**TITLE**: 1759 Summary of Collaborative Studies on Cotton Bale Moisture.

**DISCIPLINE**: Harvesting and Ginning

**AUTHORS**: David T.W. Chun
USDA-ARS Cotton Quality Research Station
P.O. Box 792
Clemson, SC 29633
Phone: 864 656-2488
Fax: 864 656-1311
Email: David.Chun@ars.usda.gov and dtwchun@mindspring.com

**ABBREVIATIONS:** ARS, Agricultural Research Service; CQRS, Cotton Quality Research Station; NCC, National Cotton Council; USDA, United States Department of Agriculture.



## ABSTRACT

Seed cotton moisture greatly influences ginning efficiency and usually seed cotton is dried to reduce moisture content because drier cotton is easier to gin and clean. The optimum moisture content of lint at the gin stand is probably between 5.0 and 8.5%. The practical narrower optimum range is between 6.0 to 8.0% so 7.0% lint moisture content is often taken as the average optimum most frequently used for efficient separation of lint from the seed. Because the classing systems offer premiums for better leaf grade, cotton is usually dried, cleaned, ginned, and packaged at moisture contents well below its eventual equilibrium moisture content in storage. To counter the resulting lower weight of excessively dry cottons, ginners sometimes resort to restoring some moisture, usually at the lint slide, to reduce bale-packaging forces and to recover the economic loss due to weight reduction resulting from drying. The temptation exists to add moisture to an excessive amount that may eventually adversely affect fiber quality. To this end, the Cotton Quality Research Station in Clemson, SC, has performed collaborative studies with various ginning laboratories to determine if the effects of moisture sprayed on fiber would affect lint quality, bale packaging and fiber quality during storage, and if there is a moisture range where the fiber quality would not be affected.

Among the first of these studies, an excessive moisture range where the initial target moisture content was as high as 15% was used and the results indicated that after 116 days of storage that bales tended to be more yellow and darker as moisture content increased. In another study where cotton was stored for 6 months and the target moisture ranged from ambient moisture to 12%, the moisture content was found to be unevenly distributed in a bale, a direct relationship of moisture content with decreased reflectance and increased yellowness of the fiber over time, and increased fungal density with increased moisture content were observed. When lower maximum target moisture ranges were studied where the final moisture content after

storage did not exceed about 7.5% moisture, the effect on fiber quality and microbial activity was minimal.


## KEYWORDS

Moisture restoration, high moisture bales, value added, fiber quality degradation, bale moisture content, bale storage.


## INTRODUCTION

Cotton is harvested in the field as seed cotton which is either directly ginned or held in modules until it can be ginned. During the ginning process, the seed is removed from the fiber. The cotton is 'cleaned' before being compressed into the cotton bales which is used by the textile mills. A key property that affects ginning is the seed cotton moisture. If the cotton moisture content is too high, the cotton will not readily separate into single locks and may form wads that may interfere with the ginning machinery. In general cotton with high moisture content does not clean as well as drier cotton. But cotton fiber strength is also proportional to the fiber moisture content: as moisture content is lowered the fiber breakage during ginning increase which can eventually result in lower yarn quality. So the optimum moisture content to balance the needs of cleaning and fiber quality at the ginning stand probably lies between 5.0 and 8.5% with a more practical narrower optimum range between 6.0 to 8.0%. The average optimum most frequently used for efficient quality separation of lint from the seed is 7% lint moisture content. Most of the U.S. cotton crop is harvested in areas and during periods of low-humidity and may arrive at the gin stand with fiber moisture of 4-5% or less. But cotton is also harvested in areas and periods of high humidity and exposure to rainfall. When this happens, cotton may arrive at the ginnery with moisture content as high as 12% or more. So ginneries must be prepared to add as well as remove moisture from the cotton being processed (Griffin, Jr. 1977; Anthony and Mayfield, 1994).

