2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 095763

Development of a High-Capacity Extractor Cleaner for Cotton Strippers

J.D. Wanjura

USDA - ARS - CPPRU, Lubbock, TX; john.wanjura@ars.usda.gov

G.A. Holt

USDA – ARS – CPPRU, Lubbock, TX

R.K. Byler

USDA – ARS – CGRL, Stoneville, MS

A.D. Brashears - Retired

USDA – ARS – CPPRU, Lubbock, TX

R.V. Baker - Retired

USDA – ARS – CPPRU, Lubbock, TX

Written for presentation at the
2009 ASABE Annual International Meeting
Sponsored by ASABE
Grand Sierra Resort and Casino
Reno, Nevada
June 21 – June 24, 2009

Abstract. *Cotton strippers have used extractor type cleaners for many years to remove large foreign material from harvested seed cotton. These machines are commonly referred to as "field cleaners" and are similar in design and operation to stick machines used in cotton gins. The field cleaners used on modern cotton strippers are capable of processing burr cotton at the harvesting rate of four row strippers but are overloaded when used on strippers with six- and eight-row-wide headers. The objective of this work is to report on the design and optimization of a new field cleaner with improved cleaning performance and processing capacity. A 0.305 m (1 ft) wide prototype machine was constructed and used in a response surface experiment to optimize cleaning performance and lint loss. Predictive equations were developed using five configuration factors: loading rate per unit width, primary saw cylinder speed, reclaiming saw cylinder speed, primary saw grid spacing, and reclaiming saw grid spacing. As observed in previous work, the results indicate that a balance must be reached in the trade-off between*

The authors are solely responsible for the content of this technical presentation. The technical presentation does not necessarily reflect the official position of the American Society of Agricultural and Biological Engineers (ASABE), and its printing and distribution does not constitute an endorsement of views which may be expressed. Technical presentations are not subject to the formal peer review process by ASABE editorial committees; therefore, they are not to be presented as refereed publications. Citation of this work should state that it is from an ASABE meeting paper. EXAMPLE: Author's Last Name, Initials. 2009. Title of Presentation. ASABE Paper No. 09----. St. Joseph, Mich.: ASABE. For information about securing permission to reprint or reproduce a technical presentation, please contact ASABE at rutter@asabe.org or 269-429-0300 (2950 Niles Road, St. Joseph, MI 49085-9659 USA).

maximizing cleaning performance and minimizing lint loss. The results also indicate that the experimental machine is capable of reaching 60% cleaning efficiency but that additional design modifications and testing are necessary for the machine to reach the lint loss design goal of less than or equal to 1%.

Keywords. Cotton, harvesting, cleaning, stripper, trash

Introduction

Stripping is the predominate cotton harvest method used in the Texas High Plains region. Cotton strippers were developed as a cost effective alternative to picker harvesters for gathering the High Plains crop which was characterized by relatively low yields (1.9 – 3.7 bales/ha), short plant heights, and storm-proof boll conformations that held mature seed cotton tightly inside the open burr. Picker harvesters were much less effective at harvesting the High Plains crop due to the storm-proof nature of the bolls and short plant stature. However, new varieties with improved yield potential and fiber quality are being introduced to the region. Today, it is not uncommon for irrigated cotton fields in the High Plains to yield in excess of 6.2 bales/ha (2.5 bales/ac). Increases in yields and trends toward larger acreages per producer have led producers to look to strippers that can cover more rows per pass (i.e. 8 row headers rather than 4 or 6) to improve field efficiency.

Field cleaners have been used for many years on stripper harvesters to reduce the large foreign matter (i.e. burrs, unopened bolls, and sticks) content of stripped cotton. This practice helps to reduce transportation and ginning costs based on incoming module weight. Overall cleaning efficiencies in the range of 50 to 60% have been observed in several field experiments over the years (Kirk et. al., 1972; Kirk et al., 1973; Brashears, 1991; Bennett et. al., 1995; and Baker and Brashears, 2000). Field cleaners, like extractor type cleaners used in the gin, utilize the “sling-off” principal to clean foreign material from harvested seed cotton. Seed cotton, held by saw teeth affixed to the surface of a spinning cylinder, is pulled over a set of grid bars where foreign material is dislodged and thrown off by centrifugal force. Thus, larger and heavier foreign material tends to be removed with greater efficiency than smaller material (i.e. leaf and pepper trash).

Kirk et al. (1970) used a second order central composite response surface experimental design to develop predictive relationships for cleaning performance and seed cotton loss as functions of field cleaner design factors. They showed that field cleaner configuration with regard to grid bar diameter, space between grids, saw to grid clearance, feed rate, and saw cylinder speed is selected based on a compromise in the trade-off between cleaning efficiency and seed cotton loss. Cleaning performance of extractor type cleaners is influenced by many factors including machine design, cotton moisture level, processing rate, adjustments, speed, and condition of the machine, the amount and nature of trash in the cotton; distribution of cotton across the machine; and the cotton variety (Baker et. al., 1994).

Modern field cleaners were designed to operate at the harvesting rate of 4-row cotton strippers, but with the increased acceptance of 6-row and 8-row strippers, the capacity of 1.52 m (5 ft) wide extractors is being exceeded. The feed rate of a 1.52 m (5 ft) wide field cleaner while harvesting 8 rows at 6.4 km/hr (4 mi/hr) in cotton yielding 4.9 bales/ha (2 bales/ac) is 17.1 bales/hr-m (5.2 bales/hr/ft) (102 cm {40 in} row spacing). This feed rate is 2.5 times the recommended feed rate for similar machines used in the gin (Baker et. al., 1994). Operating under high throughput conditions reduces the cleaning efficiency of these machines and increases the amount of usable seed cotton ejected from the cleaner along with the foreign material removed (Kirk et al., 1970; Baker et al., 1982).

