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Using High-Speed Image Analysis to Estimate Trash in Cotton

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Two new scanning type cotton trashmeters are being developed to indicate the amount of trash and foreign matter in lint cotton. These instruments are primarily intended to replace the current visual method of grading cotton for market quality. They both perform a two dimensional surface scan using a black and white television camera. High-speed microprocessors provide an analysis of the TV signal at video scan rates. Only a fraction of a second of time is required to complete all scanning, signal processing, and data analysis for each cotton sample exposure. This article discusses some common problems in TV image analysis and how they relate to cotton scanning. Also discussed are instrument precision and design features and a method of calibrating each instrument.

Trashmeter Designs: Success and Failure

One of the first surface trash scanners for cotton was developed in the late 1930s by Nickerson and Asbil [1]. The Cotton Grade Scanner, as it was called, used a moving spot of light which could be focused to 1/64 in. in diameter. The system was never successful because high-speed data processing equipment was not available to properly analyze the output signal. Following the flying spot trash scanner, the next major development occurred in the late 1950s when Cameron Baker et al. at United States Testing Company [2] introduced a trashmeter based on a television Vidicon tube. The device was called the "Scanatron" and it used high-speed electronics to count TV scan voltage pulses caused by dark spots in the cotton sample. At that time, Outlook Engineering developed a modernized version of the original Nickerson-Asbil flying spot scanner. The new spot scanner required 3 seconds to scan a 4 in. × 4 in. cotton sample. Smith [3] reported that the new Outlook Engineering trashmeter was reasonably stable and appeared to do an adequate trash classing job. However, the cotton sampling variability was too large.

During the mid-1970s Barker and Lyons [4–7] developed an instrument analysis system based on image analysis. The system used a conventional television monitor to view and scan a 50 × 65 mm surface section of a cotton sample. They concluded that trash particle count gave the best correlation with classers grade and their particle measuring system was slightly less variable at grading trash than that produced with the Shirley Analyzer nonlint measurement.

Two other trashmeter investigations should be noted. Starting in 1978, Recognition Systems, Inc., under contracts with the USDA, Cotton Incorporated, and J. G. Boswell, began developing a trashmeter using a charge coupled device for optical detection. The trashmeter was designed for color or black and white reflectance measurements and included a feature that automatically calibrated the detector by measuring a white reference between scans. Only one unit of the black and white version was completed, and its evaluation was not successful.

In 1980 Taylor [8] reported on an investigation into the feasibility of using near infrared reflectance measurements to indicate cotton trash levels. Infrared detection is very appealing since light in that region penetrates deeper into a cotton sample than does visible light. Thus it was felt that only a few observations would be required to get a good measurement of the trash throughout a sample. However, infrared detectors are extremely slow and unstable and the commercial instruments are very costly.

Simple Television Images

A conventional black and white television (TV) camera generates a continuous voltage signal which is related to the intensity of light reflected from the object being viewed. This signal is made to sweep horizontally across the field of view approximately 240 times to completely fill a single frame. Complete image exposures are repeated at a nominal rate of 30 frames per second. Some modern high-speed cameras are capable of scanning more than 300 frames per second. The early TV cameras used a Vidicon tube which involved a photo sensitive surface encapsulated in an evacuated or gas filled glass chamber. A common problem with these cells is that they can be permanently damaged with over exposure. More recently, solid state semi-conductor type detectors have been developed to overcome some of the shortcomings of the Vidicon cell. The new detectors are made with thin films of photo sensitive metal oxides semiconductor (MOS) material. They are subdivided into numerous individual segments the smallest of which is called a pixel (short for picture element). Each pixel is used in a large integrated circuit network to charge a capacitor in relation to the light energy falling on the pixel. Elaborate networks are employed to read the charge produced by each pixel. Silicon oxide detector coatings are commonly used as the photo sensitive material because of its fast response and its broad spectral characteristics.

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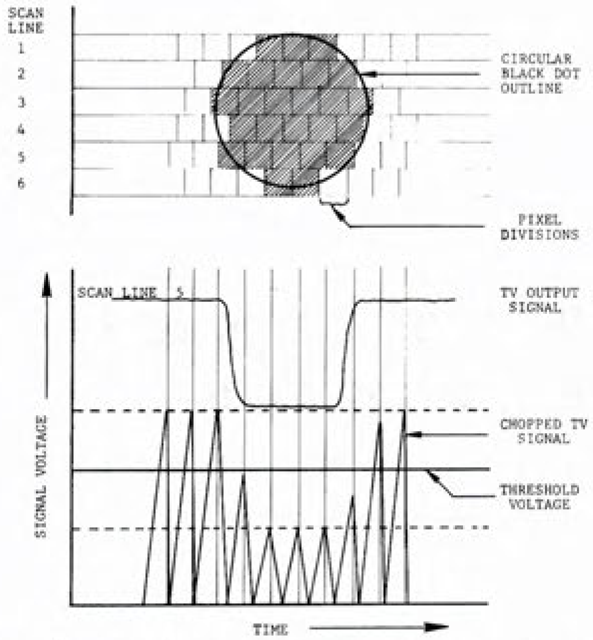

Fig. 1 Schematic of bilevel black and white television scan image analysis

Variability in manufacturing precision of the MOS type detectors will cause a fixed pattern of background shading because each pixel detector does not charge its capacitor in the same manner as all other detector-capacitor pairs. To overcome the background shading problem, detectors were developed to couple all changes along a horizontal sweep line onto the same horizontal signal bus (Charge Coupled Device). This design change solved the fixed pattern problem. However, it greatly limited the dynamic optical range and caused image blooming. Blooming is best described as image darkening because a brighter than normal spot was encountered during the same horizontal sweep. For situations where we are identifying and characterizing dark spots on a light background, blooming has the effect of making a circular black dot appear elongated in the sweep direction. Most of these TV camera problems are barely noticeable to the typical television viewer. However, they are all very apparent when using a TV camera for object image analysis, especially when an object is nearly the same size as a single pixel.

Processing of TV camera images for ease of analysis and recording with a digital computer, is performed by chopping the continuous signal into uniform time segments. Since the camera's horizontal sweep rate is constant and linear, the individual chopped signal pulses represent the reflected light level from a small element of the total image picture (pixel). The number and spacing of pixels generated in this manner do not necessarily agree with that small portion of the detector in the camera which is also called a pixel. Figure 1 shows the method of analyzing the digital image produced by scanning a circular black dot. Using this method of digital analysis we must have previously decided on a threshold level for use in selecting the pixels to represent the object being scanned. The resulting pixel image is somewhat irregular in shape. Therefore resolution of the TV scanning system is very important when viewing cotton samples with very small trash particles. We should note that pixels from one scan will line up with those in the adjacent scan if the chopping signal is synchronized with the horizontal sweep signal.

Prototype Designs

Extensive cotton trashmeter evaluations have been conducted on two different prototype designs. Both instruments use conventional black and white television cameras as scanning trash detector. We will now describe the important features of both designs and describe how they influence the instrumental judgment of the trash content of cotton.

The Spinlab Model 835 Trashmeter.* This unit [9] employs an RCA television camera which contains a Vidicon cell type detector. Of the 240 horizontal TV scan lines normally processed by the camera, 184 have been identified to analyze for trash. Within each scan being analyzed, 204 pixels are processed and counted by the computer. Therefore 37563 individual pixels are used to form each cotton exposure image. Two complete frames are analyzed and the results are averaged to minimize any effects of illuminator flutter. The TV camera is installed inside an optically black box which also contains two sample illumination sources. A cotton sample observation window measuring 5 × 7 in. is provided. The field of view being analyzed for trash measure 3.6 × 4.9 in. when projected onto the sample window. Therefore each pixel represents an area on the cotton sample surface measuring 0.0195 × 0.0242 in. There is included in the TV camera an automatic aperture mechanism which corrects for reflectance level differences between cotton exposures. Therefore the average light exposure as observed by the Vidicon cell is the same level as all other exposures regardless of the reflectance of the cotton. A predetermined threshold setting (entered as a 3 digit number ranging from a 0 to 256) is used to determine which pixels are dark enough to be counted as trash. Digital displays present as the percent of trash area and the number of trash particles observed.

