PRELIMINARY THEORETICAL ANALYSIS OF LINT CLEANING

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Abstract

This research examined the feasibility of using previously developed mathematical equations for the prediction of lint wastage and cleaning efficiency. Experimental results supported the relationships established by these equations, but also indicated that immeasurable parameters associated with production (e.g. variety, location, etc.) hinder the equations' accuracy. Consequently, to maximize processing efficiency, a real-time measurement of lint cleaner waste is needed. A purely theoretical analysis was also conducted and the results indicated that cotton ginners may be using USDA recommendations concerning split stream lint cleaning incorrectly, resulting in a six to seventeen percent reduction in cleaning efficiency.

Introduction

As the U.S. cotton industry enters the twenty-first century, it is faced with increasing production costs, a highly volatile market and increasing global competition. As a result, it is imperative that the industry improve production efficiency.

It is often believed that potential productivity improvements lie strictly with the grower. However, because of a marketing system that places value on fiber rather than seed cotton, the cotton processor can significantly affect productivity. Consequently, it is very important to improve processing proficiency without compromising competitiveness. Many processors have elected to increase hourly capacity in an effort to achieve this goal. In fact, in the last 30 years the average number of bales produced per gin has increased from 1,774 in 1967 to approximately 15,000 in 1995 (Glade et al., 1996) without significantly increasing the annual operation time.

However, as the capacity of the processing plant grows, the complexity associated with monitoring the machinery also increases. In order to maintain fiber quality and maximize production, USDA researchers have developed process control algorithms for the cotton processing plant. These algorithms are used by microprocessors in conjunction with sensors to monitor the processing machinery and make real-time decisions about machine treatments. For example, moisture and trash measurements are used to help determine the cleaning sequence needed to optimize bale value.

At the heart of the cleaning sequence is the saw-type lint cleaner. As the primary cleaning mechanism, the saw-type lint cleaner is used to remove leaf particles, motes, seed-coat fragments and bark that remain trapped in the cotton fiber after seed removal. Numerous studies have been conducted in order to understand the physics of the saw-type lint cleaner. As a result of such research, it is widely accepted that several parameters besides lint moisture content and lint trash levels are important. In fact, numerous researchers have demonstrated that lint cleaner parameters such as combing ratio, saw speed and number of grid bars can significantly affect cleaning efficiency as well as minimize lint wastage (Mangialardi, 1970; Baker, 1977; Anthony, 1999). Baker (1977) developed equations that describe the performance of lint cleaners. He also hypothesized that the accuracy of these equations is greatly influenced by the immeasurable parameters associated with production (e.g. variety and location). Hence, the use of these equations for real-time process control does not seem feasible, but the relationships should still remain true and could be very helpful in the near future. For example, if it were possible to measure the amount of lint wastage, then these equations could be used in conjunction with the existing color, trash and moisture measurements to select the optimum operating parameters for a particular lint cleaner. These relationships could also be used to assist modern cotton processing plants achieve higher capacities without increasing lint wastage or decreasing cleaning efficiency.

Objectives

The first objective of this research was to determine if the relationships developed by Baker in the late 1970s remain valid for modern cotton varieties. A second objective was to use these relationships to demonstrate the possible misuse of USDA recommendations concerning split stream lint cleaning. Finally, a third objective of this research was to support or reject Baker's assertion that lint wastage is dependent on variables that cannot be measured (e.g. variety, location, etc.).

Materials and Methods

In order to accomplish the first objective, a microgin experiment was conducted. For the experiment, two varieties were selected from the cotton storage building, in Stoneville. Variety 1, Deltapine 5409, was spindle harvested on October 30, 1999 and Variety 2, Stoneville 425RR (roundup ready gene), was spindle harvested on October 14, 1999 by the USDA Application and Production Technology Research Unit. Processing was performed using the recommended seed-cotton cleaning sequence for ginning Mid-south spindle-harvested cotton (Anthony et al., 1994). The standard sequence consists of a shelf dryer, cylinder cleaner, stick machine, shelf dryer, cylinder cleaner, and extractor feeder.

