PREDICTION OF FIBER QUALITY FOR LONG-TERM STORAGE OF SEED COTTON

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Abstract

Current and anticipated innovations in cotton harvesting equipment include onboard module builders which result in seed cotton being packed into modules of varying size and compression at varying moisture contents. The prospect of on-board module building for high-yield stripper cotton, in particular, may result in seed cotton stored for prolonged periods with higher than average moisture content, resulting in significant reduction of fiber quality. The effects of moisture content and density on cotton fiber over extended periods of time have been studied. High moisture content corresponds to high levels of burrs, sticks, immature bolls, entrained water, and leaves in the seed cotton. Differing harvest conditions due to defoliation practices, weather events, or machinery operating practices can create significant levels of difference for each of these factors from one producer to another. Collected data has been studied for relationships between moisture content, density, and trash content for a given time period of storage. An equation for each of these factors will help producers with their decisions of proper harvest time.

Introduction

Since 1960, the United States has been producing cotton with upward trends in both quantity per acre and total quantity produced. During this same time period, there has been an observable decrease in the total number of cotton gins to process the cotton. In 1960, there were over 1,400 cotton gins operating in Texas. This number is now below 300. Through the same time period cotton production grew from an average of 4 million bales up to highs of 8 to 9 million bales (Hamann et al., 2009). This obviously 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, cotton was placed in trailers which were pulled to gins by farmers, emptied by the gins in the order they were received, and then the trailers were picked up by the farmers. Cotton was dumped or blown into the trailers and packed by foot if at all. The trailers generally held two to four bales of cotton. Since the cotton was stored in the trailers until it was processed, the farmer had to own several trailers. The module builder was invented at Texas A&M University in the 1970s and changed cotton production greatly. Today almost all of the cotton in the United States is harvested mechanically and placed in module builders. The module builder allowed cotton to be stored for longer periods in modules, which are packed bricks 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 an average of 12 bales of stripper-harvested cotton or 15 bales of picker-harvested cotton. Modules are built directly on the ground and are normally covered with plastic tarps that protect the top and the top of the sides from rain and wind damage. They are carried to the gin by trucks with rolling chain floors that are capable of wedging themselves between the bottom of the module and the ground. A typical module truck is capable of carrying one module.

Cotton strippers work by stripping all of the organic material from the stalk of the cotton plant. This material includes seed, lint, burrs, leaves, and sticks. Most recent models of cotton strippers have a separation unit called a field cleaner that removes many of the burrs, sticks, and leaves from the seed cotton, which is conveyed to a basket. Cotton pickers work using round spindles with barbs cut into them which grab lint as they spin. The 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, contained in the basket, which is then dumped in the module builder. The picker does the best job of capturing cotton with little trash, followed by the stripper with the field cleaner and finally by the stripper without the field cleaner.

In most states cotton is harvested almost exclusively by pickers. In Texas, which historically produces roughly 25% of the nation's cotton crop, the majority of cotton is harvested using cotton strippers. John Deere is the only major manufacturer in the United States that is currently 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 their own modules of cotton. These units, called on-board module builders, make modules that are smaller in size than a traditional module builder. 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 conventional module builders.

The on-board module builder unit produced by John Deere compresses the 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), 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.

Since the on-board module builder allows for much more productivity per person than a traditional harvester, it is possible that there could be a push to produce a cotton stripper with similar capability. Should this be the case, cotton with higher amounts of trash could be placed into the modules at both lower and higher densities than normal.

The purpose of this research is to determine any relationship between density, moisture content, trash content, and lint (fiber) quality. The effects of these factors over time could prove to be major. As discussed above, on-board module builders package cotton both above and below the common density range of a traditional module builder. Also, there is the possibility of having more trash packaged in these modules than the amount which is commonplace today. The impact of both of these factors on fiber quality should be studied.

The containers used in the testing were selected to simulate as closely as possible the center of any type of module. It is believed that at the center of a cotton module there is very little interaction with air and as a result of this moisture migration from the center of the module outward is very slow. Anthony (1982) determined that cotton bales, which are 0.51 to 0.53 m (20 to 21 in) at their narrowest point, would equilibrate with outside moisture levels after 60 days when packaged to 192 kg/m^3 (12 lb/ft^3). Since cotton bales are so much smaller in size, their equilibration is understood to be much more rapid than for something with the dimensions of a module.