Motion Control Model 3000 Trashmeter. This unit is built into their conventional High Volume Instrument (HVI) cotton colorimeter. A small solid state Hatachi TV camera (using a CCD type detector) is installed between the two color sensing elements. To accommodate the camera, the automatic aperture system has been removed and replaced with an optical filter to reduce the admitted light energy to a level acceptable for the detector. Therefore the average output current from the detector is used to indicate the relative light reflectance from individual cotton samples. Threshold settings for this instrument are expressed as a fraction below the average sample reflectance. An observation window measuring 2.75 × 4 in. is provided for viewing cotton samples. A pneumatically operated sample compression device is used to provide a reproducible 5 lb force on the sample and against the viewing window. The TV camera is installed such that the horizontal scan lines sweep along the long (4 in.) dimension of the window. Since there are 240 visible TV scan lines of vertical sweep along the short dimension of the window, one would expect a scan line spacing of approximately 87 lines per in. However, the TV camera position in the trashmeter will determine the number of lines actually viewing the cotton sample. Additionally, vertical linearity in the camera optics will influence the scan lines distributed on the image window. Observations with small strips of dark paper (1/2 and 1 in. long) against a white background indicated that 96.4 scan- lines/in. was normal for most of the observation window. A 20 megahertz chopper is used to generate the individual pixels along the horizontal sweep of the camera. Considering the standard TV sweep frequency, there should be 1269.8 pixels per scan line. If the TV camera had been installed such that the horizontal sweep exactly matched the 4 in. length of observation window, the pixel spacing would be 317 pixels/in. Observations with several strips of paper (from 0.25 to 1.5 in.) indicated an

*Trade names are used solely to provide specific information. Mention of a trade name does not constitute a warranty or an endorsement of the product by the U.S. Department of Agriculture to the exclusion of other products not mentioned.

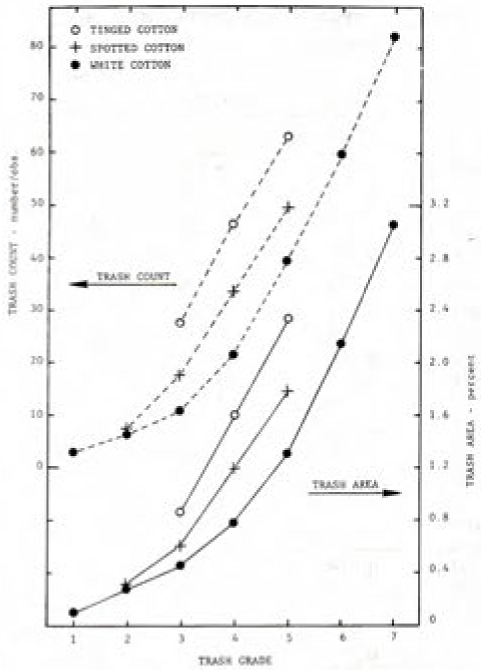

Fig. 2 Response to trash grade using 1981 USDA standard grade guide boxes on the Spinlab Model 835 trashmeter with fluorescent type sample illuminators

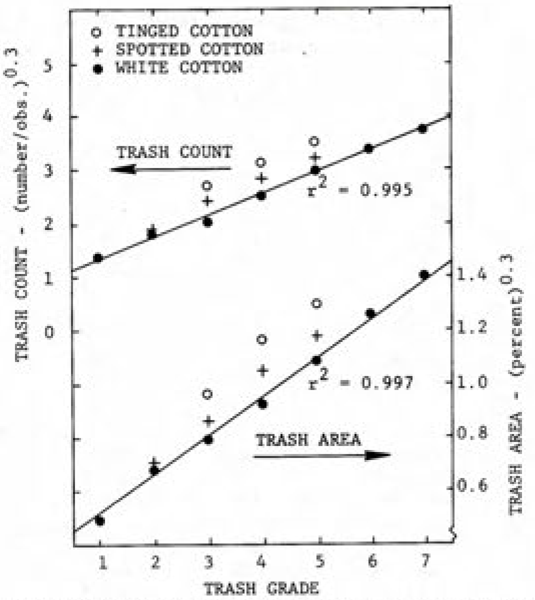

Fig. 4 Linearized response to trash grade using 1981 USDA standard grade guide boxes on the Spinlab Model 835 trashmeter with fluorescent type sample illuminators

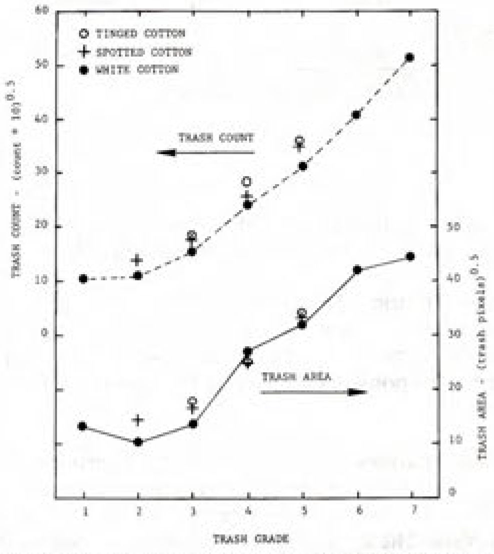

Fig. 3 Response to trash grade using 1981 USDA standard grade guide boxes on the Motion Control Model 3000 trashmeter with incandescent type sample illumination

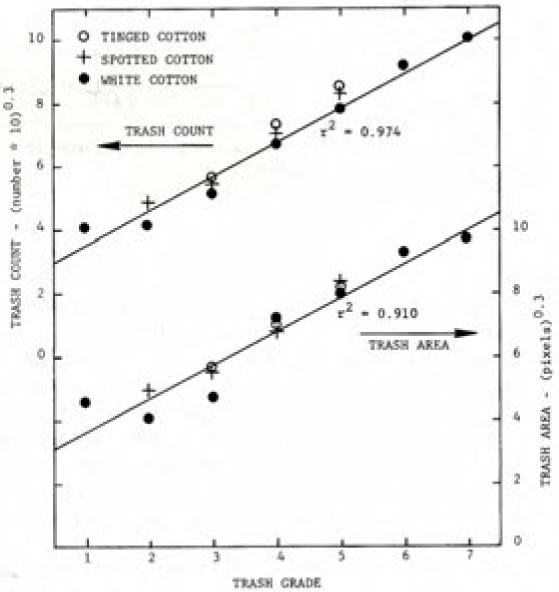

Fig. 5 Linearized response to trash grade using 1981 USDA standard grade guide boxes on the Motion Control Model 3000 trashmeter using incandescent type sample illuminators

average pixel spacing of 325 pixels/in. Since the instrument pixel count display had been reduced to a square root and truncated to two digits, we accepted the 317 pixels/in. as an accurate pixel spacing estimate. Therefore our estimate of the pixel count density was 30559 pixels/sq in. We therefore conclude that the MCI trashmeter analyzes 336,149 pixels distributed over the 11 sq in. viewing window. Two complete TV frame scans are taken and the results are averaged. Thus the average of two scans is displayed for each cotton exposure.

In conjunction with the trash or dark area pixel counting produced by the MCI trashmeter, readings of particle or spot "count" are also displayed. The count reading is produced by integrating the number of dark spots encountered along individual scan lines. Results are displayed as the square root of ten times the actual spot count (truncated to two digits). Particle count data are very useful in determining the size of trash in cotton.

Trashmeter Response to Cotton Grade Standards

The current method of evaluating cotton for trash content or leaf grade is performed as a visual inspection by a cotton classing specialist. To guide and stabilize the cotton classers, the Cotton Division of the USDA Marketing Service develops and distributes sets of standard grade guide boxes in which different cottons with different lint coloration and trash or nonlint content are placed. With the recent development of the HVI cotton grading system, a colorimeter is used to provide an accurate measurement of cotton lint color grade. To aid the HVI system development, a temporary leaf or trash grading method is currently being used. The temporary

Table 1 Linear regression results for linearized trashmeter response to predict trash grade with USDA-AMS standard grade guide box sets*

Illumination	Threshold	Area Slope	Area intercept	Area r^2	Count Slope	Count intercept	Count r^2
			Spinlab Model 835				
			1981 USDA Standard Grade Set				
Incandescent	140	7.246	−2.384	0.997	2.551	−2.173	0.995
Incandescent	140	7.194	−2.410	0.998	2.506	−2.198	0.995
Incandescent	140	7.246	−2.529	0.996	2.551	−2.349	0.993
Incandescent	140	6.944	−2.285	0.997	2.513	−2.296	0.993
Incandescent	140	7.092	−2.418	0.998	2.577	−2.459	0.993
Averages		7.143	−2.407	0.997	2.538	−2.294	0.994
Fluorescent	140	6.757	−2.419	0.997	2.481	−2.340	0.995
Fluorescent	143	6.452	−2.329	0.999	2.445	−2.526	0.994
Fluorescent	137	6.711	−2.289	0.998	2.513	−2.319	0.985
Fluorescent	110	8.547	−3.197	0.991	3.257	−3.296	0.985
Fluorescent	110	9.009	−3.351	0.990	3.425	−3.373	0.987
			1980 USDA Standard Grade Set				
Incandescent	140	6.667	−2.300	0.978	2.315	−2.074	0.988
Incandescent	140	6.711	−2.282	0.971	2.315	−2.053	0.981
Incandescent	140	6.667	−2.200	0.983	2.257	−1.774	0.990
			Motion Control Model 3000**				
			1981 USDA Standard Grade Set				
Incandescent	30	0.961	−2.541	0.910	0.919	−2.195	0.973
Incandescent	30	0.973	−2.582	0.903	0.947	−2.347	0.965
Incandescent	30	0.937	−2.466	0.929	0.962	−2.415	0.971
Incandescent	30	0.945	−2.519	0.936	0.972	−2.452	0.968
Incandescent	30	0.943	−2.476	0.939	0.978	−2.463	0.979
Incandescent	30	1.000	−2.828	0.922	1.017	−2.744	0.973
Incandescent	30	0.972	−2.686	0.947	1.000	−2.622	0.975
Averages		0.962	−2.584	0.927	0.970	−2.458	0.972
Incandescent	25	0.848	−2.470	0.938	0.861	−2.417	0.973
Incandescent	35	1.034	−2.403	0.895	1.003	−2.181	0.960
			1980 USDA Standard Grade Set				
Incandescent	30	0.852	−2.119	0.965	0.850	−1.994	0.984