The purpose of this manuscript is to report on the design and optimization of a new prototype field cleaner for cotton strippers. The design of the new machine was carried out in an effort to improve cleaning performance while operating at harvesting rates of modern 6 and 8 row cotton strippers using readily available components common to the ginning industry. Performance goals for the new field cleaner are to have an overall cleaning efficiency of approximately 60% with usable lint loss in the range of 1%. The results of this work will be used to develop a full scale prototype for field testing.

Methods

Machine Design

A prototype high capacity field cleaner (HCFC) (figure 1) was designed similar to field cleaners used on modern strippers with regard to the primary cleaning and reclaiming saw cylinder arrangement (Deere and Co., 2006). Both saw cylinders have a 45.7 cm (18 in) nominal diameter with 2.54 cm (1 in) diameter grids located around the perimeter of the saw cylinders. The saws used are channel type saws similar to those used by extractor type cleaners in a cotton gin. The stationary brush, spring loaded skimmer bar, and fixed skimmer bars help to engage the saw teeth and burr cotton before it is pulled over the grid bars. A spring-loaded skimmer bar is used to allow large foreign material (e.g. rocks, large sticks, etc.) to exit the machine and not lodge between the saw and grids thus reducing the potential for friction fires. Burr cotton and foreign material removed by the primary saw is fed to the reclaiming saw where the seed cotton is caught or “reclaimed” by the saw and the foreign material is thrown out through the grids. The cleaned seed cotton from both saws is removed by a brush type doffer cylinder and transferred to the outlet of the machine.

The 0.305 m (12 in) wide HCFC prototype is powered by two electric motors configured with variable frequency drives to allow for independent speed control of the primary and reclaiming saws. A 5.6 kW (7.5 hp) motor operates the primary cleaning and doffer brush cylinders with the doffer cylinder configured to operate 2.36 times the primary cleaning saw speed. The reclaiming saw cylinder is operated by a 3.7 kW (5 hp) motor.

Optimization Testing

A central composite response surface experimental design was used to develop predictive models relating cleaning performance with regard to total trash and constituent fractions (i.e. burrs and bolls, sticks and stems, and fine trash), lint loss, fiber quality, and lint value parameters to the machine configuration factors of primary saw speed, reclaiming saw speed, primary saw grid spacing, reclaiming saw grid spacing, and loading rate. A resolution V factorial design was used to collect response data based on the influence of the configuration factors shown in table 1. The resolution V structure allows for the estimation of linear, two-factor interaction, and quadratic terms through the use of axial design points while reducing the total number of tests compared to a full factorial design (Meyers and Montgomery, 2002). The design structure included 6 center, 32 factorial, and 10 axial points. Only 16 ($16 = 2^{5-1}$) factorial points were required under the Resolution V design but the decision to replicate these points was made to improve the estimation of important two-factor interactions. Axial points were specified in the design using an axial distance of two.

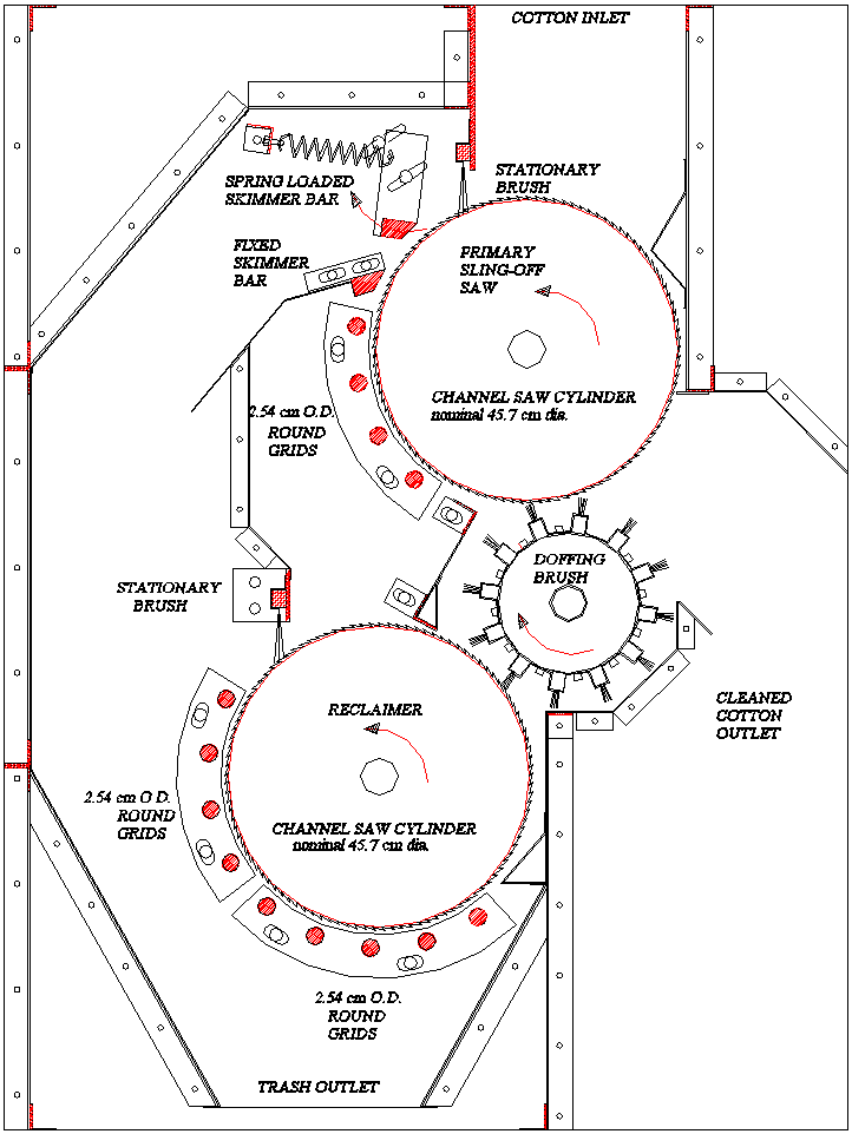

Figure 1. Schematic diagram of the high capacity field cleaner prototype.

