

TEXTILE TECHNOLOGY

Portable Color Spectrophotometer Measurements of Cotton Color in Remote Locations

James Rodgers*, Gustave Schild, Xiaoliang Cui, and Christopher Delhom

ABSTRACT

The Uster® High Volume Instrument (HVI®) is used in the U.S. to classify cotton, including cotton color. The cotton color parameters measured on the HVI are Rd (diffuse reflectance) and +b (yellowness). Comments from industry have indicated that some cotton bales appeared to have changed significantly in +b (yellowness) from their initial HVI color measurements. As a result of these reports, there was interest in “on-site”/remote location measurements of cotton color that will yield “real time” color values, with emphasis on yellowness. A program was implemented to develop portable color spectrophotometer procedures and protocols to perform rapid, precise, and accurate cotton fiber color measurements at-line in remote locations and to interface those results into the Cotton Incorporated Engineered Fiber Selection® (EFS®) System MILLNet™ software. AMS standard tiles, cotton samples, and routine cotton samples were used to perform comparative evaluations to establish the relationships between the HVI Rd and +b and portable spectrophotometer L*a*b* color parameters. The best correlations were achieved between 1) the HVI +b and portable spectrophotometer b* and 2) the HVI Rd and spectrophotometer Y. Excellent comparative results were obtained and all end-state criteria were achieved (high R²s, low spectrophotometer analytical variability, and a low number of outliers). The HunterLab MiniScan EZ (MSEZ) results were interfaced with the EFS System MILLNet™ software, and preliminary field trials were performed on more than 400 bale samples at a non-U.S.-based mill. Very good color agreement was observed between the mill’s HVI unit and the MSEZ- MILLNet™ system, with distinct and significant +b color shifts detected.

The use of high speed and high volume instrumentation to measure, class, and determine the quality of cotton is rapidly becoming a global practice. Color is an important quality parameter for cotton fiber, and it is most often obtained in the U.S. during fiber classing with the Uster® High Volume Instrument (HVI®) (USDA-AMS, 2005). The HVI unit contains a two-filter colorimeter (two regions of the visible spectrum). The fiber color parameters obtained with the HVI unit are Rd (diffuse reflectance) and +b (yellowness). During HVI color measurement, the fiber sample is placed against a glass window, and the color is measured through the glass (~6 mm thick).

Cotton is a global commodity, and it is normal for some color change to occur in cotton over the time bales are stored before being used. In the U.S., cotton properties of the bale are tested by the U.S. Department of Agriculture (USDA) soon after ginning, and the bale is stored until purchased and shipped. Previous studies have reported that the major effect on cotton fiber quality due to accelerated, non-ideal bale storage (exposure to high temperatures and humidity) is the change in fiber color, normally resulting in an increased yellowness (+b) (Cable et al., 1964; Gamble, 2007; Howell, 1956; Hughs et al., 2011). For downstream fiber processing, it has been reported that dyeing/dye shade consistency can be impacted by extensive, accelerated bale storage (Gamble, 2007; ITC, 1989; McAlister, 1994). Typical bale storage conditions can result in minor color changes that will not commercially affect the end product, and the mill can use the original USDA HVI classing data for production purposes. However, for textile mills manufacturing products that require critical color control, a percentage of each shipment is tested to determine how much of a color shift has occurred. For these textile processes, color differences outside of the mill’s tolerances between cotton bales might impact the quality of a textile mill’s end product, especially if the mill does not properly control variability within and between each laydown. Outlier shipment detection, and

J. Rodgers*, X. Cui, and C. Delhom, USDA-ARS-Southern Regional Research Center, 1100 Robert E. Lee Blvd., New Orleans, LA 70124; and G. Schild, Cotton Incorporated, 6399 Weston Parkway, Cary, NC 27513

*Corresponding author: james.rodgers@ars.usda.gov

the update of +b values for each bale within an outlier shipment, is required for critical products. Shipments that fall outside the mill's tolerance for +b color shift need to be retested. Consequently, a quicker means of identifying and testing outlier color shipments created by atypical bale storage is needed. Cotton Incorporated's Engineered Fiber Selection® (EFS®) System MILLNet™ software incorporates HVI data, including Rd and +b, and is used to determine which bales are to be selected from inventory for even-running cotton mixes. Cotton Incorporated was interested in "on-site"/remote location (e.g., warehouse) measurements of cotton color that will yield "real time" color values, with emphasis on +b. The HVI instrument is expensive, and the HVI measurements are performed in a conditioned laboratory (21°C and 65% relative humidity/RH), so at-line HVI fiber color measurements in remote locations are not an option. Recent advances in portable color instrumentation have shown great potential for rapid and accurate color measurements, and these small, portable color spectrophotometers can be utilized at-line in remote locations.

The color parameters Rd and +b are cotton-specific terms. The use of Rd and +b began with early color research on cotton by Nickerson and colleagues, cumulating in an instrument to grade cotton using Rd and +b in 1948 (Nickerson, 1931, 1950; Nickerson et al., 1950). The Nickerson equations for Rd and +b are:

$$\text{Rd} = 100\text{Y} \quad (1)$$

$$+\text{b} = 70f_Y(\text{Y}-0.847\text{Z}) \quad (2)$$

$$f_Y = 0.51[(21+20\text{Y})/(1+20\text{Y})], \quad (3)$$

where Y and Z are the tristimulus color parameters Y and Z (illuminant C, 2° observer).

