The *Journal of Cotton Science 24:229–237 (2020)*
http://journal.cotton.org, © The Cotton Foundation 2020

ENGINEERING AND GINNING

Assessing the Influence of Spindle Harvester Drum Arrangement on Fiber Quality and Yield

Marinus H. J. van der Sluijs*, John D. Wanjura, Randal K. Boman, Greg A. Holt, and Mathew G. Pelletier

ABSTRACT

On spindle type cotton harvesters, spindles are attached to bars which are arranged on rotating drums. Opposed drum harvesting units position one drum on each side of the row, whereas harvesting units with an in-line drum arrangement position both drums on the right side of the plant row. Two studies conducted in Australia and the United States focused on comparing drum arrangements in regard to harvesting efficiency and fiber quality as there has been no recent published research using high yielding commercial varieties. These studies concluded that there were slight, but insignificant differences among opposed and in-line drum arrangements in terms of harvesting efficiency and lint turn out. Although only statistically significant for the work conducted in the US, lint ginned from seed cotton harvested by the opposed drum arrangement contained more trash than that harvested by the in-line arrangement. In both countries there were small insignificant differences in terms of fiber color (both Rd and +b), length, and micronaire, after ginning and lint cleaning. Although not observed in Australia, small significant differences in length uniformity and strength were observed in favor of the opposed drum arrangement in the US. Measured only in Australia, there were no significant differences between the two drum arrangements in terms of short fiber index, fineness, and maturity. There was also no significant difference between the two drum arrangements in terms of total, fibrous and seed-coat nep content, and size.

M.H.J. van der Sluijs, Textile Technical Services, Geelong, Victoria, Australia and Deakin University, Waurn Ponds, Geelong, Victoria, Australia; J.D. Wanjura, G.A. Holt, and M.B. Pelletier, USDA-Agricultural Research Service, Lubbock, Texas, USA; and R.K. Boman, Windstar Incorporated, Edmonson, Texas, USA.
*Corresponding author: sluijs@optusnet.com.au

Traditionally, seed cotton was harvested (picked or removed from opened bolls on the cotton plant) by hand, with mechanical harvesters developed and implemented in the early 1940s. Although in 2011 only 30% of the cotton produced worldwide was harvested mechanically, some of the largest producers and exporters of cotton lint, such as the United States (US), Australia, and Brazil, harvest 100% of their seed cotton mechanically (Anonymous, 2011). The adoption of mechanical cotton harvesters was mainly due to an increase in cotton acreage and yield, which resulted in dramatic increases in production, as well as the shortage, unsuitability, inefficiency, and cost of labor (Abernathy and Williams, 1961; Doraiswamy et al., 1993; Anonymous, 2004; Anonymous, 2011). Although it has been stated (Holley, 2000; Hughs et al., 2008) that mechanical harvesting has had the greatest impact on cotton production since the invention of the cotton gin, there is no doubt that the quality of cotton harvested by hand is superior to that of mechanically harvested cotton. The introduction of mechanical harvesting, and the resultant practice of once over harvesting with the aid of chemical boll openers and defoliants, has led to trashier, more variable and sometimes higher moisture content cotton being delivered to the gins (Williamson and Riley, 1961; Doraiswamy et al., 1993; van der Sluijs and Long, 2015; van der Sluijs and Holt, 2017). Therefore, harvesting plays an important role in determining fiber and seed quality, as the quality of ginned cotton is directly related to the quality of seed cotton prior to ginning (Anonymous, 2001). Irrespective of which mechanical harvesting method is used, the setup and adjustment, training and skill of the operators, as well as the timing of defoliation and harvesting, play a major role in the amount of trash and moisture present in the seed cotton (Williamson and Riley, 1961; Anonymous, 2004; Mygdakos, 2009; Willcutt et al., 2010).

The spindle harvester is a selective type harvester that uses tapered, barbed spindles which rotate to pull seed cotton from opened bolls into the machine. Spindle harvesters account for the bulk of all cotton harvested mechanically world-wide and the efficiency of harvesting and the resultant fiber quality can be influenced by many factors including, spindle speed, and spindle size and shape (Baker et al., 2010), as well as row unit factors such as drum arrangement, compressor plate pressure, spindle tip clearance, and the use of scrapping plates. Initially, these machines were only able to harvest seed cotton from one row at a time, but, with developments over the years, these machines can now harvest up to six rows with one pass, with ever greater speed. Spindle harvesters are large and complex machines, which are expensive to purchase, costly to maintain, and require precise setup and adjustment, as well as trained and skillful operators to obtain the maximum yield and value per hectare. Compared to the stripper harvester, spindle harvesters are generally more expensive to operate and maintain (Faulkner et al., 2011a). However, compared to stripper harvesters under high yield conditions, spindle harvesters can work more productively (i.e. harvest more bales/hr^{-1}), have higher field efficiencies, and higher lint turn out since the seed cotton contains less foreign material (Faulkner, et al., 2011b; Wanjura et al., 2013).

