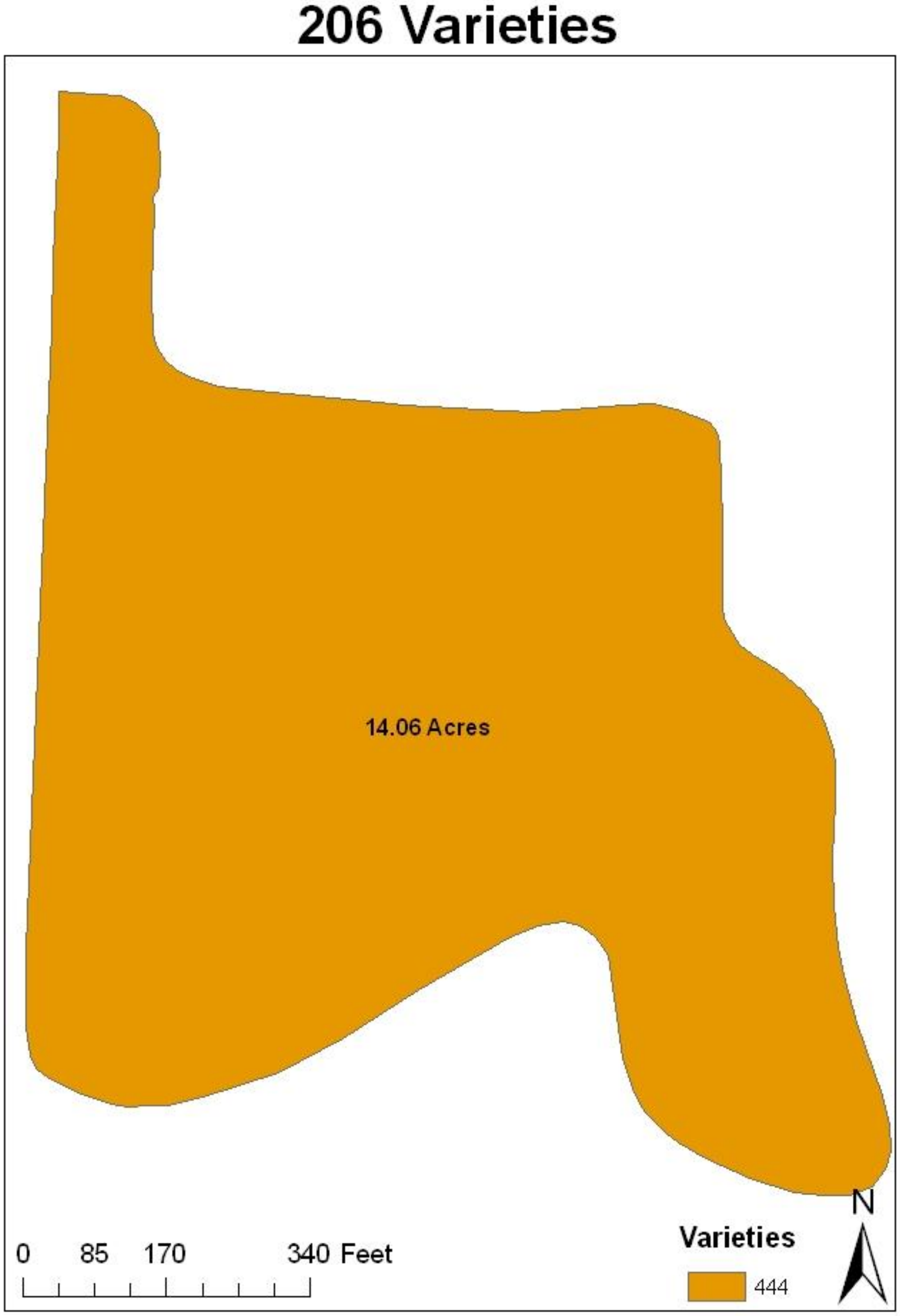

Figure 3. A. Variety planting map for field 206 during 2007 harvest season.