Since the existing research demonstrated the importance of batt weight and combing ratio, three feed rates and five combing ratios were used in this study. The actual feed rates varied from the desired rates so the batt weights were calculated from the actual rates (total input cotton weight divided total gin time) according to the following equation.

$$B = \frac{F(C)}{60\pi(D)(S)} \qquad (1)$$

where C is the combing ratio, D is the saw diameter (m), S is the saw speed (rpm), F is the feed rate (kg/m/hr), and B is the batt weight (kg/m^2). During the trial, the saw speed was held constant at 875 rpm and Table 1 presents the mean feed rates, as well as the corresponding batt weights. Each treatment was replicated three times and three samples were taken from each treatment for wagon fractionation, wagon moisture, feeder fractionation, feeder moisture, Shirley analysis (three before and three after lint cleaning), High Volume Instrument (HVI), lint moisture and Advanced Fiber Information System (AFIS). After each treatment the lint cleaner waste was collected and sent to Caroline Simpson at the Cotton Quality Research Station for Shirley analysis.

Results

Lint Wastage

Using the statistical analysis software, SAS®, an *analysis of variance*, or ANOVA, was used to partition the variation in lint wastage (LW) into variation between and within several groups of observations. The overall *F* test, presented in Table 2 was significant (F=32.37, p<0.0001), indicating that the model, as a whole, accounted for a significant amount of the variation in lint wastage. Thus, it was appropriate to proceed with testing effects. To test the different effects, the individual significance was evaluated for each effect. The effect with lowest probability of significance was removed and the remaining effects retested. This was procedure was performed until all the insignificant effects had been removed from the

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model (significance level of 0.05). The R^2 value was then used to determine the percentage of lint wastage variation accounted for by the model (R^2=0.78, 78%). The coefficient of variation (C.V.), root mean square error (MSE) and mean lint wastage were found to be 9.7756, 0.1356 and 1.3871, respectively (Table 3).

The regression results indicated that both Variety 1 and Variety 2 supported the relationships developed by Mangialardi (1970) and Baker (1977). To illustrate the similarities, a graphical comparison is presented in Figure 1. Obviously, the relationships between lint wastage, combing ratio and batt weight were similar.

However, it is also apparent from Figure 1 that there are some differences between the three-dimensional surfaces associated with Varieties 1 and 2. For example, the lint wastage of Variety 1 varied dramatically with batt weight, while Variety 2 only changed slightly. These visual differences were supported by the "contrast between varieties" presented in Table 3. The results of this contrast indicated that the regression equations were significantly different (F=9.68, p=0.0002), which supported the hypothesis that lint wastage was influenced by production parameters.

Cleaning Efficiency

An analysis of variance was also used to partition the variation in cleaning efficiency (CE) into several groups. The overall F test (F=32.59, p<0.0001), presented in Table 4 indicated that the model, as a whole, accounted for a significant amount of the variation in lint wastage.

To test the different effects, the individual significance was evaluated for each effect. The effect with lowest probability of significance was removed and the remaining effects retested. This was procedure was performed until all the insignificant effects had been removed from the model (significance level of 0.05). The R^2 value was then used to determine the percentage of lint wastage variation accounted for by the model (R^2=0.47, 47%). The coefficient of variation, Root MSE, and mean cleaning efficiency were found to be 8.6575, 4.4247, and 51.109, respectively (Table 5).

The method of least squares was used to produce a linear model of cleaning efficiency (Table 5). The results indicated that the cleaning efficiency equations were very similar to those outlined by Baker (1977); an increase in initial visible foreign matter or combing ratio produced an increase in cleaning efficiency while an increase in batt weight decreased cleaning efficiency. These similarities are obvious if the three equations are presented as follows:

$$CE = 47.6 - 46 * B - 294.7/C + 5.55 * V \text{ (Cook-Variety 1)} \qquad (2)$$

$$CE = 49.2 - 46 * B - 294.7/C + 5.55 * V \text{ (Cook-Variety 2)} \qquad (3)$$

$$CE = 51.5 - 51.1 * B - 293.4/C + 0.0135 * S + 3.94 * V \text{ (Baker)} \qquad (4)$$

where

$CE \equiv$ cleaning efficiency
$B \equiv$ batt weight
$C \equiv$ combing ratio
$S \equiv$ saw speed
$V \equiv$ initial visible foreign matter

The only significant difference between the equations developed for Variety 1 and Variety 2 was in the intercept, indicating that Variety 2 was easier to clean than Variety 1.

