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ENGINEERING AND GINNING

Effects of Harvesting Direction and Row Spacing on the Cotton Stripper Performance in Irrigated Cotton Fields

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ABSTRACT

Cotton is picked manually in Fars Province, Iran. It is not only a slow, labor-intensive operation, but extremely tedious, hard work. Due to scarcity of labor at harvesting time, mechanization of cotton harvesting is of vital importance. Therefore, a field study was conducted to evaluate the interactive effects of harvesting directions (in the rows, cross, and oblique, or skew) and row spacing (24-, 36-, and 70-cm) on cotton stripper performance. Results showed that different harvesting directions and row spacing had a significant effect on seed cotton loss. Maximum seed cotton loss was observed in the row direction treatment and minimum loss occurred in the skew treatment. The findings revealed that maximum loss was obtained from row spacing of 70 cm. Overall, these results demonstrated that cotton grown in 36-cm rows and harvested in a skewed or oblique direction had a greater impact on the reduction of seed cotton losses and produced seed cotton yield higher than the 70-cm rows harvested in the rows direction.

Cotton is grown mainly in the northern, southern and north eastern part of Iran and its production is labor-intensive. Hand picking is a common labor force requirement and the unit cost for hand harvesting is high. Manual picking is not only a slow process, but it is extremely tedious, hard work. In addition, there are not enough local workers for hand picking in the northern and southern part of the country. Therefore, mechanization of cotton harvesting is of vital importance. Since 2006, some farmers began using self-propelled spindle pickers to harvest their crops in Iran. Although spindle pickers have good technology and capacity, they are not widespread in Iran mainly because of unsuitable farm structures (such as narrow row spacing, and improper cotton cultivars which is not suitable for cotton pickers) as well as high initial cost. Additionally, the high price of spare parts is beyond the reach of the average income of an Iranian farmer.

Compared to spindle harvesters, stripper harvesters have several advantages over picker harvesters, such as lower purchase prices, fewer moving parts in the row units leading to lower fuel consumption and maintenance requirements, removal of more cotton from the plant, and omitting the second picking (Faulkner et al., 2011; Spurlock et al., 1991). Strippers harvest more foreign material than spindle harvesters. Stick content in stripper-harvested cotton can be reduced without affecting the yield by adjusting the roll spacing (Supak et al., 1992). Although the quality of cotton fibers is dependent on many factors, including genetics, environmental conditions, and handling during harvest and processing, few significant differences in fiber quality characteristics were found between spindle and stripper harvesters (Brashears and Baker, 2000; Brashears and Hake, 1995; Faircloth et al., 2004).Vories and Bonner (1995) compared fiber quality between stripped (with field cleaning) and picked dryland cotton in Arkansas. None of the high volume instrument (HVI) parameters were significantly different between harvesting methods. Brashears and Baker (2000) compared the quality of two cultivars of cotton harvested with a finger stripper, brush-roll stripper (both with field cleaners), and spindle picker. Leaf grades were similar for Paymaster 2200 Roundup Ready, regardless of the harvesting method, whereas the leaf grade for picker-harvested Delta and Pine Land 1220 was significantly lower than the same cultivar harvested with either stripper. For both cultivars, the fiber length of picked cotton was longer and the micronaire was higher than that of the same cultivar that was stripped, likely because the picked cotton included fewer immature fibers than the stripped cotton.

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One of the most important reasons for cotton stripper development was the capability of harvesting narrow row (NR) and ultra-narrow row (UNR) cotton. The production system referred to as UNR has been defined as row spacing of less than 25 cm (Atwell, 1996; Jones, 2001), but some contemporary UNR row spacing includes 19, 25, and 38- cm rows (Culpepper and York, 2000). Interest in seeding cotton in consistently spaced 19- to 25-cm rows and harvesting with a finger-stripper increased in the 1990s as a possible way to reduce production costs and increase yields (Atwell, 1996; Culpepper and York, 2000). A common characteristic of UNR cotton is the use of high plant population densities relative to wide-row cotton (76- to 101-cm rows) (Delaney et al., 2002; Jones, 2001; Perkins, 1998). Cotton grown in UNR might provide some benefits, including better water utilization and increased yield (Larson et al., 2005; Nichols et al., 2004; Vories and Glover, 2006). Cotton plants in UNR systems use less energy for vegetative growth as plants tend to be shorter and have fewer nodes (Nichols et al., 2004; Vories and Glover, 2006). Further, cotton plants concentrate their boll production in the upper positions, which should produce an earlier maturing crop (Vories and Glover, 2006). Delaney et al. (2002) pointed out that UNR cotton is grown at relatively high plant population densities to decrease branching and facilitate stipper harvesting.