However, the direct use of color spectrophotometers for fiber color measurements of Rd and +b is not straight forward. As mentioned previously, HVI is a two-filter colorimeter, whereas the advanced portable color spectrophotometers examine the entire visible region (400-700 nm, at a minimum). In addition, the portable color spectrophotometers do not directly measure Rd and +b. Rather, they use the internationally recognized three-dimensional color space systems, primarily the color systems based on tristimulus color (XYZ) (Berns, 2000; Harold, 1992). One such color system in use for color measurements

of fibers and other materials is L*a*b* or CIELAB, where L* is a measure of the fiber's lightness or darkness, a* is the fiber's greenness or redness, and b* is the fiber's blueness or yellowness. For fiber measurements, clear glass should be placed between the fiber sample and the sampling port of the spectrophotometer to prevent contamination of the instrument and to ensure a smooth, flat fiber surface for color measurement.

Using standard tiles and cotton batts provided by the Agricultural Marketing Service (AMS) of the USDA, color results on a series of color spectrophotometers established good correlations between standard CIE color parameters and HVI colorimeter color parameters (L* ↔ Rd, b* ↔ +b) (Rodgers et al., 2008, 2009; Thibodeaux et al., 2008). The strong relationships between L* ↔ Rd and b* ↔ +b were verified and validated on a multicolor spectrophotometer evaluation. Not unexpectedly, L* is normally higher than Rd, whereas very good agreement is observed between b* and +b. Good to excellent agreement was observed between the bench and portable color units when no glass is used in the color measurements, but the color agreement between units decreased when glass is used. Thus, in these preliminary multiple-unit evaluations, glass use was the major impact on the spectrophotometer color results, with L* being the primary color parameter impacted. The strong L* ↔ Rd and b* ↔ +b correlations were present regardless of glass or no-glass use. These results demonstrated that the development and use of instrumental "traceable" HVI standards, using tiles, is feasible.

A more extensive evaluation was performed on the primary expected impacts of glass use on cotton fiber spectrophotometer color measurements. L* was the color parameter most impacted, followed by b*. Glass-use impact was much greater than the impact of specular component and applied fiber pressure. Glass use is a necessity for fiber color spectrophotometer measurements; further research demonstrated that significant minimization of the glass-use impact could be achieved on color spectrophotometers by utilizing specific instrumental conditions, glass correction factors, and/or the use of glass calibration (instrument calibrated with a thin clear glass). Recommended fiber protocols were developed—specular component included (SCI), the use of thin glass (≤ 1 mm thick), and glass calibration (Rodgers et al., 2010).

The use of portable color spectrophotometers to measure fiber and yarn samples has been demonstrated and implemented in the fiber and textile industries, and several color instruments manufacturers have portable color units that are applicable for fiber, yarn, and fabric color measurements (Connelly and Harold, 1997; Reininger, 1997; Rodgers, 1996; Yaoyuenyong, 2007). Recently, a portable color spectrophotometer was used to measure the changes in cotton fiber color when fungal spores were applied to the fiber surface (Chun and Rodgers, 2011). The fiber measurements can be performed directly on the fiber, bale, or on bale samples in the manufacturing area, and the yarn measurements were performed directly on the bobbin in the laboratory and in the manufacturing area. However, these applications involved the use of the more standard three-dimensional color space systems (specifically, $L^*a^*b^*$ and $L^*c^*h^*$), not Rd and +b. Further, the internationally recognized three-dimensional color space systems are primarily used for color measurements in the synthetic fiber and polymer industries. Previous studies have shown that glass use for cotton fiber color measurements can impact the color results of portable spectrophotometers significantly more than the color results of benchtop color spectrophotometers, and that the degree of glass impact can be different for different portable color spectrophotometers (Rodgers et al., 2009). The use of glass correction factors and/or the use of glass calibration can minimize the glass impacts, but the wide differences in instrument geometries, optics, and instrumental capabilities of portable spectrophotometers necessitate the development of instrument-specific algorithms for less than three-dimensional color parameters, such as Rd and +b. Thus, new methodologies and algorithms must be developed for the direct measurement of Rd and +b on cotton by portable spectrophotometers.

As noted previously, fiber and bale color measurements in remote locations require the utilization of a portable color spectrophotometer. In addition, to incorporate the updated color results into Cotton Incorporated's MILLNet™ software, an interface to the spectrophotometer color results is required. A joint program was established between Cotton Incorporated and the USDA-Agricultural Research Service (ARS)-Southern Regional Research Center (SRRC). The objectives of this research were to develop portable color spectrophotometer procedures and protocols that could be made both in the labora-

tory and at-line in remote locations (mill, warehouse, etc.) to perform rapid, precise, and accurate cotton fiber color measurements and to interface those results into the MILLNet™ software for current/"real time" Rd and +b.