The U.S. classing system offers premiums for better leaf grade. These incentives encourages more drying to improve trash removal which can lead to cotton being dried, cleaned, ginned and packaged at moisture content well below its eventual equilibrium content in storage. Drier cotton requires higher bale-packaging forces to pack and press a bale of cotton. Ginners have resorted to moisture restoration in order to compensate for excessively dry cottons, usually at the lint slide. The justification is that reduced bale-packaging forces and return of the moisture weight which is lost during field drying and gin processing is restored without sacrificing grade (Anthony et al., 1994; Anthony and Mayfield, 1994; Mangialardi and Griffin, 1977). But the economic temptation exists at the lint slide to add a little extra moisture to give added value to the ginned cotton without regard to grade reduction during storage (Reed, 2002). The problem with this is exemplified by a survey of gins in Arkansas and Mississippi that found that while the average moisture content was 5.1% prior to moisture restoration and 6.2% after moisture restoration, that 8.6% of the bales exceed the 8% level, the high moisture level considered still safe for bale storage (Anthony, 2003). In a second survey, 7.8% of the bales were packaged at 7.5% or higher moisture content (Anthony, 2004) which may subject the bales to quality degradation during extended storage (Anthony, 2002a; Chun and Anthony, 2004). For this reason a white paper was put out concerning an acceptable cotton bale range to avoid fiber quality degradation during storage (McAlister, et al., 2005). Later the NCC quality task force adopted a bale moisture recommendation that bale moisture not exceed 7.5% (Anonymous, 2003).

**USDA Involvement with added moisture to baled cotton.** To this end, the Cotton Quality Research Station (CQRS) in Clemson, SC, has collaborated with ARS ginning laboratories, growers and others in determining the effects of moisture sprayed on fiber in regard to lint quality, bale packaging and fiber quality during storage. This undertaking included determining if there is a moisture range where fiber quality would not be affected. Of the two basic methods used by ginners to restore moisture at the lint slide, humidified air and direct water spray, the spray approach was the only method studied for two reasons. First, a variant of the spray method was at the time being promoted as a means of restoring high levels of moisture to cotton. Second, the humidified method which can be a 'gentler' method to add moisture, rarely adds more than 2% moisture to a bale (Anthony, 2002b) while the spray method can add moisture to the point of maximum absorption of the cotton. In all of the studies, the moisture content was determined using the oven method for determining moisture content of fiber (ASTM, 1971), including the control or untreated cotton and the treated cotton to which moisture was added. This paper will attempt to summarize some of the highlights of these collaborative works.

**Early Studies Reaffirms Danger of Excessive Bale Moisture During Storage**. Among these recent early studies was one done using cotton from the 2000 harvest year to determine if degradation occurs during storage when excessive amounts of water is added just before baling the ginned cotton. Details of the results and methodology can be found in the papers by Anthony (2002a) and Chun and Anthony (2004). This study examined 5 bales, 1 control bale and 4 bales with added moisture, with initial moisture contents of 6.0, 7.3, 8.9, 13.9 and 15.4%, respectively, which had been stored for just 4 months (25 May 2001 to 18 September 2001). The bales were protected by three 0.15 mm (six-mil) thick plastic bags to maximize the retention of moisture during storage to judge the response of fiber to specific moisture levels. Even with this heavy outer protection, there was moisture lost after just 4 months of storage, 6.1, 7.9, 8.2, 11.6 and 12.9%, respectively, at the high moisture treatments. But what was most obvious was the finding of gross water damage and strong earthy and musty odors in the two high moisture treatment bales, Figure 1. Only the control and the low moisture treated bale, 7.3%, exhibited no water damage or unusual odors upon opening. The fungal population density was 3x higher in the high moisture treated bale compared to the control bale which may relate to the increased yellowness and grayness of the treated bales. This increased fungal density is worrisome in that this condition may also be a potential health concern. The increased presence of fungal components may aggravate the allergic response of susceptible workers, which would be an unnecessary health risk. Of direct economic concern was the finding that yellowness and reflectance was related to increased moisture. When the average values from the paper (Chun and Anthony, 2004) for final moisture content and reflectance and yellowness are re-analyzed for relationships, there is an inverse relationship with moisture and reflectance, $R^2 = 0.986$ ( $y = 83.9 - 1.02x$); and for moisture and yellowness a direct relationship, $R^2 = 0.982$ ( $y = -21.3 + 3.23x$).

With the re-emphasis that excessive moisture may lead to microbial degradation and discounting of cotton grade, the question shifted to establishing the point where added moisture might be considered excessive. The study by Chun and Anthony (2004) used very high moisture levels and stored the cotton under conditions which tried to maintain the high moisture content during a short period of storage. So new studies were set up to look at the effects of other moisture levels and other storage times under more 'normal' conditions.