The computer software program Design Expert 7 (Design Expert v. 7.1.3, 2007, Stat-Ease Inc., Minneapolis, MN) was used to analyze the response data, develop predictive models, check model assumptions, and perform numerical optimization of the design factors. Analysis of variance methods were used to determine the appropriate order for the predictive model developed for each response variable. Backward selection was used to reduce the number of variables in each model (level of significance to leave the model: $\alpha = 0.1$) and predictive value was increased by utilizing power transformations according to Box-Cox Plot analyses (Meyers and Montgomery, 2002). Hierarchy was maintained in developing each model and requires that each individual factor in significant two factor interactions must also be included in the model, regardless of statistical significance (Meyers and Montgomery, 2002). Normal probability plots of the studentized residuals were used to check the assumption of normal residuals and the assumption of constant error was evaluated using plots of the studentized residuals vs. predicted values. Outliers in the response data were identified as those with externally studentized residuals over 3.5 (Meyers and Montgomery, 2002) and were not included in the development of predictive models. Influence and leverage statistics for the response data were

analyzed to identify response values that had a substantial influence on the predictive model. Optimization of the machine configuration factors (table 1) was carried out in Design Expert using response variables for which: 1) significant models were developed, 2) the model showed an insignificant lack of fit test (α = 0.05), and 3) the model prediction R^2 (R^2_{pred}) value was over 0.5. Desirability functions were used in Design Expert to optimize the field cleaner performance emphasizing maximum cleaning efficiency and minimum lint loss (equation 1).

Table 1. Experimental factors and associated testing levels for the central composite design used in optimizing the high capacity field cleaner prototype.

			Coded Variable Level				
Factor	**Units**	**Variable**	**– 2**	**- 1**	**0**	**1**	**2**
Loading Rate	kg/min-m	A	52	78	104	130	156
Top Saw Cylinder Speed	RPM	B	375	425	475	525	575
Bottom Saw Cylinder Speed	RPM	C	315	365	415	465	515
Top Saw Grid Spacing	cm	D	2.54	4.45	6.35	8.26	10.16
Bottom Saw Grid Spacing	cm	E	2.54	4.45	6.35	8.26	10.16

$$D = \left(\prod_{i=1}^{n} d_i^{\,r_i} \right)^{\frac{1}{\sum r_i}} \tag{1}$$

where D is the overall desirability considering all response factors in the optimization, d_i is the transformation of response variable i into a desirability function, r_i is the importance factor for response variable i, and n is the number of factors being optimized.

The loading rate range shown in table 1 corresponds to loading rates of 3.3 to 9.8 bales/hr-m (1 to 3 bales/hr-ft) of machine width. The rotational speed range for the saw cylinders in the prototype machine were centered (coded variable level = 0) on the rotational speeds corresponding to the surface speeds utilized by current commercial field cleaners (approximately 671 and 579 m/min {2200 and 1900 ft/min} for the primary and reclaiming cylinders, respectively). The diameter of the primary and reclaiming saw cylinders on current field cleaners is approximately 33.7 cm (13.25 in) with no-load rotational speeds of 630 and 550 rpm, respectively (Deere and Co., 2006).

Tests were carried out in random order using 22.7 to 27.2 kg (50 to 60 lb) initial burr cotton lot weights. Burr cotton was fed to the prototype machine by a pneumatic conveyance system which used a steady flow feed control device to regulate the material flow rate. Grid bar sets were constructed for the primary and reclaiming saws with the grid to grid spacing specified in table 1 to simplify the process of modifying the machine between runs. During each test, five burr cotton samples (200 g) were collected both before and after the material passed through the cleaner for fractionation analysis according to the method described by Shepard (1972) at the USDA ARS Cotton Ginning Research Lab in Stoneville, MS. Samples of the cleaned burr cotton were collected for moisture content analysis (Shepard, 1972). Three samples (200 g) of the waste material removed by the machine during each test were collected for fractionation analysis to determine the amount of useable seed cotton removed. Seed cotton containing a mature seed was considered “useable”. Weights of the burr cotton before and after passing through the cleaner were recorded as well as the weight of the waste material removed by the

cleaner. Cleaning performance was calculated for the machine based on the results of the seed cotton and foreign material sample fractionation analyses and pre/post cleaning burr cotton and total material removed weights.

The burr cotton cleaned by the HCFC during each test was ginned on a small scale ginning system at the USDA ARS Cotton Production and Processing Research Unit in Lubbock, TX. The gin machinery sequence consisted of an extractor feeder, 16 saw gin stand, and one stage of saw type lint cleaning. Ginning performance data were collected on each sample in terms of lint turnout and seed weight and seed cotton samples were collected at the feeder apron for moisture content analysis (Shepard, 1972). Lint samples were collected and sent for High Volume Instrument (HVI) and Advanced Fiber Information System (AFIS) fiber quality analyses at Cotton Incorporated, Cary, NC. Additional lint samples were sent to the USDA AMS Cotton Classing Office in Lubbock, TX for classing to determine the Commodity Credit Corporation (CCC) loan value for the lint from each test.