MATERIALS AND METHODS

Samples. Both ceramic tiles and cotton samples were used in this evaluation. AMS standard ceramic tiles (2 boxes, $n = 10$) and cotton batts (3 boxes, $n = 36$) were used in the first phase of the program to establish the potential of the portable spectrophotometer color measurements of Rd and +b (Fig. 1). The AMS cotton batts are well prepared and exhibit a uniform, consistent surface.



Figure 1. AMS standards, ceramic tiles, and cotton fiber batts.

Routine loose cotton lint is much more random in surface appearance, and those samples might exhibit different color behavior compared to the well-prepared, consistent AMS cotton batts. For the next phase, routine loose cotton samples were evaluated ($n = 45$). For the routine cotton samples,

75.0 ± 2.0 g of loose cotton fiber was placed into the “batt” box used to hold the individual AMS cotton batts, and the cotton was measured on the SRRC Uster HVI-1000 and the HunterLab MiniScan EZ (MSEZ) portable color spectrophotometer (Fig. 2).



Figure 2. HunterLab MiniScan EZ (MSEZ) portable spectrophotometer and glass-covered 30-mm sampling port.

For the AMS tile and cotton batt samples, the AMS-supplied standard HVI color values for Rd and +b were used as the reference values. For the HVI color of the routine samples, five measurements were made per sample and averaged to obtain the Rd and +b reference values. For all MSEZ measurements, five replicates were made and averaged per sample, and the average MSEZ color values were compared to the average HVI color values. All measurements were made at standard conditions (70 ± 2 °F and 65 ± 2% RH).

Color Measurements. For the AMS standard ceramic tiles and cotton batts, the reference Rd and +b values were obtained from the master HVI-1000 colorimeter in Memphis, TN. For the routine samples, the HVI Rd and +b values used as reference color values for the routine cottons were obtained on the SRRC HVI-1000. The HVI colorimeter uses two filters to measure the sample’s diffuse reflectance at two visible spectral regions, and Rd and +b are obtained from Uster algorithms. The cotton fiber sample is placed against a thick glass window and placed under pressure, and all color measurements are made through the glass (~6 mm thick).

The HunterLab MSEZ is a small footprint (physical size), battery operated, lightweight portable color spectrophotometer (400-700 nm) (HunterLab Associates, Reston, VA). The unit contains a 45/0 measurement geometry and a 30-mm sampling (measurement) port. The MSEZ data can be downloaded to external devices (e.g.,

computer or USB flash drive). The standard nose cone sampling port for the MSEZ is open (no covering), but a special-order glass nose cone sampling port was used for these evaluations (sampling port contained a thin piece of optical glass). As noted previously, the use of glass is needed for color measurements on cotton fibers. The use of the glass-covered sampling port yields a smooth, consistent fiber sampling presentation for color measurement, and the use of glass calibration has been shown to significantly minimize glass impact (Rodgers et al., 2010). The manufacturer’s operational procedures were followed. All MSEZ measurements were made at illuminant D65/10° observer and illuminant C/2° observer for both XYZ and L*a*b* color spaces, and mathematical comparisons were performed between the HVI Rd and +b results and the MSEZ L*a*b* and XYZ results.

Data Analysis. Comparisons were performed between the HVI Rd and +b results and various MSEZ L*a*b* and XYZ parameter results. The statistical parameters used in this evaluation included within-pooled standard deviation (Swp; five measurements), R², and number of outliers (number of samples outside specified color agreement between the HVI Rd and +b and the MSEZ “Rd” and “+b” color term selected). We used end-state criteria as the desired/targeted goals for the comparison results. After discussions with Cotton Incorporated on their desired end-state goals, the end-state criteria selected for the cotton samples were comparable Swps (< 0.25 +b and <0.50 Rd for the portable spectrophotometer), R²s > 0.90, and ≥ 70% the number of samples agreeing within ± 0.5 +b color units (HVI +b to MSEZ “+b” color term selected) and within ± 1.0 Rd color units (HVI Rd to MSEZ “Rd” color term selected) (70% confidence interval).

RESULTS AND DISCUSSION

AMS Standards. Five measurements per sample were made on the Uster HVI-1000 (for Swp comparisons) and MSEZ, using 10 AMS standard tiles (2 boxes) and 36 AMS standard cotton batts (3 boxes). All averaged value comparisons were made versus the AMS-stated values for the ceramic tiles and cotton batts. Several color parameter and mathematical algorithm comparisons were performed between the spectrophotometer color parameters and HVI Rd and +b.

The linear agreement observed between HVI +b and MSEZ b* was excellent for both tiles and batts, with slopes near unity and high R²s obtained (> 0.97) (Figs. 3 and 4). The main focus of this project was fiber samples; thus, primary emphasis was given to the cotton batt yellowness measurements. For the AMS batts, four MSEZ +b parameters were calculated from the MSEZ spectrophotometer measurements and compared to the HVI +b color results and b* from the MSEZ L*a*b* results (bias-only adjustment to match +b), linear and cubic best-fit equations, and Nickerson’s +b calculation. The best overall preliminary results were obtained for HVI +b and MSEZ b* (illuminant D65/10° observer) (Table 1). The linear, polynomial, and Nickerson algorithms yielded high R²s (≥ 0.95), but their color method agreement results (number of samples agreeing within ± 0.5 color units with the HVI +b) were often less than the method agreement observed for the MSEZ b* term, and they required extra computations.