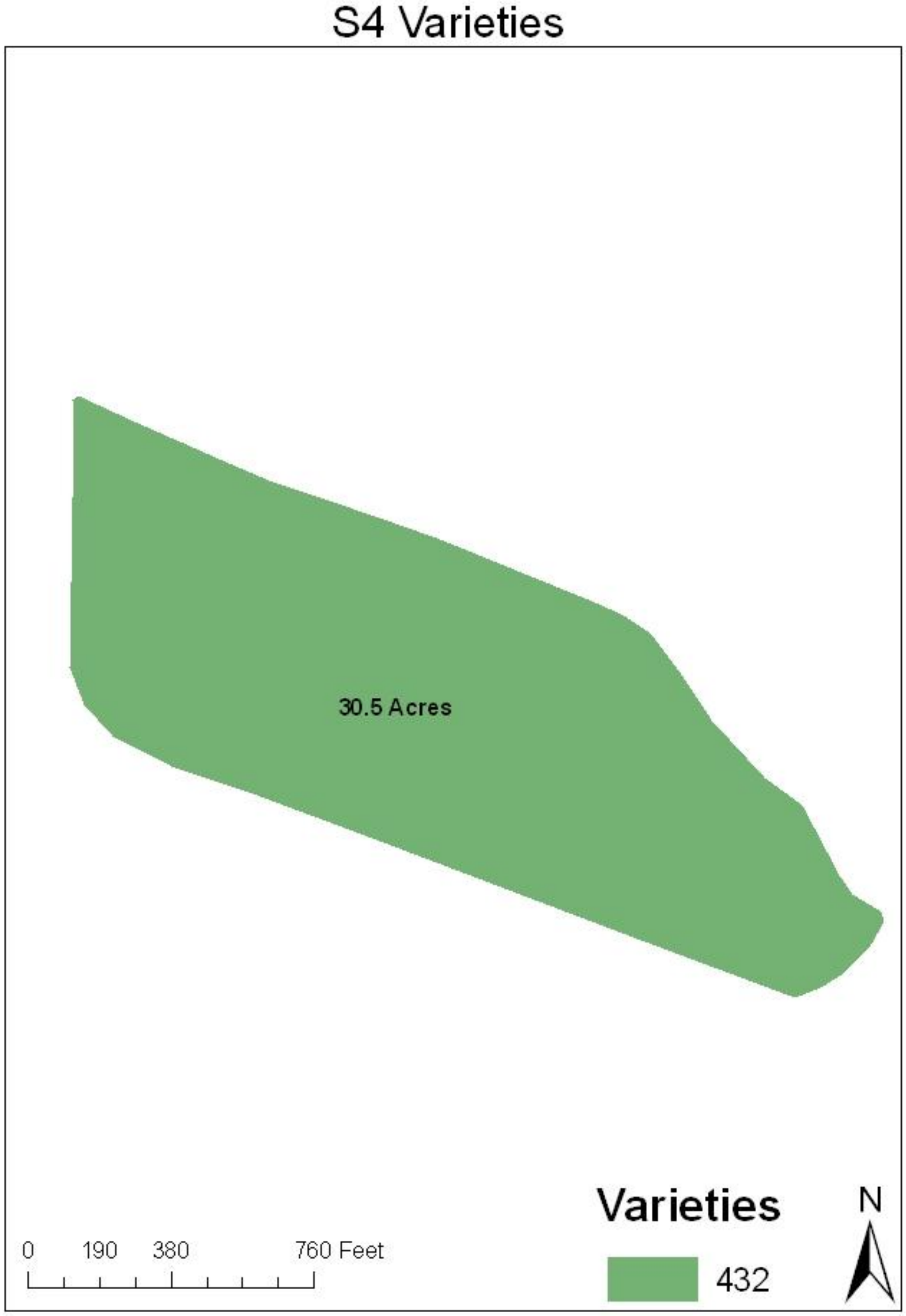

Figure 4. A. Variety planting map for field S4 during 2007 harvest season.