Classing Data

Results of the classing data statistical analysis are presented in Tables 6, 7 and 8. The information presented in Table 6 indicates that feed rate affected manual color grade, HVI color grade, leaf grade, reflectance, yellowness (+b) and trash percent area while combing ratio only affected the staple length significantly. Table 6 also demonstrates that for a few variables (staple, yellowness and HVI color grade) the interactions were significant. As a result, the means associated with these variables can be misleading when averaged across variety, combing ratio or feed rate.

However, for most of the variables the interactions were not significant. Thus, it was acceptable to average over combing ratio and variety to obtain the dependent variable means associated with the three feed rates (Table 7). The results indicated that as feed rate and consequently batt weight decrease, the cotton's grade improves. This statement can be drawn from the information presented in Table 7, which indicates that as feed rate decreased, the manual color grade, leaf grade, trash percent area and reflectance improved. There was an exception, yellowness (+b) worsened as the feed rate decreased. As illustrated in Table 7, the +b reading moved from 9.04 to 9.24 as the feed rate decreased. However, this change was small and would likely have little effect on bale value. The HVI color grade means improved with decreasing feed rate but the difference was not statistically significantly when averaged across variety.

The means associated with combing ratio are presented in Table 8 and were obtained by averaging over variety and feed rate. Although the means could be used to support further research, they cannot statistically support a conclusive trend. Only the staple length was significantly affected by the combing ratio. A summary of the findings illustrated in Tables 7 and 8 is presented in Table 9.

Example: Theoretical Analysis of Capacity Increase Using Split Stream Configuration

Assume a cotton processing plant is interested in increasing the plant's capacity from 30 bales per hour (bph) to 45 bales per hour. This plant currently owns three Lummus 158 gin stands with 100 hp motors (maximum 10 bph per machine) and three Lummus 86 tandem lint cleaners (maximum 10 bph per saw cylinder). The capacity of each gin stand can be increased from 10 bph to 15 bph by changing the 100 hp drive motor to 150 hp. Consequently, increasing the capacity of the plant from 30 to 45 bph can be solved by increasing each lint cleaner's capacity from 10 to 15 bph, assuming all other processing machinery can accept the increased capacity.

There are several ways to increase lint cleaner capacity from 10 to 15 bph. The simplest method is to replace the old lint cleaners with new, larger capacity machines. However, new lint cleaners are very expensive and often difficult to justify in a competitive market. An alternative is to use the existing machines in the split (parallel) mode (Figure 2). In this mode, the cotton is equally split as it enters the lint cleaner. After splitting, the cotton is fed to each saw cylinder (referred to as Lint Cleaner 1 and Lint Cleaner 2) for cleaning. If the split mode must be used to increase capacity, the cotton can no longer be routed through two lint cleaners in series without decreasing capacity. While this limits the machines flexibility, research has shown that under most circumstances two lint cleaners, in series, are not needed (Mangialardi and Anthony, 1996; Baker and Brashears, 1999).

According to the Cotton Ginners Handbook (Anthony et al., 1994), the combing ratio is typically doubled when two tandem lint cleaners are split stream fed. Therefore, assuming the combing ratio is 25 for a feed rate of 10 bph, the combing ratio is 50 for a feed rate of 10 bph in the split mode (5 bph to both Lint Cleaner 1 and 2). If the feed rate is then increased to 15 bph (7.5 bph to both Lint Cleaner 1 and 2) the total theoretical cleaning efficiency of the machine is 50.20% and the total lint wastage is 1.94%, assuming the initial visible foreign matter is five percent and the Model 86 lint cleaner has an effective saw-cylinder width and speed of 75 inches and 1000 rpm, respectively. Alternatively, an interpolation between the combing ratios 25 and 50 can be used to find the recommended combing ratio (37.5) at a feed rate of 7.5 bph. Under these conditions, the total cleaning efficiency is 55.40% and the total lint wastage is 1.29% (Table 10).