A common practice in UNR cotton production is the use of a finger-type stripper harvester instead of a spindle picker. Balkcom et al. (2010) reported that cotton planted in 38-cm rows produced the equivalent lint yield as of 102-cm rows during two experimental years. Also, plant heights were shorter for 38-cm rows compared to 102-cm, regardless of the growth stage. Reddy et al. (2009) implied that under irrigated production, lint yields ranged from 1580 to 1864 kg ha^{-1} in 38-cm rows and 1448 to 1519 kg ha^{-1} in 25-cm paired rows compared to 1413 kg ha^{-1} in 102-cm rows. These results demonstrated that cotton grown in 38-cm rows can close canopy early and produce lint yields higher than cotton grown in 102-cm rows at comparable plant populations, regardless of irrigation (Reddy et al., 2009). Yields were usually equal or higher for UNR cotton in Mississippi (Nichols et al., 2004). In Texas, yields were higher for NR spacing in a dryer year (1998), but yields were not different among row spacings in a wetter year (1999); however, the soil type was different each year (Jost and Cothren, 2001).

In addition to row spacing and cultivar, type of harvester and its adjustments can influence yield, harvest loss and fiber quality (Faulkner et al., 2011). Faircloth et al. (2004) demonstrated that harvested material (seed cotton plus trash) at each location was significantly higher with the stripper harvester than with the spindle harvester, but gin turnout for spindle-harvested cotton was significantly greater (35.6%) than for the stripper-harvested cotton. There is little published information available, particularly in Iran, that describes the combined influence of row spacing and harvesting directions on the mechanization of cotton picking by stripper harvester. The objectives of this study were 1) to evaluate the interactive effects of row spacing and harvesting directions on cotton stripper performance, and 2) to quantify the effect of narrow- and conventional row cotton production systems on plant characteristics and seed cotton yield in an irrigated environment.

MATERIALS AND METHODS

This study was conducted in 2014 at the Darab Agricultural Research Station in Fars Province, located in the southwestern region of Iran (28° 47’N , 57° 17 ′E ; 1120 m above sea level). The region has a semi-arid climate. Total amount of annual rainfall is approximately 265 mm, most of which occurs during winter. During the 2014 growing season, the minimum and maximum air temperatures were 13.9 and 29.9°C, respectively, and the minimum and maximum average humidity was 18.3 and 60.1% respectively. The soil texture was loam (17.95% clay, 41.75% silt, 40.3% sand) down to a depth 120 cm. Soil organic matter was 6.5 g kg^{-1}. Saturated paste extract electrical conductivity (EC) and pH were 0.62 dSm^{-1} and 7.91, respectively.

The experimental design was a randomized complete block with strip-plots arranged in three replications. The harvesting directions (HD) were: harvesting in the direction of the crop rows (D1), cross (D2), and oblique or skew (D3) as the main plots, and three row spacings (RS) as the subplots: including 24 (S1), 36 (S2) and 70 cm (S3, conventional row). All plots measured 9 m by 40 m. Cotton variety T_2 was planted on 15 June 2014 with a Pierobon TD 17.5-17 (Cordoba-Argentina) direct drill. From stand counts taken approximately 3 wks after planting plant populations were approximately 154000 plants ha^{-1} in the 24 and 36-cm row spacing and approximately 82,000 plants ha^{-1} in the 70-cm row spacing. Phosphorous and nitrogen fertilizer requirements were determined from soil test results. Triple superphosphate was applied at 90 kg P2 O5 $ha^{-1}$and urea (46% N) was applied at 125 kg ha^{-1}. All Plots furrow irrigated and irrigation was performed at 50% depletion of available water determined gravimetrically in the top 40 cm of soil. Chemical herbicides and insecticides were applied as needed and in accordance to customary practice for the growing region. Harvest-aid chemicals (Finish 6 pro and Dropp Ultra , Bayer CropScience LP) were applied by ground sprayer at 60% open bolls, based on boll counts for defoliation prior to harvest for defoliation prior to harvest. (Logan and Gwathmey, 2002).