**Longer Storage With Moderately High Moisture Contents.** Using cotton from the 2001 harvest year, a small study used four bales with target moisture contents of 6%, 8%, and 10% moisture contents and a non-augmented ambient moisture content bale. In this study the bales were wrapped with polypropylene sheet wrap bound by six plastic straps and stored for one year under normal warehouse conditions, the details of the results and methodology can be found in Chun et al. (2003). These target moisture levels were moderate levels and the actual initial moisture contents for the target moisture content of the control, 6%, 8% and 10% moisture content was 5.0%, 5.4%, 8.0% and 9.5%, respectively. After approximately one year storage of storage the moisture content had dropped to 5.7%, 6.0%, 6.8% and 7.2% moisture content, respectively. The gain in weight after one year of the control target 6% treatment was really quite modest; but the loss from the high moisture treatments was 1.2% and 2.3%, respectively, and might be noticed by a purchasing agent. The important HVI properties did not appear to be significantly different for the four moisture levels. When some of results were re-analyzed, there were some interesting trends. When yellowness or +b was compared against initial moisture content, $R^2$ = 0.60 indicating some decrease in yellowness with higher starting moisture; and reflectance also showed a tendency to decrease with increased initial moisture, $R^2$ = 0.76. When the short fiber index was plotted against the initial moisture content, $R^2$ = 0.99 which indicated that there was a strong tendency for the short fiber index to increase with the higher initial moisture treatments under long term storage of a year; even so, the actual values for short fiber index weren't significantly different, 10.15, 10.20, 10.33 and 10.48, respectively.

**Moderate Moisture and Moderate Storage Duration Study.** A larger study was undertaken using 21 bales of cotton but applying a much more modest application of moisture was conducted (Chun and McAlister, 2005). The cotton was from the 2003 harvest year. The target treatment moistures were the control, or ambient moisture, 6.5%, 7.0%, 7.5%, 8.0% and 8.5% moisture, and the bales were stored approximately 6 to 8 months. The initial moisture values were not available, but the average moisture content after storage indicated that all of the bales had moisture content below 7.5%, the highest moisture bale content was 6.7% in the targeted 8.5% bales. The microbial activity did not differ appreciably between the different bale treatments and the control. The fiber quality results were not reported with the paper, but were not expected to differ between the controls and treatments. The study attempted to observe the effects of moisture content on the edge of the recommended safe moisture content. But what was apparent from this study was the difficulty of getting consistent moisture levels just above 7.5%; and as could be expected from staying within the recommended maximum moisture content, microbial activity and fiber changes were not affected.

**High Moisture Content Effects During Storage**. Perhaps the most interesting collaboration was the study using 36 bales of cotton from the 2002 harvest year, where 12 bales were stored for each 1-, 2- and 6-months storage times using high moisture contents (Chun et al., 2006). This was a large study which was replicated enough to help resolve some of the earlier observations. In this study, 9 bales of cotton was used for each of the target moisture levels, 6% (ambient/control moisture content), 8%, 10% and 12%. Several interesting and important observations were made from that study. First was that moisture distribution was not uniform throughout a bale. During the course of storage, the control and the target 8% moisture treatment both had average moisture contents below 7.5%. However, the target 8% treatment bales had regions within the bale that exceeded the 7.5-8% moisture during the 1- and 2-month storage. When the two higher treatments are included, the general finding was that while the control bales remained essentially unchanged and moisture distribution was essentially uniform throughout storage, as the moisture treatment was increased the distribution of moisture throughout the bale became more uneven, as indicated in Figure 2, which was redrawn from a figure in Chun et al. (2006). This was observed even though the distribution of moisture in a bale became more uniform as storage time increased. Second, that moisture is directly correlated with decreases in reflectance and increases with yellowness. This decrease and increase depends on storage time. The higher moisture treatments were associated with the greatest increase in yellowness and decrease in reflectance which was also dependant on storage time (Chun et al. 2006). This is exemplified by the 6-month storage where the greatest change in RD or +b was observed for increasing moisture, Figure 3 which was redrawn from a figure in Chun et al. (2006).