The possibility of using an unevenly split stream is evaluated next in an effort to increase cleaning efficiency and decrease lint wastage. Table 10 presents the potential performance improvement if the stream is split into an 8-bph stream and a 7-bph stream with lint cleaner combing ratios of 35 and 40, respectively. In this arrangement the system can still handle 15 bph with the same amount of lint wastage, but the cleaning efficiency has increased to 55.42%. This increase in performance is small, but indicative of the performance of unequally split streams. If the streams are more unequally split into a 10-bph stream (combing ratio equals 25) and a 5 bph (combing ratio equals 50) the machine produces a total cleaning efficiency of 55.83% and total lint wastage of 1.29% (Table 10). Thus, just by unevenly routing the cotton the cleaning efficiency can be increased by approximately one percent with no increase in lint wastage.

But is it necessary to double the combing ratio when two lint cleaners are split stream fed? Griffin used this method to evaluate an "industry practice" (split mode) (Griffin, 1970). He also conducted experiments in 1967 and concluded that there was no significant difference between the grades of two lint cleaners in series and split lint cleaners, with no significant increase in fiber damage over that caused by one lint cleaner (Griffin et al., 1970).

It is believed that this split mode was proposed in an effort to achieve higher cleaning efficiency without processing the cotton through two lint cleaners in series (series lint cleaning has been shown to reduce fiber quality). However, the equations developed by Baker indicate that this improvement in cleaning efficiency was achieved at the expense of higher lint wastage (Table 10). The work by Griffin et al. (1970) supports this assertion. In fact, the authors state that the two lint cleaners in series produced approximately the same amount of total waste as two lint cleaners in the split mode (parallel), but the split mode waste contained more fiber.

Therefore, a combing ratio of 25 results in a higher cleaning efficiency and lower lint wastage, even in the split stream mode (Table 10). In fact, if a combing ratio of 25 was used for each lint cleaner in the split mode (7.5 bph per machine) a total cleaning efficiency of 58.65% could be achieved with less than 1.2% lint wastage (Table 10). This is nearly a six percent increase in cleaning efficiency when compared to combing ratios of 37.5 for each lint cleaner and almost a 17% increase in cleaning efficiency when compared to combing ratios of 50 for each lint cleaner. Figure 3 presents a plot of the theoretical cleaning efficiency and the lint wastage of a single lint cleaner for the various feed rates discussed above.

Summary

Results of a microgin experiment supported the hypothesis that immeasurable parameters (variety and/or location) significantly affect the accuracy of equations used to predict lint cleaner performance. The results also support the hypothesis that to accurately determine lint wastage a mass flow sensor must be developed.

A purely theoretical analysis, based on work conducted by Mangialardi and Baker, indicates that cotton ginners may be using USDA recommendations concerning split stream lint cleaning incorrectly, resulting in a decreased cleaning efficiency of between six and seventeen percent.

Future work should include an analysis of the lint cleaner parameters with the inclusion of fiber moisture content as a variable.

Disclaimer

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Table 1. Means of independent and dependent test variables [batt weights (kg/m^2) shown in bold].

	Mean Feed Rate (kg/m/hr)		
Combing Ratio	**154.82**	**368.62**	**506.4**
20	**0.0494**	**0.1134**	**0.1481**
25	**0.0574**	**0.1381**	**0.1968**
30	**0.0701**	**0.1421**	**0.2319**
40	**0.0874**	**0.2260**	**0.2963**
50	**0.1143**	**0.2838**	**0.3595**

Table 2. Lint wastage linear regression (all effects).

Dependent Variable: lint wastage (lw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	5.48116741	0.6090186	32.37	<.0001
Error	80	1.50532065	0.01881651		
Corrected Total	89	6.98648806			

R-Square	Coeff Var	Root MSE	lw Mean
0.784538	9.88888	0.137173	1.387148

Source	DF	Type III SS	Mean Square	F Value	Pr > F
variety	1	0.0483647	0.0483647	2.57	0.1128
combing ratio	1	0.01457051	0.01457051	0.77	0.3815
combing ratio^2	1	0.00000124	0.00000124	0	0.9935
batt weight	1	0.26648656	0.26648656	14.16	0.0003
batt weight^2	1	0.00487709	0.00487709	0.26	0.6121
combing ratio*variety	1	0.00526009	0.00526009	0.28	0.5985
combing ratio^2*variety	1	0.0123673	0.0123673	0.66	0.4199
batt weight*variety	1	0.00001713	0.00001713	0	0.976
batt weight^2*variety	1	0.0309353	0.0309353	1.64	0.2035

Table 3. Lint wastage linear regression (significant effects).

