# IMPACT OF COTTON HARVESTING AND STORAGE METHODS ON SEED AND FIBER QUALITY

A Thesis

by

MARK THOMAS HAMANN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2011

Major Subject: Biological and Agricultural Engineering

Impact of Cotton Harvesting and Storage Methods on Seed and Fiber Quality

# IMPACT OF COTTON HARVESTING AND STORAGE METHODS ON SEED AND FIBER QUALITY

A Thesis

by

MARK THOMAS HAMANN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

| | |
|---|---|
| Chair of Committee, | Calvin B. Parnell, Jr. |
| Committee Members, | William Brock Faulkner |
| | Ronald E. Lacey |
| | C. Wayne Smith |
| Head of Department, | Stephen W. Searcy |

December 2011

Major Subject: Biological and Agricultural Engineering

# ABSTRACT

Impact of Cotton Harvesting and Storage Methods on Seed and Fiber Quality.

(December 2011)

Mark Thomas Hamann, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Calvin B. Parnell, Jr.

There are currently two main types of machinery used for harvesting cotton in the United States, cotton pickers and cotton strippers with or without field cleaners. These different machine types package seed cotton with varying amounts of burrs, sticks, and leaves. Harvested cotton is placed in modules for storage prior to ginning. Recent developments in the industry include on-board module builders that package seed cotton as they harvest. This leads to three methods of storage: 1) traditional seed cotton modules, 2) half-modules, and 3) round modules utilized by harvesters with on-board module builders; all of these have different levels of packaging density.

Cotton is harvested under widely varying conditions throughout the country and the moisture content of seed cotton at the point of containerization can be an important factor in the final quality of the crop. Seed cotton is being stored for increasing periods of time before being processed by cotton gins.

The number of cotton gins in the U.S. has decreased while the production of cotton has increased. All cotton is harvested as it matures and the harvesting rate greatly exceeds the ginning rate. As a consequence of fewer gins, increased harvesting rates and increased quantities of cotton, the storage time of seed cotton prior to ginning has increased.

It is hypothesized that the impact of varying densities, varying trash contents, and increased storage times prior to ginning is impacting the quality of the cotton lint and seed. The goal of this research is to quantify the impacts of these factors.

The purpose of this research is to evaluate the effects of packaging seed cotton from any of the three different harvesting methods into varying types of storage as a function of differing moisture content and increased storage time. Results are indicated in terms of quality of both the fiber and the seed of ginned samples, as well as how the quality changes affect the value of the processed cotton.

Samples of seed cotton are sealed in plastic containers for up to three months at varying levels of moisture, density, and trash content. Temperature and oxygen levels are monitored during storage. Samples are ginned and cottonseed and fiber are analyzed.

The results of this research indicate that density does not affect the final quality of the lint and seed harvested. Increased moisture contents have a negative effect on both the quality and the value of the seed cotton, and this effect becomes more pronounced as the length of storage increases.

# ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Parnell, for pushing me to stick with my research and finish my thesis, and more importantly for employing me since my freshman year. I would also like to thank my committee members, Dr. Faulkner, Dr. Lacey and Dr. Smith, for their guidance and support throughout the course of this research.

Thanks also go to Texas AgriLife Research and The Cotton Foundation for making this research possible.

I would also like to thank all of the people who proved pivotal in the most crucial times of my research process, especially Ellisa Jimenez, Daniel Kelly, A.J. Sjolander, Francis Vanderlick, and Mary Hamann. Thank you to all of my other friends and coworkers in Scoates Hall: Dustin, Jared, Kaela, Phillip, Jarrett, Tommy, Keith, and Raleigh; you were all a pleasure to see and work with every day.

I would also like to extend a big thank you to Dr. John Wanjura not only for making this research possible by finding extra cotton for me to use in both years of my research, but also for all of the time, career, and personnel management techniques I learned from him simply through observation during all of the years of our contact.

Thanks to my parents for everything they have given me to help me succeed in life. Thanks to my dad and late grandmother for helping to put me through college.

# TABLE OF CONTENTS

CHAPTER Page

# LIST OF FIGURES

Page

# LIST OF TABLES

# CHAPTER I

# INTRODUCTION AND LITERATURE REVIEW

Since 1960, the United States has been producing cotton with upward trends in both yield and total quantity produced. During this same time period, there has been an observable decrease in the total number of cotton gins available to process cotton. In 1960, there were over 1,400 cotton gins operating in Texas, and there are fewer than 300 today (Figure 1). Cotton production in the state has remained steady, except for the past decade in which there were two peaks over twice the previous 40-year average (USDA, 2010). Increases in production accompanied by the operation of fewer gins leads to more cotton being processed at each gin facility. More cotton processed leads to longer ginning seasons and inherently longer storage times for the average cotton module.

In early years of mechanized harvesting, seed cotton was placed in trailers that were pulled to gins by farmers, emptied by the gins in the order they were received, and returned. Seed cotton was dumped or blown into the trailers and packed manually, if at all. The trailers generally held two to four bales of cotton.

---

This thesis follows the style of *Transactions of the ASABE*.

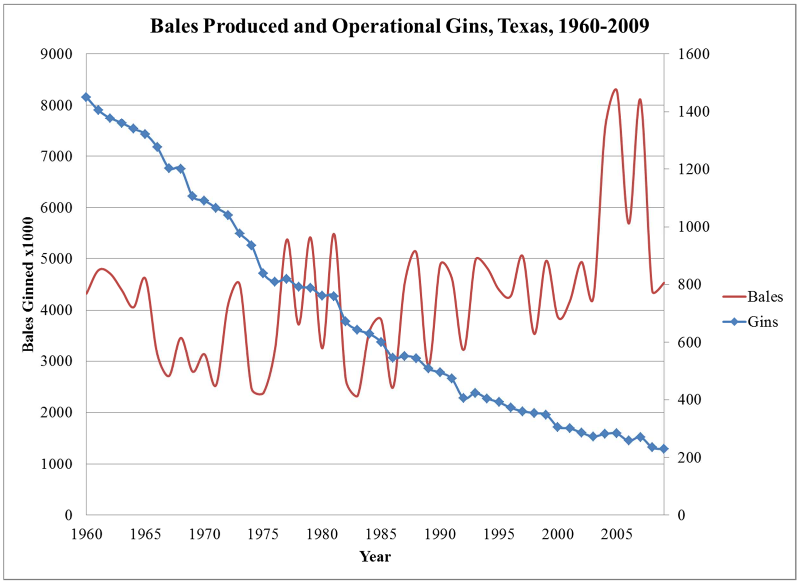

**Figure 1. Bales produced and gins operated in the state of Texas from 1960 to 2009 (USDA, 2010).**

The module builder was invented at Texas A&M University in the 1970s and changed cotton harvesting and storage protocols. Today almost all of the seed cotton in the United States is harvested mechanically and stored in modules. The module, which allows seed cotton to be stored for long periods, has a structure that can be described as a packed brick of cotton. The standard module in the United States has a length, width, and height of 9.75-, 2.44-, and 2.44-m (32-, 8-, and 8- ft), respectively. This size, packed at roughly 192 kg/m$^3$ (12 lb/ft$^3$), contains approximately 12 bales of stripper-harvested cotton or 15 bales of picker-harvested seed cotton. Modules are built directly on the ground and are normally covered with tarps that protect the top and the top of the sides from rain and wind damage. They are transported to the gin by trucks with rolling chain floors that are capable of loading the module directly from the ground. A typical module truck is capable of carrying one module.

Seed cotton may either be mechanically picked or stripped. Cotton strippers work by stripping seed cotton and much of the burrs, sticks, and remaining leaves from the stalk of the cotton plant. Cotton strippers may have a separation unit called a field cleaner that removes many of the burrs and sticks from the seed cotton. Cotton pickers use spindles with barbs to grab seed cotton out of the boll as they spin. Seed cotton is removed from the spindle by a doffer and conveyed to a basket. All three of the harvesting methods result in seed, lint, and some amount of burrs, leaves, and sticks (commonly referred to as trash) being packaged for ginning. Seed cotton accumulated in the basket of a harvester is dumped into the module builder. The picker does the best job minimizing the trash content of seed cotton, followed by the stripper with the field cleaner, and finally by the stripper without the field cleaner.

In most states seed cotton is harvested almost exclusively by pickers. In Texas, which historically has produced roughly 25% of the nation's seed cotton crop and much more in recent years (USDA, 2010), much of the seed cotton produced is harvested using cotton strippers with or without field cleaners. John Deere is currently the only major equipment manufacturer in the United States that is producing cotton strippers.

In recent years, the two major manufacturers of cotton harvesting equipment, John Deere and Case-New Holland (CNH) have released models of cotton pickers with the capability of packaging modules of seed cotton on board. These on-board module builders make modules that are smaller in size than a traditional module. The pickers are more expensive than traditional pickers but allow for a single person in a single piece of equipment to harvest an entire cotton field, rather than involving extra labor and boll buggies required for seed cotton handling using conventional module builders.

The on-board module builder unit produced by John Deere compresses the seed cotton into cylinders with diameters up to 2.44 m (8 ft) and lengths of 2.44 m (8 ft). The cotton is compressed to a density near 240 kg/m$^3$ (15 lb/ft$^3$). The CNH unit produces modules that are 4.88 x 2.44 x 2.44 m (16 x 8 x 8 ft) which is half the size of a traditional module with densities near 144 kg/m$^3$ (9 lb/ft$^3$). Four of the John Deere modules or two of the CNH modules can be carried by one module truck. It has been noted in the past that compressing seed cotton to densities ranging from 112- to 320-kg/m$^3$ (7- to 20-lb/ft$^3$) had no effect on fiber quality so long as seed moisture content levels remain below 10% wet-basis (w.b.) (Wilkes, 1978).

Since the on-board module builder allows for greater per-capita productivity than a traditional harvester, it is probable that there will be a market interest in the development of cotton strippers containing on-board module builders. It is therefore possible that producers will have access to on-board module builders for cotton strippers in the near future. Should this be the case, stripped seed cotton will be contained at higher densities than current levels.

Burrs, sticks, and leaves in freshly harvested seed cotton have higher moisture contents than the lint or seed (Sorenson and Wilkes, 1973). Humidity can play an important role in the moisture content of seed cotton. Karon and Adams (1948) reported that over a 30 day period of exposure to a constant relative humidity of 93%, cottonseed moisture levels increased to 20%. Montgomery and Wooten (1958) reported that high seed cotton moisture contents can trigger microbial activity which can have severe, negative effects on fiber quality. Lint moisture content while in the boll was found to vary from a high of 16% to a low of 5% from morning to mid-afternoon of the same day. The authors reported that change in lint color grades resulted in a 7% reduction in lint price between the minimum and maximum moisture contents over the course of 72 hours of storage in cotton trailers.

Previous research on the effect of moisture content on cotton quality has been limited by the small range of seed cotton storage times and trash contents. Sorenson and Wilkes (1973) stored module-sized samples for one month. The modules ranged in moisture content from 8 to 24.5% w.b., and densities ranged from 160- to 224-kg/m$^3$ (10- to 14-lb/ft$^3$). In these large samples, maximum temperatures of up to 69°C (156°F) were observed. The authors noted that for moisture contents less than 12%, seed cotton could be stored for at least 30 days with no discernable fiber or seed quality losses. For cotton up to 14% w.b. moisture content, the recommended storage time was reduced to no more than 10 days. For 15% moisture content, the recommended storage time was reduced to no more than five days. Their results indicated that reduced lint quality would be incurred in less than three days if stored at above 15% w.b.

Curley et al. (1987) recommended that moisture contents of seed cotton stored in modules be monitored to ensure that cotton fiber quality was not damaged as a consequence of high temperatures in the module. Temperature increases were the result of damage that had already occurred because of microbial activity. They found that reflectance (Rd) values of a cotton sample were affected in as few as five days of storage in cotton at 14-15% moisture content (w.b.) and that excessive water added during spindle harvesting could significantly affect the final moisture content of the module. They also noted that a module harvested at 16% moisture content could be exposed to temperature rises up to 30°C (55°F) higher during storage than one harvested at 9% moisture content. Yellowness (+b) was the main quality parameter affected by the increase in moisture content with increases up to 60% observed with the increase of moisture content (Curley et al., 1990).

Wilkes (1978) reported that cottonseed quality was more sensitive to high moisture content than cotton fiber quality. Wilkes (1974) noted that two indicators of decreasing seed quality in relation to moisture were decreased germination and increased free fatty acid content, at levels beginning around 12% w.b. moisture content. Free fatty acid is a product of the degradation of cottonseed oil. Increased moisture content causes triglycerides to break down into free fatty acid in order to create energy (T. Wedegaertner, personal communication, June 2008). Free fatty acid content increased with increased seed cotton moisture contents (7.5 to 13.2%) and storage time (1 to 82 days), with time having a more pronounced effect than moisture content (Harris and Wamble, 1966). In modules stored as few as 15 days with seed cotton moisture levels between 13 and 15% w.b., free fatty acid contents were found to grow between 50 and 130% from initial levels (Sorenson and Wilkes, 1973). Curley et al. (1990) reported no change in quality of cottonseed as determined by germination test results for cottonseed stored at moisture contents up to 13% w.b. However, no germination was observed for cottonseed stored at 16% w.b.

## Objectives

The objective of this research was to develop a mathematical model to quantify fiber and seed quality degradation during seed cotton storage as a function of module density, seed cotton moisture content, trash content, and storage time.

Initial tests were conducted with the objective of determining the most important storage variables relative to fiber and seed quality degradation. These were followed by a second test intended to produce more precise data to develop the mathematical model. Samples of seed cotton were placed in containers with varying moisture contents, densities, and trash contents while monitoring temperatures during specified storage times. The containers (plastic tubes) were selected to allow control of the moisture content and density of samples such that they would be similar to those found in modules.

# CHAPTER II

# TEST 1

## Methods

The experimental design consisted of four replications of 27 total treatments, consisting of three moisture content levels, three trash content levels, and three density levels in a randomized complete block design. Samples were sealed in polyvinyl chloride (PVC) containers for three to four months until ginned.

To create each sample, seed cotton was mixed with sufficient trash to simulate samples that were picked, stripped with a cleaner, and stripped without a cleaner. The trash contents reported by Faulkner et al. (2010) for each harvest treatment were used in preparing the test samples.

Four hundred fifty four kilograms (1000 lb) of DP143 (Delta and Pine Land Co.) was harvested outside of Lubbock, Texas, during the 2008 season and retained for use in this study. This seed cotton was harvested by a John Deere model 9996 cotton picker and samples from the same lot, ginned at the USDA ARS Cotton Production and Processing Research Unit in Lubbock, contained 363 kg (800 lb) per bale of seed (J. Wanjura, personal communication, 2010). One hundred thirteen kilograms (250 lb) of trash (burrs, sticks, and leaves) was obtained from the field cleaner of a cotton stripper. Trash was mixed with the picked seed cotton to simulate stripper-harvested seed cotton, for both machines with and without field cleaners. Faulkner et al. (2010) reported that picked seed cotton contained 5.1% trash, while seed cotton harvested by a cotton stripper with a field cleaner contained 19% trash, and seed cotton harvested by a cotton stripper without a field cleaner contained 38% trash. These numbers correspond to 32 kg (70 lb), 136 kg (300 lb), and 354 kg (780 lb) of trash per bale, respectively, for this test.