*A 0.3 exponential linearization model was used for all instrument data. Regression results are based on the average of 24 readings per standard grade box.
**Since this instrument displayed square root results, the data were reduced to the 0.6 power for linearization.

method involves leaf content and trash type decisions by the instrument operator. Within this grading system, estimates of nonlint content are assigned to each cotton sample by comparing the amount of leaf area observed in the cotton against a set of black and white photographs of cotton biscuits with known leaf grades. Our purpose of developing the image analysis trashmeters discussed in this report is to refine, improve, and automate the HVI leaf grading system.

In order to develop a universal method of grading cotton for trash content with image analysis type instruments, it was necessary to determine the way the instruments respond to the USDA classer's grade standards. A typical set of standard grade guide boxes was selected and numerous trashmeter data replications were recorded on both instruments. This first standard set had been prepared by the Cotton Division from cottons grown in 1981. The set contained seven white cotton grade boxes, four spotted cotton grade boxes, and three tinged cotton grade boxes. Each of the 14 boxes contain six different cotton biscuits which measured 5 × 6.5 in. Each biscuit (within a box) is manufactured to represent a specific grade of cotton for the six different growing regions of the country. Since there is some variability in measuring individual biscuits on the trashmeter, four readings were recorded on each biscuit. To establish average instrument response for each cotton grade, all 24 trashmeter readings taken from the six biscuits in each box were averaged. Figures 2 and 3 show average values for standard guide box set number 1 using the two trashmeters as we received them. Differences between the two instruments affecting these data were:

(*a*) The Spinlab trashmeter contained two 5 watt North Sky daylight type fluorescent illuminators. These illuminators produced a light source identical to that normally used by cotton graders in classing offices.

(*b*) The Motion Control trashmeter contained two incandescent illuminators which are normally used in their cotton colorimeter. Additionally, MCI linearized their trashmeter response by displaying the square root of all TV scan results.

Statistical analyses were performed to determine the best data linearization model for TV scan cotton trashmeters using the data recorded by both instruments with set No. 1 standard grade cottons. The analytical results showed that trash area and particle count data could both be linearized for trash grade using a cube root relationship. However, for convenience, we selected an approximate exponent of 0.3 (see Figs. 4 and 5). The regression analyses included only trash readings for white grade cottons. Trash data with spotted and tinged cottons, measured on the MCI trashmeter, indicated only minor differences from white cottons in the set (Fig. 5). However, significant differences were observed with the spotted and tinged cotton measured with the Spinlab trashmeter (Fig. 4). Because of other problems discovered concerning the use of fluorescent illuminators (discussed later), the Spinlab trashmeter linearization experiment was repeated using two incandescent illuminators. The data show (Fig. 6) the same high degree of linearity for white grade cottons (r^2 values were greater than 0.99) and a significant reduction in the differences due to lint yellowness. A complete listing of all regression data for both instruments, both type of illuminators, and all threshold settings used are shown in Table 1. Regression coefficients (r squared values) for the Spinlab trashmeter were consistently above 0.98 while those

Table 2 Distribution of experimental test cottons and average trashmeter response for each grade using incandescent sample illumination

Leaf grade	Number of samples	MCI 3000 Area (no. of pixels)$^{0.5}$	MCI 3000 Count (10 × No.)$^{0.5}$	Spinlab 835 Area (percent)	Spinlab 835 Count (number/obs.)
Fanhead samples					
1	1	3.67	5.50	0.15	6.25
2	19	12.15	15.13	0.82	20.37
3	30	15.33	19.63	1.62	37.55
4	43	22.75	27.88	2.67	63.37
5	17	30.04	35.11	3.38	80.23
6	10	34.26	39.32	3.98	90.57
7	2	34.96	44.88	5.31	126.33
Lint slide sample set					
3	177	17.72	20.10	0.47	17.64
4	325	26.92	28.39	0.94	33.17
5	549	39.64	39.21	2.02	60.05
6	309	53.35	50.10	3.54	89.56
7	142	62.80	57.85	4.28	115.16
8	10	74.08	65.39	5.49	136.89
Lint slide "save" samples					
3	27	17.40	20.04	0.493	19.57
4	30	23.78	26.31	0.894	32.32
5	30	34.06	35.28	1.618	52.63
6	27	52.69	49.96	3.497	92.30
7	36	66.72	61.26	4.652	126.22
8	9	73.56	66.17	5.440	138.91

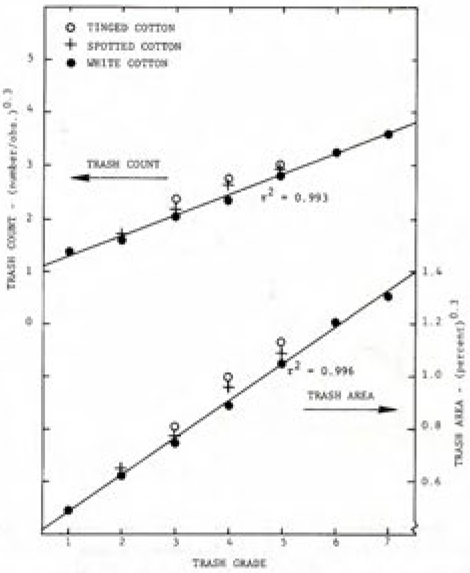

Fig. 6 Linearized response to trash grade using 1981 USDA standard grade guide boxes on the Spinlab Model 835 trashmeter with incandescent

calculated for the MCI trashmeter ranged from 0.895 to 0.965. We feel that the reduced trash grade linearity of the MCI trashmeter was due to the higher pixel resolution and the type of detector used on that instrument. We believe that a sufficient number of observations were taken to overcome any sampling differences due to the smaller sample observation window.

Trash Grading Accuracy Using Raw Cotton

Two sets of gin lint cotton samples were selected to evaluate the trashmeters for grading accuracy with raw cottons (Table 2). The first set were fan head samples collected by the USDA-AMS Memphis Laboratory from cottons grown in the 1979 and 1980 seasons. Each cotton had been given a visual leaf judgment by a cotton classing specialist. Originally, there were 141 cottons in this set. They were used previously in a preliminary evaluation of the Spinlab trashmeter [9]. Due to the extensive Shirley analyzer testing of these cottons, only 122 samples remained for the current trashmeter evaluation program. The second set of cottons were lint slide samples collected from a gin stand lint slide during a cotton cleaning experiment by the USDA-ARS Stoneville Ginning Research Laboratory. Three different samples were taken during the formation of individual cotton bales (early, middle, and late). Each sample had been given a leaf grade by a Greenwood Mississippi cotton classing specialist who used a 1981 standard set as a grading guide. A total of 504 cotton bales were included in the study. Thus the second set involved trashmeter measurements on 1512 cotton samples.

During testing of the large second set of lint slide samples, ten cottons (3 samples each) from each leaf grade were set aside to make a third "save" sample set for future repeat testing with the instruments. However, due to the actual cotton supply and a sampling error, not all grades had exactly ten cottons (Table 2). In selecting the third sample set, care was taken to select only cottons which all three samples from that bale had been given the same leaf grade by the classing specialists.

To establish the trashmeters response to these "unknown" gin lint cotton samples, three experimental replications were first performed using the fan head samples and data were recorded for both instruments. This testing involved eight exposures with each cotton sample. Care was taken to insure that each exposure involved a different cotton sample face. Average values for the cottons within each leaf grade were compared to linearized regression results from standard biscuit set number 1 (Figs. 7 and 8). Each data point represents the response value averaged for the number of cottons identified by the classer as having a given trash grade. Three such replications are shown. The specific number of cottons in each grade is indicated in Table 2. Average area response values produced with the MCI trashmeter agreed reasonably well with the 1981 standards for trash grades 2 through 5 (Fig. 7). However, the area response was slightly lower than the 1981 standards for trash grades 1 and 6. Trash count results (see also Fig. 7) show a similar trend as that produced with the area data, except that the general level of trash count observed with the fan head cottons was higher than that observed with the 1981 standards.