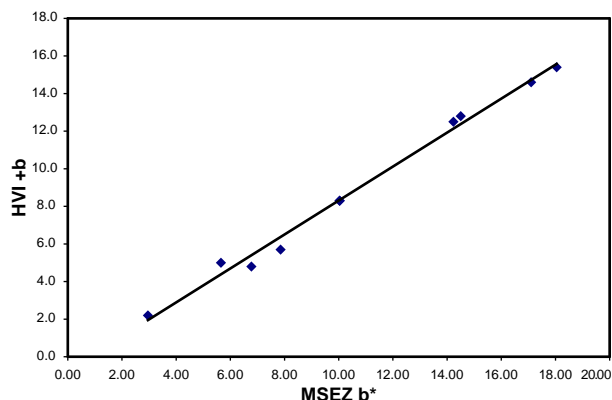


Figure 3. AMS standard ceramic tiles (n = 10), HVI +b vs. MSEZ b*. $HVI +b = 0.9036(\pm 0.03)*MSEZ b* - 0.7262(\pm 0.38)$, $R^2 = 0.9916$.

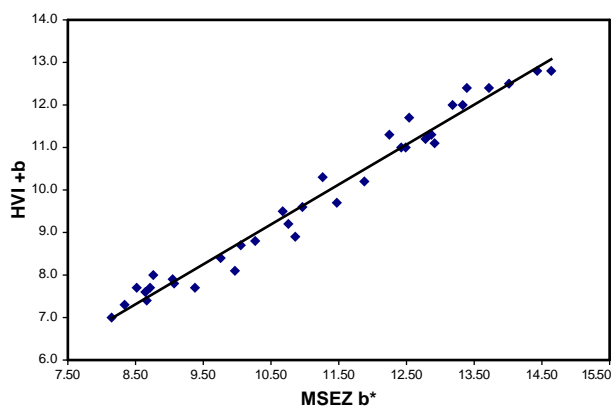


Figure 4. AMS standard cotton batts (n = 36), HVI +b vs. MSEZ b*. $HVI +b = 0.9385(\pm 0.03)*MSEZ b* - 0.6636(\pm 0.27)$, $R^2 = 0.9749$.

Table 1. HVI +b vs. various MSEZ b parameters, AMS standard cotton batts (n = 36).

Parameter	R ²	Color Agreement % Within ± 0.5
b* Only	0.975	94.4
Linear, Calculated +b	0.975	86.1
Cubic, Calculated +b	0.962	82.3
Nickerson, Calculated +b	0.950	77.0

For Rd, four MSEZ “Rd” parameters were calculated from the MSEZ spectrophotometer measurements and compared to the HVI Rd color results—Nickerson Calculated Rd (Y), linear and cubic best-fit equations for Y to Rd, and calculated Rd from the L* to Rd correlation. The best overall preliminary results were obtained for HVI Rd and the MSEZ Nickerson Calculated Rd (Y) term (Nickerson MSEZ Rd; illuminant C/2° observer) (Table 2). This parameter is calculated from the original Nickerson algorithm (equation 1; Y value for illuminant C, 2° observer), requiring only a bias adjustment to yield comparable Rd values. All mathematical algorithms yielded high R²s (≥ 0.99) and a low number of outliers (> 90% of samples agreed within ± 1.0 Rd unit). The linear, cubic, and Rd to L* based calculated Rds required extra computations compared to the bias-only adjusted Nickerson MSEZ Rd. The method agreement between HVI Rd and the Nickerson MSEZ Rd was excellent for both tiles and batts, with slopes near unity and high R²s obtained (> 0.98) (Figs. 5 and 6).

Table 2. HVI Rd vs. various MSEZ “Rd” parameters, AMS standard cotton batts (n = 36).

Parameter	R ²	Color Agreement % Within ± 1.0
Nickerson, Calculated Rd (Y)	0.996	97.2
Linear, Calculated Rd	0.996	97.2
Cubic, Calculated Rd	0.996	97.2
L*↔Rd, Calculated Rd	0.994	94.4

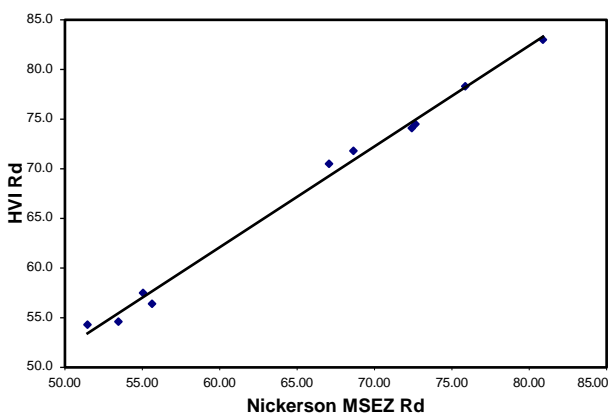


Figure 5. AMS standard ceramic tiles (n = 10), HVI Rd vs. Nickerson MSEZ Rd. $HVI Rd = 1.0153(\pm 0.03)*Nickerson MSEZ Rd + 1.19(\pm 2.12)$, $R^2 = 0.9939$.