Results

Fractionation analysis results on the seed cotton samples collected before the field cleaner are shown in table 2. The seed cotton used in the tests was relatively clean for non-field cleaned cotton as only 198 kg/bale (436.7 lbs/bale) of total trash was observed in the samples compared to a typical value of 318 kg/bale (700 lbs/bale) (Baker et al., 1994). Seed cotton samples taken before passing through the cleaner had a mean moisture content of 8.6% with a standard deviation of 0.72%.

Table 2. Foreign material content of seed cotton samples taken before the experimental field cleaner.

	Burrs & Bolls		**Sticks & Stems**		**Fine Trash**		**Total Trash**	
	kg/bale	(lbs/bale)	kg/bale	(lbs/bale)	kg/bale	(lbs/bale)	kg/bale	(lbs/bale)
Mean	122.4	(269.5)	24.7	(54.4)	51.2	(112.7)	198.3	(436.7)
Std. Dev.	17.1	(37.6)	4.8	(10.6)	10.1	(22.2)	25.5	(56.1)
Min	86.4	(190.3)	17.5	(38.6)	36.1	(79.5)	150.7	(331.9)
Max	176.7	(389.3)	44.4	(97.9)	94.9	(209.0)	261.9	(576.9)

The observation summary statistics (n, min, max, mean, standard deviation) and model statistics for each response variable are shown in table 3. All of the models of first order or higher, except for HVI elongation and +b, were significant at the 0.05 level of significance. Lack of fit tests for the significant models indicated that in each case, the modeled response variable could be described by a linear combination of the controlled factors. The predictive strength of the relationships, as indicated by the R^2_{pred} values, was strongest for the total trash reduction (0.96), lint loss (0.81), and burrs and bolls reduction models (0.79) (table 3). The models for sticks and stems reduction, fine trash reduction, and all of the HVI and AFIS fiber quality parameters did not meet the specified predictive strength criteria for use in numerical optimization of the experimental field cleaner operating factors ($R^2_{pred} > 0.5$). Field cleaners are known to be more efficient in removing burrs and large material from seed cotton and less effective at removing foreign material that is more tightly entangled in the harvested fiber such as fine trash and sticks. Exacerbating this phenomenon is the relatively low initial foreign material content of the seed cotton used in the experiments as previous studies have shown cleaning performance to increase with higher initial trash content (Baker et al., 1982; Baker et al., 1994; Brashears, 1991). The weak models developed for the HVI and AFIS fiber properties indicate little differential influence on fiber quality between operational settings for the HCFC. Subsequently, the CCC loan values observed for the lint samples spanned a narrow range of approximately 0.025 $/kg and the loan value predictive relationship indicated the ability to explain only 6% of the variation in new values.

Table 3. Observed response and predictive model statistics from the optimization tests on the experimental field cleaner.

Analysis	Response Variable	Units	Mean	Std. Dev.	Transformation Type	Model Type	Model Significance Test (P Value)	Lack of Fit Test (P Value)	R^2_{Pred}
Fractionation	Lint Loss	kg/bale	3.8	1.7	Natural log	*R2FI	<0.0001	0.7109	0.8112
Fractionation	Total Trash Reduction	kg/bale	87.2	21.4	Inverse Sq. Root	RQuadratic	<0.0001	0.8414	0.9559
Fractionation	Burrs & Bolls Reduction	kg/bale	65.3	17.7	None	RLinear	<0.0001	0.299	0.7869
Fractionation	Sticks & Stems Reduction	kg/bale	10.0	5.3	Square Root	RLinear	<0.0001	0.2622	0.3951
Fractionation	Fine Trash Reduction	kg/bale	11.7	3.7	None	RQuadratic	0.0002	0.5838	0.3144
HVI	MIC		4.0	0.1	None	RQuadratic	0.0114	0.3119	0.0563
HVI	UHM	cm	3.06	0.03	None	Mean	n/a	-	-
HVI	UI	%	81.7	0.6	None	Mean	n/a	-	-
HVI	STR	g/tex	30.0	0.4	None	R2FI	<0.0001	0.5935	0.31
HVI	ELO	%	5.9	0.2	None	Quadratic	0.1695	-	-
HVI	Rd	%	81.0	1.3	None	R2FI	0.0235	0.8621	-0.0447
HVI	+b		8.8	0.3	None	R2FI	0.0806	-	-
HVI	Area	%	0.3	0.1	None	RLinear	0.0224	0.864	0.0214
HVI	SFC	%	8.5	0.3	None	Mean	n/a	-	-
AFIS	Nep Size	um	692.1	12.7	None	R2FI	0.0026	0.3446	0.1924
AFIS	Neps per Gram	#/g	340.3	25.2	None	R2FI	0.0003	0.8615	0.2144
AFIS	L(w)	cm	2.60	0.04	None	RLinear	0.0003	0.7129	0.2141
AFIS	L(w) CV	%	36.7	0.8	None	RLinear	0.0281	0.7024	0.0095
AFIS	UQL (w)	cm	3.23	0.03	None	RLinear	0.0178	0.75	0.0333
AFIS	SFC (w)	%	9.1	0.7	Power	RLinear	0.0045	0.7918	0.1024
AFIS	L(n)	cm	1.99	0.05	None	RLinear	0.0008	0.9104	0.1876
AFIS	L(n) CV	%	55.3	1.6	None	RLinear	0.0242	0.8483	0.0331
AFIS	SFC (n)	%	28.8	1.8	None	RLinear	0.0092	0.8288	0.0709
AFIS	L5% (n)	cm	3.7	0.0	None	RLinear	0.0275	0.7663	0.0239
AFIS	Total Trash	cnt/g	507.8	94.2	None	Mean	n/a	-	-
AFIS	Trash Size	um	338.2	13.2	None	Mean	n/a	-	-
AFIS	Dust	cnt/g	417.4	80.8	None	Mean	n/a	-	-
AFIS	Trash	cnt/g	90.1	17.0	None	Mean	n/a	-	-
AFIS	VFM	%	1.5	0.3	None	Mean	n/a	-	-
AFIS	SCN Size	um	1093	91.8	None	Mean	n/a	-	-
AFIS	SCN	cnt/g	18.7	5.4	None	R2FI	0.0256	0.3762	0.029
AFIS	Fineness	mTex	156.8	2.2	None	RLinear	0.0208	0.9941	0.0318
AFIS	IFC	%	6.3	0.4	None	RQuadratic	0.0065	0.9915	0.0725
AFIS	Maturity Ratio		0.9	0.0	None	RQuadratic	0.0225	0.8699	-0.0303
CCC	Loan Rate	$/kg lint	1.276	0.0044	None	RLinear	0.0007	0.9218	0.0616