Trash area and trash count results using the fan head

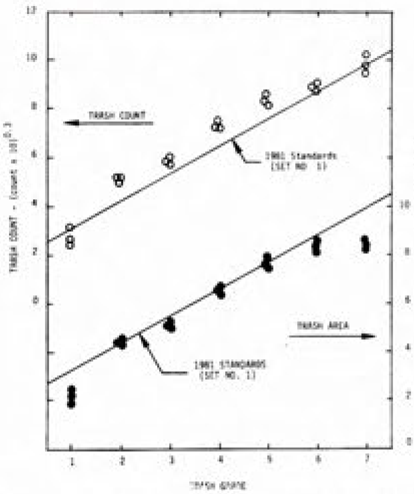

Fig. 7 Comparison of the average area and count response for 122 fanhead cotton samples with the linearized grade standard response using the MCI 3000 trashmeter (3 replications shown)

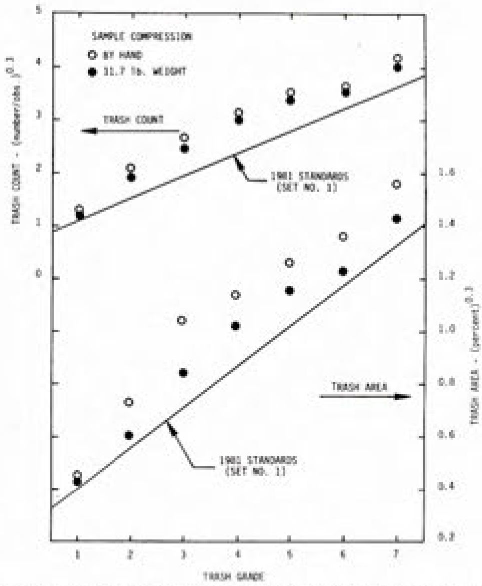

Fig. 9 Comparison of the average area and count response for 122 fanhead cotton samples with the linearized grade standard response using the Spinlab 835 trashmeter with incandescent bulbs

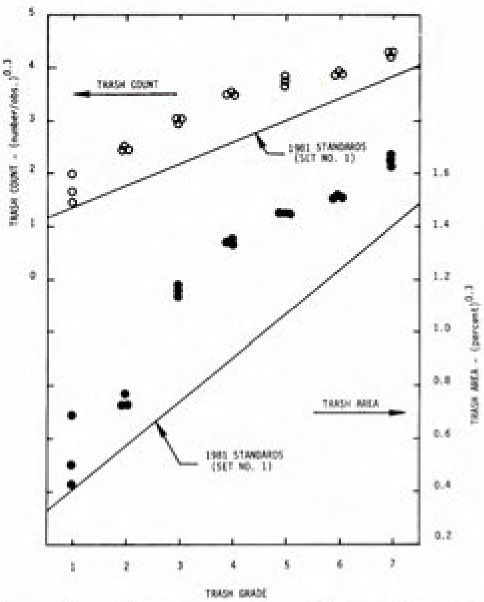

Fig. 8 Comparison of the average area and count response for 122 fanhead cotton samples with the linearized grade standard response using the Spinlab 835 trashmeter with fluorescent bulbs (3 replications shown)

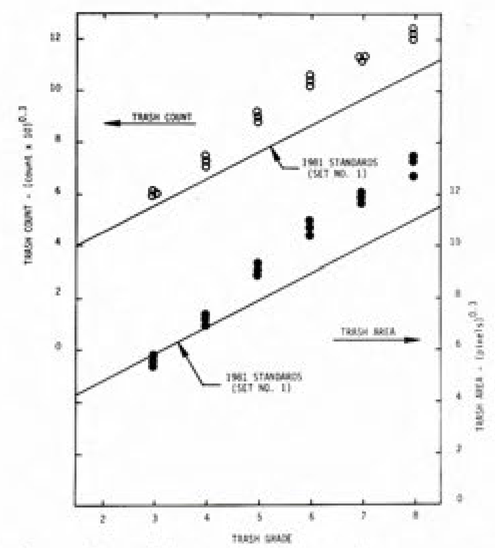

Fig. 10 Comparison of the average area and count response for 504 lint slide cotton samples with the linearized grade standard response using the MCI 3000 trashmeter (3 replications shown)

cottons on the Spinlab 835 trashmeter were significantly different from the MCI results (Fig. 8). These data show that both the average trash area and trash count were significantly higher than that observed with the 1981 standards. The data not only showed that the gin lint sample results were high over the entire grade range but all three replications were consistently high. We therefore chose to make two additional replications with the fan head samples using the Spinlab trashmeter (see Fig. 9). Each additional replication involved a design change which was intended to achieve a lower area response on the gin lint cottons. The first change involved replacing the two illuminators with two 12 volt incandescent diffuse illuminators (used during the previous evaluations [9]). Sample compression by hand was continued. The gin lint area response results were slightly lower and in better agreement with the 1981 standard set. However, we felt that there remained a significant amount of surface texture and shadowing which was being counted as trash. Therefore, the second testing change involved the addition of an 11.7 pound weight to provide uniform compression to the samples. The weight measured 4 × 5 in. and it was placed on the top of each sample and each standard biscuit prior to triggering the TV scan. The gin lint area and count results for this replication were in better agreement with the 1981 standard set. However, both area and count response values for all grades remained higher than that observed using the standards. The largest differences occurred in the middle grades (i.e., grades 3, 4, and 5; Fig. 9).

With the only remaining technical difference between the two trashmeters being the type of TV camera used and its image pixel resolution used for data processing, we decided to test the lint slide samples. Trash area and count results for both trashmeters were in very good agreement with each other (Figs. 10 and 11). However, except for trash grade three cottons with the MCI trashmeter, all response values for both trashmeters were higher than the linearized response of the 1981 standards. Therefore, since both instruments agreed with each other, we concluded that a portion of the high trash readings on lint samples could be partially due to a grading bias by the cotton classer.

Table 3 Trashmeter grading accuracy compared to classer's leaf using grade A 1981 USDA standard guide box set for calibration*

Grade error	MCI 3000 Compressed automatically Area	MCI 3000 Compressed automatically Count	Spinlab model 835 (Fluorescent) Compressed by hand Area	Spinlab model 835 (Fluorescent) Compressed by hand Count	Spinlab model 835 (Incandescent) Compressed by hand Area	Spinlab model 835 (Incandescent) Compressed by hand Count	Spinlab model 835 (Incandescent) Compressed with 12 lb/wt Area	Spinlab model 835 (Incandescent) Compressed with 12 lb/wt Count
Fan head sample set								
−2	8				1		1	
−1	37	9			6	2	13	4
None	48	43	7	4	22	19	39	33
1	7	39	22	30	32	40	31	44
2		8	33	43	25	27	12	13
3		1	27	17	8	10	2	6
4			9	6	6	2	1	
5			2					
Average	−0.46	0.49	2.17	1.91	1.23	1.28	0.52	0.84
Lint slide samples								
−2								
−1	12	2					5	1
None	25	19	* * * * Not tested		* * * *		26	18
1	36	48					34	56
2	22	29					28	24
3	6	2					6	1
4							1	
Average	0.85	1.10					1.08	1.06
Lint slide "save" samples			Compressed with 12 lb/wt**					
−2	1		1	1				
−1	16	2	11	1			3	
None	33	32	35	15	* Not tested *		32	16
1	19	32	16	36			27	57
2	25	30	26	30			29	26
3	6	3	10	17			8	1
Average	0.69	0.99	0.87	1.44			1.09	1.12

*Expressed as a percent of cottons in the sample set.
**A threshold setting of 110 was used for this experiment only. All other data are for the control threshold settings of 140 and 30 percent.

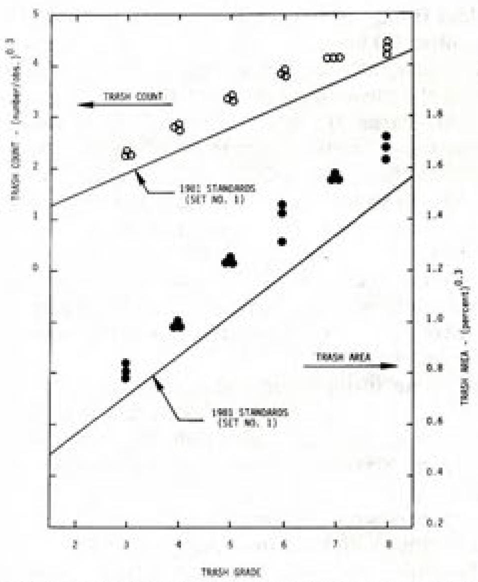

Fig. 11 Comparison of the average area and count response for 504 lint slide cotton samples with the linearized grade standard response using the Spinlab 835 trashmeter with incandescent bulbs (3 replications shown)

Trash Meter Grade Calibrations

Ultimately, we want a trash grading system that provides accurate and reliable estimates of the amount of mill processing waste and processing difficulties caused by the various types of trash in cotton. However, since the current trash classing system has been in place for many years and it has proven very effective, we must also develop the relationship between trashmeter response and classers leaf or trash grade. Later, we will discuss the relationship between trashmeter response and Shirley Analyzer nonlint content. Estimating mill waste is beyond the scope of this paper.