In a spindle harvester, spindles are attached to bars which are arranged on rotating drums (Figure 1). Opposed drum units have two drums, one positioned on each side of the row. The drums on opposed drum units rotate in opposite directions so that the spindles on either drum move toward the plant row when entering the harvesting zone (Figure 1a). The advantage of this configuration is that the cotton plant is harvested from both sides, which can result in higher harvesting efficiency under some field conditions (Willcutt et al., 2010). The in-line drum arrangement has both drums on the right side of the row and results in the cotton plant being harvested only from one side (Figure 1b). The in-line unit was introduced by John Deere (JD) in 1989 with the release of the JD 9960 (Deutsch and Junge, 1989; Deutsch and Junge, 1990). The advantage of this drum arrangement is that there are substantially fewer parts required for manufacturing and repair since all spindles, spindle nuts, bars, and cam tracks are built with the same orientation (i.e. right-handed threading and spindle teeth cut in one direction). The risk of replacing a part with the wrong orientation is eliminated and dealers need carry fewer parts. It also results in a reduction in the weight of the unit due to a simpler header frame design (Deutsch and Junge, 1989; Deutsch and Junge, 1990; Willcutt et al., 2010). Initial trials, conducted in 1986, showed that the harvesting efficiency for the in-line units was slightly better than that of the opposed drum units at various yields (Deutsch and Junge; 1989, Deutsch and Junge, 1990). Figure 1 shows a diagram of the two different drum arrangements, namely the opposed (A) and in-line (B) drum arrangements.

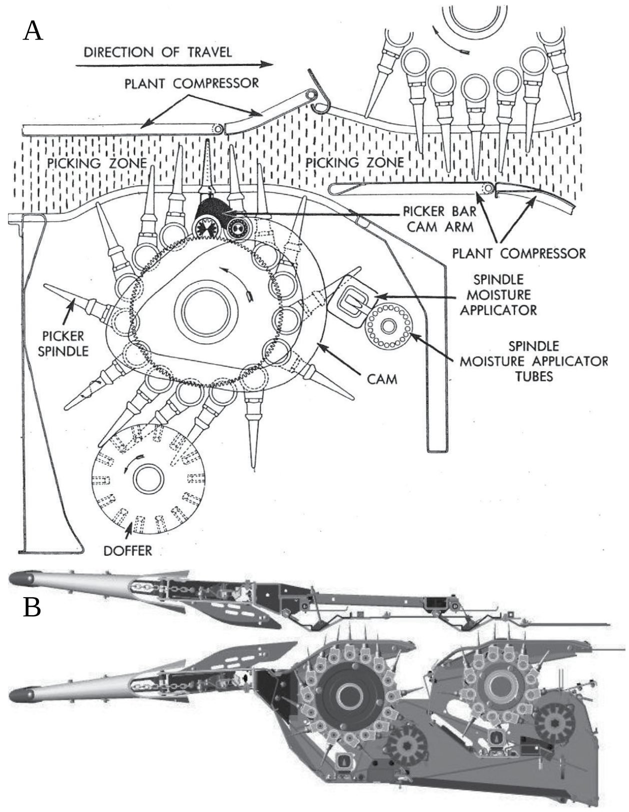

Figure 1. A. Opposed drum arrangement with drums on both sides of the plant row. B. In-line drum arrangement of the John Deere Pro-16 row unit with both drums on the right side of the plant row (Wanjura et al. 2017).

This study is a more in-depth version of that reported by van der Sluijs (van der Sluijs, 2020) and aims to specifically investigate harvesting efficiency and fiber quality, using high yielding (≥1500 kg ha^{-1} fiber) commercial varieties from the two different drum arrangements. Spindle harvesters with in-line and opposed drum row units were compared under commercial crop production conditions in Australia and the United States in 2014 and 2010, respectively.

MATERIALS AND METHODS

Australia. For this study, seed cotton was obtained from one field at the Australian Cotton Research Institute (ACRI) at Narrabri (30°19'S 149 °47'E) in the Namoi Valley (central region) of New

South Wales (NSW). The cotton was produced during the 2013/2014 growing season (planted in 2013; defoliated, harvested, and ginned in 2014). A summary of the field operations employed is presented in Table 1.