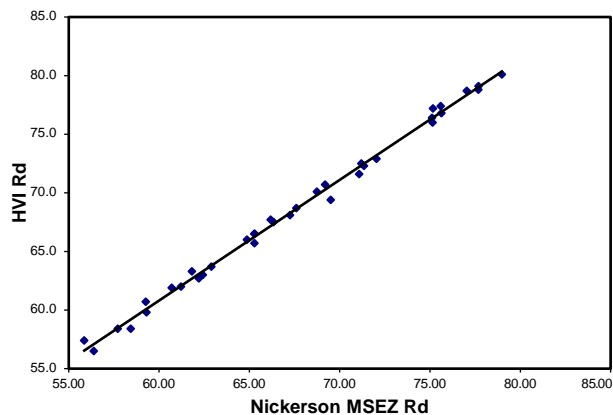


Figure 6. AMS standard cotton batts (n = 36), HVI[®] Rd vs. Nickerson MSEZ Rd. $HVI\ Rd = 1.0293(\pm 0.01) * Nickerson\ MSEZ\ Rd + 0.9494(\pm 0.84)$, $R^2 = 0.9957$.

In addition to obtaining the best spectrophotometer “Rd” and “+b” comparisons to the HVI Rd and +b, one of the end-state criteria was comparable analytical variability (Swp) for both the HVI and spectrophotometer parameters, with a target of $Swp < 0.25 +b$ and $Swp < 0.50\ Rd$ color units for both methods. For +b, acceptable Swps were observed for both the MSEZ and HVI for tiles (HVI = 0.01; MSEZ = 0.03) and batts (HVI = 0.08 and MSEZ = 0.16). Similar results were observed for Rd for both tiles (HVI = 0.05; MSEZ = 0.11) and batts (HVI = 0.15 and MSEZ = 0.41). Although the Swps for the tiles and cotton batts were higher for the Nickerson MSEZ Rd and +b results, they remained less than one half of the method agreement range of $\pm 0.50 +b$ and $\pm 1.0\ Rd$ color units and less than the end-state criteria targets.

Small but distinct biases were observed for both +b and Rd between the HVI and MSEZ color results. For +b, a small bias of approximately 1.4 was observed between the HVI +b and MSEZ b^* color results for the cotton samples, with the MSEZ yielding the slightly higher yellowness results. Upon adjustment, the agreement between HVI +b and MSEZ b^* was excellent, with only two outliers (> 0.5 color unit difference between the HVI +b and MSEZ b^*), as shown in Fig. 7 and Table 1. Overall, the +b– b^* color agreement was greater than 94% for the ± 0.5 color unit specified outlier limit. These outlier results were well within the end-state criteria for HVI +b portable spectrophotometer b-term method agreement ($\geq 70\%$ of the samples agreeing within ± 0.5 color units). Similar results were observed for Rd, as shown in Table 2. A slight bias of approximately 1.0 was observed

between the HVI Rd and Nickerson MSEZ Rd color results for the cotton samples, with the MSEZ yielding slightly lower diffuse reflectance results. For MSEZ +b and Rd, the bias-only calculations were used. For the end-state criteria, the bias-only adjusted equations yielded the best overall results. In addition, the use of bias-only calculations avoids complex adjustments later when the technique is applied to multiple instruments.

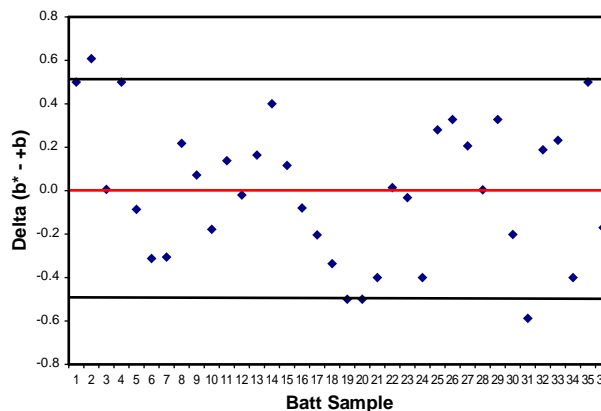


Figure 7. AMS standard cotton batts (n = 36), Delta (MSEZ b^* - HVI +b); red line = 0.0, solid black line = ± 0.5 .

Routine Cottons. The initial comparative evaluations used the AMS cotton batts for fiber analyses. However, routine loose cotton samples might exhibit different color behavior compared to the well-prepared, consistent AMS cotton batts. The color comparative program was expanded to include routine, loose cotton samples. Color measurements were performed on 45 cotton samples representing a large diversity in age and location (37 samples from AMS representing the 2010 cotton crop and eight aged cottons from 2005 samples). Five measurements per sample were made on the Uster HVI-1000 and the MSEZ. All comparisons were made versus the SRRC HVI-1000 Rd and +b results. Based on the results from the AMS tiles and cotton batts evaluation, only the HVI Rd and Nickerson MSEZ Rd and HVI +b and MSEZ b^* color parameters were compared.