As with both of these factors, the impact of moisture content should be studied. Burrs, sticks, and leaves retain more moisture than does lint, so their moisture content is generally higher for these items, and thus cotton containing these items. It is also possible that cotton can be harvested at higher moisture contents during or after rain events, or with more immature bolls attached to the plant. Lint moisture content while in the boll has been found to vary from a high of 16% to a low of 5% from morning to mid-afternoon (Montgomery et al., 1958). High moisture content can trigger microbial activity which has severe effects on fiber quality.

There has been research in the past on the effect of moisture content on cotton quality, without a full range of densities, and with no recorded difference in trash content. Sorenson et al. (1973) stored module-sized samples for one month. They ranged in moisture content from eight to 24.5% wet-basis. Densities ranged from 160 to 224 kg/m^3 (10 to 14 lb/ft^3). In these large samples, maximum temperatures of up to 156°F were observed. The author noted that for moisture contents less than 12%, cotton could be stored for at least 30 days with no discernable fiber quality loss. For cotton up to 14% moisture content, the storage time was reduced to 10 days. For 15% moisture content the storage time is three to five days, and above 15% moisture content cotton modules will last less than three days before a loss in fiber quality. It was also noted that little change in fiber quality was actually observed during testing.

Methods

454 kg (1000 lb) of Delta Pine cotton (variety 143) was harvested outside of Lubbock, Texas during the 2008 season and was retained for use in this study. This cotton was harvested by a John Deere model 9996 cotton picker. The cotton was found to have a turnout of 34.7% after single stage cleaning. Turnout is the proportion of clean, ginned lint to all of the material that enters the gin.

113 kg (250 lb) of trash was also obtained from the field cleaner of a cotton stripper. This consisted of burrs, sticks, and leaves. The trash was mixed with the picked cotton to simulate stripper-harvested cotton, for both machines with and without field cleaners. Faulkner et al. (2009) reported that picked cotton contained 5.1% trash, while cotton harvested by a cotton stripper with a field cleaner contains 19% trash, and cotton harvested by a cotton stripper without a field cleaner contains 37.8% trash. All numbers reported are for dry matter proportions only.

The moisture content of the lint and of the trash was determined daily before any lint was used according to ASTM standard D2495. Every evening, three samples were placed in aluminum pans and weighed using a Mettler-Toledo balance (model PB3002-S FACT, Mettler-Toledo, Columbus, Ohio, USA). They were then dried for no less than 12 hours in a Memmert drying oven (model EW-52200-06, Memmert, Schwabach, Germany). 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:

$$\%WB = \frac{WM - DM}{WM - MP} \times 100 \qquad (1)$$

where:
%WB = % wet-basis moisture
DM = dry mass of sample
MP = mass of aluminum pan
WM = wet mass of sample

It was decided that 2.7 kg (6 lb) of total dry matter should be used for each sample. Each sample was split into two equally sized and mixed blocks because of sizing issues. The total amount of moist lint needed for was calculated using equation 2:

$$ML = \frac{DL}{100 - \%WB} \times \frac{100 - \%TN + \%TI}{100} \qquad (2)$$

where:
ML = amount of moist lint necessary
DL = amount of dry lint desired
%TN = percentage of trash needed
%TI = percentage of trash in lint (5.1% in these tests)

The exact amount of lint needed was gathered and placed inside of a plastic bag, contained inside of a box, set on top of the balance. The amount of moist trash needed was calculated using equation 3:

$$MT = \frac{DL \times \frac{(\%TN - \%TI)}{100}}{100 - \%WB} \qquad (3)$$

where:
MT = amount of moist trash necessary

The lint and trash samples were mixed together, re-weighed, removed from the plastic bag, and placed in an air wash (figure 1). The air wash has a basket inside made of screen material (figure 2). It has a hole on either side of the basket, around which it rotates. These holes allow air to be drawn across the cotton. Air enters the holes in the side of the basket, and as the basket rotates, air is pulled out of the bottom of the air wash and across a filter screen. A fan (model HP-33, Cadillac Products, Chicago, Illinois, USA) was used to pull the air across the sample.