Dependent Variable: lint wastage (lw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	178.6363309	25.5194758	1387.84	<.0001
Error	83	1.5261968	0.0183879		
Uncorrected Total	90	180.1625277			

R-Square	Coeff Var	Root MSE	lw Mean
0.78155	9.775603	0.135602	1.387148

Source	DF	Type III SS	Mean Square	F Value	Pr > F
variety	2	5.24053323	7.62026662	414.42	<.0001
batt weight	1	0.25190845	0.25190845	13.7	0.0004
combing ratio^2*variety	2	0.88155156	0.44077578	23.97	<.0001
batt weight^2*variety	2	0.35560208	0.17780104	9.67	0.0002

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Between varieties	2	0.35584993	0.17792497	9.68	0.0002

Parameter	Estimate	Standard Error	t Value	Pr > |t|
variety 1	1.777568233	0.06406845	27.74	<.0001
variety 2	1.377855594	0.06028773	22.85	<.0001
batt weight	-2.291550717	0.61911927	-3.7	0.0004
combing ratio^2*variety 1	0.00019896	0.00003222	6.17	<.0001
combing ratio^2*variety 2	0.000098578	0.00003166	3.11	0.0025
batt weight^2*variety 1	-1.594373118	1.66463101	-0.96	0.3409
batt weight^2*variety 2	2.608052797	1.72170529	1.51	0.1335

Table 4. Cleaning efficiency linear regression (all effects).

Dependent Variable: cleaning efficiency (ce)

Source	DF	Squares	Sum of Mean Square	F Value	Pr > F
Model	7	4505.360355	643.622908	32.59	<.0001
Error	251	4956.40579	19.746637		
Corrected Total	258	9461.766145			

R-Square	Coeff Var	Root MSE	ce Mean
0.476165	8.6946	4.443719	51.10896

Source	DF	Type III SS	Mean Square	F Value	Pr > F
variety	1	9.189692	9.189692	0.47	0.4957
1/combing ratio	1	1697.677259	1697.677259	85.97	<.0001
batt weight	1	2507.088353	2507.088353	126.96	<.0001
initial visible foreign matter	1	1987.789407	1987.789407	100.66	<.0001
(1/combing ratio)*variety	1	0.852858	0.852858	0.04	0.8355
batt weight*variety	1	3.690724	3.690724	0.19	0.6659
initial visible foreign matter*variety	1	1.509133	1.509133	0.08	0.7824

Table 5. Cleaning efficiency linear regression (significant effects).

Dependent Variable: cleaning efficiency (ce)

Source	DF	Sum of Squares	Sum of Mean Square	F Value	Pr > F
Model	5	681029.4382	136205.8876	6956.95	<.0001
Error	254	4972.9139	19.5784		
Uncorrected	259	686002.3522			

R-Square	Coeff Var	Root MSE	ce Mean
0.47442	8.657481	4.424749	51.10896

Source	DF	Type III SS	Mean Square	F Value	Pr > F
variety	2	12739.57373	6369.78687	325.35	<.0001
1/combing ratio	1	1697.68707	1697.68707	86.71	<.0001
batt weight	1	2561.13981	2561.13981	130.81	<.0001
initial visible foreign matter	1	2417.81076	2417.81076	123.49	<.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Between Varieties	1	141.7579671	141.7579671	7.24	0.0076

Parameter	Estimate	Standard Error	t Value	Pr> |t|
variety 1	47.6103634	1.91664014	24.84	<.0001
variety 2	49.1566242	1.93181761	25.45	<.0001
1/combing ratio	-294.7416654	31.65201234	-9.31	<.0001
batt weight	-45.9957855	4.02151794	-11.44	<.0001
initial visible foreign matter	5.5458732	0.49905384	11.11	<.0001

Table 6. Mean squares and F values generated by SAS® for classing variables.