For +b, excellent overall linear agreement was observed between HVI +b and MSEZ b^* for the routine loose cotton samples. The +b– b^* slope was near unity, and a high R^2 obtained (> 0.94) (Fig. 8). As observed for the AMS cotton batts, the MSEZ b^* values were slightly higher than the HVI +b values. In general, the absolute differences between HVI +b and MSEZ b^* for

the routine samples are slightly higher than the absolute differences observed for the AMS cotton batts; the average absolute difference for the routine samples was approximately 1.7, whereas the average absolute difference for the AMS cotton batts was approximately 1.4 units lower than the MSEZ b^* values. The observed slight differences in HVI +b and MSEZ b^* between the AMS cotton batts and routine cotton samples is not unexpected, as the AMS cotton batts were carefully prepared (aligned, smooth and consistent surface, same age), whereas the routine samples were measured “as is” (no blending or sample preparation; 5-yr age difference between samples). When a 1.7 adjustment was made to the MSEZ b^* values, excellent agreement was observed between HVI +b and MSEZ b^* . The +b- b^* agreement was greater than 91% for ± 0.5 , well within the end-state criteria for HVI +b portable spectrophotometer b-term method agreement.

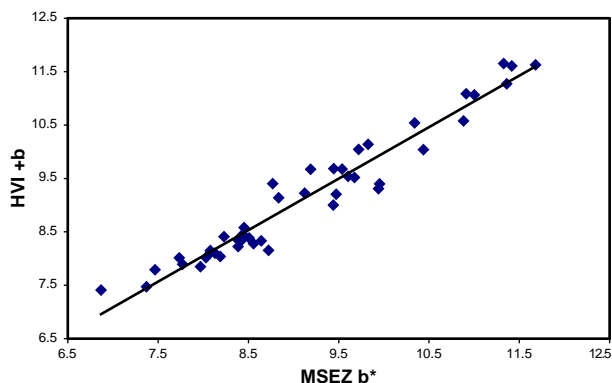


Figure 8. Routine, loose cotton samples ($n = 45$), HVI +b vs. MSEZ b^* . $HVI +b = 0.9641(\pm 0.04) * MSEZ b^* - 1.302(\pm 0.35)$, $R^2 = 0.9438$.

Excellent linear agreement was observed between HVI Rd and Nickerson MSEZ Rd for the routine samples, with a high R^2 (> 0.95) (Fig. 9). The Nickerson MSEZ Rd results for the routine cottons were approximately 2.8 units lower than the HVI Rd results, but they were only approximately 1.0 units lower than the HVI Rd results for the AMS cotton batts—a significant increase in bias. When a 2.8 adjustment was made to the Nickerson MSEZ Rd values, the method agreement was greater than 77% for ± 1.0 Rd, within the end-state criteria. The surface preparation/presentation differences noted previously between the AMS batts and routine, loose cotton samples is the leading contributor to the increase in Rd bias. The +b term is calculated

from the differences in reflectance between two spectral regions (and therefore not as impacted by changes in surface presentation on the surface diffuse reflectance); whereas the Rd is a direct measurement of the sample’s diffuse reflectance, and therefore is more impacted by changes in surface presentation than +b.

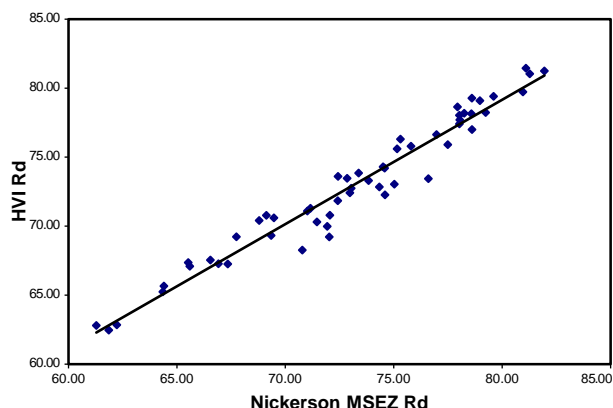


Figure 9. Routine, loose cotton samples ($n = 45$), HVI Rd vs. Nickerson MSEZ Rd. $HVI +b = 0.9013(\pm 0.03) * Nickerson MSEZ Rd + 7.0582(\pm 2.10)$, $R^2 = 0.9533$.

Engineered Fiber Selection (EFS) System MILLNet™ Software Interface. MILLNet™ software enables mills to readily understand the quality of cotton they purchase and easily receive, price, and consume cotton in an even-running manner using HVI data. Mills using MILLNet™ software can receive and import HVI data directly from their own HVI line or from files sent to them by their supplier (e.g., ANSI X12 4010 EDI, Excel, ASCII file).

Customers manufacturing high-quality critical products, using HVI data received in advance of their cotton shipments, indicated that they would benefit from a cost-effective method of quickly and accurately testing color differences at the time the bales are physically received at the warehouse. These customers range from large mills that have an Uster HVI line to mills that do not have color testing equipment.