Figure 1. Air wash.

Figure 2. Air wash basket.

To obtain higher moisture contents than the cotton initially had, steam was added to the mixture and pulled across the samples. Water was added to bring the cotton to levels of 10, 12, and 14% wet-basis moisture. The steam outlets from a Sussman Electric Boiler (model MBA9, Sussman Automatic Company, Long Island City, New York, USA) were directed near the two holes on the air wash which allow air to enter. The steam was then drawn into the air wash and across the tumbling cotton sample by the fan. As the cotton and trash tumbled, the steam became entrained in the samples as water. The entire layout can be seen in figure 3. Periodically the samples were removed from the air wash to check the total mass. The total desired mass was calculated using equation 4:

$$TM = \left[\%MCD - \frac{(\%MCL \times ML + \%MCT \times MT)}{ML + MT}\right] \times \frac{ML + MT}{100 - \%MCD} \quad (4)$$

where:
TM = total wet mass of sample
%MCD = percent moisture content desired
%MCL = percent moisture content of lint
%MCT = percent moisture content of trash

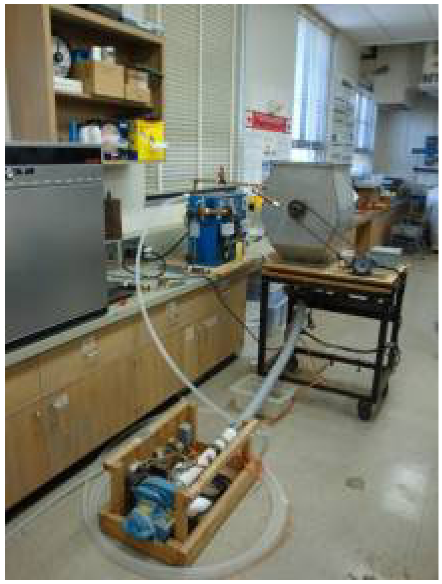

Figure 3. Cotton moisturizing setup.

After the cotton was moisturized to the predetermined level, it was placed in pieces of pre-cut polyvinyl chloride (PVC) sewer and drain-grade pipe. The pipes were 15 cm (6 in) in diameter and of varying lengths. Each sample contained 2.72 kg (6 lb) of dry cotton and trash, with varying amounts of water. The lengths were 0.57, 0.75, and 1.13 m (22.25, 29.6, and 44.5 in), which correspond to densities of 256, 192, and 128 kg/m^3 (16, 12, and 8 lb/ft^3), respectively. This range represents and encompasses all densities that should be seen in practice. The cotton was packed into the tubes, which were sealed at one end, using the packing device shown in figure 4. The packer is adjustable for varying lengths of pipe. After all of the cotton was packed into a tube, the pipe was sealed on the open end and placed onto a rack for storage.

Figure 4. Cotton being packed into a tube.

There were four replications of each possible combination of density, moisture, and trash content. A randomized complete block design was used. Given the three density levels of 128, 192, and 256 kg/m^3, the three moisture contents of 10, 12, and 14% wet basis, and the three trash content levels of 5.1, 19, and 37.8% dry basis, a total of 27 samples for each replication or 108 samples total were compressed and stored. The samples were blocked by replication.

Samples were kept in the sealed containers for 105 to 114 days. 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 each sample as it was opened. This fraction was placed in a small brown paper bag, weighed on the Mettler-Toledo balance, and placed in a large container. The moisture content of the samples at opening was measured using the oven method described above, but using paper bags instead of aluminum pans. An average initial and final mass of empty bags were tabulated to use in lieu of attempting to remove all of the cotton from the bags.

Ginning of the samples commenced following the completion of their opening. The samples were ginned over the course of three days at the Texas A&M Cotton Improvement Center. 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), one colored orange and the other red. From each fully ginned sample, a minimum of 100 grams of cotton were gathered from no less than three random places in the gin's basket and placed into brown paper bags.