		Source of Variation						
Classing Technique		Variety (var)	Combing Ratio (cratio)	Feed Rate (frate)	frate* cratio	var* cratio	var* frate	var* frate* cratio
Color Grade Index	Manual	1207	5.747	75.63	10.88	10.08	32.55	13.24
		(124.5)*	(0.59)	(7.8)*	(1.12)	(1.04)	(3.36)*	(1.37)
	HVI	1566	18.77	82.39	12.61	14.34	52.73	17.86
		(125.3)*	(1.5)	(6.59)*	(1.01)	(1.15)	(4.22)*	(1.43)
High Volume Instrument	Staple	27.56	1.472	0.1878	0.6646	0.1540	0.1868	1.531
		(57.65)*	(3.08)*	(0.39)	(1.39)	(0.32)	(0.39)	(3.2)*
	Leaf	0.8767	0.2059	7.924	0.1743	0.4715	0.0337	0.1780
		(5.46)*	(1.28)	(49.39)*	(1.09)	(2.94)*	(0.21)	(1.11)
	Micronaire	0.0027	0.0018	0.0274	0.0054	0.0165	0.0005	0.0186
		(0.2)	(0.14)	(2.07)	(0.41)	(1.24)	(0.04)	(1.41)
	Strength	574.0	3.702	3.636	4.15	0.2388	1.487	1.269
		(310.1)*	(2.00)	(1.96)	(2.24)*	(0.13)	(0.80)	(0.69)
	RD	371.5	2.635	13.78	0.8272	2.04	2.733	1.00
		(317.6)*	(2.25)	(11.78)*	(0.71)	(1.74)	(2.34)	(0.85)
	Plus B	19.44	0.073	1.026	0.0746	0.1116	0.1446	0.5529
		(83.91)*	(0.32)	(4.43)*	(0.32)	(0.48)	(0.62)	(2.39)*
	Trash	0.0171	0.0037	0.0712	0.0114	0.0077	0.0047	0.0037
	Area (%)	(2.31)	(0.50)	(9.58)*	(1.53)	(1.04)	(0.64)	(0.49)
	Length	4.035	1.219	0.218	0.625	0.149	0.488	1.914
		(63.44)*	(2.82)	(0.11)	(1.29)	(0.19)	(0.05)	(2.62)*
	Uniformity	234.1	10.59	0.4230	4.838	0.7020	0.1690	9.827
		(5.75)*	(1.74)	(0.31)	(0.89)	(0.21)	(0.70)	(2.73)*

* Significant at the 0.05 level ( ) F values

Table 7. Classing variable means for feed rate averaged over combing ratio and variety

		Feed Rate		
Classing Technique		Low	Medium	High
Color Grade Index	Manual**	41	42	42
		(94.56) a	(93.53) a b	(93.31) b
	HVI**	42	42	42
		(93.44) a	(92.42) a	(92.29) a
High Volume Instrument	Staple	34.64	34.67	34.70
	Leaf	2.33 a	2.82 b	2.98 c
	Micronaire	4.810	4.783	4.767
	Strength	29.71	29.80	30.10
	RD	72.49 a	72.07 a b	71.83 b
	Plus B	9.24 a	9.13 a b	9.04 b
	Trash Area (%)	0.1811 b	0.2256 a	0.2389 a
	Length	107.8	108.0	108.0
	Uniformity	82.53	82.51	82.42

** Modes rather than means

Table 8. Classing variable means for combing ratio averaged over feed rate and variety

		Combing Ratio				
Classing Technique		20	25	30	40	50
Color Grade Index	Manual**	41	32	42	41	41
		(93.80)	(94.63)	(93.70)	(93.54)	(93.33)
	HVI**	42	42	42	42	42
		(92.46)	(94.13)	(92.93)	(92.07)	(92.00)
HVI	Staple	34.83 a b	34.94 a	34.57 b c	34.50 c	34.50 c
	Leaf	2.667	2.704	2.889	2.685	2.593
	Micronaire	4.785	4.781	4.770	4.796	4.800
	Strength	30.29	30.27	29.87	29.29	29.63
	RD	72.24	72.80	71.89	71.87	71.85
	Plus B	9.161	9.207	9.122	9.072	9.124
	Trash Area (%)	.2111	.2130	.2352	.2056	.2111
	Length	108.3	108.7	107.8	107.4	107.4
	Uniformity	82.65	82.54	82.39	82.33	82.54