*R indicates that the model is reduced to include significant variables and those to support hierarchy.

The models developed to estimate lint loss, total trash reduction, and burrs & bolls reduction are shown in tables 4 – 6, respectively. The model predicting lint loss contains all five factors (A: loading rate, B: primary saw cylinder speed, C: reclaiming saw cylinder speed, D: primary saw grid spacing, and E: bottom saw grid spacing) and interaction terms: A*C, B*D, C*D, and D*E. Loading rate, primary saw cylinder speed, and reclaiming saw grid spacing were not statistically significant variables but were included to maintain hierarchy. The signal to noise ratio for the lint loss model is 21 indicating that the model can adequately distinguish changes in the response variable from noise in the measured data. A model with signal to noise ratio greater than 4 is considered adequate in its ability to discern changes in the response variable from noise (Whitcomb et al., 2003).

Table 4. Model coefficients and statistics for the natural log transformed lint loss (kg/bale) relationship in terms of the coded factors.

Ln(Lint Loss) =	**Coefficient Estimate**	**Std. Error**	**F - Value**	**P > F**
Intercept	1.265	0.024	-	-
A-Loading Rate	-0.028	0.026	1.21	0.2788*
B-Primary Saw Cylinder Speed	-0.049	0.026	3.67	0.0632*
C-Reclaiming Saw Cylinder Speed	0.111	0.026	18.91	0.0001
D-Primary Saw Grid Spacing	0.378	0.026	217.58	< 0.0001
E-Reclaiming Saw Grid Spacing	-0.007	0.027	0.074	0.7873*
AC	-0.093	0.029	10.51	0.0026
BD	0.068	0.029	5.55	0.024
CD	0.076	0.029	7.05	0.0117
DE	-0.091	0.029	9.96	0.0032
	SS	**df**	**F - Value**	**P > F**
Model	6.93	9	30.36	< 0.0001
Lack of Fit	0.34	16	0.76	0.7109
	R^2	**R^2_{adj}**	**R^2_{Pred}**	**Signal to Noise**
Reduced 2 Factor Interaction Model	0.8836	0.8545	0.8112	21

*Coefficients included in model to maintain hierarchy.

Table 5. Model coefficients and statistics for the inverse square root transformed total trash reduction (kg/bale) relationship in terms of the coded factors.

1/sqrt(Total Trash Reduction) =	Coefficient Estimate	Std. Error	F - Value	P > F
Intercept	0.1060	0.0006	-	-
A-Loading Rate	0.0026	0.0004	37.42	< 0.0001
B-Primary Saw Cylinder Speed	-0.0009	0.0004	4.06	0.0517*
C-Reclaiming Saw Cylinder Speed	0.0018	0.0004	18.26	0.0001
D-Primary Saw Grid Spacing	-0.0148	0.0004	1234.92	< 0.0001
E-Reclaiming Saw Grid Spacing	-0.0024	0.0004	32.46	< 0.0001
AB	-0.0010	0.0005	4.14	0.0495
AC	0.0012	0.0005	6.62	0.0145
AD	-0.0020	0.0005	17.32	0.0002
BD	-0.0011	0.0005	5.4	0.0261
BE	-0.0008	0.0005	2.91	0.097
DE	0.0027	0.0005	33.69	< 0.0001
D^2	0.0046	0.0005	91.69	< 0.0001

	SS	df	F - Value	P > F
Model	0.011	12	124.07	< 0.0001
Lack of Fit	7.08E-05	14	0.59	0.8414

	R^2	R^2_{adj}	R^2_{Pred}	Signal to Noise
Reduced Quadratic Model	0.977	0.9692	0.9559	45.5

*Coefficients included in model to maintain hierarchy.

Table 6. Model coefficients and statistics for the reduced linear model for burrs & bolls reduction (kg/bale) in terms of the coded factors.

Burrs & Bolls Reduction =	Coefficient Estimate	Std. Error	F - Value	P > F
Intercept	65.16	1.163	-	-
A-Loading Rate	-2.37	1.280	3.42	0.0714
D-Primary Saw Grid Spacing	16.90	1.280	174.37	< 0.0001
E-Reclaiming Saw Grid Spacing	4.10	1.280	10.26	0.0026

	SS	df	F - Value	P > F
Model	11867.2	3	63.71	< 0.0001
Lack of Fit	1581.5	23	1.27	0.299

	R^2	R^2_{adj}	R^2_{Pred}	Signal to Noise
Reduced Linear Model	0.8198	0.807	0.7869	29.1

The model for total trash reduction indicated the strongest predictive strength and includes all five factors as well as the interaction terms: A*B, A*C, A*D, B*D, B*E, D*E, and D^2. The total trash reduction model signal to noise ratio is 45.5 and only one controlled factor was included to support hierarchy (primary saw cylinder speed). The model for burrs & bolls reduction includes the primary

factors of loading rate, primary saw grid spacing, and reclaiming saw grid spacing. The burrs & bolls reduction model signal to noise ratio of 29.1 is adequate.