The samples were delivered to the Texas Tech Fiber and Biopolymer Research Institute (FBRI) in Lubbock, TX for High Volume Instrument (HVI) testing. FBRI uses Uster HVI testing systems (model 1000, Uster Technologies Inc., Charlotte, North Carolina, USA), and five replications of the HVI test were conducted on each sample analyzed. HVI testing returns results for Micronaire, Length (in), Uniformity (%), Strength (g/tex), Elongation (%), Reflectance (%), Yellowness, Color Grade, and Leaf Grade.

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.

Results and Discussion

A Wilks' Lambda multivariate analysis was run for all of the inputs in the model. The results of this analysis can be seen in table 1. For moisture content and trash content, the effects 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 1. Wilks' Lambda test results.

Effect	Sig.
Moisture Content	0.000
Density	0.211
Trash Content	0.003
Moisture Content*Density	0.782
Moisture Content*Trash Content	0.576
Density*Trash Content	0.825
Molisture Content*Density*Trash Content	0.902

For each response an analysis of variance (ANOVA) test was run. Non-significant factors were removed using backward elimination. None of the tests returned high R^2 values. This means that although a trend may have been seen, depending on the response being considered only thirteen to thirty eight percent of the variability in the data can be explained by the model. A more focused group of input variables in the future should allow us to gather results which have better fits to certain models. The results described below are ranked in order of R^2, from highest to lowest.

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. It was determined that there was one factor which had a significant effect on elongation. Moisture content was found to be very significant ($p<0.0001$). The relationship found was that lower moisture content leads to a higher elongation value. Figure 5 illustrates the relationship. We hypothesize that higher moisture content leads to a greater amount of microbial activity. This activity creates weak places in fibers, which lead to easier breakage during ginning and fiber testing. This would explain the relationship observed above.

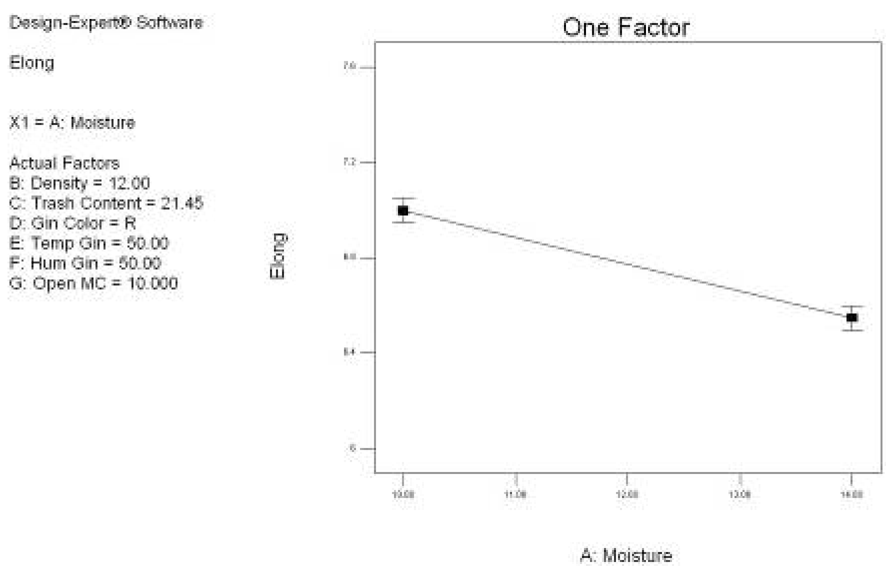

Figure 5. Elongation as a result of moisture content.

Yellowness

Yellowness (+b) was shown to be affected by both moisture and trash contents. Both terms were very significant ($p<0.0001$). The relationship can be seen in the three-dimensional response surface in figure 6. As moisture content increased, the yellowness also increased. This is logical given the relationship described for elongation is accurate. As the microbial activity happens, there is discoloration of the fiber. As the trash content increased, the yellowness decreased. We hypothesize that this is due to the moisture absorbance properties of the trash. 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 had a higher rate of absorption than the lint, and retained more of the moisture, allowing less activity to occur in the lint.