It should be noted that the standard biscuits in a classing guide box are said to represent the range of trash allowed for that grade. Any amount of trash in excess of that represented by the standard causes that cotton to be reduced in grade. Therefore, we assumed that the regression line produced by linearizing the grade standard data, forms the midpoint of the trash grading zone. With this information, we can use the following equation to convert trashmeter readings into leaf grades.

$$\text{Grade} = A + B \times (\text{Reading})^{y} \qquad (1)$$

Where: y = linearizing exponent (0.3 for Spinlab 835 and 0.6 for MCI 3000)
A = regression intercept
B = regression slope

The resulting grade values should be rounded to the nearest whole number. Regression coefficients should be determined with a USDA leaf grade standard reference biscuit set. Since an acceptable leaf grade standard does not currently exist, we arbitrarily selected the white cottons in the 1981 USDA grade standard set for our reference.

Instrument trash grade values were calculated for each cotton sample using the average standard biscuit regression coefficient from Table 1 in the foregoing equation with the

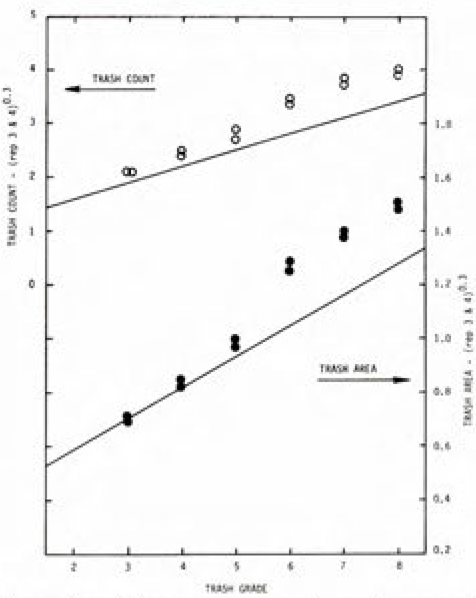

Fig. 12 Comparison of the average area and count response for 50 lint slide cotton samples with the linearized grade standard response using fluorescent bulbs at 110 threshold setting (2 replications shown)

average trash area and trash count reading for that sample. Trash grading errors for both instruments were determined for each cotton by subtracting the classer's leaf grade call from the instrument's trash grade value. This approach provided a convenient quantitative method of evaluating the trashmeters. Frequency distributions of trash grading error by instrument and cotton sample set are tabulated (Table 3). The numerical results of the experiment with fan head samples show that based on a large set of cottons the MCI trashmeter average area agreed quite well with the average classer's leaf call (−0.46 average grade error for trash and 0.49 average grade error for count) but only 48 and 43 percent of the trash area and count grades produced with the instrument agreed exactly with the classer's leaf grade. More importantly, the fan head sample data show that the Spinlab trashmeter (using fluorescent illuminators and sample compression by hand) had measured a significant amount of unexpected dark areas which was indicated by an average trash area grade error of 2.17 and an average count grade error of 1.91. Additionally, only 7 percent of the trash area graded samples agreed exactly with the classers grade while only 4 percent of the trash count graded samples agreed with the classer. Trash grade values were calculated for the two additional replications recorded with the Spinlab trashmeter using incandescent sample illumination (Table 3). Trash grades for these latter experiments were significantly improved but the average grade error remained higher than values calculated for the Motion Control trashmeter (the average area grade error was 0.52 and the count grade error was 0.84). The percent of cottons that agreed exactly with the classer improved to 39 and 33 percent for area grade and count grade, respectively. We felt that the cottons had become very lumpy (bad preparation) because of the extensive handling during the many test replications.

Grade calculations for the large set of lint slide cottons were performed for both trashmeters to confirm instrument area and count response discussed previously. There were 504 bales in this set and three replications were performed at the point of sampling. Therefore there were three cotton samples from the same bale available for a classer's leaf grade judgment. A consistent leaf call was made on 304 (60 percent) bales while the call on 196 (39 percent) bales differed by one grade and 3 bales had a two grade difference. A "consensus" classers grade was assigned to each bale. The third sample grade was ignored. Only two bales failed to meet the consensus criteria and their data were discarded. Based on classer's grades as a reference, instrument grading errors were calculated for both trashmeters using both the full set of lint slide samples and those that were retested as "save" samples.

At the request of the instrument manufacturer, two additional replications of the save portion of the lint slide samples were made on the Spinlab trashmeter using the fluorescent illuminators at a threshold of 110 and with the 11.7 pound weight for sample compression. The average response was similar to that observed with incandescent illumination (Fig. 12). Calculated grade error results for these replications show a reduced error based on trash area and an increased error based on trash count (Table 3).

Results of the gin lint cotton observation experiments show that when both instruments use incandescent sample illumination and a method of providing the appropriate constant sample compression, the resulting trash grades agree reasonably well with each other but they do not necessarily agree with the cotton classer. However, the data also show that there was (as seen by both trashmeters) more trash in the lint slide samples than in the biscuits represented by the grade standard guide boxes. Since most of the lint slide samples contained large quantities of trash (no grade 1 or grade 2 samples were present), there appeared to exist a reluctance on behalf of the classer to call the trash grades high enough. The count results also show that the trash particles observed in the lint slide samples were smaller than those observed in the 1981 standard biscuits. This characteristic was demonstrated by the fact that the average count grade error was consistently higher than the area grade error for both instruments and for all cotton sample sets using incandescent sample illumination.

Trash Size Considerations

When a cotton classing specialist determines the leaf grades for a cotton sample, he first makes a judgment concerning the "amount" of trash present (mostly leaf particles), he then makes minor adjustments to the trash grade for leaf size and the type of other trash observed. Leaf includes dried and broken plant foliage of various kinds and it is divided into two general groups: (1) large leaf and (2) "pin" or "pepper" leaf. Large leaf is generally less objectionable since it is more easily removed by the cleaning process. If the leaf is judged to be predominantly large, the leaf grade may be adjusted up from the basic amount grade. Conversely, the grade may be adjusted down if the leaf is judged to be predominantly pepper leaf. In addition to leaf, other visible material such as stems, hulls, bark, seeds, shale, and grass may be detected by both the classer and with scanning type trashmeters. However, since the TV cameras used in the trashmeters were black and white (trash color was not available for identifying the other types of trash) all dark areas were combined into a general "trash" category.

To gain some insight into the way trashmeters interpret different size trash particles, we manufactured several dot papers, each with the same size dots uniformly distributed over the paper. Sixteen different dot-size papers were made using dots ranging from 0.015 in. to 0.275 in. in diameter. All of the dot papers were measured for total dot area at several threshold settings with both instruments (see Figs. 13 and 14). The results indicated similar trends for both instruments. A significant area magnification for threshold settings nearest the average reflectance level (20 percent for MCI and 160 for Spinlab). The data also show that the commonly used threshold settings (30 percent for MCI and 140 for Spinlab) also produced a significant area magnification. More importantly, at these threshold settings, the area magnification is greatly increased for smaller dots. At the recommended threshold settings dots smaller than 0.03 in., the area magnification factor may cause the instrument to indicate an

Table 4 Trash grade multiple regression results for the best two variable model to predict cotton leaf grade with trashmeters using incandescent illumination*

Trashmeter	Threshold	B Coefficients			R^2
		Intercept	$(Area)^y$	Size	
1981 USDA standard grade set					
Spinlab 835	140	−2.386	7.119	Omitted	0.998
Spinlab 835	140	−2.060	7.114	−0.090	0.998
M.C.I. 3000	30	−2.112	0.892	Omitted	0.928
M.C.I. 3000	30	1.084	0.905	−0.296	0.996
Fan head samples					
Spinlab 835	140	−0.171	4.211	Omitted	0.72
Spinlab 835	140	2.281	4.909	−0.982	0.75
M.C.I. 3000	30	−0.699	0.727	Omitted	0.75
M.C.I. 3000	30	0.234	0.840	−0.245	0.79
Lint slide samples					
Spinlab 835	140	0.384	3.862	Omitted	0.80
Spinlab 835	140	1.476	4.556	−0.551	0.84
M.C.I. 3000	30	0.712	0.478	Omitted	0.81
M.C.I. 3000	30	1.561	0.646	−0.235	0.84