The moisture contents of the seed cotton and of the trash were determined daily according to ASTM Standard D2495 (ASTM, 2006) before any seed cotton or trash was used to make samples. Every evening, three 100- to 120-g subsamples of seed cotton and trash were placed in aluminum pans and weighed using a Mettler-Toledo balance (model PB3002-S FACT, Mettler-Toledo, Columbus, Ohio, USA). Subsamples were dried for no less than 12 hours in a Memmert drying oven (model EW-52200-06, Memmert, Schwabach, Germany) so that updated moisture contents were available each morning. They were weighed again upon completion of drying, as were the masses of the pans. The wet-basis moisture content was calculated using equation 1:

$$\%WB = \frac{WM - DM}{WM} \times 100 \tag{1}$$

where:

%WB = % wet-basis moisture,

DM = mass of sample after drying, and

WM = mass of sample before drying.

Due to the capacity of the moisture addition chamber, a target weight of 2.7 kg (6 lb) of total dry matter was set for each sample. The seed cotton used had an average initial moisture content of 7.5 ± 0.13% (mean ± 95% CI) w.b. The moisture content of the trash was 10.5 ± 0.10% w.b. Steam was drawn across seed cotton-trash mixture to raise the test sample moisture contents. The mass of seed cotton, trash, and moisture added for each sample to attain test conditions can be seen in Table 1. For example, to obtain a sample representative of cotton harvested by a stripper with a field cleaner at 12% w.b. moisture content, 2540 g (5.6 lb) of seed cotton would be mixed with 422 g (0.93 lb) of trash and the mixture would have steam passed across it to add 154 g (0.34 lb) of water vapor.

**Table 1. Masses of seed cotton, trash, and steam to achieve Test 1 sample conditions.**

| Target moisture | Material | Picker (g) | Stripper w/ FC (g) | Stripper w/o FC (g) |
|---|---|---|---|---|
| 10% | Seed Cotton | 2940 | 2540 | 1980 |
| | Trash | 0 | 422 | 994 |
| | Moisture | 82 | 68 | 50 |
| 12% | Seed Cotton | 2940 | 2540 | 1980 |
| | Trash | 0 | 422 | 994 |
| | Moisture | 168 | 154 | 136 |
| 14% | Seed Cotton | 2940 | 2540 | 1980 |
| | Trash | 0 | 422 | 994 |
| | Moisture | 260 | 246 | 228 |

Each sample was placed in an air wash for moisture addition. The air wash system has a basket inside a stainless steel box made of screen material (Figure 2). Pipe used as the axle of the air wash basket allowed rotation of the material in the basket as steam passed through. The openings in the pipe axle allowed air and steam to be drawn through the seed cotton samples. A fan (model HP-33, Cadillac Products, Chicago, Illinois, USA) was used to create negative pressure in the box, pulling steam into the screen basket and through the sample. Because of the size of the steam addition system it was necessary to split each sample in half.

**Figure 2. Air wash system used to increase moisture contents of test samples. The basket containing the samples was rotated while steam was pulled through the pipe axle (not shown) and the cotton samples.**

Steam was added to bring the samples to levels of 10-, 12-, or 14% w.b. moisture. The steam from a Sussman Electric Boiler (model MBA9, Sussman Automatic Company, Long Island City, New York, USA) was directed near the pipe openings of the air wash system which allow steam to enter. As the cotton and trash tumbled, the steam was absorbed into the samples (Figure 3). Periodically the samples were removed from the air wash for up to three minutes to check the moisture contents. During this time the samples were contained in plastic bags to retain moisture. Moisture contents were determined by measuring the mass added to the samples.

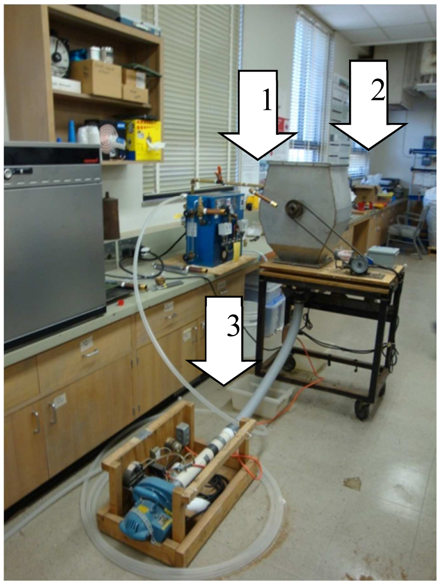

**Figure 3. Moisture addition system for Test 1. The steam generator (1), air wash (2), and fan (3) used to increase the moisture contents of the seed cotton samples. Steam was drawn through the pipe openings into the test samples.**

After the seed cotton moisture had been increased to the appropriate level, it was placed in specific lengths of pre-cut PVC pipes. The pipes were 15 cm (6 in.) in diameter and of varying lengths such that each sample contained 2.72 kg (6 lb) of dry cotton and trash, with varying amounts of water. In order to obtain the desired densities of 128-, 192-, and 256-kg/m$^3$ (8-, 12-, and 16-lb/ft$^3$), the pipes were cut to lengths of 0.57-, 0.75-, and 1.13-m (22.3-, 29.6-, and 44.5-in). This range encompasses all densities that should be seen in common module formation practice. Cotton was packed into the tubes using a custom packing device (Figure 4). After all of the cotton was packed into a tube, the pipe was sealed with a PVC cap on the open end and placed onto a rack in a climate controlled room for storage. For the first week of storage images were taken daily with a thermal imaging camera. The samples appeared to be at room temperature based on the coloration of the images.

**Figure 4. Cotton being sealed in plastic tube for storage.**

It was hypothesized that oxygen would be consumed during aerobic decomposition of the seed cotton, after which it was expected that anaerobic decomposition would occur. In order to confirm this and observe the amount of time the transition would take, two of the samples (runs 105 and 106) were fitted with oxygen sensors (Maxtec model MAX-14, Maxtec, Salt Lake City, Utah, USA). Sensors were threaded into one of the end caps of the samples. These samples were chosen because they were both containerized at 14% w.b., both contained 5.1% trash content, and they were at opposite ends of the density spectrum studied. Readings were taken every weekday.

Samples were kept in the sealed containers for 105 to 114 days to simulate storage in a module. All samples were opened the same day by using a band saw to cut off one of the PVC caps. A small amount of cotton was taken from the end of each sample as it was opened to determine the moisture content. Average moistures at opening for each target category can be seen in Table 2. Each subsample was placed in a small brown paper bag and immediately weighed on the Mettler-Toledo balance. The moisture content of the samples at opening was measured using the oven method (ASTM, 2006), but using paper bags instead of aluminum pans. This was done because of the quantity of samples to be weighed. An average initial and final (dried) mass of ten empty bags was tabulated to use in lieu of attempting to remove all of the cotton from the bags.

**Table 2. Target moisture content versus average actual moisture content for each input level.**

| Target M.C. (%w.b.) | M.C. at open (%w.b. ± Std. Error) |
|---|---|
| 10 | 10.2 ± 0.07 |
| 12 | 12.1 ± 0.08 |
| 14 | 14.4 ± 0.55 |

After opening, samples were ginned over the course of three days at the Texas A&M Cotton Improvement Lab. Each sample was run through an extractor-feeder one time to remove as much of the added trash as possible before ginning. Samples were immediately ginned on one of two Continental Eagle 10-saw gins (Continental Gin Co., circa 1960). From each ginned sample, a minimum of 100 g of cotton lint was gathered from no less than three random places in the gin's lint basket and placed into paper bags. From the seed tray at least 150 g of cottonseed was placed into paper bags and refrigerated for two months until shipped for analysis.

Lint samples were delivered to the Texas Tech Fiber and Biopolymer Research Institute (FBRI) in Lubbock, Texas, for High Volume Instrument (HVI) testing. FBRI uses Uster HVI testing systems (model 1000, Uster Technologies Inc., Charlotte, North Carolina, USA). Five replications of the HVI test were conducted on each sample, and the average reported. HVI results included micronaire, upper half mean length (length, in.), uniformity (%), strength (g/tex), elongation (%), reflectance (%), yellowness, color grade, and leaf grade. The seed samples were delivered to Mid-Continent Laboratories, Inc. in Memphis, Tennessee, for analysis of free fatty acid content.

Results of the HVI testing were combined with input factors and analyzed using statistics packages from SPSS (SPSS 16.0, SPSS Inc, Chicago, Illinois, USA) and Stat-Ease (Design-Expert 7.1.6, Stat-Ease Inc, Minneapolis, Minnesota, USA). A confidence level of 95% was used. Results were tested for normality and the input factors fit to a multiple linear regression, analyzed for P-values, $R^2$, and F statistics relating to output factors. Analysis of Variance (ANOVA) tests were conducted to determine significance. The raw data acquired in this test are attached as Appendix A.

## Results and Discussion

A Wilks' Lambda multivariate analysis was run for all of the inputs in the model in order to identify differences in the means of the data groups. The results of this analysis can be seen in Table 3. The effects of moisture content and trash content are significant ($p<0.05$). Thus for any responses, moisture content and trash content needed to show $p<0.05$ to be significant. For all other effects, the value was not significant. For density or any of the interactions to be significant on the $p<0.05$ level, the p-value of the response table must be smaller than the desired p divided by the number of factors, or $p<0.0167$.

**Table 3. Wilks' Lambda results for Test 1. For effects for which p<0.05 in the table, a p<0.05 will be significant in further analyses. For all others p<0.0167 will be required in further analyses (0.05/3 factors = 0.0167).**

| **Effect** | **Sig.** |
|---|---|
| Moisture Content | 0.000 |
| Package Density | 0.211 |
| Trash Content | 0.003 |
| Moisture Content*Density | 0.782 |
| Moisture Content*Trash Content | 0.576 |
| Density*Trash Content | 0.825 |
| Moisture Content*Density*Trash Content | 0.902 |

For each cotton fiber value response, an ANOVA test was run. Non-significant factors ($p>0.05$) were removed using backward elimination. None of the tests returned high $R^2$ values ($R^2>.95$). This means that although a trend may have been seen, depending on the response being considered only 13 to 38% of the variability in the data can be explained by the model.

### *Micronaire*

The ANOVA test (Table 4) for micronaire resulted in the finding that moisture content (p=0.0064) and trash content (p<0.0001) were significant factors. The three-dimensional response graph (Figure 5) shows their effect of on micronaire. $R^2$ value was 0.264. For this test, lower moisture contents at the time of containerization led to lower micronaire. The same is true for trash content, which has more of an effect than initial moisture as can be noted from its steeper slope. The reason for this relationship between micronaire, trash content, and moisture content at containerization is not understood.

**Table 4. ANOVA table for micronaire. The input variables of moisture and trash content were significant.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Block | 1.00 | 3 | 0.33 | | |
| Model | 0.44 | 4 | 0.11 | 8.89 | <0.0001 |
| Moisture | 0.13 | 2 | 0.066 | 5.32 | 0.0064 |
| Trash Content | 0.31 | 2 | 0.16 | 12.47 | <0.0001 |
| Residual | 1.23 | 99 | 0.12 | | |
| Cor Total | 2.68 | 106 | | | |

According to the 2009 CCC Loan Chart (USDA, 2009), there was a premium of up to 0.15 cents per pound of lint for the higher micronaire values (>3.7) returned.

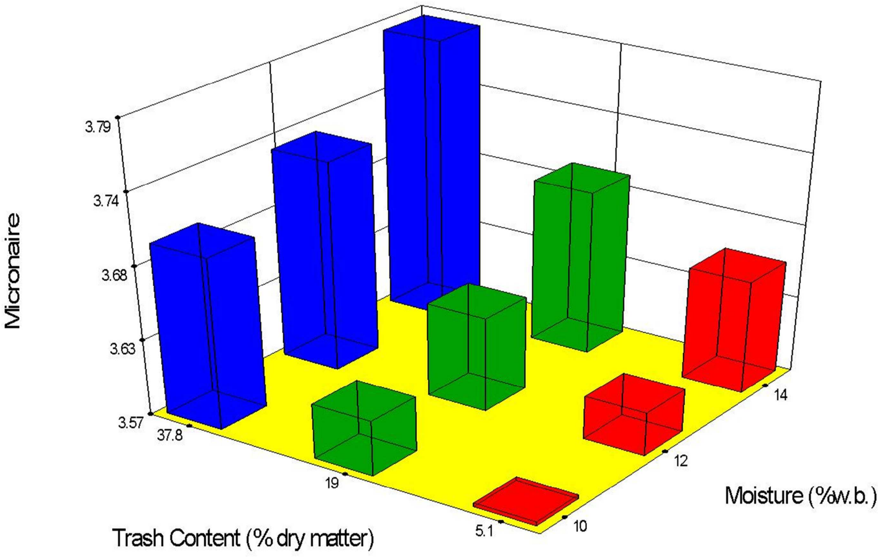

**Figure 5. Micronaire as a function of trash and moisture contents.**

### *Length*

Length was affected by both moisture content (p=0.0074) and trash content (p=0.023) (Table 5). A three-dimensional response graph is shown in Figure 6. As moisture content increased or trash content decreased, the fibers were found to be longer. It is hypothesized that the moisture content is related to length because the dryer fibers become brittle and are more susceptible to breakage during the cleaning or ginning process.

**Table 5. ANOVA table for upper half mean length. Significant factors were moisture and trash content.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Block | 1.084E-3 | 3 | 3.613E-4 | | |
| Model | 3.203E-3 | 4 | 8.008E-4 | 4.55 | 0.0021 |
| Moisture | 1.817E-3 | 2 | 9.087E-4 | 5.16 | 0.0074 |
| Trash Content | 1.382E-3 | 2 | 6.909E-4 | 3.92 | 0.0230 |
| Residual | 0.017 | 99 | 1.762E-4 | | |
| Cor Total | 0.022 | 106 | | | |

The relationship with trash content is not as clear, but a possible explanation is that this is a result of the moisture absorbance properties of the trash and the process of moisture addition for the test. As noted in the procedure, although both were stored in the same conditions, the trash maintained moisture content 3% higher than the level of the seed cotton. This means that the equilibrium moisture content for the trash was higher than the seed cotton at room conditions. Since the moisture was added to the mixture of trash and lint, both materials had an opportunity to absorb and retain the moisture. The trash is believed to have had a higher rate of absorption than the lint, and retained more of the moisture, allowing less activity to occur in the lint.

All of the lengths were above the highest price point on the loan chart (1.14 in.) so there was no difference in value for the samples.