[Table 1 reference added by layout artist.]

The cotton variety used for the trial was Sicot 71 BRF, a widely adopted variety with good disease resistance and fiber quality, with an expected fiber yield of 2800 kg ha^{-1} (Stiller, 2008). The field was subjected to standard management practices for irrigated Upland cotton in Australia. The field was first subjected to harvest aids by air with a mixture of leaf defoliant (0.1 L ha^{-1} Dropp® liquid from Bayer Crop Science), boll opener (0.2 L ha^{-1} Prep™ from Bayer Crop Science) and defoliant aid spray (l ha^{-1} D-C-Tron® from Caltex). The field was sprayed by air a second time with a mixture of leaf defoliant (0.15 L ha^{-1} Dropp®), boll opener (2 L ha^{-1} of Prep™) and defoliant aid spray (l ha^{-1} D-C-Tron®).

Only part of the field was utilized for this trial, the trial being conducted using a randomized complete block design, with four replications. Seed cotton from the plots (8 by 10 meter), containing eight rows spaced at one meter, was harvested by a JD 9986 spindle harvester (John Deere, Moline, IL), with Pro16 row units, in an in-line drum arrangement and a Case IH 2555 spindle harvester (CNH America, Racine, WI), with an opposed drum arrangement. Both harvesters were equipped with two row units which were maintained and operated via normal industry practice and the manufacturer's recommendations with no scrapping plates. Harvesting took place during the early afternoon (13:00 to 14:00), with the ambient air conditions of the field (average temperature of 24.4 °C and relative humidity of 32.1%) continually monitored via the weather station situated at ACRI to ensure that harvested seed cotton did not have a surface moisture level greater than the recommended level of 12% (van der Sluijs and Long, 2015).

A 0.5 kg seed cotton sample was collected from each replicate produced and was ginned using a 20-saw gin with a pre-cleaner (Continental Eagle, Prattville, AL) located at ACRI. Lint was then subsampled and subjected to two lint cleaning passages using a purpose built laboratory-scale lint cleaner, designed and built by CSIRO Manufacturing, which is based on the operating principals of the controlled-batt saw lint cleaner, recognized as the standard type of cleaner used in the ginning industry (Gordon et al., 2010, Gordon et al., 2011). The lint cleaner was fitted with a 25.4 cm saw and four grid bars, with the saw operated at a speed of 855 rpm, and a combing ratio of 23:1. Fiber samples were fed into the lint cleaner, with a prepared batt of 100 g m^{-2}. Samples were taken from these treatments for fiber quality analysis.

The seed cotton harvested from each plot was weighed to calculate the weight of usable fiber as a percentage of the weight of un-ginned seed cotton (lint turn out). To determine the harvest efficiency, the seed cotton left on the plants in the field was removed and weighed with the ground loss not included in determining harvest efficiency. Harvest efficiency for the portion of the work conducted in Australia was calculated according to equation 1:

$$Harvest\ Efficiency = 100 \times \frac{SC_m}{SC_m + SC_h} \quad \text{Equation 1}$$

where:

SC_m = weight of seed cotton harvested by the machine,

SC_h = weight of seed cotton harvested from the plants by hand after machine harvest.

Fiber samples were subjected to objective measurement by an HVI™ model 1000 (Uster® Technologies Inc, Knoxville, TN) located at Auscott Limited Classing (Sydney, NSW). Two sub samples of each sample were tested to determine color (reflectance Rd, and yellowness +b), trash count, % trash area, leaf grade, UHML (mm), length uniformity index % (UI%), short fiber index % (fibers shorter than 12.7 mm) (SFI%), bundle strength (g tex^{-1}) and micronaire. Five sub samples of each sample were also subjected to analysis by AFIS PRO (Uster® Technologies Inc, Knoxville, TN) located at CSIRO Manufacturing (Geelong, VIC) to determine total, fiber and seed-coat nep content and size, total, trash and dust content and size, as well as visible foreign matter percent (VFM%). Three sub samples of each sample were tested to determine maturity ratio (MR) and fiber fineness (FN) by the Cottonscope instrument (BSC Electronics, Perth, WA) also located at CSIRO Manufacturing.

Table 1. Field size, planting, harvest aid application, harvest, and gin date for the study conducted in Australia

Field size (ha)	Planting date	1st Harvest Aid date	2nd Harvest Aid date	Harvest date	Gin date
76	15 Oct 2013	12 Apr 2014	26 Apr 2014	16 May 2014	10 July 2014

To test for statistical differences between the two harvesting treatments, an ANOVA was conducted on the experimental data using Genstat 16.0 (Lawes Agricultural Trust, IACR Rothamsted, UK). Where significant statistical differences at the 0.05 and lower level were identified, Fisher's least significant differences (LSD) were calculated from which the differences between means were derived. For ease of interpretation, non-significant results were designated as "ns".