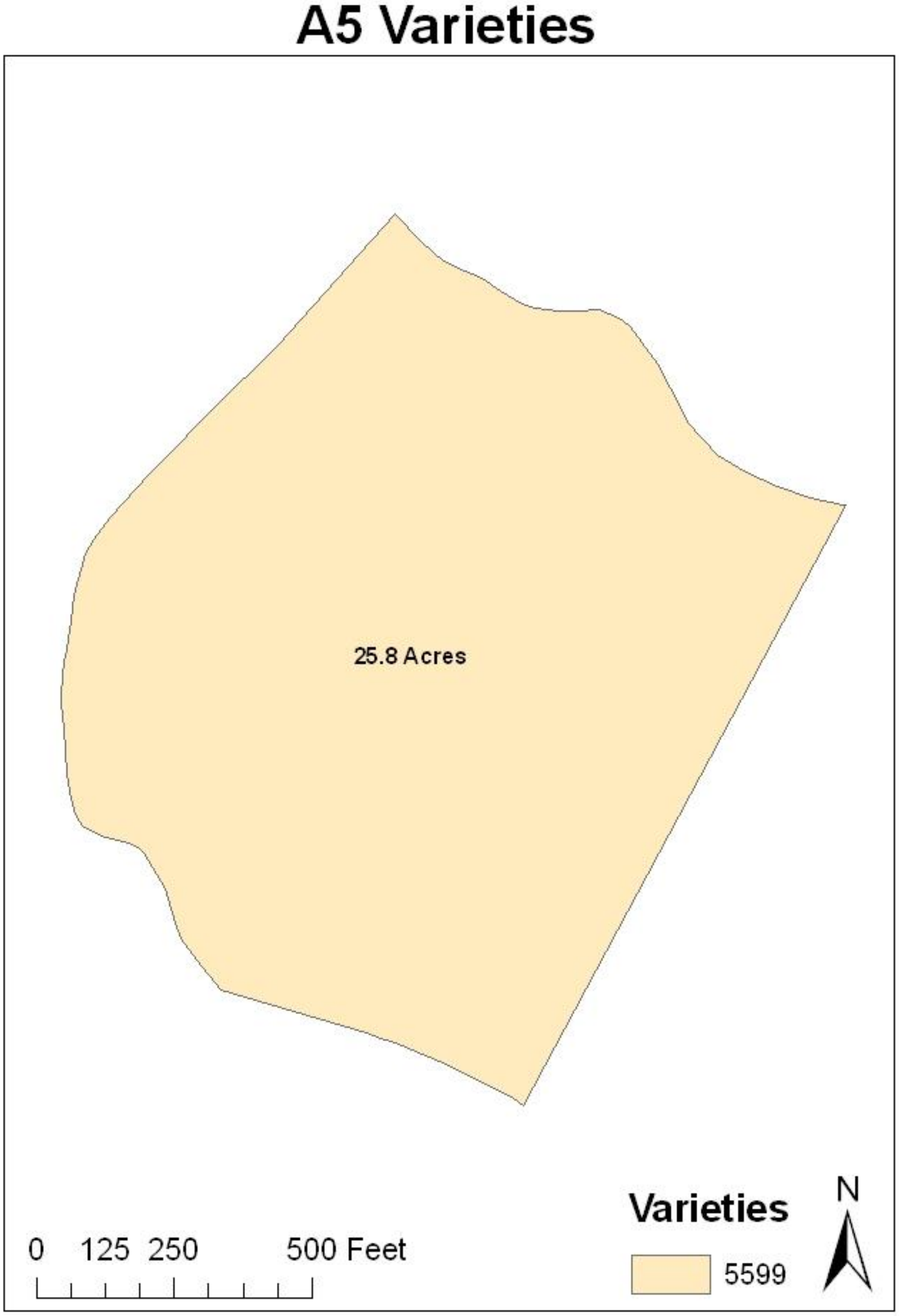

Figure 5. A. Variety planting map for field A5 during 2007 harvest season.