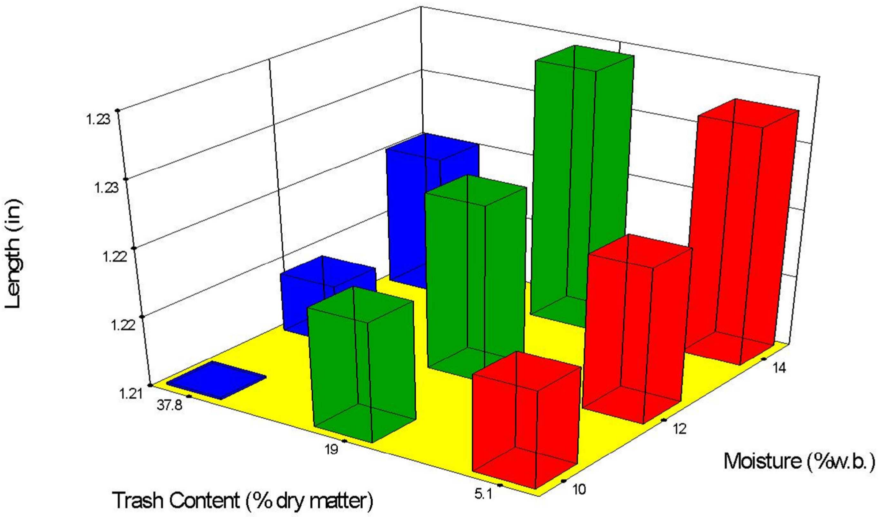

**Figure 6. Upper half mean length as a function of moisture and trash contents.**

### *Uniformity*

Uniformity analysis resulted in the finding that trash content was significant (p=0.0218) (Table 6). According to Figure 7, trash content had varying effects on the quality of uniformity. The returned level for picker cotton samples was not significantly different from either stripper trash level, but stripper with field cleaner was significantly different from stripper without field cleaner (LSD=0.266). $R^2$ for this relationship is 0.073. The reason for this relationship is not understood.

**Table 6. ANOVA table for uniformity. Trash content was the only significant input factor.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Block | 1.55 | 3 | 0.52 | | |
| Model | 2.55 | 2 | 1.28 | 3.98 | 0.0218 |
| Trash Content | 2.55 | 2 | 1.28 | 3.98 | 0.0218 |
| Residual | 32.43 | 101 | 0.32 | | |
| Cor Total | 36.53 | 106 | | | |

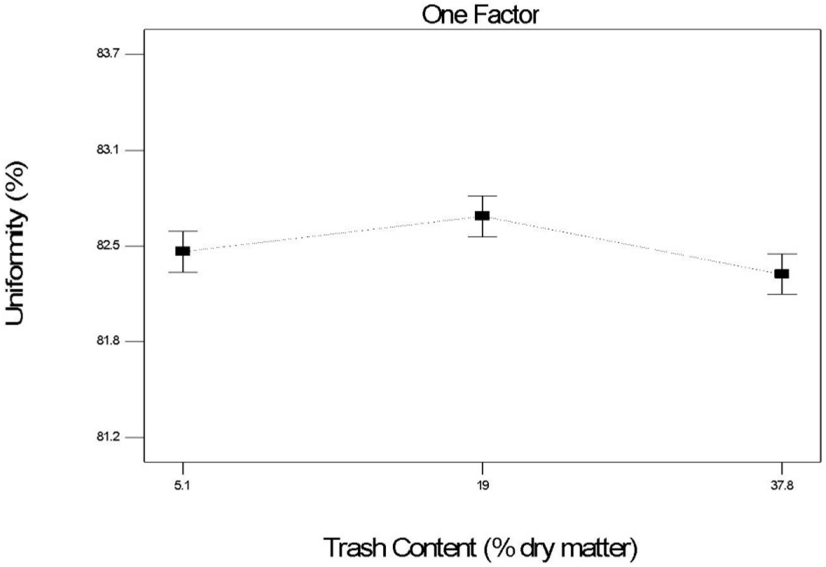

**Figure 7. Response graph for uniformity.**

### *Elongation*

All samples were analyzed using the same HVI machine, so elongation was considered. Had the samples been analyzed on different machines, these values would have been left out of the model since there is no calibration standard for elongation and the returned values could not have been compared across machines. Of the fiber factors considered, only moisture content was found to be significant ($p<0.0001$), with lower moisture content leading to a higher elongation values (Table 7). The $R^2$ value for this relationship was 0.389. From the low moisture content value of 10% to the high value of 14%, the elongation value decreased from 7.02 to 6.56 percent, with each value significantly different from all others (Figure 8). Least significant difference value was 0.113. It was hypothesized that higher moisture content would lead to a greater amount of microbial activity. Said activity may create weak places in fibers, which could lead to easier breakage during fiber testing, and thus lower elongation values. This would explain the relationship observed above.

**Table 7. ANOVA table for elongation. Moisture was the significant factor for the response.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Block | 0.36 | 3 | 0.12 | | |
| Model | 3.75 | 2 | 1.87 | 32.08 | <0.0001 |
| Moisture | 3.75 | 2 | 1.87 | 32.08 | <0.0001 |
| Residual | 5.90 | 101 | 0.058 | | |
| Cor Total | 10.02 | 106 | | | |

Elongation is not a value which is considered for pricing, so the increased value at lower moisture contents, while resulting in a more desirable fiber, would not add to the value of the cotton.

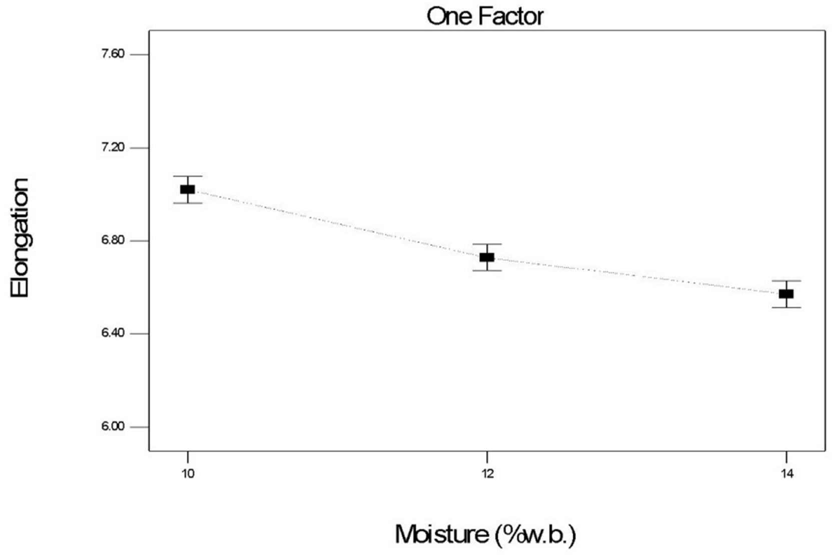

**Figure 8. Elongation as a function of moisture content.**

### *Reflectance*

The reflectance of the samples was responsive to both moisture content (p=0.0004) and density (p=0.0368). ANOVA information can be seen in Table 8. Figure 9 is a three dimensional graph of the responses. The $R^2$ value for this test was 0.192. The explanation for the response moisture content for this result is the same as that for length. As the moisture content is increased, the amount of microbial activity is increased, resulting in more discolored fiber, be it more yellow or gray and thus less reflective. The relationship with density is not understood.

**Table 8. ANOVA table for reflectance. Moisture content and density were significant.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Block | 6.37 | 3 | 2.12 | | |
| Model | 38.92 | 4 | 9.73 | 5.87 | 0.0003 |
| Moisture | 27.71 | 2 | 13.85 | 8.36 | 0.0004 |
| Density | 11.32 | 2 | 5.66 | 3.41 | 0.0368 |
| Residual | 164.10 | 99 | 1.66 | | |
| Cor Total | 209.39 | 106 | | | |

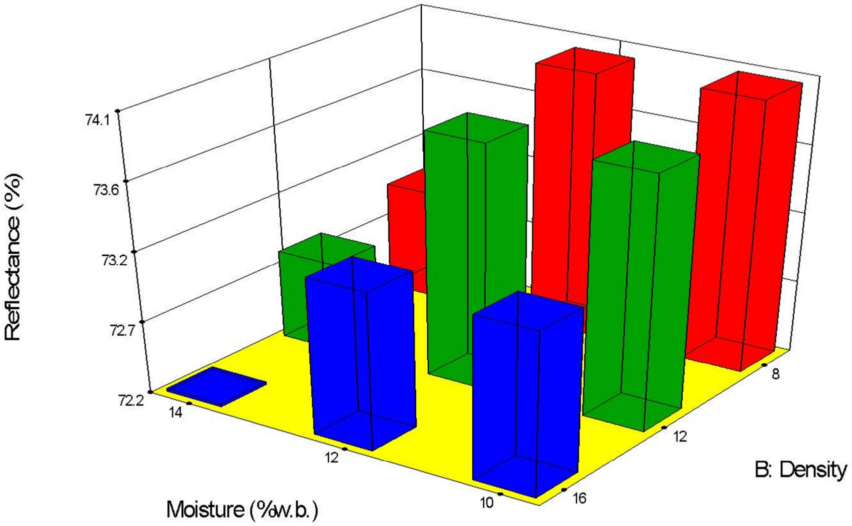

**Figure 9. Response for reflectance as related to moisture content. As moisture increased, reflectance levels decreased.**

### *Yellowness*

Yellowness (+b) was shown to be affected by both moisture content ($p<0.0001$) and trash content ($p=0.0002$) (Table 9). The relationship can be seen in the three-dimensional response in Figure 10. $R^2$ value for this response is 0.325. As moisture content increased, the yellowness also increased. This result agrees with previous findings (Curley et al., 1990). This is logical given the relationship described for elongation is accurate. As the microbial activity occurs, there is discoloration of the fiber. As the trash content increased, the yellowness decreased. One explanation for this relationship is similar to that for the variation in length, having to do with the moisture adsorption properties of the trash and the method of moisture addition. Yellowness values do not have direct effects on the price of cotton lint according to loan charts, but are combined with reflectance as one color value.

**Table 9. ANOVA table for yellowness. Moisture content and trash content were significant.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Block | 0.45 | 3 | 0.15 | | |
| Model | 2.97 | 4 | 0.74 | 11.93 | <0.0001 |
| Moisture | 1.84 | 2 | 0.92 | 14.80 | <0.0001 |
| Trash Content | 1.13 | 2 | 0.57 | 9.09 | 0.0002 |
| Residual | 6.17 | 99 | 0.062 | | |
| Cor Total | 9.59 | 106 | | | |

For this set of samples, the range of returned color values resulted in a variation of 1.5 cents per pound of lint, with the brighter, whiter cotton being worth more (USDA, 2009).

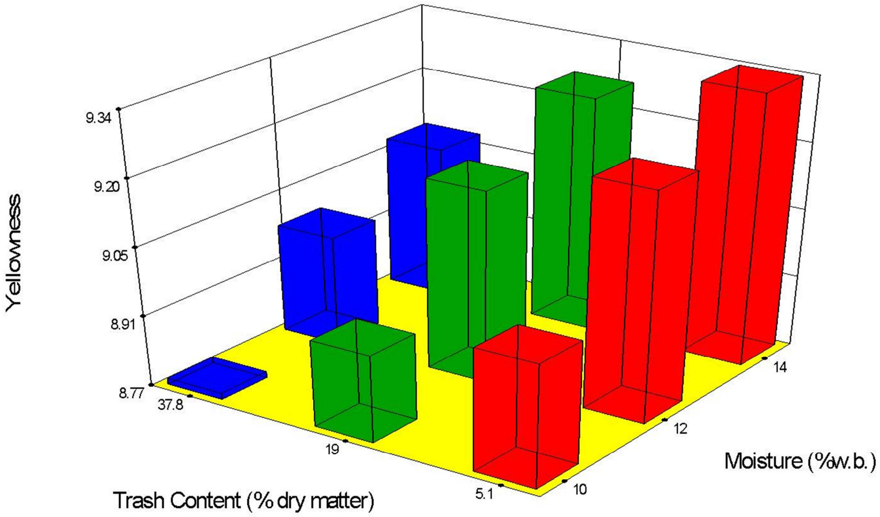

**Figure 10. Yellowness as a function of moisture content and trash content.**

### *Free Fatty Acid*

As free fatty acid contents increase, cottonseed can be used for fewer purposes. Due to lower germination rates, cottonseed should only be used for planting if levels are well below 1% as compared to the oil content. It should not be pressed for oil if levels exceed 4%, and should not be fed to cattle above 18% (T. Wedegaertner, personal communication, June 2008). Free fatty acid contents in the cottonseed oil ranged from 0.7 to 1.5 percent. Moisture content was the only term which significantly affected free fatty acid ($p<0.0001$) (Table 10). $R^2$ value was 0.284. As can be seen in Figure 11, free fatty acid contents increased with higher moisture content during storage.

**Table 10. ANOVA table for free fatty acid content of the cottonseed. Moisture content was the only significant factor.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Block | 0.20 | 3 | 0.065 | | |
| Model | 0.85 | 2 | 0.43 | 19.62 | <0.0001 |
| Moisture | 0.85 | 2 | 0.43 | 19.62 | <0.0001 |
| Residual | 2.16 | 99 | 0.022 | | |
| Cor Total | 3.21 | 104 | | | |

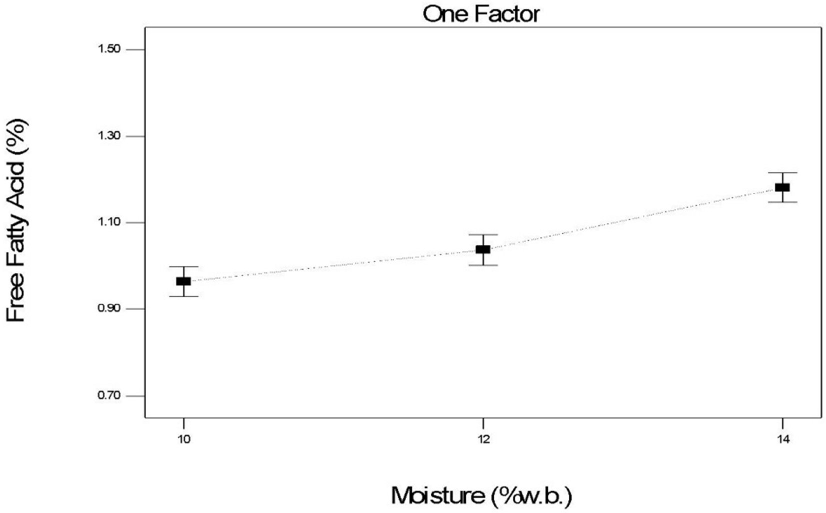

**Figure 11. Free fatty acid versus moisture content during storage.**

All of the free fatty acid levels seen are below the maximum level of 1.8% allowed before a grade deduction according to the National Cottonseed Products Association (NCPA, 2010), so no difference in cottonseed value as a result of increased moisture content would be expected at these levels.

The test variables had no significant effect on the responses uniformity and strength. Color grade was not analyzed statistically because it is a combination of reflectance and yellowness. The data for this series of tests is attached as Appendix A.