United States. The cotton used in the portion of this study conducted in the US was grown and harvested under commercial production conditions in a cooperating producer's field near Ralls, TX (33° 42.746'N, 101° 23.577'W). This study was conducted concurrently with a portion of the work detailed by Wanjura et al. (2013) at site 4. The cotton grown was FiberMax 9180 B2F which produced an average lint yield of 1496 kg ha^{-1} in the sub-surface drip irrigated field. The field was first subjected to harvest aids by air with a mixture of leaf defoliant (0.37 L ha^{-1} Ginstar® liquid from Bayer Crop Science) and boll opener (2.34 L ha^{-1} Prep™ from Bayer Crop Science). The field was sprayed by air a second time with desiccant (1.75 L ha^{-1} Gramoxone Inteon™ from Syngenta Crop Protection). All other in-season fertilizer and herbicide/pesticide applications were made per local recommendations by the cooperating producer. A summary of the field operations employed is presented in Table 2.

A randomized complete block experimental design with four replicates was used to investigate differences in yield and fiber quality between two spindle harvester row unit designs: opposed drum as operated on a Case IH Module Express 625 (CNH America, Racine, WI) and in-line drum as operated on a John Deere 9996 with Pro16 row units (John Deere, Moline, IL). Harvesting efficiency for the spindle harvesters was measured relative to the lint yield obtained by a John Deere 7460 brush-roll stripper harvester (John Deere, Moline, IL) according to equation 2:

$$\textit{Harvest Efficiency}_{i,j} = \frac{\textit{Spindle Harvester Lint Yield}_{i,j}}{\textit{Stripper Lint Yield}_{j}} * 100$$

Equation 2

where:

Harvest Efficiency $_{i,j}$ = lint harvesting efficiency for spindle harvester drum arrangement i (opposed or in-line drum) in rep j,

Spindle Harvester Lint Yield $_{i,j}$ = spindle harvester lint yield for row unit type i in rep j, and

Stripper Lint Yield $_{j}$ = lint yield of the brush roll cotton stripper in rep j.

The non-selective harvesting mechanism used by stripper harvesters produces greater harvesting efficiency and subsequent lint yields compared to spindle harvesters (Faulkner et al., 2011a; Wanjura et al., 2017). Thus, stripper-harvested lint yields represent the maximum lint yield available via mechanical harvesting and provide a realistic basis on which to compare harvesting efficiencies.

The CNH Module Express 625 and John Deere 7460 were operated by the cooperating producer while the John Deere 9996 was operated by United States Department of Agriculture Agricultural Research Services (USDA ARS) personnel. Spindle harvester ground speed was set to 6.4 km h^{-1} in first gear on both machines in which ground speed is synchronized with row unit drum speed. Both spindle harvesters used six-row wide headers while the stripper used an eight-row wide header, all with row spacing of 102 cm. The opposed drum row units utilized scrapping plates on both drums and had compressor plate spring tension settings of four and three holes on the front and rear drums, respectively. The in-line drum row units utilized scrapping plates on the rear drums only and utilized compressor plate spring tension settings of two and a half and three holes on the front and rear drums, respectively. Substantial crop flow restriction through the in-line drum units was encountered in prior work when scrapping plates were used on both drums under similar crop yield conditions. Substantial differences in yield between opposed and in-line drum arrangements were not anticipated due to differences in front drum scrapping plate use.

Each of the stripping rolls on the John Deere 7460 stripper were configured with alternating brushes and two-ply rubber bats. The two stripping rolls within each row unit were timed so that the plants were always engaged by a brush and a bat (i.e. brush-to-bat timing), never by two bats simultaneously to prevent excessive harvest aggressiveness that can lead to bark

Table 2. Field size, planting, harvest aid application, and ginning dates for the study conducted in the US

Field size (ha)	Planting Date	1st Harvest Aid Date	2nd Harvest Aid Date	Gin Date
43	19 May 2010	20 Oct 2010	01 Nov 2010	20 Dec 2010

contamination. Spacing between bats and brushes on each row unit (i.e. the space through which the plant stalks pass) were set to 19 mm. Ground speed of the stripper was moderated based on header and field cleaner load but was maintained at about 3.2 km h^{-1} to produce maximum stripping efficiency. All harvesters were maintained and operated according to manufacturer recommendations.