Appendix B: 2008 Field Layout Maps

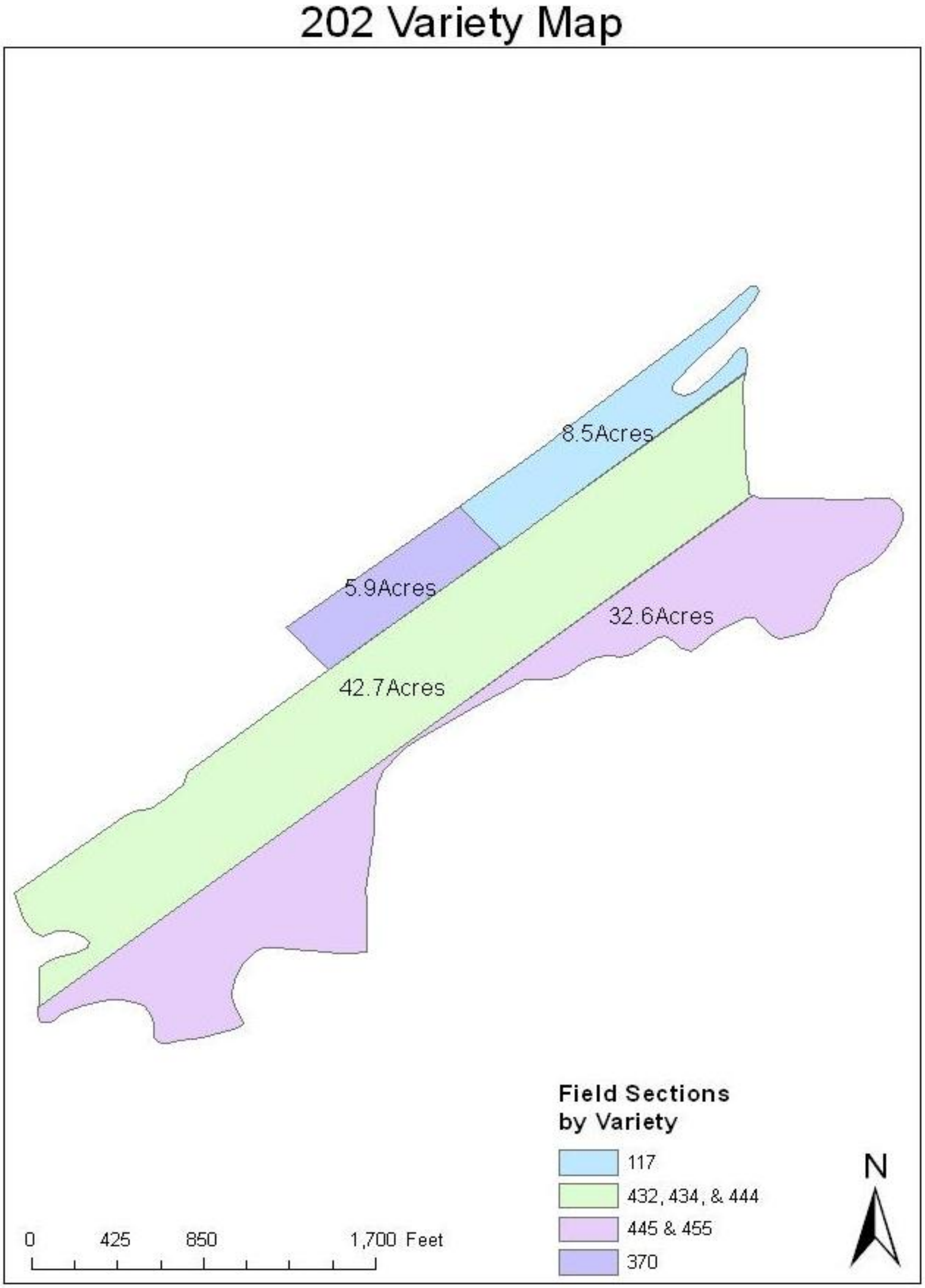

Figure 1. B. Variety planting map for field 202 during 2008 harvest season.