### ***Oxygen Sensors***

As can be seen in the data collected from the oxygen sensors (Figure 12), oxygen levels of the samples decreased rapidly, reaching 0% within two weeks of containerization. The level of 0% oxygen is characterized by the manufacturer as outputting a voltage less than 0.20 mV. This confirmed that aerobic decomposition was occurring within the samples, but the effects of aerobic and anaerobic decomposition (if occurring) could not be differentiated since both samples monitored went through both processes.

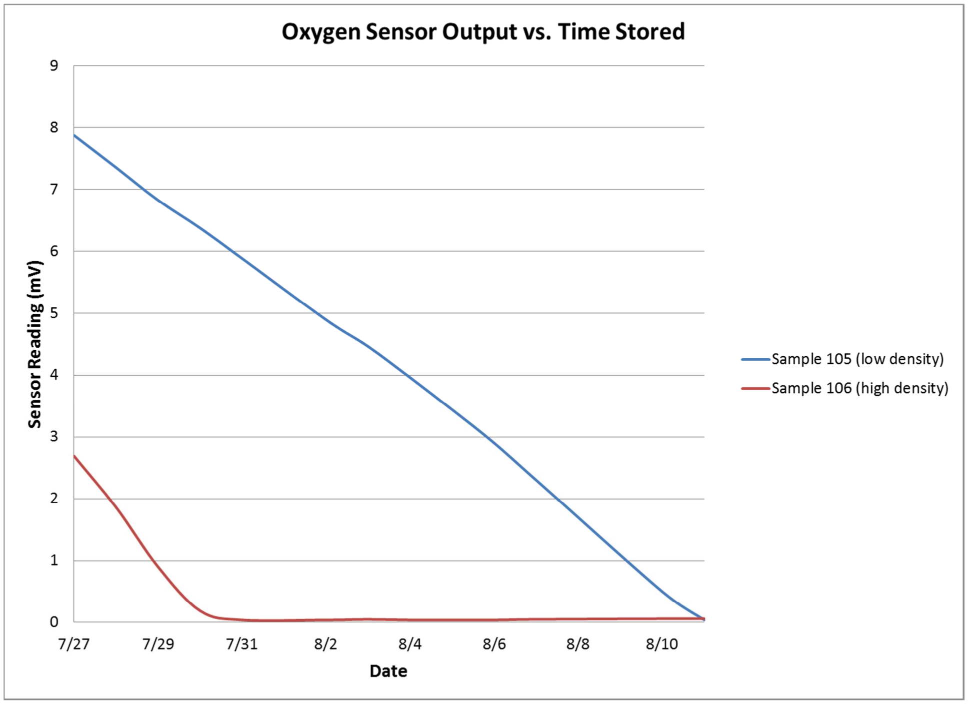

**Figure 12. Oxygen sensor output versus time stored. After 15 days both samples had reached 0% oxygen.**

## Summary

The first round of tests was conducted in order to determine the effects of varied levels of moisture, trash, and density on the final qualities of cottonseed and cotton lint. Three levels of each of these factors were used in the tests. Seed cotton and trash were mixed to reach levels representative of picker-, stripper with field cleaner-, and stripper without field cleaner-harvested cotton. Moisture was added in the form of steam that was pulled across tumbling samples of cotton. Samples were moisturized to 10-, 12-, and 14% w.b. Samples were packaged in PVC containers cut to lengths necessary to replicate densities of 128-, 192-, and 256-kg/m$^3$.

Samples were stored over three months and opened for processing. After ginning, lint and seed samples of each replication were analyzed for quality. Moisture affected the lint qualities of micronaire, length, elongation, reflectance, and yellowness, as well as the free fatty acid content of the cottonseed. Trash content affected the qualities of micronaire, length, and yellowness. Density had a significant effect only on reflectance.

Trash content consistently produced the opposite effect of what was expected on the cotton fiber qualities measured. It is expected that this was a result of the method of moisture addition to the seed cotton. In planning for a second series of tests the decision was made to conduct experiments on a more concentrated group of samples. Moisture content was chosen as the single variable in the second set of tests.

# CHAPTER III

# TEST 2

## Methods

Following analysis of Test 1, a second set of experiments was conducted using moisture and storage time as the two independent variables. The hypothesis for this series of tests was that using small samples we would be able to observe and determine the effects of increased moisture and time on cotton quality. It was also hypothesized that the samples would maintain temperatures above room temperature during any ongoing biological activity. The oxygen sensors placed in two samples during the Test 1 both reached zero in two weeks. For this reason it was also decided that the ability to distinguish between cotton fiber and cottonseed quality losses during aerobic and anaerobic decomposition would be helpful. Oxygen level sensors were added to one replication of all treatments to differentiate between the two types of activity (Figure 13). Changes in seed and fiber quality in an environment with oxygen level of zero are caused by anaerobic activity. The protocol for this test required that samples contain 12-, 15-, 18-, and 21% moisture (w.b.). These levels were chosen to produce more pronounced results than seen in Test 1. Samples were opened at one month or as oxygen was depleted (whichever came first), two-, and three-month intervals. Three replications of each treatment were used, for a total of 36 samples.

**Figure 13. Oxygen sensor is installed on a seed cotton sample.**

Three hundred forty kg (750 lb) of All-Tex APEX B2F cotton harvested in the fall of 2009 was used for this series of tests. This cotton was harvested by the same picker used for the first test. Samples were again sized to 2.7 kg (6 lb) of dry matter, and contained only picked cotton with no extra trash. Therefore the samples were assumed to represent cotton containing approximately 36 kg (80 lb) of trash per bale. This number is higher than that of the cotton used in the first round because samples of this batch of cotton ginned at the USDA gin lab in Lubbock, TX contained 431 kg (950 lb) of seed per bale (J. Wanjura, personal communication, July 2010). All of the samples were placed into 0.75 m (29.6 in.) long pipes of the same type as used in Test 1 to produce 192 $kg/m^3$ (12 $lb/ft^3$) density.

Small samples of seed cotton were dried before each of the four days of packaging using the protocol from Test 1 to determine the moisture content of the cotton. Any changes in the bulk seed cotton moisture could be detected and accounted for. A basket was designed to increase the moisture of an entire sample to the desired level at once (Figure 14). Instead of having the steam pulled across the tumbling sample by a fan, the steam generator from the first test was placed below the basket. The frame containing the basket was wrapped with plastic to ensure that the steam traveled upward only. The steam then rose and crossed the cotton sample.

**Figure 14. Moisture addition system for Test 2. Moisture was added during the second series of tests using a large basket with the outlets of the steam generator placed directly beneath it. This container was wrapped in plastic (removed for picture) so that the steam exited through the seed cotton samples and the top of the frame.**

Because of the sizing of the wire which enclosed the basket, small amounts of cotton were able to escape during the tumbling process. Because of this, the method of weighing the samples before and after steaming to determine moisture contents was not practical. A new method was used in which 4.5 kg (10 lb) samples of ambient-moisture seed cotton were placed in the basket. The cotton was removed on the basis of time run instead of mass gained. An absorption rate curve was developed to predict sample moisture content as a function of time exposed to steam. After the cotton samples were allowed to run for the determined amount of time, they were removed from the basket and placed in a trash bag. The samples were weighed immediately and a small sample was taken to verify moisture content analysis using an oven-drying method (ASTM, 2006). Cotton in excess of that required to compose each sample was discarded. The seed cotton used for this test had an average moisture content of 8.2% w.b. at ambient conditions. The amounts of seed cotton and moisture addition necessary for each sample, as well as the total desired weight and the total run time required can be seen in Table 11.

**Table 11. Seed cotton and moisture addition table for Test 2. Steam was used to raise the moisture contents of the test samples. This system used a predetermined, moisture content versus time relationship to obtain the moisture contents needed for the test samples.**

| Moisture | Seed Cotton (g) | Moisture (g) | Run Time (min) | Total (g) |
|---|---|---|---|---|
| 12% | 2970 | 128 | 20 | 3100 |
| 15% | 2970 | 238 | 50 | 3210 |
| 18% | 2970 | 355 | 90 | 3320 |
| 21% | 2970 | 481 | 150 | 3450 |

The total desired mass of moist seed cotton was placed into sealed containers. Each container had a 3.2 mm (0.125 in.) hole drilled halfway up the length of the tube, through which a type-T thermocouple was placed in the center of the sample after the sample had been packed and sealed at the ends. Silicone caulk was then applied to the outside of the hole to seal the samples. The third set of twelve samples had holes drilled opposite the thermocouple to accept M16x1 threads. An oxygen sensor (Maxtec model MAX-14, Maxtec, Salt Lake City, Utah, USA) was used to monitor the oxygen levels of these samples. All data from the thermocouples and oxygen sensors were recorded using two Omega data collection devices (model OME-DAQ-56, Omega Engineering, Stamford, Connecticut, USA) recording at a frequency of 0.0007 Hz.

The third set of twelve samples to be sealed was opened as the containers ran out of oxygen or after one month, whichever came first. This would allow for the differentiation of the fiber and seed quality changes as a result of aerobic and anaerobic decomposition. The second set of samples sealed was opened after two months and the third set was opened after three months. Upon opening, two moisture sub-samples were taken randomly from each half of the sample for the same method of oven analysis used in Test 1. Average moisture contents at opening can be seen in Table 12. The remaining samples passed once through an extractor feeder and were spread out in a climate-controlled environment for no less than 66 hours so that moisture levels could equilibrate. Samples were ginned using the same gins from Test 1. Lint and seed samples were again sent to the Texas Tech Fiber and Biopolymer Research Institute and Mid-Continent Labs for HVI and free fatty acid analysis, respectively.

**Table 12. Target moisture content versus measured moisture content at opening.**

| Target M.C. (%w.b.) | M.C. at open (%w.b. ± Std. Error) |
|---|---|
| 12 | 12.6 ± 0.29 |
| 15 | 15.2 ± 0.25 |
| 18 | 17.3 ± 0.45 |
| 21 | 20.3 ± 0.73 |

Results of the HVI and Free Fatty Acid testing were analyzed using a statistics package from Stat-Ease (Design-Expert 7.1.6, Stat-Ease Inc, Minneapolis, Minnesota, USA). A confidence level of 95% was used. Results were tested for normality and the input factors fit to a multiple linear regression, analyzed for P-values, $R^2$, and F statistics relating to output factors. The data acquired in this test are attached as Appendix B.

## Results and Discussion

Data gathered from the thermocouples can be seen in Figure 15. The samples never increased in temperature relative to the room. After being taken from the steam chamber and containerized, they cooled to room temperature and fluctuated daily only as much as the room. Authors of previous research (Curley et al., 1987) of module-sized samples noted increases of at least 30°C for replications at 16% moisture. It is believed that the reason no notable temperature increases were seen in these samples is because of their small size. This means that all of the changes in cotton quality seen in Test 2 were caused by biological activity acting at room temperature, and no losses were caused by heat. Because no dramatic changes were seen in temperature it is expected that changes in the quality of the samples were less dramatic than they would have been in full-sized modules.

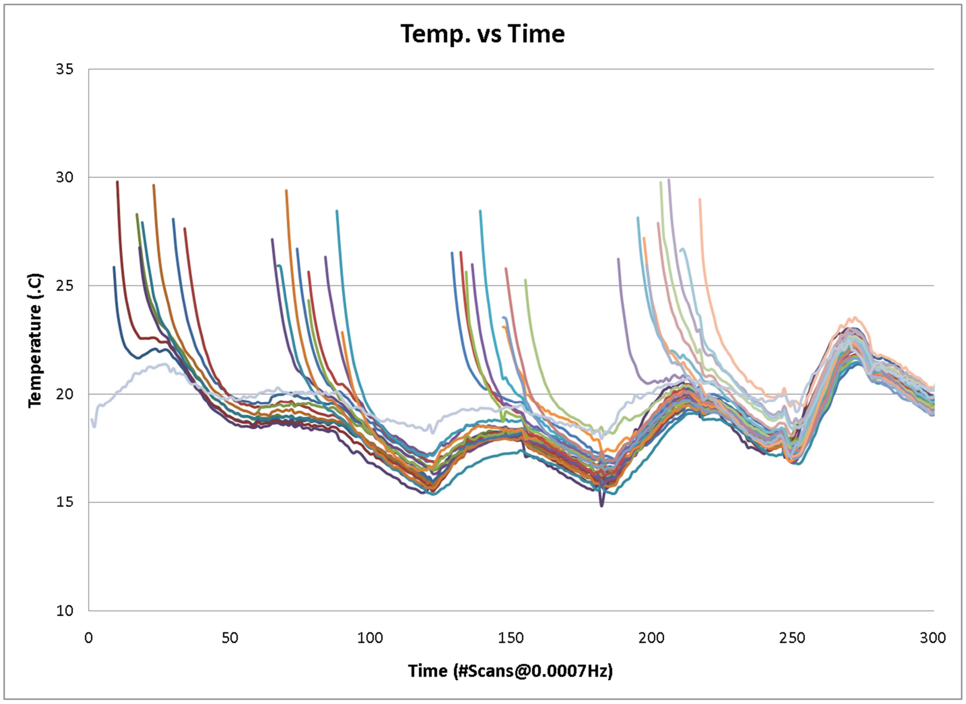

**Figure 15. Temperature versus time data for samples 1-36, with control included. After initial cooling of the samples their temperature followed the same trends as room temperature.**

The first set of samples opened, also the last set containerized, were numbered 25-36. These samples were opened as oxygen levels reported by the sensors they had installed reached 0% (signified by an output <0.2mV by the sensors), or after one month. The relationship between oxygen level and time can be seen in Figure 16. Samples with the highest moisture content reached 0% oxygen fastest. There was a 3-day period of collection whose data was lost. This location on the time scale of the chart is signified by an asymptote at 1262 samples.

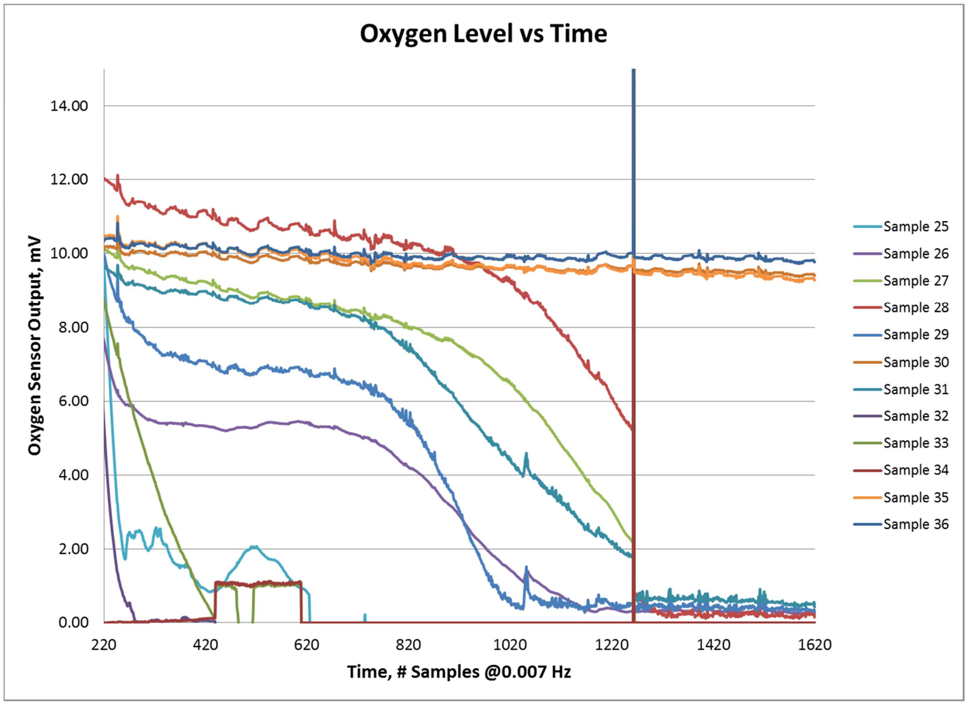

**Figure 16. Oxygen level versus time stored for samples 25-36.**

## *Strength*

Strength was affected by the time stored ($p<0.0001$) (Table 13). As can be seen in Figure 17, the returned value dropped from 26 to 25.3 g/tex (LSD=0.263) during the initial month of storage, after which there appeared to be no further change in the response. $R^2$ for this response was 0.546.