*Model: Grade = B1 + B2 × $(Area)^y$ + B3 × Size

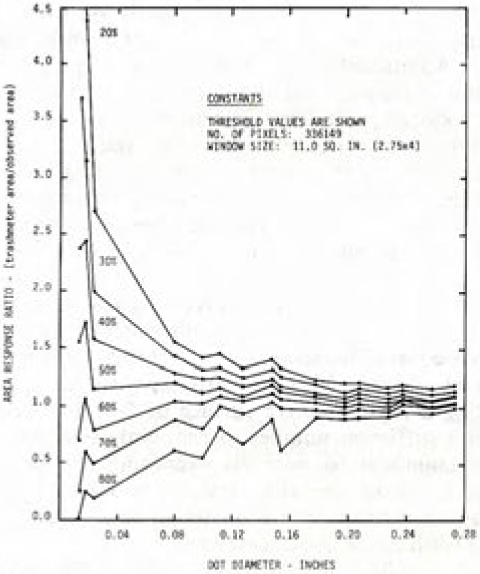

Fig. 13 Motion Control Model 3000 trashmeter area response to various sizes of black circular dots uniformly positioned on white paper

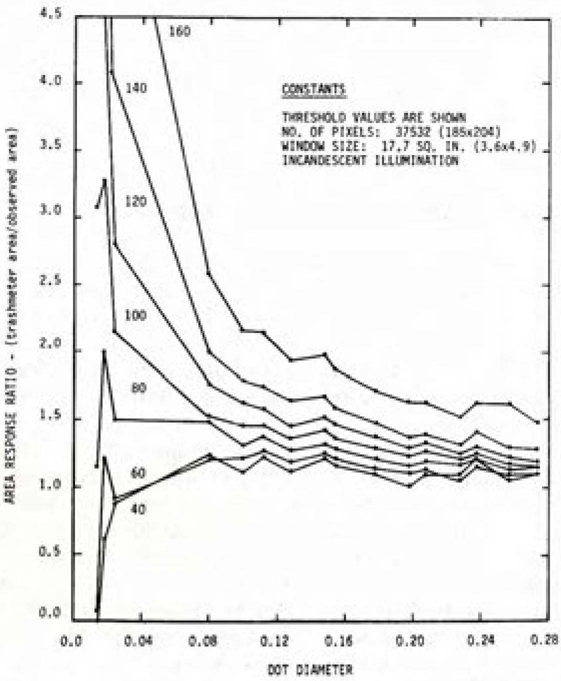

Fig. 14 Spinlab Model 835 trashmeter area response to various sizes of black circular dots uniformly positioned on white paper

area greater than 2 times the actual dot area. It should be noted that the dots used for this experiment were made with black ink on very white paper. The relative reflectance contrast between a real trash particle on the surface of a grey or yellowed cotton is not as large as that observed with the dot paper. Therefore real trash particles should not produce the level of area magnification indicated with the dot papers.

In order to develop a single trash grading relationship that encompassed both trash amount and particle size in a manner familiar to cotton classers, we chose to combine trash area and trash count into a characteristic particle size parameter (*P*). For the Motion Control Model 3000 trashmeter, the average number of area pixels per particle can be determined directly from the displayed instrument data.

$$Pm = Km \times (\text{``Trash''})^2/(\text{``Count''})^2 \qquad (2)$$

Where: Km = 10, a constant used to convert data to pixels/particle (or mm/particle when the pixel size is defined).

It should be remembered that the above count integration was based on trash particle and scan interactions, which can occur at any cordal position. Therefore the actual observed particle diameter should be slightly larger than one would estimate with the particle size parameter.

For the Spinlab Model 835 trashmeter, the size parameter may be determined from:

$$Ps = (Ks \times \text{``Area''}/\text{``Count''})^{0.5} \qquad (3)$$

Where: Ks = 375.63, a constant used to convert percent area to pixels per particle (or mm/particle when the pixel size is defined).

Here again the actual particle diameter should be slightly larger than indicated by the size parameter.

Grade Calibrations Including Trash Size

The combined trashmeter response equation now takes the following form:

$$Grade = A + B(Area)^y + C(P) \qquad (4)$$

Where: y = 0.6 for MCI and 0.3 for Spinlab A, B, and C are determined from a multiple regression with a calibration set of cottons.

Table 5 Trashmeter grading accuracy compared to the classer's leaf grade using the two variable calibration based on a 1981 USDA standard guide box set*

Grade error	MCI 3000 $trash^{0.6}$ + size	Spinlab 835 $area^{0.3}$ + size	
		Fluorescent	Incandescent
Fan head samples			
−1	1		9
None	23	6	32
1	63	25	39
2	12	36	14
3	1	22	5
		9	1
		2	
Average	0.89	2.11	0.76
Lint slide samples			
−1			4
None	14		26
1	53	*Not tested*	36
2	31		29
3	2		5
			1
Average	1.22		1.09
Lint slide "save" samples			
−1		7	17
None	30	35	42
1	34	21	28
2	29	27	13
3	6	10	
4			
Average	1.08	1.00	0.38

*Expressed as a percent of cottons in the sample set.

Based on the combined trash area and particle size parameter data, multiple regressions were calculated for both trashmeters using the 1981 USDA standard grade set and both sets of cotton samples (Table 4). These data show a significant improvement in the USDA standard grade regression for the MCI trashmeter when particle size was added (0.928 to 0.996). Additionally, since the explained variance was very high for the Spinlab trashmeter with grade standards ($r^2 = 0.998$), very little improvement in the regression was expected by adding particle size. No significant improvement was observed. Applying the same statistical procedures to the data collected for raw cotton samples, the regression data show the best coefficient of explained variance for the Spinlab 835 trashmeter was 0.75 for the 122 fan head samples and 0.84 for the 504 lint slide cottons. Similarly, for the MCI 3000 trashmeter these coefficients were 0.79 and 0.84, respectively. Linearized area correlations are included for comparison purposes (Table 4). The good agreement between classer's leaf grade and instrument trash grade, suggests that there is significant validity in the two variable models. We feel that a large portion of the 16 to 21 percent unexplained variance in lint samples involves grading parameters such as preparation, luster, and trash color or type which can influence both instrument and classer's grade estimates. Note that preparation and luster are both carefully controlled when standard grade guide boxes are prepared. Thus a high degree of explained variance was expected with grade standards.

Instrument trash grade values were recalculated for each raw cotton sample using the two variable model and the appropriate coefficients determined with the multiple regression analysis of the 1981 standards. As before, individual sample grade errors were calculated by subtracting the classer's grade. Frequency distributions of the instrument grading errors were similar to that discussed earlier (Table 5). Average error results for the Spinlab trashmeter were between the average values produced with calibrations based on either trash area or trash count alone (compare Table 5 averages with Table 3). However, in each case, the average two variable grade error for the MCI trashmeter was larger than either single variable calibration error. We feel the increase in grading error for the MCI trashmeter was due to the high pixel resolution of that instrument. Using smaller pixels enhances the instruments ability to characterize trash particle size. Therefore, since the particle size distribution on the USDA standard grades did not agree with the size distribution found in the raw cotton samples, the two variable calibration over-compensated for trash particle size.

The two variable multiple regression method, which now includes the particle size magnification effect, tends interchange the trash area grade for particle size. This condition is especially true for the high grade cottons where only a few trash particles may exist. Therefore, in developing a trash standard for instruments, one should consider the size of particles appropriate for each grade.

Trash Grading Confidence

One very important factor in determining the ultimate utility of any type of trashmeters as an instrument for cotton quality classification will be its ability to consistently produce the same trash grade for each bale of cotton checked. Ideally, trash grade readings should agree exactly regardless of the instrument manufacturer or the specific instrument installation. Additionally, the grade produced for a particular bale should be the same for all trashmeter operators including cotton producers, classers, merchants, and buyers alike. Realistically, we usually tend to relax repeatability requirements in order to meet a desired testing productivity requirement. Eventually the trashmeter acceptance will be principally based on trash grading repeatability when it is operated at a production rate compatible with the HVI system.

As with many measurements involving raw cotton in bale form, the gross inhomogeneity must be considered in the testing procedure. Therefore, when a trashmeter is used by an operator who is not skilled in identifying trash for the purpose of selecting a representative surface or face for trash identification a sufficient number of randomly selected surfaces must be examined to properly represent the entire bale. Whereas, a cotton specialist, trained in selecting a typical face, may want to use a trashmeter to help identify the appropriate trash or leaf grade category.

Two approaches were used to estimate the number of trashmeter face exposures required to provide the desired trash grading confidence. First, a statistical t-test analysis was performed using trashmeter sampling variability data in conjunction the appropriate grade limits that had been established with the linearized grade standard regression analysis. Second, the statistical analysis was tested experimentally by retesting the same set of cottons. Repeatability measurements were recorded using eight observations per sample during three replications with the 122 fan head cotton samples and during four replications with the 159 lint slide save cotton samples. Data for repeatability calculations based on four observations were taken as the first four observations recorded in the eight observation experiment.