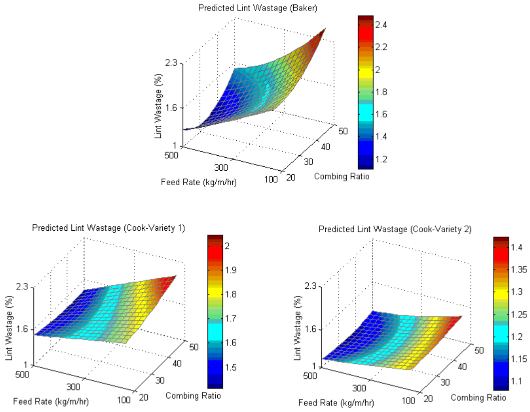
** Modes rather than means

Table 9. Summary of classing variable statistical analysis

	Lint Cleaner Parameter	
Classification Parameter	Batt Weight Decrease (averaged over combing ratio)	Combing Ratio Increase (average over batt weight)
Manual Color Grade	Improve	No Trend Established
HVI Color Grade	No Trend Established	No Trend Established
Staple Length	No Trend Established	Worsen
Leaf Grade	Improve	No Trend Established
Micronaire	No Trend Established	No Trend Established
Strength	No Trend Established	No Trend Established
Reflectance	Improve	No Trend Established
Yellowness	Worsen	No Trend Established
Percent Trash Area	Improve	No Trend Established
Length	No Trend Established	No Trend Established
Uniformity	No Trend Established	No Trend Established

Table 10. Predicted cleaning efficiencies and lint wastage for tandem lint cleaner

	Feed Rate Per Saw Cylinder (bph)		Combing Ratio			
Total Feed Rate (bph)	LC1	LC2	LC1	LC2	Total Lint Wastage (%)	Total Cleaning Efficiency (%)
10	10	-	25	-	1.00	53.87
10	5	5	50	50	1.88	59.74
10	5	5	25	25	1.53	63.42
15	7.5	7.5	50	50	1.94	50.20
15	7.5	7.5	37.5	37.5	1.29	55.40
15	8	7	35	40	1.29	55.42
15	9	6	30	45	1.29	55.61
15	10	5	25	50	1.42	55.83
15	7.5	7.5	25	25	1.19	58.65


Predicted Lint Wastage (Baker)

Predicted Lint Wastage (Cook-Variety 1)

Predicted Lint Wastage (Cook-Variety 2)

Figure 1. Comparison between theoretical predictions of lint cleaner waste.

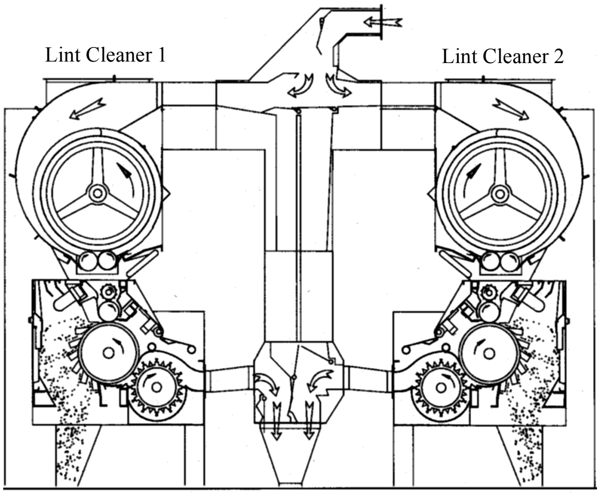


Figure 2. Cross-sectional view of tandem lint cleaners in the split-stream configuration. (*Courtesy of Lummus Corporation*)

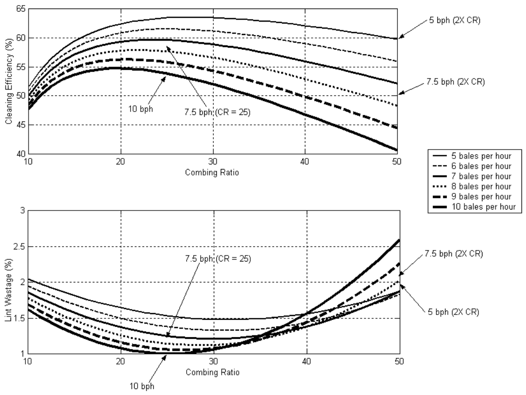


Figure 3. Theoretical performance of a single saw-type lint cleaner for various feed rates, assuming 5% initial visible foreign matter, a saw speed of 1000 rpm and an effective saw-cylinder width of 75 inches. [Note: 2X is an abbreviation for double and CR is an abbreviation for combing ratio.]