**Table 13. ANOVA table for strength. Time stored was the only significant factor.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Model | 3.61 | 2 | 1.81 | 19.22 | <0.0001 |
| Time | 3.61 | 2 | 1.81 | 19.22 | <0.0001 |
| Residual | 3.01 | 32 | 0.09 | | |
| Lack of Fit | 0.70 | 9 | 0.08 | 0.78 | 0.6384 |
| Pure Error | 2.30 | 23 | 0.10 | | |
| Cor Total | 6.62 | 34 | | | |

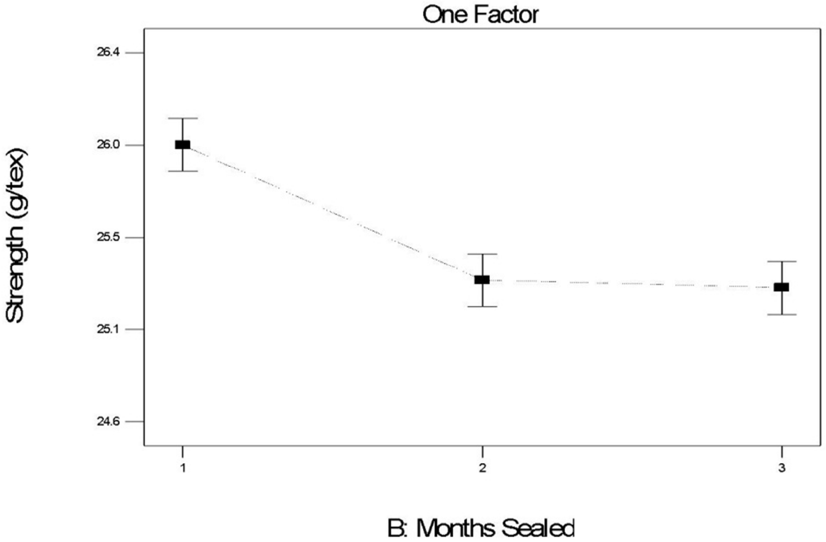

**Figure 17. Strength value versus number of months sealed.**

### *Uniformity*

Uniformity was affected by time stored (p=0.0143) (Table 14). As the samples were stored for longer time periods the uniformity of the samples increased (Figure 18). $R^2$ value for this response was 0.233. The reason for the increase in uniformity values between months two and three is not understood.

**Table 14. ANOVA table for uniformity. Uniformity was affected by the amount of time the samples were stored.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Model | 1.68 | 2 | 0.84 | 4.86 | 0.0143 |
| Time | 1.68 | 2 | 0.84 | 4.86 | 0.0143 |
| Residual | 5.53 | 32 | 0.17 | | |
| Lack of Fit | 1.20 | 9 | 0.13 | 0.71 | 0.6927 |
| Pure Error | 4.33 | 23 | 0.19 | | |
| Cor Total | 7.21 | 34 | | | |

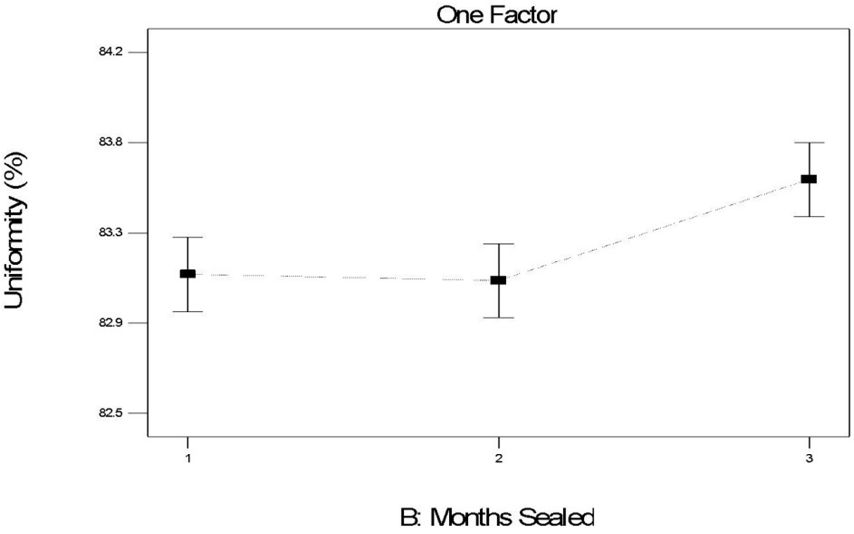

**Figure 18. Response graph for uniformity.**

### *Reflectance*

The reflectance (Rd) of the samples was responsive to moisture content ($p<0.0001$) and time stored ($p=0.0361$) (Table 15). The $R^2$ value for this relationship is 0.854. As the moisture content increased, the reflectance decreased. Reflectance increased between months one and two, and then decreased between months two and three. These relationships can be seen in Figure 19. It is believed that the increased moisture content caused increased biological activity which lead to more graying and thus lower reflectance values in the cotton.

**Table 15. ANOVA table for reflectance. Moisture content and time stored were significant.**

| **Source** | **Sum of Squares** | **Degrees of Freedom** | **Mean Square** | **F Value** | **p-value Prob > F** |
|---|---|---|---|---|---|
| Model | 76.39 | 5 | 15.28 | 35.03 | <0.0001 |
| Moisture | 73.14 | 3 | 24.38 | 55.91 | <0.0001 |
| Time | 3.24 | 2 | 1.62 | 3.72 | 0.0361 |
| Residual | 13.08 | 30 | 0.44 | | |
| Lack of Fit | 2.4 | 6 | 0.40 | 0.90 | 0.5131 |
| Pure Error | 10.69 | 24 | 0.50 | | |
| Cor Total | 89.47 | 35 | | | |

As stated above, yellowness and reflectance combine for the value of color, so there is no direct correlation noted between decreased reflectance and decreased price.

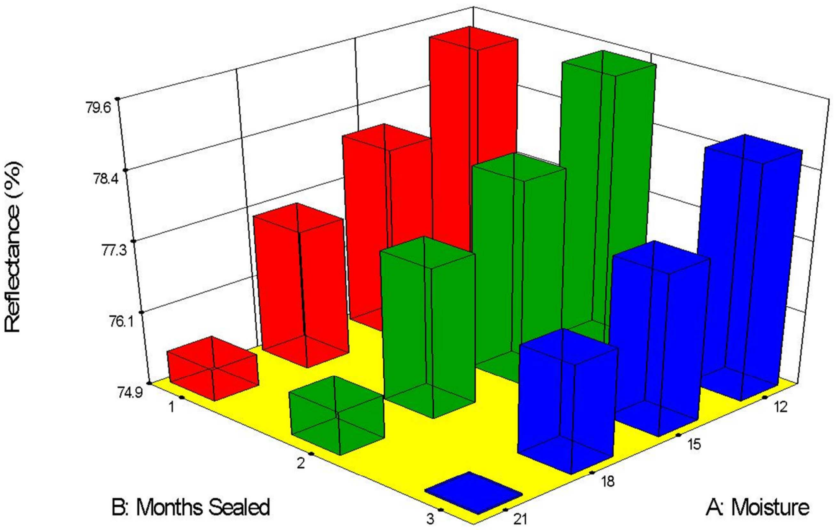

**Figure 19. Reflectance as a function of moisture content.**

### *Yellowness*

Yellowness (+b) was shown to be affected by moisture content and time stored (Table 16). The relationship between moisture and yellowness ($p<0.0001$) was consistent with Test 1. As moisture content increased, yellowness increased. It is hypothesized that increased biological activity in the sample caused by increased moisture contents resulted in discoloration in the form of yellowness. Also, as the amount of time stored increased the yellowness increased ($p<0.0001$). The $R^2$ value for yellowness is 0.866. It is hypothesized that the increased time of storage gave more time for biological activity to occur, which in turn meant more yellowing of the fiber. The relationship between moisture, storage time, and yellowness is shown in the graph below (Figure 20).

**Table 16. ANOVA table for yellowness. Moisture content and time stored were both significant.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Model | 8.84 | 5 | 1.77 | 36.69 | <0.0001 |
| Moisture | 4.21 | 3 | 1.40 | 30.68 | <0.0001 |
| Time | 4.63 | 2 | 2.32 | 50.69 | <0.0001 |
| Residual | 1.37 | 30 | 0.05 | | |
| Lack of Fit | 0.30 | 6 | 0.05 | 1.11 | 0.3869 |
| Pure Error | 1.07 | 24 | 0.05 | | |
| Cor Total | 10.21 | 35 | | | |

Yellowness is combined with reflectance to create the color value for a cotton sample. For this reason, the direct value change of the cotton caused by yellowness is not listed.

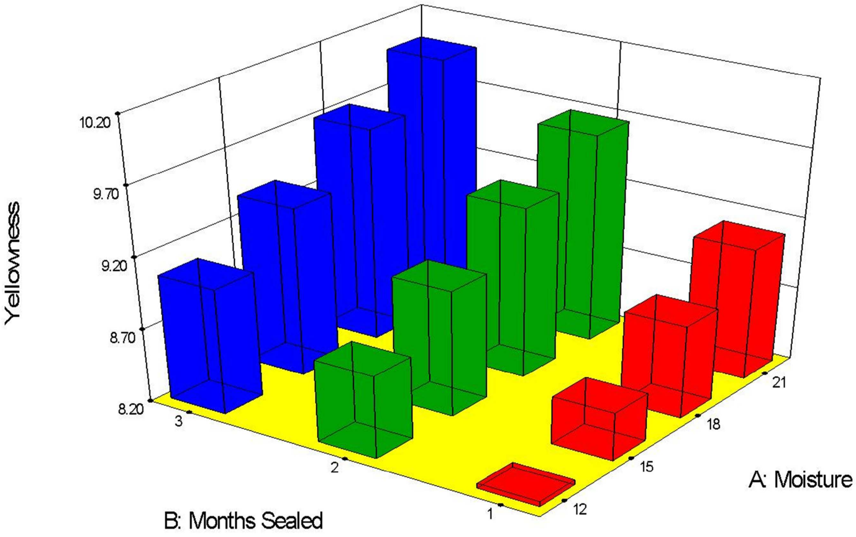

**Figure 20. Three-dimensional graph for yellowness as a function of storage time and moisture content.**

### *Free Fatty Acid*

Free fatty acid content was affected by time stored (p=0.0187) and the interaction between time stored and moisture content (p=0.0373) (Table 17). As moisture content increased for the samples ginned during the first month of storage, free fatty acid contents decreased. For samples ginned in month three, the opposite is true (Figure 21). The $R^2$ value for this relationship is 0.539. The results gathered from the third month's samples were expected. However, the response to moisture content experienced during the first month's samples was unexpected. It is not understood. The samples ginned during the second month had results similar to those ginned in the third month.

**Table 17. ANOVA table for free fatty acid content of the cottonseed. Time stored and the interaction between time stored and moisture content were significant.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Model | 2.52 | 11 | 0.23 | 2.55 | 0.0267 |
| Moisture | 0.21 | 3 | 0.07 | 0.78 | 0.5166 |
| Time | 0.85 | 2 | 0.42 | 4.72 | 0.0187 |
| Moisture x Time | 1.46 | 6 | 0.24 | 2.71 | 0.0373 |
| Pure Error | 2.15 | 24 | 0.09 | | |
| Cor Total | 4.67 | 35 | | | |

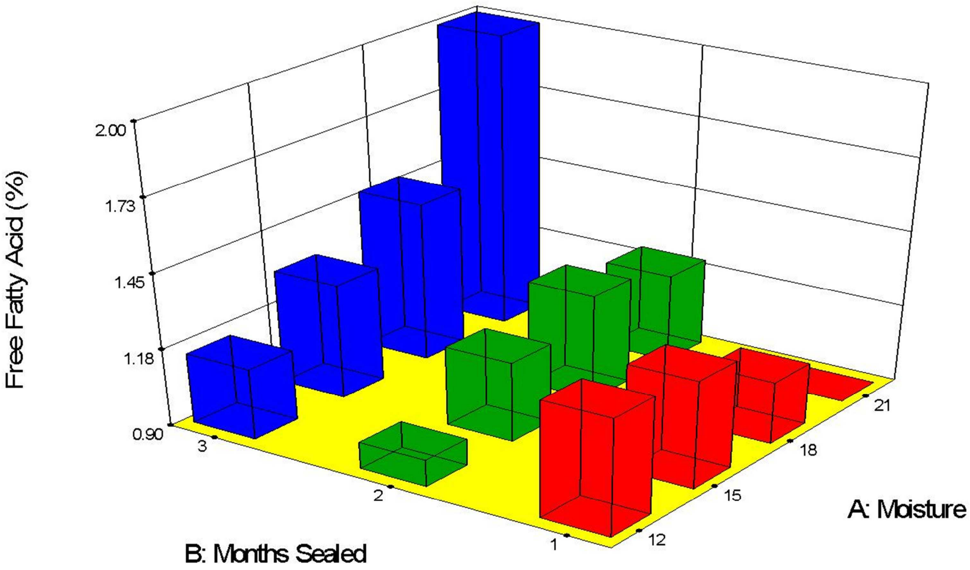

**Figure 21. Three-dimensional response for free fatty acid content of cottonseed.**

### *Lint Value*

The results were also analyzed for price. Values for each sample were estimated according to the 2009 CCC Loan Chart (USDA, 2009). Because the response values of micronaire, strength, uniformity, and length displayed no statistical relationships with moisture content or time stored, premiums and discounts for these values were not applied. Also, because trash content in the samples was a result of handling methods, all samples were treated according only to their color grades. Therefore the monetary values gathered for each sample were based solely on the color values returned, which were a combination of yellowness and reflectance. All other components of the HVI test results were ignored for this response. The samples valued ranged in price from \$0.520 to \$0.573 per pound of lint.