The statistical data show that from five to ten observations are required for 70 percent testing repeatability when using the Spinlab 835 trashmeter and each exposure is recorded with a different gin lint sample face (Tables 6 and 7). The number of observations required depended on the illuminator, threshold setting, and on the particle count or area measuring method. However, when this instrument was used to measure surface trash on grade standards (only one face observed), the required number of observations was reduced to the range of two to six, which depended mostly on the sample illumination. In a similar manner, the gin lint cotton data suggest that the number of observations required when using

Table 6 Trashmeter sampling variability and the number of exposures required for 70 percent repeatability of the same grade using the trash area measurement

Threshold setting	Sample illumination	Grade 3 avg.	Grade 3 C.V.	Grade 4 avg.	Grade 4 C.V.	Grade 5 avg.	Grade 5 C.V.	Exposures required*
				Spinlab Model 835				
				Fan head samples				
137	Fluorescent	0.81	49	2.22	30	NT		8
140	Fluorescent	1.15	45	2.62	24	3.41	22	10
143	Fluorescent	1.47	33	3.25	19	NT		5
140	Incandescent	0.432	44	1.14	28	1.83	27	10
				Lint slide samples				
110	Fluorescent							
140	Incandescent	0.46	50	0.85	40	1.94	30	10
				1980 Grade standards**				
140	Fluorescent	0.37	10	0.71	6	1.34	6	2
				1981 Grade standards**				
110	Fluorescent	0.32	14	0.51	9	0.80	11	4
140	Fluorescent	0.46	4	0.79	4	1.32	8	6
140	Incandescent	0.39	6	0.68	7	1.21	6	2
				Motion Control Model 3000				
				Fan head samples				
35	Incandescent	11.2	42	16.8	27	NT		18
30	Incandescent	14.6	38	23.1	28	30.3	28	18
40	Incandescent	19.1	28	32.3	21	NT		10
				Lint slide samples				
30	Incandescent	17.9	33	24.6	29	38.5	23	15
				1980 Grade standards**				
30	Incandescent	16.8	17	26.4	11	34.8	7	5
				1981 Grade standards**				
30	Incandescent	14.4	16	27.4	9	32.6	9	4
				1982 Grade standards**				
30	Incandescent	23.2	12	30.5	12	39.3	10	7
				Field survey (Lubbock, TX)**				
30	Incandescent	15.6	13	26.5	9	37.0	3	4

*Using a two sided t-test at 95 percent confidence.
**Observations on only one sample face.

Table 7 Trashmeter sampling variability and the number of exposures required for 70 percent repeatability of the same grade using the trash count measurement

Threshold setting	Sample illumination	Grade 3 avg.	Grade 3 C.V.	Grade 4 avg.	Grade 4 C.V.	Grade 5 avg.	Grade 5 C.V.	Exposures required*
				Spinlab Model 835				
				Fan head samples				
137	Fluorescent	25.2	28	58.1	19	NT		5
140	Fluorescent	30.3	28	64.9	19	79.5	15	9
143	Fluorescent	37.2	23	77.0	15	NT		5
149	Incandescent	16.8	34	40.0	20	60.5	17	5
				Lint slide samples				
110	Fluorescent							
140	Incandescent	17.5	30	30.1	24	59.1	17	5
				1980 Grade standards**				
140	Incandescent	12.0	16	21.1	16	43.0	8	3
				1981 Grade standards**				
110	Fluorescent	7.6	18	12.3	17	23.0	13	4
140	Fluorescent	10.7	16	21.6	11	38.7	10	3
140	Incandescent	10.4	12	19.3	12	39.8	10	3
				Motion Control Model 3000				
				Fan head samples				
35	Incandescent	13.7	30	21.0	20	NT		10
30	Incandescent	18.3	27	28.4	18	34.5	19	12
40	Incandescent	24.2	19	39.3	16	NT		7
				Lint slide samples				
30	Incandescent	20.6	24	27.3	19	39.3	16	10
				1980 Grade standards**				
30	Incandescent	17.0	15	23.6	8	32.1	8	5
				1981 Grade standards**				
30	Incandescent	15.8	15	23.8	13	30.5	6	5
				1982 Grade standards**				
30	Incandescent	20.7	17	29.8	10	35.4	7	6
				Field survey (Lubbock, TX)**				
30	Incandescent	19.5	11	27.7	9	41.0	5	3

*Using a two sided t-test at 95 percent confidence.
**Observations on only one sample face.

different faces with the MCI 3000 ranged from seven to eighteen depending on the threshold setting and the count or area trash measuring method. Additionally, using this instrument with the grade standard biscuits the number of observations required was reduced to the range of three to seven. From these data we conclude that the number of observations required depends mostly on the cotton sample consistency and secondly on the instrument window size. For both instruments, the particle count was shown to be the most consistent single estimator for leaf grade.

Repeatability data from the retesting experiment using gin lint cottons showed that the Spinlab Model 835 trashmeter using incandescent illumination and eight observations for trash count had the best agreement with previously recorded trash grades (82 percent; Table 8). Data from the same experiment show that the Motion Control Model 3000 indicated the lowest trash grade repeatability when only four observations were made per cotton and trash area is used to define the grade (46 percent). Trash grade repeatability for the MCI trashmeter was consistently improved when both trash area and trash count were used in a single two variable grade equation. The maximum value for this instrument was 70 percent with eight observations on the lint slide cottons. Except for one occasion when fluorescent illumination was used (threshold 110), the Spinlab trashmeter produced the best repeatability when the grade was calculated from count alone. The only case that indicated 70 percent same grade repeatability based on four observations was the Spinlab trashmeter using incandescent illumination with the lint slide samples and trash count as the basis for determining grade. We feel that the major difference between instrument repeatability was due to observation window size.

Table 8 Percent same grade repeatability of the trashmeters with gin lint cottons using linearized calibrations for the leaf in white grades of a 1981 grade standard guide box set

Grade difference	MCI 3000 Trash$^{0.6}$	MCI 3000 Count	MCI 3000 Both*	Spinlab 835 Area$^{0.3}$	Spinlab 835 Count	Spinlab 835 Both*
Fan head samples**						
None	48	56	63	(54)	(68)	(58)
1	46	41	35	(41)	(32)	(39)
2	5	3	1	(5)	(1)	(2)
3	1		1			
Lint slide "save" samples***						
(8 Observations)						
None	59	66	70	71(63)	82(61)	74(68)
1	40	33	29	29(37)	18(38)	26(32)
2	1			(1)	(1)	
(4 Observations)						
None	46	56	59	50(50)	70(54)	57(55)
1	46	40	39	47(44)	29(45)	42(43)
2	6	4	1	3(6)	1(1)	1(3)
3	1		1		1	

*Both area and count combined into the two variable model (Table 4).
**Based on 8 observations on each sample for three replications on 122 cottons. The numbers in parenthesis indicate fluorescent illumination.
***Based on four replications on 159 cotton samples.

Estimating Shirley Analyzer Waste

The overriding purpose of any trash grading system must include considerations to the predictability of manufacturing mill waste and the associated loss in product quality caused by cleaning equipment used to remove the trash. Since a full scale trashmeter evaluation program involving mill waste collection and measurements was too extensive, we chose to use the Shirley Analyzer to estimate waste.

To determine how well the response of the video scan trashmeters relate to visible waste in cotton, nonlint content data were collected for all gin lint cotton samples used in the study. Fan head cottons were cleaned with the USDA-ARS Clemson, South Carolina Shirley Analyzer using a standard 2-pass cleaning procedure involving 100 gram samples [10]. Two replications were recorded. In a three way statistical comparison with classer's leaf call, the best correlation with Shirley visible nonlint content was 0.83 for the MCI trashmeter while a correlation of 0.89 with classer's leaf grade was observed (Table 9). Similarly, the best correlation with Shirley total nonlint content was 0.84 for the Spinlab trashmeter using fluorescent illumination, while a correlation of 0.76 with classer's leaf grade was noted. Shirley analyzer cleaning of the lint slide samples was performed by the USDA Cotton Ginning Research Laboratory at Stoneville, Miss. For this group of cottons, three 50 gram samples were cleaned from each of the three larger samples taken from each bale (i.e., nine 50-gram samples per bale). Since all of these samples were only identified by bale number, no individual sample correlations could be performed. Therefore, all 24 trashmeter readings (eight on each sample) were averaged together to get a bale response for the instrument. Based on this very extensive testing, all trashmeter correlations with Shirley visible nonlint content were 0.94 while a correlation of 0.92 with classer's leaf grade was observed (Table 9). Similar high correlation with Shirley total nonlint content was observed. We should note that the correlation between Shirley visible and Shirley total was unusually high for both sets of cottons (Table 9). To demonstrate the accuracy in using trashmeters for estimating visible waste, we developed the following model:

$$\text{Visible Waste} = C1 + C2 \times \text{Area} + C3 \times \text{Particle Size}$$