Plant measurements included plant height in cm (PHT) and total number of bolls per plant (TB). Average plant height was determined based on 30 plants per plot. Height was measured from the soil surface to the terminal of the plant. Observations on harvester performance included harvest loss (ground and stalk losses) and foreign matter content. Entire plots were harvested utilizing a tractor-mounted mechanical stripper (Javiyu CD300, DOLBI, Argentina), with finger header (Fig.1). The harvester was equipped with a bur extractor. Before mechanical harvesting, a location within each experimental plot was randomly selected and marked. At each assigned location, all seed cotton on plants within a 15-m length of row was picked carefully by hand and the field yield was determined in that portion of the field. Approximately 2 m from the end of the hand-harvested row, a second 15-m length was marked, and the pre-harvest loss was determined by collecting seed cotton that had fallen on the ground by natural causes so that each plot was clean. After the stripper passed, any cotton left on the ground was collected and weighed to determine ground losses (drop loss). In addition, cotton remaining on the stalk was also hand-picked and weighed to determine stalk loss. This analysis assumes that the yields in both 15-m sections were equal. The loss for each section was determined as a percentage of total yield. Forward speed on each plot was calculated as the time required for the machine to travel a distance of 30-m. The effective field capacity (EFC), theoretical field capacity (TFC), and field efficiency (e) were calculated by recording the time consumed for actual work and the time of other miscellaneous activities such as turning adjustment under field operating conditions.

Fig.1- Pull behind cotton stripper

TFC was calculated as: TFC = W×S/10 and EFC was calculated as: EFC = TFC× e.
Where W = machine working width (m), S = machine forward speed (km/hr), TFC = theoretical field capacity (ha/hr), e = field efficiency (decimal), and EFC = effective field capacity (ha/hr). A 3-kg sample of seed cotton was collected from each plot and from each harvester basket for determination of foreign matter content (bur, stick, leaf). Data were analyzed using standard analysis of variance techniques with M Stat-C (Freed and Eisensmith, 1986). Means were compared for significance using Duncan's test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Harvest Losses. Analysis of variance indicated that harvesting direction and row spacing had significant effects on harvest losses (Table 1). Harvest losses of the cotton stripper included ground and stalk loss. Maximum seed cotton loss was observed in the D1 treatment (9.6%) and minimum seed cotton loss occurred in the D3 treatment. In regard to seed cotton losses, there was no significant difference between D2 and D3 treatments (Fig. 2). It seems that as the harvester header operates in the oblique direction, cotton plants enter the metal fingers sector in a uniform, well-distributed pattern, without empty spaces or overloading the header. The results revealed that seed cotton loss increased as row spacing increased during harvest. Seed cotton losses in the S1 and S2 treatments were significantly less than the S3 treatment (Fig. 3). The increase in seed cotton loss in S3 might be due to more empty spaces in the harvest header and high harvest speed as compared to S1 and S2 treatments. When harvesting direction was changed from D1 to D3, seed cotton loss was reduced by 1.5 %, whereas replacing S1 and S2 treatments with S3 led to the seed cotton loss reduction by 3.2 and 3% respectively (Figs. 2, and 3).

Table 1- *P*-Values for Harvest Loss, Forward Speed, Effective Field Capacity, Boll Number, Plant Height, Total Trash and Seed Cotton Yield Between Harvest Direction and Row Spacing

Source	P>F						
	HL	FS	EFC	TB	PHT	SCY	TR
HD[Z]	0.017	< 0.0001	0.0170	0.3422	0.1911	0.0321	< 0.0001
RS	0.0038	0.0345	0.0004	0.0005	0.0248	0.0003	0.0041
HD × RS R.S	0.0024	0.2943	0.346	0.4537	0.2337	0.0442	0.3892

[Z] HL: harvest losses, FS: forward speed, EFC: Effective Field Capacity, TB: boll per plant, PHT: plant height, SCY: seed cotton yield, TR: total trash, HD: harvest direction, RS: row spacing, Significance level ($p \leq 0.05$).

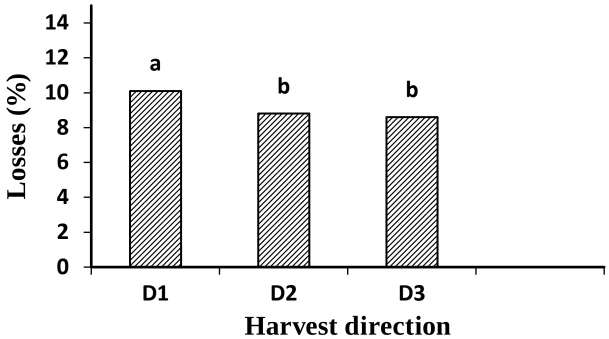

Fig. 2- Harvest losses as affected by harvesting direction.