A portion of the 43 ha field was divided into four replicates, each 72 rows wide by the length of the field (839 m). Harvester treatments were randomly assigned to 24 row wide subdivisions within each replicate, each with sufficient land area to produce one equivalent rectangular module (ASAE 2019) containing approximately 13 lint bales. Field replications were configured within a single irrigation zone so to not introduce additional yield variation due to irrigation application uniformity differences among zones. Harvest was conducted on November 2, 2010 with the in-line drum row unit machine and on November 3 with the opposed drum row unit machine. Stripper harvest was conducted on November 18 after chemical desiccation had taken maximum effect. No adverse weather events (high winds, rain, hail, or snow) occurred between harvest days with any of the machines. Harvest was conducted in the afternoon of each day with ambient air temperature and relative humidity conditions maintaining seed cotton equilibrium moisture content conditions below 12% (Table 3).

All modules were ginned at the same commercial gin using the same machinery sequence that included: module feeder, nine cylinder horizontal cleaner (cotton on top of cylinders), 12 cylinder horizontal cleaner (cotton between cylinders and cleaning grids), #1 inclined cylinder cleaner, #2 inclined cylinder cleaner, extractor-type cleaner (three-saw stick machine), auger-distributor, extractor-feeder, saw-type gin stand, #1 saw-type lint cleaner, battery condenser, and bale press. Each module was weighed and processed by the gin separately so that all lint and seed produced could be measured accurately. The total lint weight ginned from each module included the weights of all full-size bales and the weight of any remnant lint ejected from the press at the end of each module. Weight data recorded for each module included seed cotton, lint, and seed weights. A lint sample was collected from each full-size lint bale and HVI fiber quality analysis was conducted on the samples by the United States Department of Agriculture Agricultural Marketing Service (USDA AMS) Cotton Classing Office at Lubbock, TX. The 2010 USDA Commodity Credit Corporation loan chart (USDA-CCC, 2010) was used to assign monetary value to the lint harvested in the US.

Statistical analysis of response variables was conducted in SAS (SAS v. 9.2, SAS Institute, Cary, NC) using the General Linear Models procedure (Proc GLM). Field replication was used as the blocking factor in each analysis and a 0.05 level of significance was used to declare significant differences between row unit configurations (in-line vs. opposed).

RESULTS AND DISCUSSION

AUSTRALIA

Yield, Harvest Efficiency and Lint Turn Out. Table 4 summarizes the average per hectare weight of seed cotton harvested, weight of seed cotton left on the plants, weight of lint harvested, percent harvest efficiency, and percent lint turn out. Ground loss was not determined in this study. There was a statistically significant difference between the two drum arrangements (519 kg) in terms of the average amount of seed cotton harvested. There were also differences, although insignificant, in the amount of seed cotton left on the cotton plants, the amount of cotton fiber produced after ginning and lint turn out.

On average, the harvester with the opposed drum arrangement harvested 23.8% more seed cotton than the harvester with the in-line drum arrangement. This difference may be attributed to increased trash as shown in Table 5 but was probably more influenced by the size of the trial which was conducted in conjunction with breeding trials. The plant loss was 3.1% and 6.0%, for the opposed and in-line drum arrangements, respectively. This was contrary to an earlier trial, conducted in 1986, which showed that the harvesting efficiency for the in-line drum arrangement was slightly better than that of the op-

Table 3. Harvest dates, ambient conditions, and total land area harvested by each machine utilized in the US portion of the study

Harvester	Harvest Date	Avg. Air Temp (ºC)	Avg. Air RH (%)	Total Harvested Area (ha)
Spindle-Opposed drum	03 Nov 2010	16.0	21.4	7.82
Spindle-In-line drum	02 Nov 2010	21.5	23.1	7.97
Brush-roll Stripper	18 Nov 2010	12.9	37.4	7.98

posed drum arrangement (Deutsch and Junge, 1989; Deutsch and Junge, 1990). In that trial it was noted that the results could have been influenced by the fact that low-yielding varieties (1682 to 842 kg ha^{-1}) were used. In the current study, while there was more cotton fiber produced after ginning from the harvester with the opposed drum arrangement, the lint turn out from the harvester with the in-line drum arrangement was 1.17% higher than that harvested with the opposed drum arrangement. This small difference in lint turn out was in all likelihood due to the fact, that although not significant, the seed cotton harvested with the opposed drum arrangement contained on average more trash (such as bark, leaf and sticks), as indicated by the AFIS PRO trash, dust and VFM% results after ginning prior to lint cleaning (Table 5).