Analysis of the model coefficient estimates for the lint loss model indicate that the two most important variables in the model are the primary saw grid spacing and reclaiming saw cylinder speed. Wider primary saw grid spacing and faster reclaiming saw speeds result in an increase in lint loss by the experimental HCFC. Intermediate variables in the lint loss model are primary saw cylinder speed, loading rate, and reclaiming saw grid spacing. These intermediate variables were not significant but were included to maintain hierarchy in the model.

The most important variable in the total trash reduction model is the primary saw grid spacing. Increasing the grid spacing around the primary saw cylinder results in an increase in total trash reduction. Wider spacing between the grids provides more unobstructed area for both trash and seed cotton not fully restrained by saw teeth to be thrown out by the machine. Intermediate variables are loading rate, reclaiming saw grid spacing, and reclaiming saw speed. Primary saw cylinder speed was not significant and has the least influence on total trash reduction but was included in the model to support hierarchy.

Similar to the total trash reduction and lint loss models, the most important variable in the burrs & bolls reduction model was the primary saw grid spacing. Reclaiming saw grid spacing and loading rate were intermediate variables in the model. Similarities in variable importance of the burrs & bolls reduction model to the total trash reduction model were expected and reflect the trends seen in previous research on extractor type cleaners (Kirk et al., 1970; Kirk et al., 1973; Baker et al., 1982).

Optimization

The primary function of an extractor cleaner used on a stripper harvester is to remove foreign material from harvested cotton. The optimum configuration of a field cleaner is one which removes the maximum amount of foreign material from the harvested seed cotton while rejecting a minimal amount of usable cotton with the separated trash. The models developed from this work demonstrate that a compromise must be reached between minimizing lint loss and maximizing cleaning performance when configuring the experimental field cleaner for field use. This result is not unique to this work.

The three predictive models which met the specified criteria for use in numerical optimization of the field cleaner were: lint loss, total trash reduction, and burrs & bolls reduction. Five optimization scenarios (table 7) were investigated using varying importance factors for the lint loss and total trash reduction models. Scenario one was arranged to select factor levels which emphasized minimizing lint loss with limited focus on maximizing cleaning performance while scenario five selected factor levels that maximized total trash reduction while allowing more lint loss than scenario one. An importance level of one was assigned in each scenario to maximizing burrs & bolls reduction because the solutions which produced maximum levels of total trash reduction also produced high levels of reduction for the burrs & bolls trash component. The importance level for a particular variable can range from 1 (least important) to 5 (most important) in Design Expert.

Table 7. Objective importance factors, factor levels, and predicted performance for five scenarios optimizing the cleaning performance and lint loss characteristics of the experimental high capacity field cleaner.

	Objective Importance Factor			Factor Levels					Predicted Performance Levels		
Scenario	Minimize Lint Loss	Maximize Total Trash Reduction	Maximize Burrs & Bolls Reduction	Loading Rate (kg/min-m)	Primary Saw Cylinder Speed (RPM)	Reclaiming Saw Cylinder Speed (RPM)	Primary Saw Grid Spacing (cm)	Reclaiming Saw Grid Spacing (cm)	Lint Loss (kg/bale)	Total Trash Reduction (kg/bale)	Burrs & Bolls Reduction (kg/bale)
1	5	1	1	78	525	365	5.15	8.25	2.4	84.8	61.0
2	4	2	1	78	525	365	6.27	8.25	2.8	99.6	70.9
3	3	3	1	78	525	365	7.16	8.24	3.2	109.0	78.8
4	2	4	1	78	525	365	7.90	8.25	3.5	114.0	85.4
5	1	5	1	116	525	365	8.25	8.25	4.1	121.1	85.1

Lint loss ranged from 2.4 to 4.1 kg/bale (5.2 to 9.0 lbs/bale) while total trash reduction ranged from 84.8 to 121.1 kg/bale (187 to 267 lbs/bale) over scenarios one through five, respectively. Burrs & Bolls reduction increased from 61 to 85.1 kg/bale (134 to 188 lbs/bale) for scenarios one through five, respectively. Analysis of the factor levels in table 7 indicates consistent levels over all scenarios for primary saw cylinder speed (525 rpm), reclaiming saw cylinder speed (365 rpm), and reclaiming saw grid spacing (8.25 cm {3.25 in}). Loading rate remained at 78 kg/min-m (53 lbs/min-ft) for scenarios one through 4 but increased to 116 kg/min-m (78 lbs/min-ft) for scenario five when cleaning efficiency was the focus of the optimization. The primary saw grid spacing ranged from 5.15 to 8.25 cm (2 to 3.25 in) over scenarios one through five, respectively. Selection of the grid spacing around the primary saw, as indicated in the model analysis, has the greatest influence on lint loss and total trash reduction.

The design goal for the HCFC is to achieve an overall cleaning performance of 60% while maintaining a lint loss of approximately 1%. The goal for cleaning efficiency is met when the HCFC is configured as in scenarios 4 and 5 considering a mean initial foreign matter content of 198.3 kg/bale (436.7 lbs/bale) (table 2). However, none of the scenarios meet or exceed the lint loss goal. During testing, excessive amounts of seed cotton were observed bypassing the primary saw cylinder at the spring loaded skimmer bar. Further design modifications to this element will likely improve the lint loss performance of the HCFC.