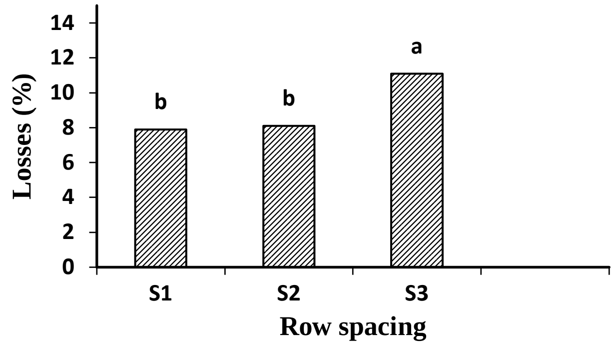

Fig. 3- Harvest losses as affected by row spacing.

The results also showed that different row spacing can increase the effectiveness of harvesting direction in reducing seed cotton losses. D × S interaction had a significant effect on seed cotton losses during the harvest operation (Table1). Minimum seed cotton losses were observed for D3 × S2 and D2 × S2 treatments and the maximum occurred for the D1 × S3 treatment; although there were no significant difference between D1 × S3 and D2 × S3 or D3 × S3 treatments (Table 2). The results also revealed that D1 × S1 or D1 × S2 had a greater impact in reducing seed cotton losses than D1 × S3 treatment (Table 2). In comparison, D2 and D3 treatments in combination with NR and UNR (S1, S2) relative to conventional row (S3) were the most effective for reducing of seed cotton losses.

Effective Field Capacity (EFC). Different harvesting directions and row spacings had significant effects on the combine forward speed and EFC (Table 1). The D2 and D3 treatments relative to D1 treatment led to a significant forward speed reduction by 71.4 and 28.6% during harvesting, respectively (Table 3). The results also indicated that maximum EFC occurred in the D1 treatment (0.68 ha h^{-1}) and harvesting in the direction of oblique and cross (D3, D2) reduced EFC by 26.4 and 69.1% compared to D1, respectively. A comparison of mean values of EFC showed that when row spacing was decreased from 70 to 36 and 24 cm, EFC was reduced by 13.2 and 26.4%, respectively (Table 3). The decrease in EFC in S1 and S2 might be attributed to the low harvest speed to prevent overloading the header cross auger and the cleaning system. The D × S interaction had no significant effect on EFC (Table 1).

Table 2- Seed Cotton Losses as Affected by Harvesting Direction and Row Spacing

Harvesting direction	Row spacing (cm)	Harvest losses (%)
In-Row	24	8.2c[Z]
	36	9.3b
	70	11.2a
Cross	24	7.8cd
	36	7.3d
	70	11.2a
Oblique	24	7.5d
	36	7.3d
	70	11.1a

[Z] Values with the same lowercase letter in each column are not significantly different ($P < 0.05$, Duncan's).

Plant Mapping, Seed Cotton Yield and Foreign Matter Content. Total boll number (TB) in the S3 treatment was significantly more than S1 and S2 treatments (Table 4). When row spacing was decreased from 70 to 36 and 24 cm, TB was reduced by 39.6 and 45.9%, respectively (Table 4). These results agree with are similar to the results of previous studies that have reported TB were decreased through row spacing reduction (Jahedi et al., 2013; Vories and Glover, 2006). The results also revealed that different row spacings had a significant effect on plant height. Cotton height was approximately 11.6 and 7.9 cm less in the 24- and 36-cm row spacing, respectively, than the 70-cm row spacing (Table 4). The reduction in plant height and TB was consistent with the findings of Nichols et al. (2004) and Jost and Cothren (2001).

Table 3- Forward Speed (FS) and Effective Field Capacity (EFC) as Affected by Harvesting Direction and Row Spacing

Treatments	FS (Kmh^{-1})	EFC ($ha\ h^{-1}$)
Harvesting direction		
In-Row	2.1a^{Z}	0.68 a
Cross	0.6c	0.21 c
Oblique	1.5b	0.50 b
Row spacing (cm)		
24	1.28a	0.39 c
36	1.32 a	0.46 b
70	1.58 a	0.53 a

^{Z} Values with the same letter in each column are not significantly different ($P < 0.05$, Duncan's).