In production use, cotton samples tested with the HunterLab MSEZ are cut from within the bale following standard ASTM sample preparation methods. Measuring cotton color directly on the bale just below the wrapper will not yield reliable results due to dirt and possible yellowing just beneath the wrapper. The samples are then brought to a computer running the MILLNet™ software in the warehouse or laboratory.

A custom USB interface to the HunterLab MSEZ was written to import data into the MILLNet™ software by bale number. Both Rd and +b measurements are collected during each sample read. A minimum of three readings from various parts of the sample are required to obtain an Rd and +b average for the sample. The average of these data are then adjusted using user-defined correction offsets for Rd and +b. The values of these offsets are determined by the customer to allow for differences between MiniScan units and to adjust the readings to more closely fit the values obtained by the company's own properly calibrated HVI line readings or calibration readings taken against the USDA's Universal Standards cotton samples. After entering the adjusted results into the sample database, the data are then imported as a shipment. Within MILLNet™ software, reports can then be run to check the Rd and +b tolerances set by the mill for the shipment or used directly for fiber processing purposes. An example data entry session is shown in Fig. 10 with actual data taken from a single sample. The internal HunterLab MSEZ sample ID is also shown for reference purposes.

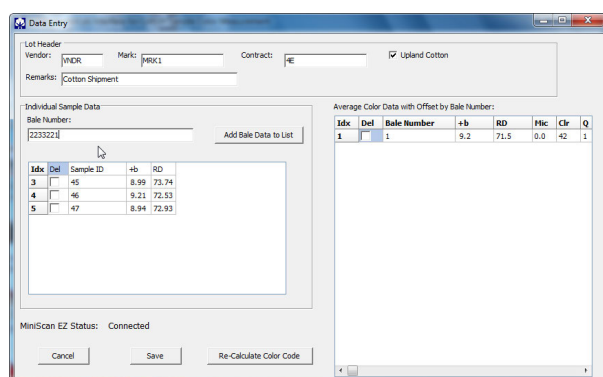


Figure 10. Example MILLNet™ HunterLab MiniScan EZ data entry.

The MILLNet™ system to HunterLab MSEZ interface was initially field tested at a non-U.S.-based mill. The mill used the HunterLab MSEZ spectrophotometer to review cotton bales from several lots selected due to perceived high shifts in color, with emphasis on +b. These samples were also evaluated on their Uster HVI-1000. More than 400 samples were tested, and the color agreement between the HVI-1000 and MSEZ color measurement methods was very good, with the change in the original +b values readily observed by the MSEZ for five lots (Table 3). A slight but consistent bias was observed for +b (≤ 0.5 +b), but this bias was much less the change in color between the original HVI +b and the HVI +b at the mill. The mill also reported that the interface and hardware were easy to operate.

CONCLUSIONS

Comments from industry have indicated that some cotton bales appeared to have changed significantly in color from their initial HVI color measurements, especially for +b. A program was implemented to develop portable color spectrophotometer procedures and protocols to perform rapid, precise, and accurate cotton fiber color measurements at-line in remote locations and to interface those results into the MILLNet™ software. Using AMS standard tiles, AMS standard cotton batts, and routine loose cotton samples, comparative evaluations were performed to establish the relationships between the HVI Rd and +b and portable spectrophotometer $L^*a^*b^*$ and XYZ color parameters (illuminants D65/10° observer and illuminant C/2° observer). The portable spectrophotometer measurements were rapid

Table 3. Field trial color results, original HVI vs. Mill HVI vs. MSEZ, Rd and +b (n = 439).

LOT	n ^y	Rd			+b		
		OHVI ^z	MHVI ^z	MSEZ ^z	OHVI ^z	MHVI ^z	MSEZ ^z
1	88	81.7	80.5	78.9	7.6	9.8	9.4
2	87	80.5	79.1	76.9	8.3	10.6	10.2
3	88	80.5	79.3	77.6	7.9	10.0	9.5
4	88	82.5	81.9	80.3	7.4	9.5	9.0
5	88	82.6	81.2	79.3	8.6	11.1	10.7
AVG^x	439	81.6	80.4	78.6	7.9	10.2	9.8

^z OHVI = Original HVI-1000 color values; MHVI = Mill HVI-1000 color values; MSEZ = MILLNet-HunterLab MiniScan EZ color values

^y n = number of cotton samples

^x AVG = average

(< 3 min. measurement per sample), precise, and accurate. Excellent linear agreement was obtained between HVI Rd and +b and MSEZ Rd (Y parameter) and +b (b* parameter) for both AMS ceramic tiles, cotton fiber batts, and routine cottons (R^2 s > 0.9). Low spectrophotometer analytical variability (within standard deviations, Swps) was obtained for the HVI and MSEZ color measurements, with all variabilities meeting the end-state targets. Color method agreement between the HVI +b and MSEZ +b was excellent, with greater than 94% of the AMS standard cottons and greater than 91% of the routine cottons agreeing within ± 0.5 color units. Overall color method agreement between the HVI Rd and Nickerson MSEZ Rd was good, with greater than 97% of the AMS standard cottons and greater than 77% of the routine cottons agreeing within ± 1.0 color units. The Rd measurement was more impacted by the surface presentation than +b (no sample preparation for the routine cottons). Thus, the measurement of cotton fiber Rd and +b using a portable spectrophotometer was shown to be feasible, and all end-state criteria were achieved. The color results can be downloaded to the MILLNet™ software for bale selection. Initial field tests for the MILLNet™ software to HunterLab MSEZ interface was performed at a non-U.S.-based mill on more than 400 lint samples. The mill reported that the interface and hardware were easy to operate. The color agreement between the MSEZ and mill HVI-1000 were quite good, with the shifts in +b color values at the mill readily observed.