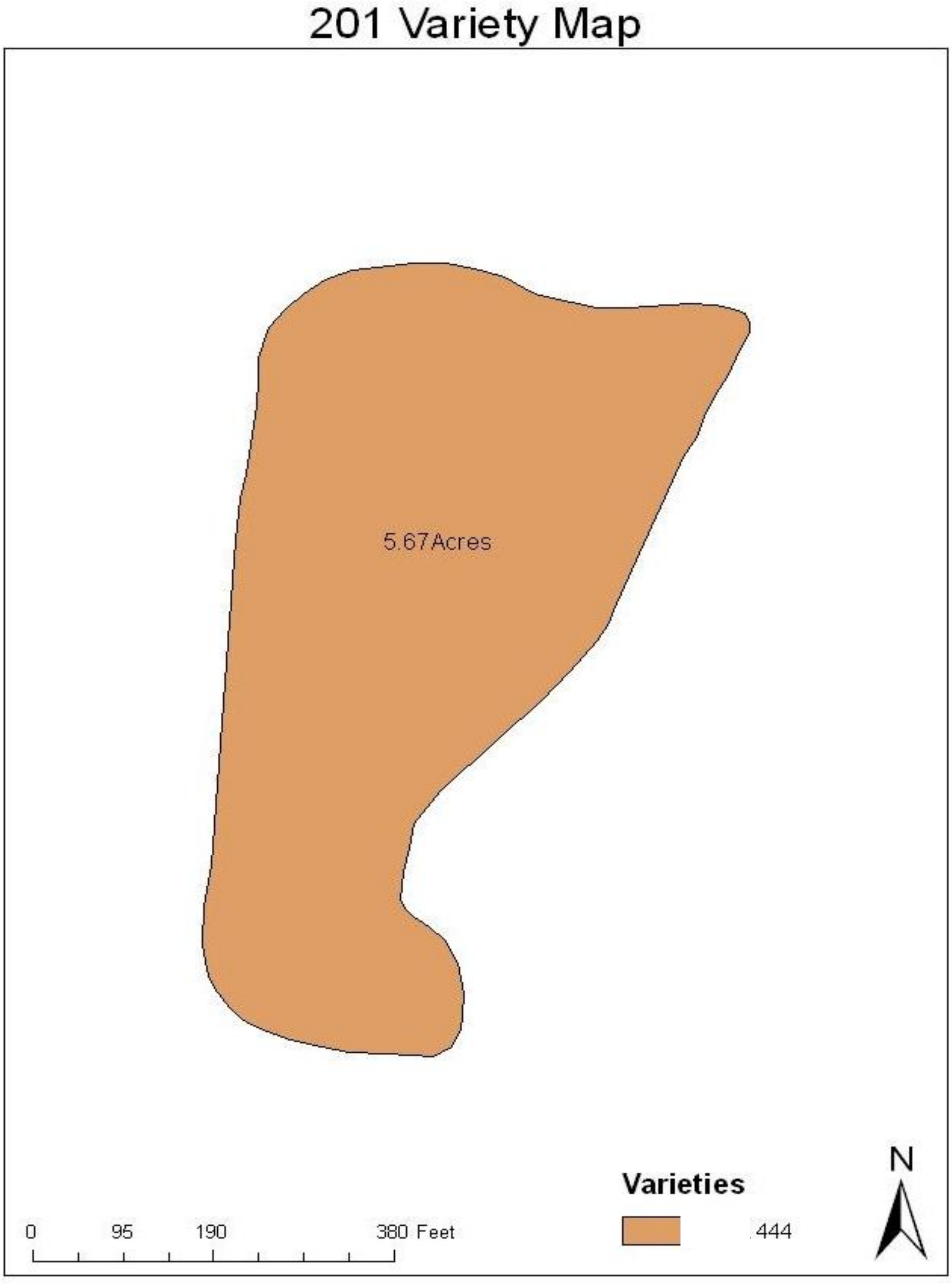

Figure 2. B. Variety planting map for field 201 during 2008 harvest season.