Moisture (p<0.0001), time stored (p=0.0002), and the interaction between moisture and time stored (p=0.0403) significantly affected lint value (Table 18). As moisture content increased from 12 to 21% w.b. there was very little change in lint value if it was stored for a short period of time. However, as time stored increased, there was a more drastic response to increases in moisture content by lint values. The relationship between these factors and price can be seen in Figure 22. The $R^2$ value for this relationship is 0.774.

**Table 18. ANOVA table for lint price. Moisture content, time stored, and the interaction between the two were significant.**

| Source | Sum of Squares | Degrees of Freedom | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| Model | 55.79 | 11 | 5.07 | 7.47 | <0.0001 |
| Moisture | 27.99 | 3 | 9.33 | 13.74 | <0.0001 |
| Time | 16.98 | 2 | 8.49 | 12.51 | 0.0002 |
| Moisture x Time | 10.82 | 6 | 1.80 | 2.66 | 0.0403 |
| Pure Error | 16.29 | 24 | 0.68 | | |
| Cor Total | 72.08 | 35 | | | |

The final equation describing this relationship is below (eq. 2):

$$P = 56.11 + 4.49 \times 10^{-3} \times M + 0.06 \times T - 3.66 \times 10^{-3} \times M \times T \tag{2}$$

where:

P = price (cents per pound),

M = moisture content (% w.b.) and

T = time stored (days).

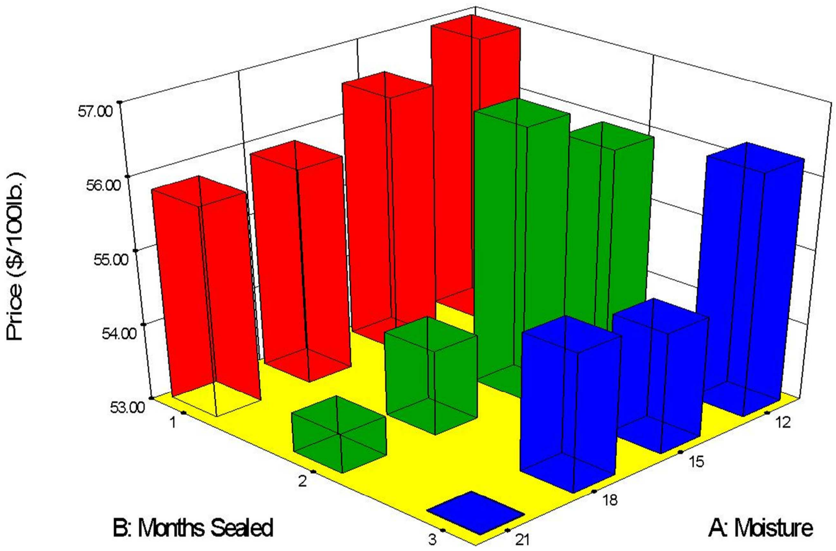

**Figure 22. Lint value as a function of moisture content and storage time.**

## Summary

The second round of tests was conducted in order to determine the effects of varied levels of moisture content and storage time on the final qualities of cottonseed and cotton lint. Four levels of moisture content and three levels of time stored were chosen to represent a range in which a reaction to both factors could be seen. Trash contents were maintained at levels equivalent to picker-harvested cotton. Densities were maintained at levels representing seed cotton packaged by a traditional module builder. Moisture was added in the form of steam that was drawn across tumbling samples of cotton via a temperature gradient. Samples were moisturized to 12-, 15-, 18- and 21% w.b. Storage times were 1-, 2-, and 3-months.

Each sample included a thermocouple. Temperature readings were taken every 23 minutes for the duration of the storage period. When compared to the control sensor, the readings evidenced that the samples fluctuated in temperature daily with their environment but never rose above room temperature after their initial cooling period. The small size of the samples is believed to be the reason increased temperatures similar to those noted by Sorenson and Wilkes (1973) were not observed.

The set of samples to be stored for one month were outfitted with oxygen sensors so that levels could be monitored along with temperature, and they could be opened when oxygen levels within the sample reached zero. All but three of the samples reached 0% oxygen before one month of storage and were ginned prior to this time. After ginning, lint and seed samples of each replication were analyzed for quality.

Moisture affected the lint qualities of reflectance and yellowness, as well as the free fatty acid content of the cottonseed. Storage time affected the lint qualities of strength, uniformity, reflectance and yellowness, as well the free fatty acid content of the cottonseed. Both of these factors, as well as the interaction between them, were significant for price. Increased moisture content and increased storage time had negative effects on the response of lint value.

The relationships between micronaire, length, and elongation as related to moisture content were not observed in the second round of tests. The micronaire values in Test 1 averaged 3.7, while they averaged only 2.6 in the second test. The reason for this difference is likely the initial condition of the cotton used. West Texas was hit by an early freeze in the 2009 crop year and most of the cotton in the region had not reached full maturity. Length values were the same. Elongation values cannot be compared across the tests because they may not have been analyzed by the same HVI machine and there is no calibration standard for elongation tests.

Any differences in the reactions of the physical properties of the samples could have been due to differences in processing. A different device was used for moisture addition. Samples from Test 1 were opened at the same time and were ginned as quickly as possible. Samples from Test 2 were opened, run through an extractor-feeder and ginned after roughly three days of equilibration with laboratory conditions.

# CHAPTER IV

# SUMMARY

Results from Test 1 indicate that micronaire, length, elongation, reflectance, yellowness, and free fatty acid content were affected by differing levels of moisture and trash. Moisture content was the most prevalent factor, affecting elongation, free fatty acid content, yellowness, micronaire, length, and reflectance. Moisture content was followed by trash content, which was found to be a significant factor for the responses of yellowness, micronaire, and length. Density was significant only for the response of reflectance.

Increased moisture during storage negatively impacted values of elongation, reflectance, yellowness, and free fatty acid content. These responses are logical as increased moisture levels encourage higher levels of biological activity, which causes discoloration and possibly weakening of the fiber. It also led to more rapid degradation of the seed, in which cottonseed oil was broken down to free fatty acid.

Increased trash content during storage was shown to be beneficial for the qualities of yellowness and micronaire during Test 1. This was an unexpected result. One possible explanation for this is the moisture addition technique used, in which the moisture contents of the seed cotton and the incorporated trash were increased simultaneously. It is possible that the trash absorbed moisture at a faster rate than the seed cotton. If this happened, the seed cotton may have had lower moisture contents during storage, meaning less pronounced fiber quality changes in the samples with high trash contents. The increased trash contents appear to benefit the quality of the samples by up to 1.65 cents per pound added to the value of the lint.

In summary the type of seed cotton module used, as determined by density, was not important in considering final lint or seed quality. As expected, moisture content played a large role, with higher moisture contents leading to discounts in cotton prices. Increased trash content led to increased seed and fiber quality, but this was believed to be an effect of the moisture addition method as it was the opposite reaction expected.

Test 2 was conducted using moisture content and time stored as the independent variables. The results of Test 2 show that increases in moisture content cause an increase in yellowness and a decrease in reflectance, as well as an increase in free fatty acid content of the cottonseed. Also, increased storage time caused decreases in strength and reflectance, and increases in uniformity, yellowness, and free fatty acid levels. There was an interaction between moisture content and time stored for the response of yellowness. This interaction showed that as the time stored increased there was a less pronounced increase in yellowness because of moisture content. The interaction between time stored and moisture content was also significant for lint price. As time stored increased, the relationship between moisture content and price became more pronounced. Increases in both factors negatively impacted the value of the fiber. The best choice for a producer, as in previous research, would be to harvest at the lowest moisture content possible, especially if the cotton will be stored for a long period of time.

The protocols used in this research effort were effective in allowing the detection of changes in fiber and seed quality of small samples caused by varying moisture contents, trash contents, and density levels. The use of the protocols described above allowed for detailed results and relationships to be observed. We were able to associate monetary losses in lint value with input values of density, trash content, moisture content, and time stored.

The expected relationship between increased moisture content and increases in temperature was not observed. It is believed that this is due to the small sample sizes. It is expected that more dramatic quality changes would have been observed with larger samples. There were differences in the observed reactions to increased moisture content between the first and second tests. These changes are believed to be caused by the differences in handling and processing techniques.

The results of this research are important to cotton producers when making harvesting decisions. Varying storage densities do not have an effect on fiber or seed degradation. The harvest and storage of cotton at moisture contents above 12% w.b. should be avoided to prevent losses in fiber quality, and thus reduced lint prices. Lint prices can be expected to begin to decrease as little as one week after placement of the module in storage if the moisture is above 15%. Deterioration will be more rapid as moisture contents increase.

Ginners may also use this information in making decisions about the processing order of seed cotton stored on their yards. If a module is known to have high moisture content, it may be a good practice to move it to the top of the queue.

In future research on this topic it would be beneficial in terms of the magnitude of results and representation of real-world scenarios for the researcher to use larger samples of seed cotton. In regards to adding moisture, a better method would be to bring samples of seed cotton and trash to the desired content separately. Given the ever-increasing storage time of packaged seed cotton it may also be good to study changes in quality over longer time periods.

# REFERENCES

ASTM Standards. 2006. ASTM International, ASTM D2495-01: Standard test method for moisture in cotton by oven-drying. West Conshohocken, Penn.: ASTM.

Curley, R., B. Roberts, T. Kerby, C. Brooks, and J. Knutson. 1987. Effect of seed cotton moisture level and storage time on the quality of lint in stored modules. In *Proc. Beltwide Cotton Conferences,* 504-505.Memphis, Tenn.: National Cotton Council.

Curley, R., B. Roberts, T. Kerby, C. Brooks, and J. Knutson. 1990. Effect of moisture on moduled seed cotton. In *Proc. Beltwide Cotton Conferences*, 683-686.Memphis, Tenn.: National Cotton Council

Faulkner, W. B., J.D. Wanjura, R.K. Boman, B.W. Shaw, C.B. Parnell. 2010. Evaluation of modern cotton harvest systems on irrigated cotton: harvester performance. *Trans. ASABE.*, in press.

Harris, W. B. and A. C. Wamble. 1966. Deterioration of cottonseed meats during storage. *J. Am. Oil Chem. Soc.* 44(7): 457-459.

Karon, M. L. and M. E. Adams. 1948. Note on the hygroscopic equilibrium of cottonseed and cottonseed products. *J. Am. Oil Chem. Soc.* 25(1): 21-22

Montgomery, R. A. and O. B. Wooten. 1958. Lint quality and moisture relationships in cotton through harvesting and ginning. USDA-ARS Publication 42-14. Washington, D.C.: USDA Agriculture Research Service.

NCPA, 2010. National Cottonseed Products Association, Cottonseed Trading Rules. Available at: www.cottonseed.com/tradingrules. Accessed 28 December 2010.

Sorenson, J. W., Jr., and L. H. Wilkes. 1973. Quality of cottonseed and lint from seed cotton stored for various periods of time before ginning. *Proc. 1973 Seed Cotton Handling and Storing Seminar*. 41-67. Raleigh, N.C.: Cotton Incorporated.

USDA. 2009. United States Department of Agriculture, Commodity Credit Corporation Cotton Loan Rates. Available at: www.afpo.usda.gov. Accessed 2 July 2011.

USDA. 2010. United States Department of Agriculture, Annual Cotton Ginnings Report: 1960-2010. National Agricultural Statistics Database. Washington, D.C.: USDA National Agricultural Statistics Service. Available at: www.nass.usda.gov. Accessed 23 July 2010.

Wilkes, L. H. 1974. Breakthroughs in seed cotton storage and handling. In *Proc. Beltwide Cotton Production Conferences,* 14-15. Memphis, Tenn.: National Cotton Council.

Wilkes, L. H. 1978. Seed cotton storage: effects on seed quality. In *Proc. Beltwide Cotton Production Conferences,* 215-217. Memphis, Tenn.: National Cotton Council.

# APPENDIX A

# TEST 1 DATA

Table A-1. Data acquired from Test 1.

| Sample | Run | Block | Moisture | Density | Trash Content | MIC | LENGTH | UNIF. | STRENGTH | ELON. | Rd | +b | CGRD | FFA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (%w.b.) | (lb/ft$^3$) | | | (in.) | (%) | | | (%) | | | (%) |
| 5 | 1 | Block 1 | 12 | 8 | Picker | 3.6 | 1.20 | 82.0 | 28.0 | 7.0 | 72.9 | 9.4 | 32-2 | 1.0 |
| 21 | 2 | Block 1 | 14 | 12 | Picker | 3.7 | 1.23 | 82.8 | 29.4 | 6.3 | 71.0 | 9.2 | 42-1 | |
| 49 | 3 | Block 1 | 10 | 12 | Stripper w/ FC | 3.7 | 1.21 | 82.2 | 29.6 | 7.1 | 72.9 | 8.7 | 41-3 | 0.7 |
| 85 | 4 | Block 1 | 10 | 12 | Stripper w/o FC | 3.6 | 1.21 | 81.5 | 28.8 | 6.8 | 75.1 | 8.9 | 31-4 | 1.1 |
| 37 | 5 | Block 1 | 10 | 8 | Stripper w/ FC | 3.7 | 1.23 | 82.3 | 28.5 | 6.7 | 74.1 | 8.2 | 41-1 | 0.8 |
| 45 | 6 | Block 1 | 14 | 8 | Stripper w/ FC | 3.7 | 1.23 | 82.2 | 30.0 | 6.4 | 73.9 | 8.8 | 41-3 | 1.3 |
| 97 | 7 | Block 1 | 10 | 16 | Stripper w/o FC | 3.8 | 1.21 | 81.3 | 29.3 | 7.0 | 73.5 | 8.9 | 41-3 | 1.0 |
| 9 | 8 | Block 1 | 14 | 8 | Picker | 3.6 | 1.26 | 83.4 | 28.9 | 6.5 | 72.3 | 9.1 | 42-1 | 1.3 |
| 13 | 9 | Block 1 | 10 | 12 | Picker | 3.7 | 1.22 | 82.0 | 28.6 | 7.3 | 73.7 | 8.8 | 41-3 | 1.0 |
| 53 | 10 | Block 1 | 12 | 12 | Stripper w/ FC | 3.7 | 1.23 | 82.0 | 29.3 | 6.9 | 74.5 | 8.9 | 41-3 | 0.9 |
| 33 | 11 | Block 1 | 14 | 16 | Picker | 3.7 | 1.21 | 82.3 | 28.8 | 6.7 | 71.0 | 9.5 | 42-1 | 1.2 |
| 29 | 12 | Block 1 | 12 | 16 | Picker | 3.6 | 1.23 | 82.7 | 28.5 | 6.5 | 75.1 | 9.2 | 31-3 | 1.0 |
| 57 | 13 | Block 1 | 14 | 12 | Stripper w/ FC | 4.0 | 1.25 | 83.0 | 28.5 | 6.5 | 71.5 | 9.6 | 42-1 | 1.3 |
| 61 | 14 | Block 1 | 10 | 16 | Stripper w/ FC | 3.8 | 1.20 | 82.3 | 29.3 | 7.2 | 73.8 | 8.9 | 41-3 | 0.7 |
| 81 | 15 | Block 1 | 14 | 8 | Stripper w/o FC | 3.9 | 1.21 | 82.0 | 29.2 | 6.9 | 72.5 | 9.1 | 42-1 | 0.9 |
| 93 | 16 | Block 1 | 14 | 12 | Stripper w/o FC | 3.7 | 1.21 | 81.6 | 28.8 | 7.0 | 71.1 | 8.7 | 42-2 | 1.1 |
| 101 | 17 | Block 1 | 12 | 16 | Stripper w/o FC | 3.7 | 1.22 | 81.7 | 28.9 | 7.2 | 71.9 | 8.5 | 41-4 | 1.1 |