ACKNOWLEDGMENTS

The authors acknowledge the support and assistance of James Knowlton of the Agricultural Marketing Service (AMS) in Memphis, TN. We also wish to acknowledge Jeannine Moraitis and Sarah Lillis for their outstanding work in running all samples. This research was funded by Cotton Incorporated.

DISCLAIMER

The use of a company or product name is solely for the purpose of providing specific information and does not imply approval or recommendation by the United States Department of Agriculture to the exclusion of others.

REFERENCES

- Berns, R.S. 2000. Billmeyer and Saltzman's Principles of Color Technology, 3rd ed., John Wiley and Sons, New York, NY.
- Cable, C., H. Smith, and Z. Looney. 1964. Changes in quality and value of cotton bales and samples during storage. USDA, Economic Res. Serv., Agric. Marketing Serv., Marketing Res. Rep. 645. U.S. Gov. Print. Office, Washington, DC.
- Chun, D., and J. Rodgers. 2011. Effect of fungal spores on cotton color. *J. Cotton Sci.* 15: 52–60.
- Connelly, R., and R. Harold. 2005. Benefits of hand-held color measurement equipment. p. 18–20 *In* Color Technology in the Textile Industry, 2nd Ed. American Association of Textile Chemists and Colorists (AATCC), Research Triangle Park, NC.
- Gamble, G. 2007. The effect of bale ageing on cotton fiber chemistry, processing, and yarn quality. *J. Cotton Sci.* 11: 98–103.
- Harold, R. 1992. Reprint from Industrial Finishing, September 1992, p. 1–4.
- Howell, L. 1956. Influence of certificate stocks on spot-futures price in upland cotton (*Gossypium hirsutum* L.) as a function of storage temperature. USDA Tech. Bull. 1151. U.S. Gov. Print. Office, Washington, DC.
- Hughs, S., G. Gamble, C. Armijo, and D. Tristao. 2011. Long-term storage of polyethylene film wrapped cotton bales and effects on fiber and textile quality. *J. Cotton Sci.* 15:127–136.
- International Textile Center [ITC]. 1989. Effects of ageing on cotton quality. *Textile Topics* 6:1–3.
- McAlister, D. 1994. The effect of cotton ageing on the color variation of dyed fabric. M.S. thesis. Inst. Textile Tech., Charlottesville, VA.
- Nickerson, D. 1931. A colorimeter for use with disc mixtures. *J. Optical Soc. Am.* 21:640–642.
- Nickerson, D. 1950. Munsell rennotations used to study color space of Hunter and Adams. *J. Optical Soc. Am.* 40:85–88.
- Nickerson, D., R. Hunter, and M. Powell. 1950. New automatic colorimeter for cotton. *J. Optical Soc. Am.* 40:446–449.
- Reininger, S. 1997. Textile applications for hand-held color measuring instrument. *Textile Chemists Colorists* 29:13–17.

- Rodgers, J. 1996. Analytical methodology considerations in a comparative study of portable color measurement instrumentation, Inter-Society Color Council (ISCC) 65th Annual Meeting, Orlando, FL, May 5-7.
- Rodgers, J., S. Kang, C. Fortier, X. Cui, C. Delhom, and J. Knowlton. 2010. Minimization of operational impacts on spectrophotometer color measurements for cotton. *J. Cotton Sci.* 14:240–250.
- Rodgers, J., D. Thibodeaux, J. Campbell, and X. Cui. 2009. Feasibility of “traceable” color standards for cotton color. *AATCC Rev.* 9(1):42–47.
- Rodgers, J., D. Thibodeaux, X. Cui, V. Martin, M. Watson, and J. Knowlton. 2008. Instrumental and operational impacts on spectrophotometer color measurements. *J. Cotton Sci.* 12:287–297.
- Thibodeaux, D, J. Rodgers, J. Campbell, and J. Knowlton. 2008. The feasibility of relating HVI® color standards to CIELAB coordinates, *AATCC Rev.* 8(11):44–48.
- USDA Agricultural Marketing Service [USDA-AMS]. Cotton Program Brochure 2005. Cotton Classification, Understanding the Data, April 2005 [Online]. Available at <http://www.ams.usda.gov/AMSV1.0/getfile?dDocName=STELPRDC5074569> (verified 3 July 2013).
- Yaoyuenyong, G. 2007. Effects of illuminants and retail environments on color of textiles fabric. Ph.D. diss. Florida St. Univ., Tallahassee, FL.