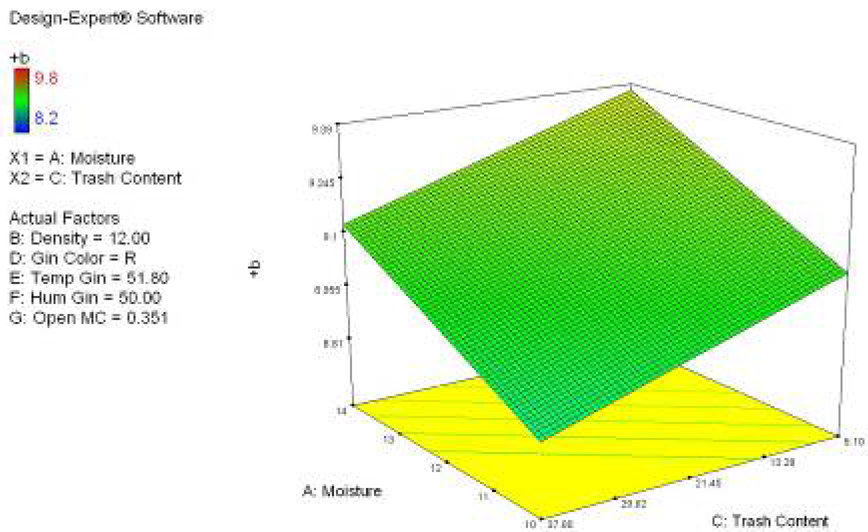

Figure 6. Yellowness as a result of moisture content and trash content.

Micronaire
The three-dimensional response surface (figure 7) shows the effect of moisture content (p=0.0085) and trash content (p<0.0001) on micronaire. A lower moisture content at the time of containerization leads to a 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 at this point. More time will be focused on finding any explanations for this in the future.

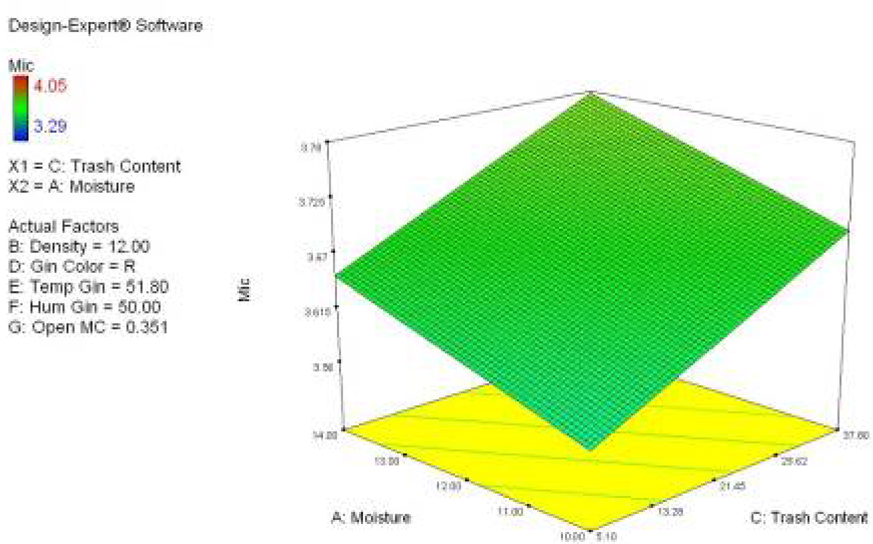

Figure 7. Response surface for micronaire.

Length
Length was affected by both moisture content (p=0.0019) and trash content (p=0.0253). A three-dimensional response surface is shown in figure 8. As moisture content increases, the fibers are found to be longer. As trash

content decreases, fibers are also found to be longer. We hypothesize that the moisture content is tied to length because the dryer fibers become brittle and are more susceptible to breakage during the cleaning or ginning process. The relationship with trash content is not understood at this point.