Table 4- Total Boll Number, Plant Height, Seed Cotton Yield and Total Trash as Affected by Harvesting Direction and Row Spacing

Treatments	TB	PHT (cm)	SCY ($Kg\ ha^{-1}$)	TR (%)
Harvesting direction				
In-Row	8.3a^{Z}	84.2a	3618.9b	9.4 b
Cross	6.8 a	84 a	3745.1b	11.6 a
Oblique	7.6 a	85.3 a	3952.5a	12.4 a
Row spacing (cm)				
24	5.7b	79.4b	3854.6 a	13.4 a
36	6.4 b	83.1b	3974.1 a	12.8 a
70	10.6 a	91 a	3487.8 b	8.9 b

^{Z} Values with the same letter in each column are not significantly different ($P < 0.05$, Duncan's).

Table5- Seed Cotton Yield (SCY) and Harvest Losses (HL) as Affected by Harvesting Direction and Row Spacing

Harvesting direction	Row spacing (cm)	HL (%)	SCY ($K\ gha^{-1}$)
	24	8.2c^{Z}	3646.4cd
In-Row	36	9.3b	3791.1bc
	70	11.2a	3419.2d
	24	7.8cd	3893.3abc
Cross	36	7.3d	3960.8 abc
	70	11.2a	3381.2 d
	24	7.5d	4024.4ab
Oblique	36	7.3d	4170.2a
	70	11.1a	3663.3bcd

^{Z} Values with the same letter in each column are not significantly different ($P < 0.05$, Duncan's).

The minimum seed cotton yield was observed in the D1 treatment, whereas the D3 treatment led to a significant seed cotton yield that was 9.1% greater than the D1 treatment (Table 4). The increase in seed cotton yield in D3 could be due to the reduction of ground and stalk losses as compared to D1 and D2 treatments (Table 5). Cotton grown in 24 and 36-cm rows (S1, S2) produced significantly more seed cotton yield than in 70-cm rows (Table 4). In addition, relative to S1, the S2 treatment was more effective in increasing seed cotton yield (3.1%), although there was no significant difference between them during harvest (Table 4).

In this study, differences in seed cotton yield between narrow and conventional rows were most likely due to the high plant population and the effect of the stripper on seed cotton loss. This agrees with the findings of Nichols et al. (2004), Vories and Glover (2006), and Reddy et al. (2009) who reported a trend of higher yield with reduction of row spacing. The results also showed that D × S interaction had a significant effect on seed cotton yield (Table 1). Maximum seed cotton yield was observed for the D3 × S2 treatment and the minimum occurred for the D1 × S3 and D2 × S3 treatments during harvest (Table 5).The increase in seed cotton yield in D3×S2 could be due to well-distribution uniformity of cotton plants on the header fingers sector, and subsequently, the reduction of ground and stalk losses as compared to D1 × S3 and D2 × S3 treatments. Relative to D1 × S2, the D2 × S2 treatment was more effective in increasing seed cotton yield (4.5%), although there was no significant difference between them (Table 5). This can be attributed to the effect of harvesting direction, which significantly reduced ground and stalk losses during harvest. It can be concluded that the D × S interaction relative to sole application of D or S, was the most effective for producing higher seed cotton yield and lower harvest losses (Table 5).

Percentage trash based on the total sample weight, is shown in Table 4. Significant differences in total foreign matter content were detected between harvesting direction and row spacing treatments after harvest (Table 1). The percentage total trash (burs, sticks, bits of leaves) was higher for D3 and D2 treatments as compared to D1 (Table 4). These differences likely were due to the decrease in number of plants and subsequently more empty spaces in the harvest header stripper for D1 relative to D2 and D3 harvesting directions. The results also revealed that stripper harvesting of NR cotton (S1 and S2) as compared to S3, typically increased the total trash content of harvested seed cotton. Relative to S1, the S2 treatment was more effective in the reduction of total foreign matter, although there was no significant difference between them. These findings agree with to those of Valco et al. (2001) who reported that the initial foreign matter of seed cotton is typically higher for UNR cotton compared to cotton in conventional rows for stripper.

SUMMARY AND CONCLUSIONS

Harvesting direction and row spacing were related to differences in stripper performance, seed cotton loss and cotton yield. Maximum seed cotton loss was observed in the direction of the row treatment and minimum loss occurred in skew harvesting. Seed cotton loss increased as row spacing increased during harvest. The results also showed that different row spacings can increase the effectiveness of harvesting direction with reduction in seed cotton loss. Cotton grown in 24- and 36-cm rows (S1, S2) produced significantly more seed cotton yield than in 70-cm rows. It can be concluded that D × S interaction relative to the sole application of D or S treatments was more effective in producing higher seed cotton yield and lower harvest losses.

DISCLAIMER

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