Table 9 Coefficients of simple correlation among trash grading methods

	Shirley nonlint Visible	Shirley nonlint Total	MCI grade Area	MCI grade Both	Spinlab grade Area	Spinlab grade Both
Fan head cottons ($N=122$)*						
Classer's Leaf	0.74	0.69	0.87	0.89	0.85(0.75)**	0.85(0.76)
Shirley Visible	1.0	0.96	0.77	0.83	0.81(0.80)	0.81(0.81)
Shirley Total	0.96	1.0	0.72	0.80	0.81(0.83)	0.81(0.84)
Lint slide cottons ($N=504$)*						
Classer's Leaf	0.87	0.87	0.90	0.92	0.89	0.90
Shirley Visible	1	0.99	0.94	0.94	0.94	0.94
Shirley Total	0.99	1	0.93	0.93	0.93	0.94

*Shirley nonlint data were based on two (100 gram) samples per bale and instrument trash grades were based on eight observations for fan head samples.
**Numbers in parenthesis indicate fluorescent sample illumination.
***Shirley nonlint data were based on nine (50 gram) samples per bale and 24 instrument observations for lint slide samples.

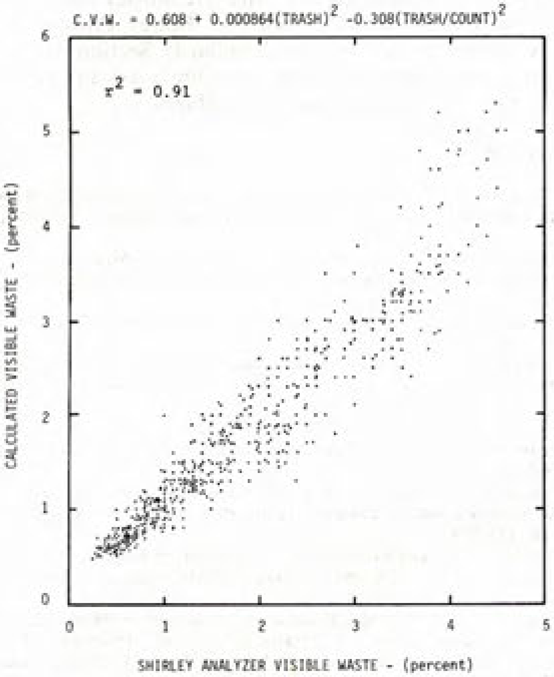

Fig. 15 Relationship of predicted trash content to observed Shirley Analyzer visible nonlint content using the Motion Control Model 3000 trashmeter

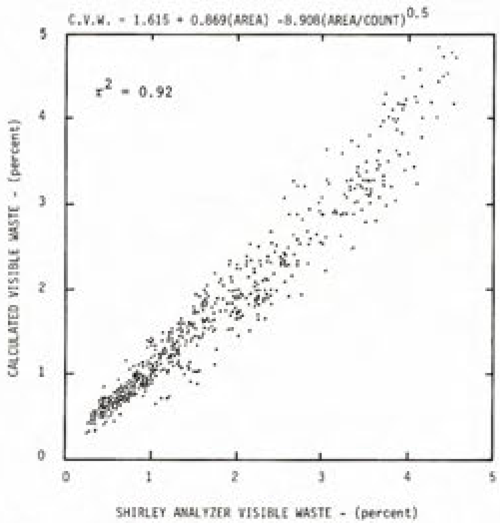

Fig. 16 Relationship of predicted trash content to observed Shirley Analyzer visible nonlint content using the Spinlab Model 835 trashmeter

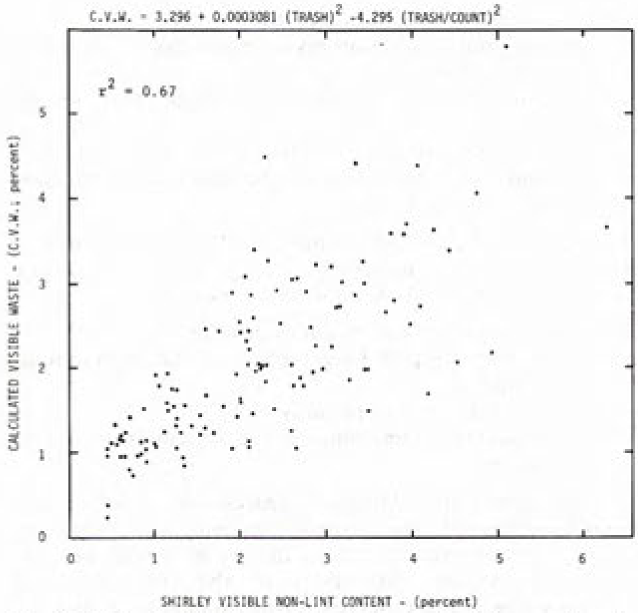

Fig. 17 Estimated visible waste for the fanhead cotton samples using 2 Shirley measurements and 8 observations with the Motion Control Model 3000 trashmeter

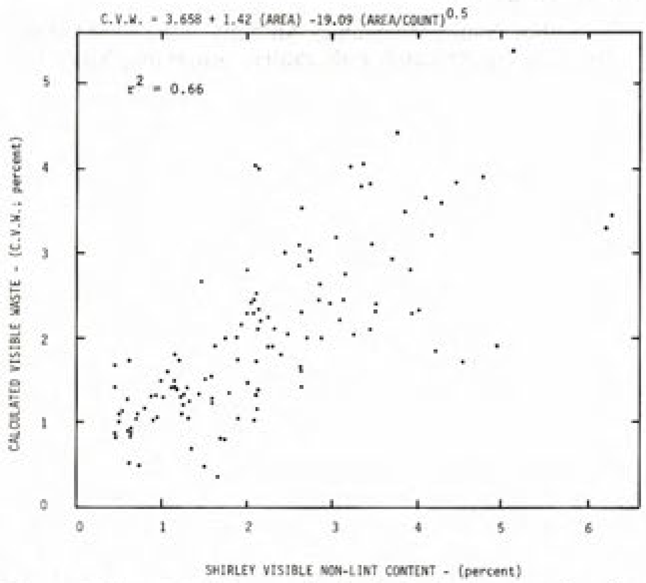

Fig. 18 Estimated visible waste for the fanhead cotton samples using 2 Shirley measurements and 8 observations with the Spinlab Model 835 trashmeter (incandescent illumination)

Statistical methods, similar to those discussed previously for developing the trash grade, were used. As expected, the measured trash area was shown to have a linear relationship with Shirley visible nonlint content. As noted in the foregoing, area correlation coefficients to 0.94 were observed ($r^2 = 0.88$). However, addition of the particle size parameter as the second variable improved the correlations considerably. Examples of trashmeter calculated waste for the lint slide cottons are shown (Figs. 15 and 16). These data are based on the best two variable statistical model to predict visible nonlint content using the average of nine (50-gram) Shirley measurements per bale and the average of 24 trashmeter readings per bale. More realistic correlations are shown for the fanhead cottons (Figs. 17 and 18), since these data are based on two (100-gram) Shirley measurements per bale and eight trashmeter observations per instrument.

Conclusions and Recommendations

Based on the data presented here and experiences gained during the instrument development period, we conclude that television based video scan trashmeters can do a reasonably accurate job of determining trash grade and, with a lesser degree of accuracy, estimate the actual nonlint content of cotton. Both trashmeter systems were extremely stable throughout the four month evaluation period. No observable drift or level change could be detected on the MCI Model 3000 trashmeter. Similarly, drift was not apparent with the Spinlab Model 835 trashmeter. However, level changes did occur when we changed or repositioned the sample illuminators.

In order that four sample observations can reasonably and consistently provide a cotton trash grade, we recommend:

(a) Incandescent sample illumination be used.
(b) A minimum sample observation window of 18 sq in. should be standard.
(c) A standard video chop rate of 20 megahertz should be used.
(d) All samples should be compressed to a uniform pressure of 0.5 psi against the observation window prior to scanning.

We recommend that both trashmeter manufacturers further define procedures for instrument users to inspect the system and prevent errors due to the following problems.

(a) Camera out of focus or out of position.
(b) Nonlinear sweep of TV camera or nonuniform sample illumination.
(c) Dust or trash in the optical system.
(d) Residual trash remaining on the window from cotton to cotton.

We recommend that additional research work be performed on standardizing individual instruments using a universal dot pattern calibration tile. Based on the tile as a reference for adjusting individual instruments to the same level, a statistically significant group of cottons should be graded by classing experts and used as a calibration basis. These trash grade standards should contain trash particles that are representative in both particle size and amount of trash.

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