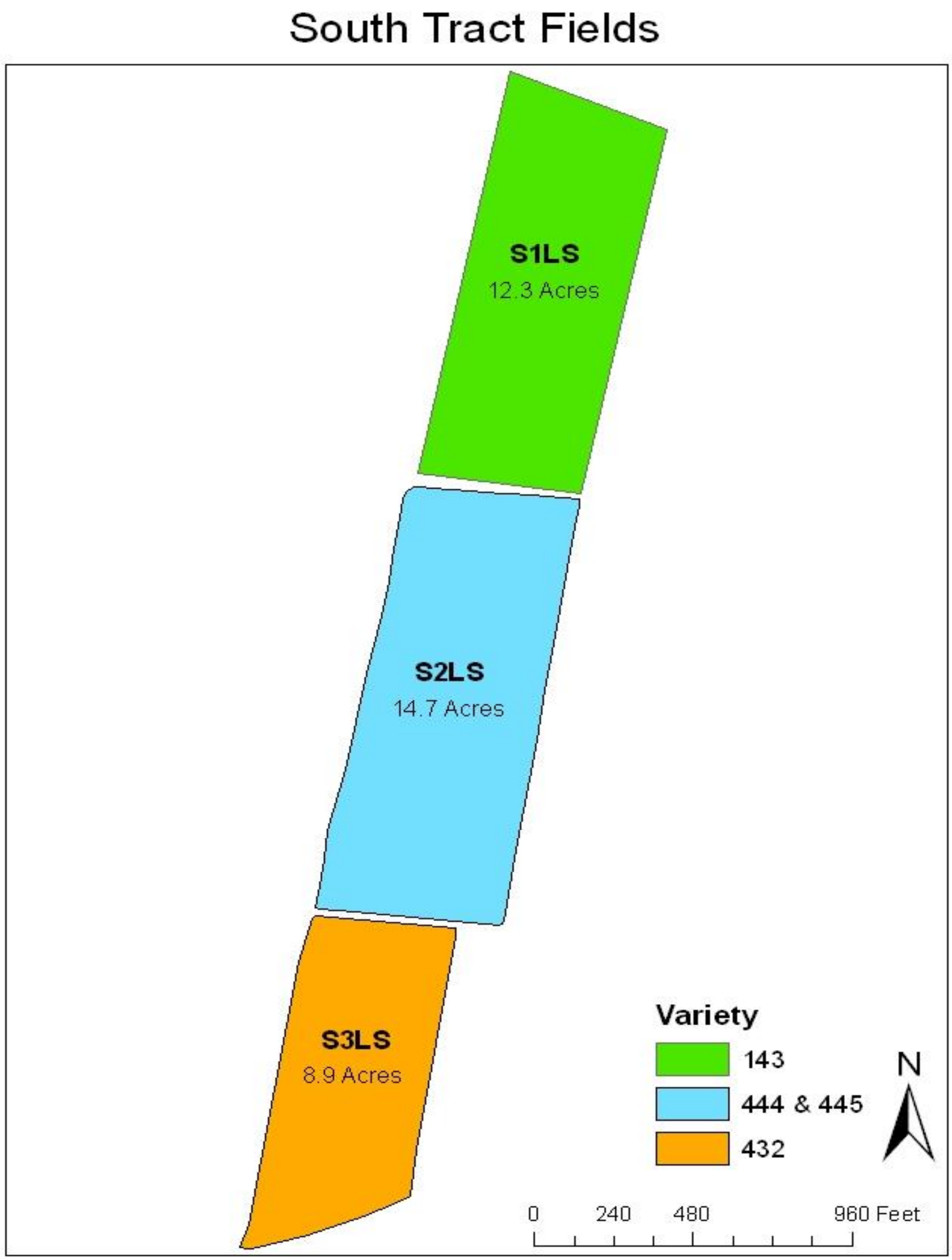

Figure 3. B. Variety planting map for South tract during 2008 harvest season. Fields S1LS, S2LS, and S3LS.