The total trash reduction response to loading rate and primary saw grid spacing of the HCFC is shown in figure 2. A local maximum is located at primary saw grid spacing of approximately 8.26 cm (3.25 in) over the loading rate range of 52 to 104 kg/min-m (35 to 70 lbs/min-ft). Inspection of the response surface shown in figure 2 in this region indicates that cleaning performance increases with increases in loading rate. This result contrasts that of previous research and indicates that additional investigation of the HCFC is needed to better refine the cleaning performance relationship with regard to loading rate and primary saw grid spacing.

The lint loss response to loading rate and primary saw grid spacing of the HCFC is shown in figure 3. Over the ranges shown for loading rate and primary saw grid spacing, lint loss increases as expected.

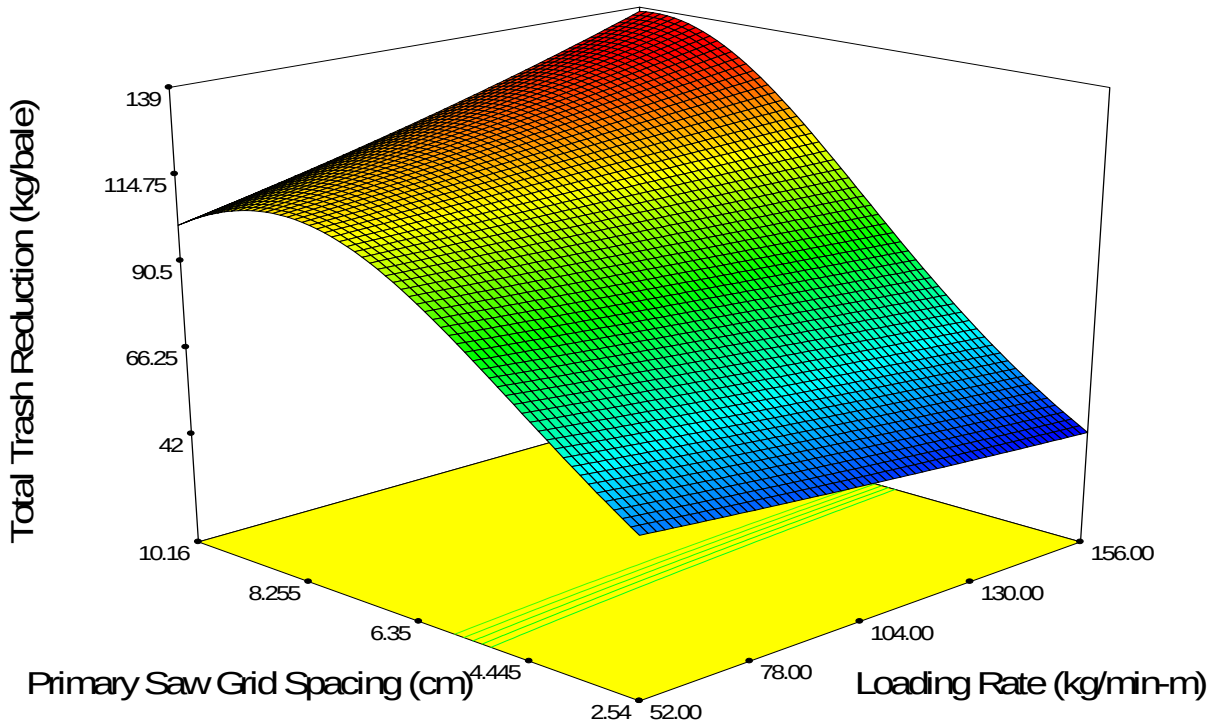

Figure 2. Three dimensional plot of the total trash reduction response to the loading rate (kg/min-m) and primary saw grid spacing (cm) of the HCFC.