**Summary**. In closing, a number of studies were begun to determine the range of cotton moisture that would be safe to store cotton bales. This came about largely due to the recent popularity of moisture restoration at the gin which appeared to go beyond merely compensating for the moisture lost during ginning and restoring enough moisture to compensate for problems dealing with bale-packing forces. The initial studies began with validating if the historical warnings against storing cottons which were beyond about 7.5-8.0% moisture were still current under today's ginning and warehousing. When grade loss and obvious microbial damage was observed under short-term storage, additional studies involving more moderate moisture levels and varying storage times were examined. The results were not always clear-cut or definitively suggestive of a single safe moisture content that maximized the potential of moisture restoration at the gin slide, but a few points stood out when the results of these collaborative studies were looked at as a whole. First the uniform dispersal of moisture in a bale was not always assured and very often the actual vs. the target moisture content did not agree, both on the low and high end of what was expected. Second, beyond the economic value of moisture restoration, no fiber quality improvement stood out that might offset the changes to color, as lower reflectance and increased yellow, which were observed. Finally, the moisture content range where the least or no harm to the fiber seemed to be observed in most of the studies appeared to be at or below 8.0% moisture for the short- and long-term studies in agreement with historical recommendations (Anthony and Mayfield, 1994). So taking into account that the dispersal of moisture may not be uniform in the cotton bale and that the actual moisture content may vary from what is applied, the recommendation by the NCC quality task force to adopt a bale moisture recommendation that bale moisture not exceed 7.5% (Anonymous, 2003) seems a prudent recommendation supported by testing.

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Figure 1. Typical yellow or dark discoloration water damage observed when the polyethylene coverings were removed from the bales where moisture was added.

Figure 2.  The relationship between the average moisture content in a bale after 1-, 2- and 6-months of storage, and the target moisture [6% (control), 8%, 10%, and 12%].  Each half-error bar represents 2 s.e.

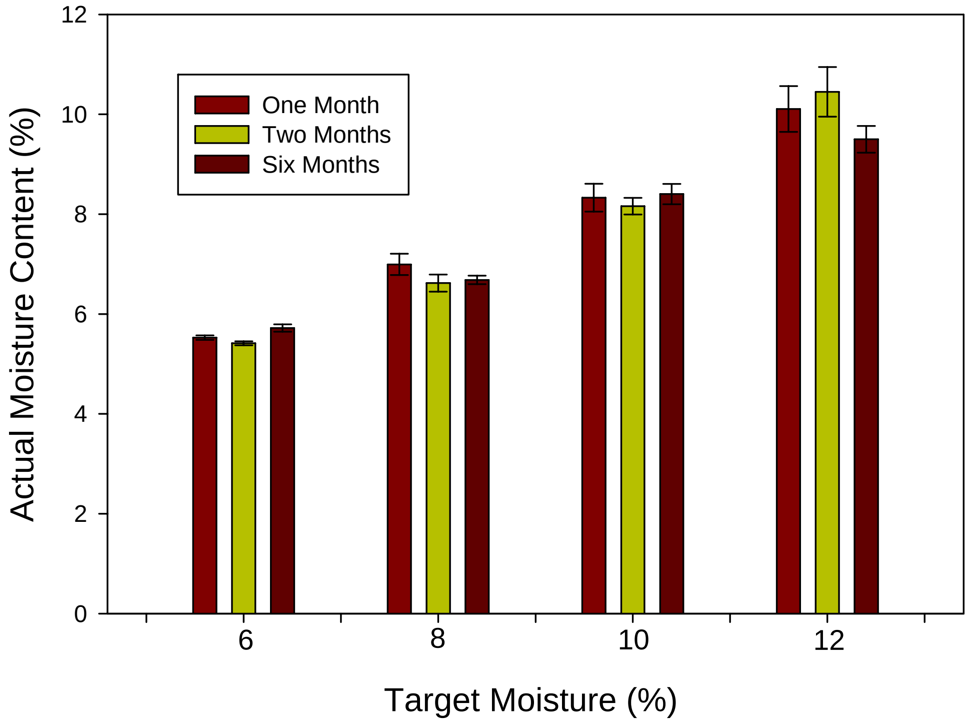

Figure 3. The individual sample moisture content plotted against its individual reflectance (Rd) or Yellowness (+b), from the 6-month storage bales.