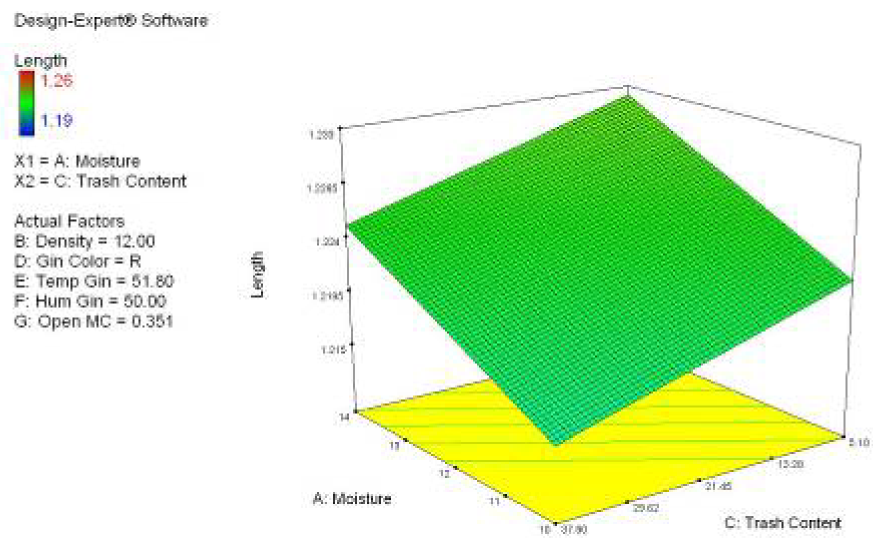

Figure 8. Response surface for length.

Reflectance

The reflectance of the samples was responsive to moisture content ($p=0.0007$). The hypothesis for this is similar to that of the yellowness. As the moisture content is increased, the amount of microbial activity is increased, resulting in more discolored fiber, be it more yellow or more gray and thus less reflective.

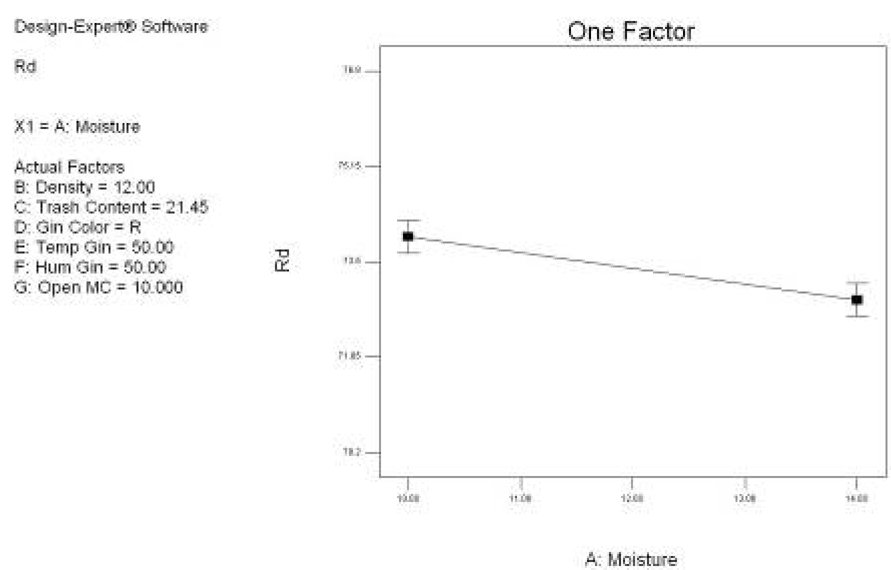

Figure 9. Response for reflectance due to moisture content.

The results above are due to a protocol that has allowed the authors to notice significant changes in fiber quality. In the near future another round of testing will commence with more focus applied to the input variables which caused greater changes in the seed and fiber quality and less to the variables which were not as significant.

Conclusion

Seed cotton samples were contained at varied moisture contents, densities, and trash contents for roughly four months before being opened and ginned. Ginned lint samples were evaluated by a cotton classing office. Their results have been analyzed and compiled.

A protocol for the observation of the effects of density, moisture content and trash content has been developed. This protocol, described above, allows differences in cotton fiber quality results to be observed. These differences include elongation, yellowness, micronaire, length, and reflectance. Each has its own relationship to moisture content and trash content. While moisture was not a factor in any of the above responses, it will not be ruled out as a factor until results from seed quality testing are obtained and analyzed.

The hypotheses developed and described above will be further studied in a second round of tests, as will the relationships for which we currently have no explanations. Factors which are not significant will be eliminated for the second round of testing. At the end of the second set of experiments an equation for each response as well as the magnitude of any quality differences in monetary terms will be possible.

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