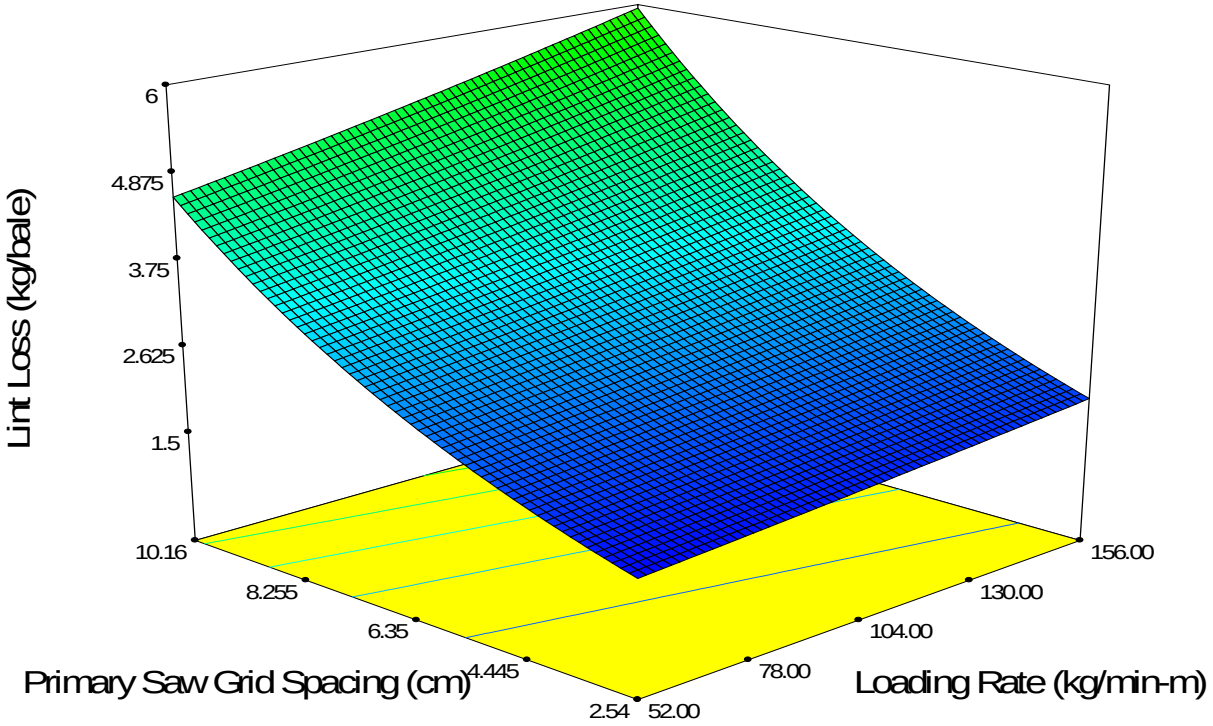

Figure 3. Three dimensional plot of the lint loss response to the loading rate (kg/min-m) and primary saw grid spacing (cm) of the HCFC.

Conclusions

An experimental field cleaner was designed in an effort to improve cleaning performance while increasing processing capacity up to the harvesting rate of modern eight row cotton strippers. A central composite response surface experiment was conducted to optimize the cleaning performance and lint loss of the new field cleaner through the selection of five configuration factors: loading rate, primary saw cylinder speed, reclaiming saw cylinder speed, primary saw grid spacing, and reclaiming saw grid spacing. The data collected during the experiment were used to develop second order predictive equations for the machine response in terms of component and total trash removal, lint loss, and HVI and AFIS fiber quality parameters. The models indicating the highest R^2_{pred} were those for total trash reduction ($R^2_{pred} = 0.96$), lint loss ($R^2_{pred} = 0.81$), and burrs & bolls reduction ($R^2_{pred} = 0.79$) and were used in subsequent numerical optimization to maximize cleaning performance and minimize lint loss.

Configured to maximize cleaning performance, test results indicate that the HCFC could be expected to remove approximately 121.2 kg/bale (267 lbs/bale) of total foreign material (61%) while rejecting approximately 4.1 kg/bale (9 lbs/bale) of useable lint (1.875%). Design modification to the skimmer bar located on the primary saw cylinder is needed to help reduce the amount of useable lint rejected with the separated material removed by the HCFC. Additional evaluation of the experimental field cleaner is needed to identify optimum settings for loading rate and primary saw grid spacing. Configured as optimized in this work, the HCFC can reach a total cleaning efficiency above the 60% design goal. It is anticipated that design modifications to the primary saw cylinder skimmer bar and additional testing to optimize the loading rate and primary saw grid spacing will improve the lint loss performance of the HCFC to a level at or below the 1% lint loss design goal.

Acknowledgements

The financial support and fiber analysis contribution of Cotton Incorporated is gratefully acknowledged.

Disclaimer

Mention of trade names or commercial products in this manuscript is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

References

Baker, R.V., P.A. Boving, and J.W. Laird. 1982. Effects of Processing Rate on the Performance of Seed Cotton Cleaning Equipment. Transactions of the ASAE 25(1): 187-192.

Baker, R.V., W.S. Anthony, and R.M. Sutton. 1994. Seed cotton cleaning and extracting. In *Cotton Ginners Handbook*. Agricultural Handbook No. 503. Washington D.C.: USDA ARS.

Baker, R.V., and A.D. Brashears. 2000. Combined Effects of Field Cleaning and Lint Cleaning on Stripper Harvested Cotton. Proceedings of the 2000 Beltwide Cotton Conference (2): 1616-1621. Memphis, TN: National Cotton Council.

Bennett, B.K, S.K. Misra, A.D. Brashears, and T.L. Dowty. 1995. Effect of Bur Extractor on Trash in Seed Cotton and Fiber Quality for Different Harvest Dates. Proceedings of the 1995 Beltwide Cotton Conference, pp. 649 – 652. Memphis, TN: National Cotton Council.

Brashears, A.D. 1991. Field Cleaner Efficiency as Affected by Variety. ASAE paper no. 911078. Presented at the 1991 meeting of the American Society of Agricultural Engineers. St. Joseph, MI: ASAE.

Deere and Co. 2006. Operator's Manual – 7460 Cotton Stripper. OMN300472 Issue C6. Moline, Il: Deere and Company.

Kirk, I.W., T.E. Corley, and F.A. Kummer. 1970. Performance relations for a saw grid seed cotton cleaner. Transactions of the ASAE 13(2): 171-176.

Kirk, I.W., A.D. Brashears, and E.B. Hudspeth. 1972. Field performance of cleaners on cotton stripper harvesters. Transactions of the ASAE 15(6): 1024–1027.

Kirk, I.W., E.B. Hudspeth, Jr., and A.D. Brashears. 1973. Optimizing saw-grid cleaner design for cotton stripper harvesters. Transactions of the ASAE 16(3): 446-449.

Meyers, R.H. and D.C. Montgomery. 2002. *Response Surface Methodology*. 2nd Ed. New York, NY.: John Wiley and Sons, Inc.

Shepard, J.V. 1972. Standard Procedures for Foreign Matter and Moisture Analytical Tests Used in Cotton Ginning Research. Agricultural Handbook No. 422. Washington D.C.: USDA-ARS.

Whitcomb, P., M. Anderson, and S. Kraber. 2003. Response surface methodology. In Response Surface Methods for Process Optimization. Minneapolis, Minn.: Stat-Ease, Inc.