Fiber Quality. Following two lint cleaner passages there were small, statistically insignificant, differences between the two harvester drum arrangements, in terms of UHML, UI%, SFI%, strength and micronaire (Table 6). The fiber reflectance and yellowness results translated into a color classing grade of Middling (31) which is equal to the Australian base grade. In terms of fineness (FN) and maturity (MR), as determined by Cottonscope, there were also no significant differences between the two harvester drum arrangements (Table 6).

Although the fiber produced from the opposed drum arrangement contained, on average, higher trash levels, in terms of HVI and AFIS PRO measurements, than the fiber produced by the in-line drum arrangement, the differences were small and statistically insignificant (Table 7). This result was not unexpected as the trash results for the cotton fiber prior to lint cleaning showed that the trash levels of the opposed drum arrangement contained numerically higher trash levels than the fiber produced by the in-line drum arrangement (Table 7).

Table 4. Average weight per plot of seed cotton harvested, seed cotton left on the plants, lint harvested, harvest efficiency, and lint turn out for the study in Australia

Drum arrangement	Seed cotton harvested (kg ha^{-1})	Seed cotton left on plant (kg ha^{-1})	Cotton lint harvested (kg ha^{-1})	Harvest efficiency* (%)	Lint turn out (%)
Opposed	2701	86	1045	96.9	38.7
In-line	2182	139	858	94.0	39.3
p-value	<0.001	ns	ns	ns	ns

* Harvest efficiency calculated using equation 1.

Table 5. AFIS PRO trash results after ginning prior to lint cleaning for the study in Australia

Drum Arrangement	Total Trash (cnt g^{-1})	Trash (cnt g^{-1})	Total trash size (μm)	Dust (cnt g^{-1})	VFM (%)
Opposed	1200	215	344	985	4.04
In-line	884	164	345	720	3.11
p-value	ns	ns	ns	ns	ns

VFM = visible foreign matter.

Table 6. HVI and Cottonscope fiber properties after lint cleaning for the study in Australia

Drum Arrangement	HVI							Cottonscope	
	Micronaire	UHML (mm)	UI (%)	SFI (%)	Strength (g tex^{-1})	Rd	+b	FN (mtex)	MR
Opposed	4.50	29.46	81.2	10.1	30.0	79.2	7.8	201	0.88
In-line	4.56	29.21	81.4	10.3	29.3	79.1	7.8	200	0.88
p-value	ns	ns	ns	ns	ns	ns	ns	ns	ns

UHML = upper half mean length, SFI = short fiber index, UI = uniformity index, Rd= reflectance, +b = yellowness, FN = fiber fineness, MR = maturity ratio.

Table 7. HVI and AFIS PRO trash after lint cleaning for the study in Australia

Drum Arrangement	HVI			AFIS PRO				
	Trash count	% Area	Leaf grade	Total trash (cnt g^{-1})	Total trash size (μm)	Trash (cnt g^{-1})	Dust (cnt g^{-1})	VFM (%)
Opposed	14	0.14	2.0	165	350	30	134	0.54
In-line	13	0.25	2.1	148	348	26	122	0.49
p-value	ns	ns	ns	ns	ns	ns	ns	ns

There was no significant difference between the two drum arrangements in terms of total, fibrous and seed-coat nep content, and size (Table 8).

UNITED STATES

Yield, Harvest Efficiency and Lint Turn Out. Seed cotton, lint, and seed yields for the two drum arrangements are presented in Table 9 along with harvesting efficiency and lint turnout. Values for each parameter are shown for the cotton stripper for reference only. The p-values listed in Table 9 indicate the significance of the F test for differences between drum arrangements only.

Differences between drum arrangements were small and not statistically significant for any of the yield parameters presented in Table 9. Harvest-time crop conditions vary with in-season environmental conditions in the US Southern High Plains but conditions in 2010 were characterized by mature, well opened bolls which created favorable conditions for efficient harvesting. Harvest efficiency levels for the opposed and in-line drum arrangements averaged 99.4 and 97.5%, respectively and were not statistically different. Similar to the Australian results, lint turn out was slightly higher for the in-line row unit arrangement (37.0% vs. 36.5%) but again, the difference was not statistically significant.

Fiber Quality. Results of HVI fiber quality analysis on the lint samples collected from each bale after ginning are shown in Table 10. No differences between harvester unit drum arrangements were observed for micronaire, UHML, reflectance, and yellowness, which averaged 4.33, 29.49 mm, 80.7, and 7.9, respectively. Similar to the results of this work from Australia, strength averaged 31.45 g tex^{-1} for the opposed drum arrangement which was significantly higher than that of the in-line drum arrangement by 0.75 g tex^{-1}. Uniformity was significantly higher for the opposed drum row unit type which averaged 82.0% compared to 81.4% for the in-line drum arrangement. However, leaf grade averaged 2.0 for the in-line drum arrangement which was significantly lower than that of the opposed drum arrangement at 2.3. Considering all HVI fiber quality attributes, loan value was 1% higher for the in-line drum arrangement.