**Table A-1. Continued.**

| Sample | Run | Block | Moisture | Density | Trash Content | MIC | LENGTH | UNIF. | STRENGTH | ELON. | Rd | +b | CGRD | FFA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (%w.b.) | (lb/ft$^3$) | | | (in.) | (%) | | | (%) | | | (%) |
| 77 | 18 | Block 1 | 12 | 8 | Stripper w/o FC | 3.7 | 1.19 | 81.7 | 28.5 | 6.8 | 73.2 | 8.8 | 41-3 | 0.9 |
| 89 | 19 | Block 1 | 12 | 12 | Stripper w/o FC | 3.8 | 1.21 | 81.8 | 28.5 | 7.0 | 74.7 | 8.9 | 31-4 | 1.1 |
| 73 | 20 | Block 1 | 10 | 8 | Stripper w/o FC | 3.8 | 1.21 | 82.1 | 29.5 | 7.3 | 74.9 | 8.7 | 31-4 | 1.0 |
| 69 | 21 | Block 1 | 14 | 16 | Stripper w/ FC | 3.8 | 1.23 | 83.3 | 29.7 | 6.2 | 73.4 | 9.0 | 41-3 | 1.0 |
| 105 | 22 | Block 1 | 14 | 16 | Stripper w/o FC | 3.9 | 1.21 | 81.8 | 29.0 | 6.6 | 73.6 | 9.4 | 32-2 | 1.0 |
| 25 | 23 | Block 1 | 10 | 16 | Picker | 3.6 | 1.23 | 83.0 | 29.2 | 6.7 | 76.8 | 9.1 | 31-3 | 0.9 |
| 65 | 24 | Block 1 | 12 | 16 | Stripper w/ FC | 3.8 | 1.23 | 82.9 | 29.0 | 6.4 | 75.1 | 9.4 | 32-1 | 0.9 |
| 1 | 25 | Block 1 | 10 | 8 | Picker | 3.8 | 1.22 | 82.9 | 30.0 | 7.6 | 75.4 | 9.2 | 31-3 | |
| 41 | 26 | Block 1 | 12 | 8 | Stripper w/ FC | 3.7 | 1.21 | 82.2 | 29.2 | 6.7 | 71.2 | 9.0 | 42-2 | 0.9 |
| 17 | 27 | Block 1 | 12 | 12 | Picker | 3.8 | 1.21 | 81.4 | 30.0 | 6.4 | 72.9 | 9.4 | 32-2 | 1.0 |
| 50 | 28 | Block 2 | 10 | 12 | Stripper w/ FC | 3.8 | 1.22 | 82.9 | 28.9 | 7.0 | 75.2 | 8.8 | 31-4 | 1.2 |
| 70 | 29 | Block 2 | 14 | 16 | Stripper w/ FC | 3.8 | 1.23 | 83.2 | 29.3 | 6.0 | 72.1 | 9.3 | 42-1 | 1.0 |
| 38 | 30 | Block 2 | 10 | 8 | Stripper w/ FC | 3.6 | 1.23 | 83.0 | 28.3 | 7.0 | 71.8 | 9.1 | 42-1 | 0.9 |
| 26 | 31 | Block 2 | 10 | 16 | Picker | 3.7 | 1.24 | 82.7 | 29.4 | 7.0 | 71.6 | 9.1 | 42-1 | 0.8 |
| 82 | 32 | Block 2 | 14 | 8 | Stripper w/o FC | 3.7 | 1.23 | 83.2 | 29.4 | 6.4 | 72.0 | 8.7 | 41-3 | 0.8 |
| 78 | 33 | Block 2 | 12 | 8 | Stripper w/o FC | 3.7 | 1.24 | 82.4 | 29.8 | 6.5 | 76.3 | 9.2 | 31-3 | 1.0 |
| 46 | 34 | Block 2 | 14 | 8 | Stripper w/ FC | 3.7 | 1.22 | 82.3 | 28.9 | 6.6 | 73.8 | 8.9 | 41-3 | 1.2 |

**Table A-1. Continued.**

| Sample | Run | Block | Moisture | Density | Trash Content | MIC | LENGTH | UNIF. | STRENGTH | ELON. | Rd | +b | CGRD | FFA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (%w.b.) | (lb/ft$^3$) | | | (in.) | (%) | | | (%) | | | (%) |
| 90 | 35 | Block 2 | 12 | 12 | Stripper w/o FC | 3.7 | 1.22 | 81.5 | 28.9 | 6.7 | 73.2 | 8.9 | 41-3 | 0.9 |
| 34 | 36 | Block 2 | 14 | 16 | Picker | 3.6 | 1.23 | 82.3 | 28.9 | 6.7 | 71.4 | 9.5 | 42-1 | 1.2 |
| 106 | 37 | Block 2 | 14 | 16 | Stripper w/o FC | 3.9 | 1.22 | 82.4 | 29.4 | 7.0 | 70.4 | 9.2 | 42-2 | 1.0 |
| 2 | 38 | Block 2 | 10 | 8 | Picker | 3.6 | 1.22 | 82.2 | 28.9 | 6.8 | 73.0 | 8.8 | 41-3 | 1.0 |
| 94 | 39 | Block 2 | 14 | 12 | Stripper w/o FC | 3.9 | 1.24 | 83.2 | 29.3 | 6.5 | 72.9 | 8.9 | 41-3 | 1.0 |
| 30 | 40 | Block 2 | 12 | 16 | Picker | 3.8 | 1.23 | 81.8 | 29.4 | 6.7 | 74.9 | 9.7 | 32-1 | 0.8 |
| 86 | 41 | Block 2 | 10 | 12 | Stripper w/o FC | 3.8 | 1.21 | 81.7 | 29.1 | 6.8 | 73.6 | 8.9 | 41-3 | 1.1 |
| 58 | 42 | Block 2 | 14 | 12 | Stripper w/ FC | 4.0 | 1.23 | 82.1 | 29.0 | 6.5 | 75.7 | 9.2 | 31-3 | 1.4 |
| 66 | 43 | Block 2 | 12 | 16 | Stripper w/ FC | 4.0 | 1.20 | 82.8 | 29.0 | 7.0 | 75.8 | 9.2 | 31-3 | 1.1 |
| 22 | 44 | Block 2 | 14 | 12 | Picker | 3.9 | 1.24 | 83.7 | 29.6 | 6.4 | 74.4 | 9.0 | 31-4 | 1.3 |
| 54 | 45 | Block 2 | 12 | 12 | Stripper w/ FC | 3.8 | 1.21 | 81.7 | 29.7 | 6.4 | 73.8 | 9.3 | 32-2 | 1.2 |
| 62 | 46 | Block 2 | 10 | 16 | Stripper w/ FC | 3.6 | 1.21 | 82.6 | 29.1 | 6.8 | 72.8 | 8.7 | 41-3 | 1.0 |
| 10 | 47 | Block 2 | 14 | 8 | Picker | 3.7 | 1.24 | 82.9 | 29.3 | 6.3 | 73.0 | 9.5 | 32-2 | 1.2 |
| 42 | 48 | Block 2 | 12 | 8 | Stripper w/ FC | 3.8 | 1.23 | 82.8 | 29.4 | 6.3 | 74.2 | 9.1 | 31-4 | 1.7 |
| 102 | 49 | Block 2 | 12 | 16 | Stripper w/o FC | 3.9 | 1.20 | 81.9 | 28.6 | 6.9 | 74.3 | 9.2 | 31-4 | 1.1 |
| 6 | 50 | Block 2 | 12 | 8 | Picker | 3.8 | 1.22 | 82.3 | 29.0 | 7.0 | 74.2 | 9.1 | 31-4 | 1.0 |
| 74 | 51 | Block 2 | 10 | 8 | Stripper w/o FC | 3.8 | 1.22 | 81.6 | 30.0 | 7.1 | 75.7 | 8.9 | 31-3 | 0.9 |
| 14 | 52 | Block 2 | 10 | 12 | Picker | 3.7 | 1.22 | 82.7 | 28.6 | 6.9 | 74.1 | 9.0 | 31-4 | 1.1 |

**Table A-1. Continued.**

| Sample | Run | Block | Moisture | Density | Trash Content | MIC | LENGTH | UNIF. | STRENGTH | ELON. | Rd | +b | CGRD | FFA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (%w.b.) | (lb/ft$^3$) | | | (in.) | (%) | | | (%) | | | (%) |
| 98 | 53 | Block 2 | 10 | 16 | Stripper w/o FC | 3.9 | 1.21 | 82.8 | 29.9 | 6.6 | 73.4 | 9.2 | 42-1 | 1.0 |
| 18 | 54 | Block 2 | 12 | 12 | Picker | 3.8 | 1.22 | 82.3 | 29.1 | 6.6 | 75.1 | 9.3 | 31-3 | 1.3 |
| 23 | 55 | Block 3 | 14 | 12 | Picker | 3.4 | 1.23 | 82.6 | 28.6 | 6.5 | 73.7 | 9.4 | 32-2 | 1.5 |
| 39 | 56 | Block 3 | 10 | 8 | Stripper w/ FC | 3.3 | 1.23 | 82.5 | 29.1 | 7.5 | 75.1 | 9.0 | 31-4 | 1.0 |
| 7 | 57 | Block 3 | 12 | 8 | Picker | 3.4 | 1.23 | 82.6 | 28.7 | 6.7 | 72.9 | 9.7 | 32-2 | 0.9 |
| 35 | 58 | Block 3 | 14 | 16 | Picker | 3.4 | 1.23 | 82.5 | 28.7 | 6.6 | 73.7 | 9.6 | 32-2 | 1.3 |
| 63 | 59 | Block 3 | 10 | 16 | Stripper w/ FC | 3.3 | 1.23 | 83.1 | 28.6 | 7.0 | 74.2 | 9.3 | 32-2 | 1.1 |
| 51 | 60 | Block 3 | 10 | 12 | Stripper w/ FC | 3.6 | 1.23 | 81.9 | 29.1 | 6.8 | 74.7 | 8.9 | 31-4 | 1.0 |
| 43 | 61 | Block 3 | 12 | 8 | Stripper w/ FC | 3.7 | 1.24 | 83.1 | 29.7 | 6.5 | 74.7 | 9.4 | 32-1 | 1.1 |
| 107 | 62 | Block 3 | 14 | 16 | Stripper w/o FC | 3.7 | 1.22 | 82.9 | 28.8 | 6.3 | 72.2 | 9.4 | 42-1 | 1.2 |
| 95 | 63 | Block 3 | 14 | 12 | Stripper w/o FC | 3.7 | 1.23 | 83.0 | 29.9 | 6.6 | 73.2 | 9.2 | 42-1 | 1.3 |
| 91 | 64 | Block 3 | 12 | 12 | Stripper w/o FC | 3.8 | 1.22 | 82.5 | 29.6 | 6.8 | 73.2 | 8.6 | 41-3 | 1.3 |
| 75 | 65 | Block 3 | 10 | 8 | Stripper w/o FC | 3.6 | 1.23 | 82.2 | 30.3 | 6.6 | 74.8 | 8.9 | 31-4 | 0.9 |
| 11 | 66 | Block 3 | 14 | 8 | Picker | 3.4 | 1.23 | 82.4 | 29.8 | 6.4 | 72.5 | 9.3 | 42-1 | 1.4 |
| 27 | 67 | Block 3 | 10 | 16 | Picker | 3.5 | 1.23 | 83.4 | 28.6 | 6.6 | 71.9 | 8.8 | 42-1 | 1.0 |
| 47 | 68 | Block 3 | 14 | 8 | Stripper w/ FC | 3.5 | 1.25 | 83.3 | 28.3 | 6.9 | 71.9 | 9.8 | 42-1 | 1.5 |
| 99 | 69 | Block 3 | 10 | 16 | Stripper w/o FC | 3.7 | 1.19 | 82.4 | 28.4 | 6.9 | 73.2 | 9.2 | 42-1 | 0.9 |
| 87 | 70 | Block 3 | 10 | 12 | Stripper w/o FC | 3.5 | 1.21 | 82.3 | 29.9 | 7.1 | 73.9 | 8.7 | 41-3 | 0.8 |

**Table A-1. Continued.**

| Sample | Run | Block | Moisture | Density | Trash Content | MIC | LENGTH | UNIF. | STRENGTH | ELON. | Rd | +b | CGRD | FFA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | (%w.b.) | (lb/ft$^3$) |  |  | (in.) | (%) |  |  | (%) |  |  | (%) |
| 19 | 71 | Block 3 | 12 | 12 | Picker | 3.5 | 1.22 | 81.3 | 30.2 | 6.7 | 74.1 | 9.4 | 32-2 | 1.1 |
| 15 | 72 | Block 3 | 10 | 12 | Picker | 3.5 | 1.22 | 82.1 | 29.0 | 7.0 | 75.4 | 9.0 | 31-4 | 0.9 |
| 71 | 73 | Block 3 | 14 | 16 | Stripper w/ FC | 3.6 | 1.23 | 81.9 | 28.2 | 6.6 | 70.2 | 9.8 | 42-1 | 1.3 |
| 83 | 74 | Block 3 | 14 | 8 | Stripper w/o FC | 3.5 | 1.22 | 81.9 | 29.1 | 6.8 | 74.8 | 9.1 | 31-4 | 1.4 |
| 59 | 75 | Block 3 | 14 | 12 | Stripper w/ FC | 3.6 | 1.22 | 82.0 | 29.8 | 6.5 | 73.2 | 9.0 | 41-3 | 1.2 |
| 31 | 76 | Block 3 | 12 | 16 | Picker | 3.4 | 1.24 | 82.7 | 29.2 | 6.6 | 72.3 | 9.3 | 42-1 | 1.3 |
| 103 | 77 | Block 3 | 12 | 16 | Stripper w/o FC | 3.5 | 1.25 | 83.0 | 28.2 | 6.8 | 74.5 | 8.7 | 41-3 | 0.9 |
| 79 | 78 | Block 3 | 12 | 8 | Stripper w/o FC | 3.6 | 1.22 | 82.3 | 29.3 | 6.8 | 74.4 | 8.8 | 41-3 | 1.0 |
| 3 | 79 | Block 3 | 10 | 8 | Picker | 3.7 | 1.21 | 81.9 | 28.6 | 7.2 | 75.0 | 9.2 | 31-3 | 1.0 |
| 67 | 80 | Block 3 | 12 | 16 | Stripper w/ FC | 3.5 | 1.23 | 81.6 | 27.4 | 6.7 | 71.1 | 9.0 | 42-1 | 1.1 |
| 55 | 81 | Block 3 | 12 | 12 | Stripper w/ FC | 3.5 | 1.24 | 83.7 | 28.6 | 7.0 | 73.4 | 9.7 | 32-2 | 1.0 |
| 20 | 82 | Block 4 | 12 | 12 | Picker | 3.4 | 1.22 | 82.3 | 29.5 | 6.6 | 74.5 | 9.2 | 31-4 | 0.9 |
| 32 | 83 | Block 4 | 12 | 16 | Picker | 3.6 | 1.24 | 82.4 | 28.6 | 6.3 | 73.1 | 9.0 | 41-3 | 1.3 |
| 52 | 84 | Block 4 | 10 | 12 | Stripper w/ FC | 3.6 | 1.23 | 83.5 | 28.6 | 7.3 | 73.6 | 9.3 | 32-2 | 0.9 |
| 80 | 85 | Block 4 | 12 | 8 | Stripper w/o FC | 3.5 | 1.23 | 83.1 | 28.5 | 6.6 | 73.7 | 9.2 | 31-4 | 1.2 |
| 100 | 86 | Block 4 | 10 | 16 | Stripper w/o FC | 3.8 | 1.23 | 82.3 | 28.2 | 7.1 | 70.9 | 8.6 | 41-4 | 1.2 |
| 16 | 87 | Block 4 | 10 | 12 | Picker | 3.6 | 1.19 | 81.4 | 28.9 | 7.0 | 73.3 | 8.8 | 41-3 | 0.8 |
| 60 | 88 | Block 4 | 14 | 12 | Stripper w/ FC | 3.7 | 1.22 | 82.8 | 29.2 | 6.8 | 72.8 | 9.1 | 41-3 | 1.3 |