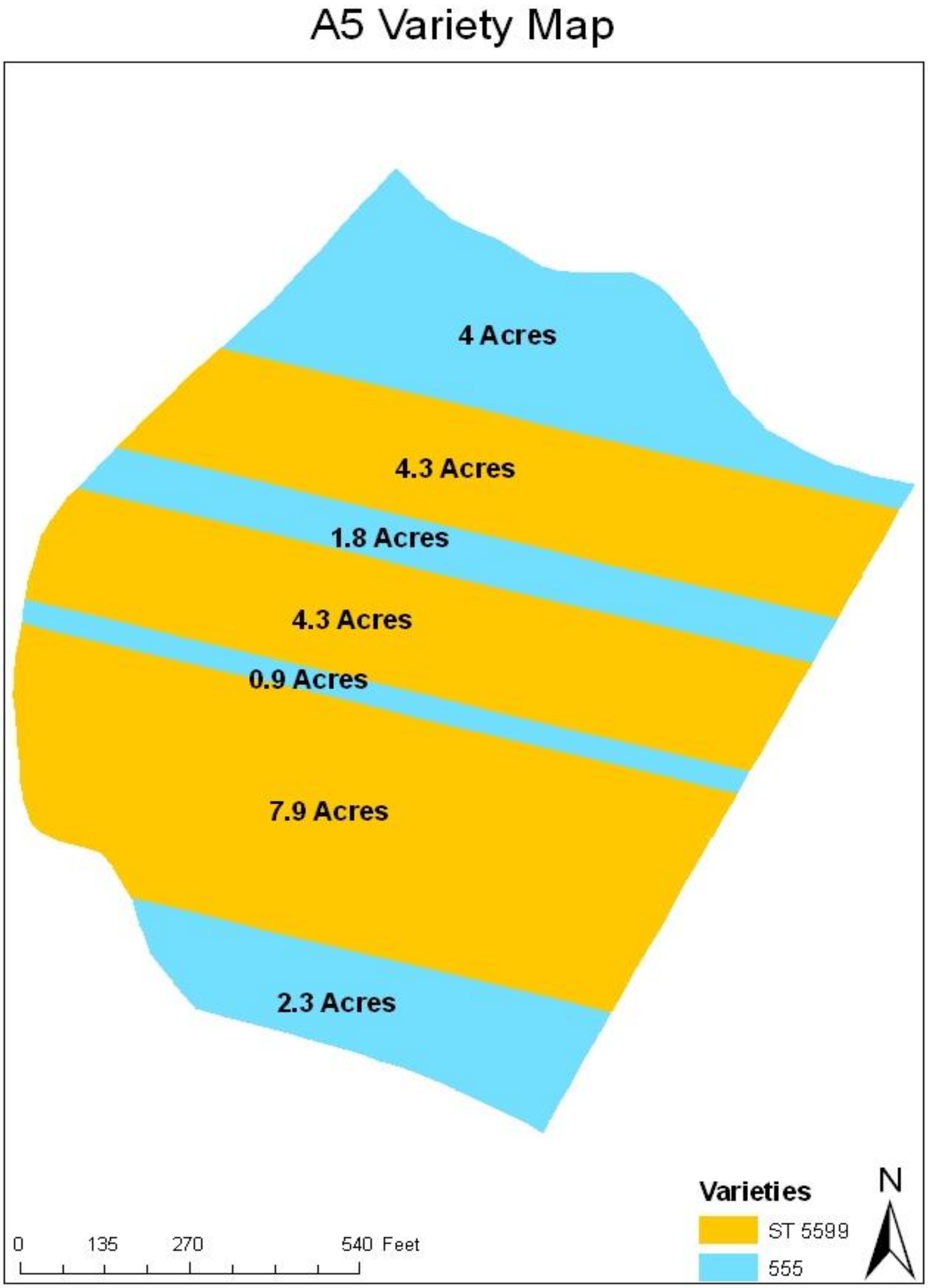

Figure 4. B. Variety planting map for field A5 during 2008 harvest season.

Appendix D: Glossary of Gin Turnout Variables

TO- Turnout- Percentage of lint (by weight) remaining after cotton has been ginned

SCI-Spinning Consistency Index

MIC- Micronaire- A measure of fiber fineness and maturity.
Premium range is 37-42
Base Range is 35-36 and 43-49
Discount Range is <= 34 and >=50

Mat- Fiber Maturity- The ratio of fibers with 0.5 or more circularity ratio divided by the amount of fibers with 0.25 or less circularity. The higher the maturity ratio, the more mature the fibers and the better the fibers are for dyeing.

UHML- Upper Half Mean Length- average length of the longer one half of the fibers. Reported in 100ths and 32nds of an inch

UI- Uniformity Index- ratio between mean length and upper half mean length. Expressed as a percentage.
Very high is >85
High is 83-85
Intermediate is 80-82
Low is 77-79
Very low is <77

SFI- Short Fiber Index- the amount of short fibers in a sample that are below one half inch in length. As short fiber index increases the quality decreases.

Str- Fiber Strength- reported in grams per tex. A tex is the weight in grams of 1000 meters of fiber. Strength is the force in grams required to break a bundle of fibers one tex in size.

Elg- Elongation- The distance to the maximum of the stress curve less the distance attributed to crimp, multiplied by 100, and divided by break gage (1/8 inch)

Rd- Reflectance- brightness or dullness of a sample

b- Yellowness- degree of color pigmentation. Based on the Hunter's scale.

Tr Cnt- Trash Count-A count of the number of times a trash particle is encountered during a scan of the sample surface. Highly correlated to Trash Area.

Tr Area- Trash Area- percentage of the surface area of a sample that is occupied by trash.

Vita

Jason Clay Head was born in Clarksville, Tennessee on May 25, 1985. He attended elementary and middle schools in that town and graduated from Clarksville High School in May 2003.

The following August he entered the University of Tennessee at Martin and received a Bachelor of Science in Plant and Soil Science with a minor in Biology in May 2007. While at UT-Martin he was initiated into the Alpha Gamma Rho Agriculture Fraternity as well as the honorary society, Order of Omega. In the fall of 2007 he entered the graduate school at The University of Tennessee at Knoxville and accepted a teaching assistantship with the Biosystems Engineering and Soil Science Department. While pursuing his masters he was awarded membership in Gamma Sigma Delta. His Master of Science degree with a major in Biosystems Engineering Technology was conferred in August 2009.