Table 8. AFIS PRO fiber properties after lint cleaning for the study in Australia

Drum Arrangement	Total Nep (cnt g^{-1})	Fibrous Nep (cnt g^{-1})	SCN (cnt g^{-1})	Nep size (µm)	SCN size (µm)
Opposed	568	544	24	682	1012
In-line	567	542	25	682	1001
p-value	ns	ns	ns	ns	ns

SCN = seed-coat neps.

Table 9. Yields, lint turn out, and harvest efficiency by drum arrangement for the study conducted in the US

Drum Arrangement	Seed Cotton Yield (kg ha^{-1})	Lint Yield (kg ha^{-1})	Seed Yield (kg ha^{-1})	Harvest Efficiency* (%)	Lint Turn Out (%)
Opposed	4116	1501	2210	99.4	36.5
In-line	3988	1474	2160	97.5	37.0
p-value**	ns	ns	ns	ns	ns
Stripper	4794	1513	2288	n/a	31.6

* Harvest efficiency based on spindle harvester lint yield relative to stripper lint yield (equation 2).

**p-value indicating significance of F test for differences between opposed and in-line drum arrangements only. Data for stripper is shown for reference only.

Table 10. HVI fiber quality results for lint samples pulled from bales after ginning for the US study

Drum Arrangement	Micronaire	UHML (mm)	Strength (g tex^{-1})	UI (%)	Leaf Grade	Rd	+b	Loan Price ($ kg^{-1})
Opposed	4.35	29.59	31.45	82.0	2.3	80.6	7.9	1.25
In-line	4.32	29.40	30.70	81.4	2.0	80.9	7.9	1.26
p-value*	ns	ns	0.0081	0.0090	0.0109	ns	ns	0.0066
Stripper	4.30	29.40	31.08	81.5	2.3	81.4	7.6	1.24

UHML = upper half mean length, UI = uniformity index, Rd= reflectance, +b = yellowness

* p-value indicating significance of F test for differences between opposed and in-line drum arrangements only. Data for stripper is shown for reference only.

CONCLUSION

It is generally accepted that harvesting machinery and practices play an important role in determining yield and harvesting efficiency, as well as fiber quality. This study was conducted to determine the effect of spindle harvester drum arrangement on fiber quality and harvesting efficiency.

Based on the work detailed herein from Australia and the US, slight differences among opposed and in-line drum arrangements in regard to harvesting efficiency and lint turn out were not large enough to produce significant differences in lint yield. Although only statistically significant for the work conducted in the US, lint ginned from seed cotton harvested by the opposed drum arrangement contained more trash than that harvested by the in-line arrangement. In both countries there were small insignificant differences in terms of fiber color (both Rd and +b), length, and micronaire, after ginning and lint cleaning. Although not observed in Australia, small significant differences in length uniformity and strength were observed in favor of the opposed drum arrangement in the US. While measured only in Australia, there were no significant differences between the two drum arrangements in terms of short fiber index, fineness, and maturity. There were also no significant differences between the two drum arrangements in terms of total, fibrous and seed-coat nep content, and size.

ACKNOWLEDGMENT

The authors thank CSIRO Agriculture and Manufacturing for their financial support and the generous cooperation of Auscott Classing for fiber testing. Also acknowledged is the assistance of Michael Bange, Warwick Stiller, Kellie Cooper, and Darin Hodgson at ACRI as well as Mark Freijah, Jan Hair, Glenda Howarth, and Nicole Phair-Sorensen for technical assistance in Geelong. In the US, the authors gratefully acknowledge the cooperating cotton producer and cotton gin for their help in data collection, Plains Cotton Growers for financial support, and John Deere Des Moines Works and Case IH for equipment availability and setup help.

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 Textile Technical Services or the US Department of Agriculture. USDA is an equal opportunity provider and employer.

REFERENCES

Abernathy, G.H., and J.M. Williams. 1961. Baling Seed Cotton for Storage and Handling. Trans. ASAE. 4(2):182–184.

Anonymous. 2001. Report of an expert panel on ginning methods. p. 27. *In* 60th Plenary Meeting of the ICAC, 16-21 Sept. 2001, Victoria Falls, Zimbabwe.

Anonymous. 2004. Picking of Cotton. The ICAC Recorder. 24(1):4–9.