**Table A-1. Continued.**

| Sample | Run | Block | Moisture | Density | Trash Content | MIC | LENGTH | UNIF. | STRENGTH | ELON. | Rd | +b | CGRD | FFA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (%w.b.) | (lb/ft$^3$) | | | (in.) | (%) | | | (%) | | | (%) |
| 44 | 89 | Block 4 | 12 | 8 | Stripper w/ FC | 3.6 | 1.22 | 83.2 | 29.2 | 7.3 | 73.0 | 8.9 | 41-3 | 1.0 |
| 8 | 90 | Block 4 | 12 | 8 | Picker | 3.5 | 1.23 | 81.9 | 28.7 | 6.7 | 76.4 | 9.0 | 31-3 | 1.1 |
| 76 | 91 | Block 4 | 10 | 8 | Stripper w/o FC | 3.7 | 1.21 | 82.1 | 28.3 | 7.1 | 73.7 | 9.1 | 31-4 | 0.8 |
| 24 | 92 | Block 4 | 14 | 12 | Picker | 3.5 | 1.22 | 81.9 | 28.5 | 6.1 | 74.5 | 9.2 | 31-3 | 0.9 |
| 28 | 93 | Block 4 | 10 | 16 | Picker | 3.4 | 1.25 | 82.8 | 28.4 | 7.1 | 72.5 | 8.7 | 41-3 | 1.1 |
| 96 | 94 | Block 4 | 14 | 12 | Stripper w/o FC | 3.8 | 1.22 | 81.8 | 28.3 | 6.7 | 71.4 | 9.2 | 42-1 | 1.3 |
| 88 | 95 | Block 4 | 10 | 12 | Stripper w/o FC | 3.6 | 1.23 | 82.7 | 27.7 | 6.9 | 71.1 | 8.6 | 41-4 | 1.0 |
| 40 | 96 | Block 4 | 10 | 8 | Stripper w/ FC | 3.5 | 1.21 | 82.0 | 28.6 | 7.2 | 73.0 | 9.0 | 41-3 | 1.2 |
| 64 | 97 | Block 4 | 10 | 16 | Stripper w/ FC | 3.4 | 1.22 | 82.9 | 28.3 | 7.2 | 74.1 | 9.4 | 32-2 | 1.1 |
| 48 | 98 | Block 4 | 14 | 8 | Stripper w/ FC | 3.6 | 1.26 | 82.8 | 28.6 | 7.1 | 73.5 | 9.4 | 32-2 | 1.2 |
| 68 | 99 | Block 4 | 12 | 16 | Stripper w/ FC | 3.5 | 1.25 | 83.5 | 28.9 | 6.6 | 72.0 | 9.4 | 42-1 | 1.1 |
| 84 | 100 | Block 4 | 14 | 8 | Stripper w/o FC | 3.8 | 1.26 | 83.3 | 28.2 | 6.6 | 72.6 | 9.1 | 42-1 | 1.3 |
| 4 | 101 | Block 4 | 10 | 8 | Picker | 3.5 | 1.22 | 82.3 | 28.0 | 7.4 | 73.8 | 8.8 | 41-3 | 0.9 |
| 104 | 102 | Block 4 | 12 | 16 | Stripper w/o FC | 3.8 | 1.20 | 81.4 | 28.5 | 6.8 | 71.5 | 9.2 | 42-1 | 0.9 |
| 56 | 103 | Block 4 | 12 | 12 | Stripper w/ FC | 4.0 | 1.18 | 81.3 | 29.4 | 6.9 | 73.1 | 9.6 | 32-2 | 0.8 |
| 108 | 104 | Block 4 | 14 | 16 | Stripper w/o FC | 4.1 | 1.21 | 82.6 | 29.2 | 6.8 | 70.8 | 9.0 | 42-2 | 1.1 |
| 12 | 105 | Block 4 | 14 | 8 | Picker | 3.9 | 1.22 | 82.5 | 30.1 | 6.5 | 72.5 | 9.7 | 42-1 | 1.0 |
| 36 | 106 | Block 4 | 14 | 16 | Picker | 3.8 | 1.22 | 82.5 | 29.2 | 6.7 | 73.2 | 9.4 | 32-2 | 1.1 |

**Table A-1. Continued.**

| Sample | Run | Block | Moisture | Density | Trash Content | MIC | LENGTH | UNIF. | STRENGTH | ELON. | Rd | +b | CGRD | FFA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (%w.b.) | (lb/ft$^3$) | | | (in.) | (%) | | | (%) | | | (%) |
| 72 | 107 | Block 4 | 14 | 16 | Stripper w/ FC | 3.7 | 1.24 | 82.8 | 29.1 | 6.5 | 73.5 | 9.1 | 42-1 | 0.9 |
| 92 | 108 | Block 4 | 12 | 12 | Stripper w/o FC | 3.7 | 1.23 | 83.6 | 29.5 | 6.9 | 72.7 | 9.0 | 41-3 | 1.1 |

# APPENDIX B

# TEST 2 DATA

**Table B-1. Data acquired from Test 2.**

| Std. | Run | Block | Moisture | Mic | Length | Unif | Strength | Elon | Rd | Yellow | FFA | CGRD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | (%w.b.) |  | (in.) | (%) |  |  |  |  | (%) |  |
| 22 | 1 | Block 1 | 21 | 2.6 | 1.23 | 83.1 | 26.8 | 7.0 | 74.1 | 10.1 | 1.5 | 32-1 |
| 16 | 2 | Block 1 | 15 | 2.7 | 1.22 | 83.1 | 25.1 | 8.1 | 77.5 | 9.5 | 1.5 | 21-4 |
| 10 | 3 | Block 1 | 21 | 2.7 | 1.22 | 83.5 | 25.1 | 7.7 | 75.8 | 10.1 | 2 | 22-2 |
| 13 | 4 | Block 1 | 12 | 2.7 | 1.24 | 83.8 | 25.3 | 8.2 | 79.6 | 8.9 | 1.1 | 21-1 |
| 25 | 5 | Block 1 | 12 | 2.6 | 1.21 | 82.5 | 24.8 | 8.0 | 78.6 | 9.2 | 1.1 | 21-1 |
| 7 | 6 | Block 1 | 18 | 2.6 | 1.25 | 83.8 | 25.1 | 7.9 | 77.7 | 9.6 | 1.5 | 21-3 |
| 34 | 7 | Block 1 | 21 | 2.7 | 1.24 | 83.6 | 24.6 | 7.5 | 74.5 | 10.0 | 2.5 | 32-1 |
| 31 | 8 | Block 1 | 18 | 2.6 | 1.23 | 83.9 | 25.2 | 7.9 | 76.4 | 9.7 | 1.7 | 22-2 |
| 1 | 9 | Block 1 | 12 | 2.6 | 1.24 | 83.5 | 25.9 | 8.3 | 79.1 | 9.0 | 1.3 | 21-1 |
| 19 | 10 | Block 1 | 18 | 2.6 | 1.24 | 84.2 | 25.7 | 7.9 | 76.8 | 9.6 | 1.3 | 21-4 |
| 4 | 11 | Block 1 | 15 | 2.7 | 1.24 | 84.1 | 25.6 | 8.4 | 77.3 | 9.5 | 1.5 | 21-4 |
| 28 | 12 | Block 1 | 15 | 2.7 | 1.24 | 84.1 | 25.4 | 8.2 | 77.0 | 9.6 | 1 | 21-4 |
| 20 | 13 | Block 2 | 18 | 2.6 | 1.23 | 83.0 | 25.4 | 8.1 | 76.7 | 9.5 | 1.9 | 21-4 |
| 5 | 14 | Block 2 | 15 | 2.6 | 1.22 | 83.0 | 24.9 | 8.1 | 77.9 | 9.1 | 1.4 | 21-2 |
| 2 | 15 | Block 2 | 12 | 2.6 | 1.21 | 83.2 | 25.5 | 8.2 | 79.8 | 8.8 | 0.9 | 21-1 |
| 23 | 16 | Block 2 | 21 | 2.7 | 1.23 | 83.3 | 25.7 | 7.7 | 76.0 | 10.0 | 1.4 | 22-2 |
| 8 | 17 | Block 2 | 18 | 2.6 | 1.22 | 82.9 | 25.3 | 7.9 | 77.2 | 9.4 | 1.3 | 21-4 |
| 14 | 18 | Block 2 | 12 | 2.6 | 1.21 | 82.8 | 25.1 | 7.9 | 78.4 | 8.8 | 1.2 | 31-1 |
| 35 | 19 | Block 2 | 21 | 2.6 | 1.23 | 83.2 | 25.3 | 7.2 | 75.7 | 9.6 | 0.9 | 32-1 |
| 17 | 20 | Block 2 | 15 | 2.6 | 1.23 | 83.3 | 25.6 | 8.0 | 79.0 | 9.0 | 1.2 | 21-1 |
| 29 | 21 | Block 2 | 15 | 2.5 | 1.22 | 82.9 | 25.5 | 8.0 | 79.0 | 9.1 | 1.0 | 21-1 |
| 26 | 22 | Block 2 | 12 | 2.5 | 1.23 | 83.0 | 25.1 | 8.3 | 79.2 | 8.7 | 0.9 | 21-2 |
| 32 | 23 | Block 2 | 18 | 2.6 | 1.23 | 83.6 | 25.0 | 8.2 | 77.7 | 9.3 | 0.7 | 21-4 |

**Table B-1. Continued.**

| Std. | Run | Block | Moisture | Mic | Length | Unif | Strength | Elon | Rd | Yellow | FFA | CGRD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (%w.b.) | | (in.) | (%) | | | | | (%) | |
| 11 | 24 | Block 2 | 21 | 2.6 | 1.23 | 83.3 | 25.1 | 7.5 | 76.3 | 9.8 | 1.4 | 22-2 |
| 15 | 25 | Block 3 | 12 | 2.7 | 1.22 | 82.8 | 25.7 | 8.5 | 80.1 | 8.3 | 1.5 | 21-2 |
| 27 | 26 | Block 3 | 12 | 2.6 | 1.22 | 83.0 | 26.0 | 8.5 | 78.8 | 8.3 | 1.4 | 31-1 |
| 36 | 27 | Block 3 | 21 | 2.6 | 1.22 | 82.7 | 25.7 | 8.5 | 74.7 | 9.3 | 0.7 | 31-3 |
| 18 | 28 | Block 3 | 18 | 2.7 | 1.19 | 81.0 | 25.9 | 8.1 | 77.9 | 8.4 | 1.1 | 31-1 |
| 24 | 29 | Block 3 | 21 | 2.6 | 1.22 | 83.0 | 25.6 | 8.5 | 76.0 | 8.6 | 0.7 | 31-2 |
| 21 | 30 | Block 3 | 15 | 2.6 | 1.23 | 82.6 | 26.1 | 8.4 | 78.5 | 8.7 | 1.3 | 31-1 |
| 3 | 31 | Block 3 | 12 | 2.6 | 1.24 | 84.2 | 26.4 | 8.6 | 79.7 | 8.4 | 1.1 | 21-2 |
| 9 | 32 | Block 3 | 18 | 2.6 | 1.23 | 83.3 | 26.1 | 8.3 | 77.7 | 9.3 | 1.1 | 21-4 |
| 6 | 33 | Block 3 | 15 | 2.6 | 1.23 | 83.3 | 25.6 | 8.3 | 77.2 | 8.4 | 1.4 | 31-1 |
| 30 | 34 | Block 3 | 15 | 2.8 | 1.24 | 83.5 | 26.3 | 8.8 | 78.9 | 8.3 | 1.2 | 31-1 |
| 33 | 35 | Block 3 | 18 | 2.5 | 1.22 | 82.8 | 26.2 | 8.1 | 76.2 | 9.3 | 1.2 | 31-3 |
| 12 | 36 | Block 3 | 21 | 2.7 | 1.23 | 83.5 | 25.8 | 8.4 | 75.0 | 9.1 | 1.3 | 31-4 |

# VITA

Mark Thomas Hamann
C/O Dr. Parnell
MS 2117 TAMU
College Station, Texas 77843-2177

**Education**

Master of Science in Biological and Agricultural Engineering
*Texas A&M University (December 2011)*
Bachelor of Science in Agricultural Engineering
*Texas A&M University (May 2008)*

**Honors**

Alpha Epsilon Honor Society

**List of Professional Presentations**

**ASABE Annual International Meeting**

- *Economic Analysis and Design of a Semi Tractor Trailer for Cotton Transport*, Providence, RI, June 2008
- *Effects of Cotton Module Storage on Lint Quality*, Reno, NV, June 2009
- *Advances in Cotton Ginning Simulation – Transportation Resource Management*, Reno, NV, June 2009
- *Effects of Moisture and Storage Time on Seed and Lint Quality*, Pittsburgh, PA, June 2010

**Beltwide Cotton Conference**

- *Economic Analysis of Transporting Seed Cotton with Semi Tractor Trailers,* Nashville, TN, January 2008
- *Design and Decision Support Software for Cotton Module Transportation Using A Semi Tractor Trailer*, San Antonio, TX, January 2009
- *Effects of Cotton Module Storage on Lint Quality*, New Orleans, LA, January 2010