Anonymous. 2011. Cotton Production Practices. 164 p. International Cotton Advisory Committee, Washington, D.C.

ASAE. 2019. Cotton Module Builder and Transporter Standard. ANSI/ASAE S392.2. ASABE, St. Joseph, MI.

Baker, K.D., E. Hughs, and J. Foulk. 2010. Cotton quality as affected by changes in spindle speed. Appl. Eng. Agric. 26(3):363–369.

Deutsch, T.A., and S.A. Junge. 1989. 9960 Cotton Picker. Paper No. 891537. 19 p. International Summer Meeting of the ASAE, Quebec.

Deutsch, T.A., and S.A. Junge (1990). 9960 Cotton Picker. p. 109–111. *In* Proc. Beltwide Cotton Prod. Res. Conf., Las Vegas, NV. 9-14 Jan. 1990. Natl. Cotton Counc. Am., Memphis, TN.

Doraiswamy, I., P. Chellamani, and A. Pavendhan. 1993. Cotton Ginning. Textile Progress 24(2):29.

Faulkner, W.B., J.D. Wanjura, E.F. Hequet, R.K. Boman, B.W. Shaw, and C.B. Parnell 2011a. Evaluation of Modern Cotton Harvesting Systems on Irrigated Cotton: Harvester Performance. Appl. Eng. Agric. 27(4):497–506.

Faulkner, W.B., J.D. Wanjura, E.F. Hequet, B.W. Shaw, and C.B. Parnell. 2011b. Evaluation of Modern Cotton Harvest Systems on Irrigated Cotton: Economic Returns. Appl. Eng. Agric. 27(4):515–522.

Gordon, S.G., K.M. Bagshaw, and F.A. Horne. 2010. The Effect of Lint Cleaning on Cotton Fibre Quality. The Australian Cotton Grower. 31(4):34–38.

Gordon, S.G., K.M. Bagshaw, and F.A. Horne. 2011. The Effect of Lint Cleaner Elements, Settings and Fiber Moisture Content on Fiber Quality. Trans. ASABE. 54(6):1–12.

Holley, D. (2000). The Second Great Emancipation - The Mechanical Picker, Black Migration, and how they shaped the Modern South. The University of Arkansa Press, Fayetteville, AR.

Hughs, S.E., T.D. Valco, and J.R. Williford. 2008. 100 Years of Cotton Production, Harvesting, and Ginning Systems Engineering: 1907–2007. Trans. ASABE. 51(4):1187–1198.

Mygdakos, E. G. 2009. Factors Affecting Picker Capacity, Area Harvested and Harvesting Cost of Cotton. J. Food, Agric. and Env. 7(3-4):214–223.

Stiller, W. 2008. "Sicot 71BRF." Plant Varieties Journal. 21(3):194–197.

USDA-CCC. 2010. 2010 Commodity Credit Corporation (CCC) loan schedule of premiums and discounts for upland and ELS cotton. USDA-CCC, Washington, D.C.

van der Sluijs, M.H.J. 2020. The Influence of Drum Arrangement of Spindle Harvesters on Fiber Quality and Yield. p. 1-8. *In* Proc. Beltwide Cotton Conf., Austin, TX. 8-10 Jan. 2020. Natl. Cotton Counc. Am., Memphis, TN.

van der Sluijs, M.H.J., and G. A. Holt. 2017. Survey Results of the Research Needs and Requirements of the Ginning Industries in Australian and the United States. J. Cotton Sci. 21(1):40–50.

van der Sluijs, M. H.J., and R.L. Long. 2015. The Effect of Seed Cotton Moisture during Harvesting on – Part 1 – Fiber Quality. Textile Res. J. 86(18):1925–1934.

Wanjura, J.D., K. Baker, and E.M. Barnes. 2017. Harvesting. J. Cotton Sci. 21(1):70–80.

Wanjura, J.D., R.K. Boman, M.S. Kelley, C.W. Ashbrook, W.B. Faulkner, G.A. Holt, and M. G. Pelletier. 2013. Evaluation of Commercial Cotton Harvesting Systems in the Southern High Plains. Appl. Eng. Agric. 29(3): 321–332.

Willcutt, M.H., M.J. Buschermohle, G.W. Huitink, E.M. Barnes, J.D. Wanjura, and S.W. Searcy. 2010. The Spindle-Type Cotton Harvester. Texas A&M Agrilife Research and Extension Center, Lubbuck, TX.

Williamson, E.B., and J.A. Riley. 1961. Interrelated Effects of Defoliation, Weather and Mechanical Picking on Cotton Quality. Trans. ASAE. 4(2):164–165 & 169.