

Response of cotton (*Gossypium hirsutum* L.) to different tillage systems and intra-row spacing

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Received 10 March 2004; received in revised form 13 January 2005; accepted 18 January 2005

Abstract

The earliness is of great importance to cotton production in Mediterranean-type environments due to detrimental effects of autumn rainfall on lint quality. However, farmers commonly avoid early sowing due to risks of cold soil temperature and waterlogging after sowing in spring. Ridge-tillage system is one approach to increase soil temperature and mitigate adverse effects of waterlogging. The ridge-tillage system is also advantageous in reducing inputs in tillage operations. However, a limited experimental data are available about the effects of ridge-tillage system on earliness of harvesting, lint yield and quality of cotton in the Mediterranean-type environments. Thus, the objective of this study was to determine how ridge-tillage (RT)-planting system and intra-row spacing affect cotton lint yield, earliness and fiber quality compared with conventional tillage (CT)-planting system. Field experiments were conducted on a clay soil (Vertisol) in Hatay province (36°39'N–36°40'E, 83 m a.s.l.) in the Eastern Mediterranean Region of Turkey during 2000 and 2001. The experiment was laid out as a split-plot with three replications with tillage systems as main plots and intra-row spacings (13, 17, 21 and 25 cm) as subplots. The effects of tillage systems on lint yield and earliness were inconsistent among years. The RT-planting system resulted in 13.5% higher lint yield and 14.5% more earliness in 2001 when abundant rainfall occurred after sowing, while significant effects of tillage systems were not observed in 2000. The intra-row spacings significantly affected lint yield and earliness in both years. The earliness increased with closer spacing, while the highest lint yield was obtained from 17 cm intra-row spacing in both years. However, the fiber quality parameters were not significantly affected by tillage systems, intra-row spacings and tillage system × spacing interaction in both years. Finally, the results suggest that RT-planting system with 17 cm intra-row spacing can be used in cotton production instead of CT-planting system in the Eastern Mediterranean Region of Turkey. Ridging in 17 cm intra-row spacing also seems to be suitable to mechanical harvesting.

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Keywords: Cotton (*Gossypium hirsutum* L.); Ridge tillage; Conventional tillage; Intra-row spacing; Lint yield; Earliness; Fiber quality

1. Introduction

Although cotton (*Gossypium hirsutum* L.) is a perennial crop with indeterminate growth habit, it is grown as an annual crop commercially. Therefore, it is

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very responsive to changes in environmental conditions. Changes in temperature, humidity and soil moisture may result in allocation of energy to sinks other than lint production. The yield potential of cotton grown in the Mediterranean-type environments is generally high due to long, warm and sunny growing season. However, inadequate emergence due to cool soil temperature or waterlogging after sowing and poor fiber quality owing to early autumn rainfall were the main constraints of cotton production in that type of environments. The adequate stand establishment is essential to high yield with acceptable fiber quality. Ridge-tillage system is one approach to improve stand establishment by increasing soil temperature and reduce adverse water logging effects after sowing. Ridge-tillage planting system could also help increase yield and earliness by improving soil water and temperature regimes in root zone during the first growing period (Benjamin et al., 1990; Lal, 1990; Unger and Musick, 1990). The earliness has further importance to cotton production in Mediterranean-type environments due to detrimental effects of autumn rainfall on lint quality. Early maturity in cotton could also reduce production costs by decreasing pesticide applications, irrigation, etc. (Jost and Cothren, 2001).

The ridge-tillage system also offers a further advantage of reducing inputs for tillage operations. The two essential equipments for the RT-planting system are a ridge lister and scrubber. On the other hand, the CT-planting system, which is a widespread tillage system for cotton in the Eastern Mediterranean Region of Turkey, commonly involves eight or more trips through the field, such as shedding stalk, disking (twice), ploughing, further disking (twice or more), harrowing (twice) and firming.

Yield responses of cotton to ridge tillage reported in the literature have been inconsistent. In some studies, reduced or equivalent cotton yields have been produced with RT compared with conventional planting systems (Brown et al., 1985; Stevens et al., 1992; Bauer and Busscher, 1996; Wheeler et al., 1997). However, others have reported enhanced yields of cotton by RT compared with CT-planting system (Carter and Colwick, 1971; Constable et al., 1992; Wiese et al., 1994; Clark et al., 1996; Hunt et al., 1997; Blaise and Ravindran, 2003). Research indicates that any yield benefits of RT may not be

observed until several years after adopting the system (Triplett et al., 1996). Yield increases are attributed to improved soil moisture under RT-planting system (Harmon et al., 1989; Baumhardt et al., 1993; Daniel et al., 1999).

The population density, determined by a combination of row and intra-row spacing, also significantly affects both yield and quality of cotton under different production systems. The effects of row spacing on cotton lint yield were extensively studied earlier by several researchers (Hawkins and Peacock, 1971, 1973; Bridge et al., 1973; Baker, 1976; Buxton et al., 1979; Smith et al., 1979; Unay and Inan, 1996). Recent investigation on row spacing of cotton have shown that the highest yields produced from 76 cm row spacing regardless of tillage systems in a semi-arid Mediterranean environment in Turkey (Ozpinar and Isik, 2004). In ridge planting system, ridges are difficult to build and maintain in row widths of less than 76 cm (Griffith et al., 1990). Therefore, 76 cm row spacing in ridges seems to be suitable for mechanical harvesting. However, response of cotton to intra-row spacing under different tillage systems was less studied under the Mediterranean conditions. The optimization of intra-row ridge spacing also affects earliness, yield and fiber quality.

The objective of this study was to investigate the effects of different tillage systems and intra-row spacing on lint yield, earliness of harvesting and some fiber quality properties of cotton in a Mediterranean-type environment in Turkey.

2. Material and methods

2.1. Site, soil and climate

The experiments were carried out during 2000 and 2001 growing seasons at experimental fields of Ozbugday Seed Company, in Hatay, which is located in the Eastern Mediterranean region of Turkey (36°39'N, 36°40'E, 85 m above sea level). The soil of the experimental site, developed from alluvial deposits of river terraces, is typical for the Eastern Mediterranean region in Turkey and is classified as Chromoxeret by USDA (1998) Soil Taxonomy and as Vertisol by FAO/UNESCO (1974) having relatively high clay content with the predominant clay minerals

smectite and kaolinite. The soil of experimental was clay in texture (159 g kg⁻¹ sand, 374 g kg⁻¹ silt, 468 g kg⁻¹ clay) with 11.12 g kg⁻¹ organic matter, 0.67 g kg⁻¹ total nitrogen content, available phosphate and potassium contents of 9.08 and 273.91 mg g⁻¹, respectively and slightly alkaline (Table 1).

The climatic data were obtained from the agro-meteorological station operated by the State Farm, Hatay, about 3 km from the experimental site (Table 2). Hatay province has typical Mediterranean climate with hot-dry summers and mild-rainy winters. Total annual precipitation at the study site was 519 mm in 2000 and 721 mm in 2001. Precipitation during the growing period (May–September) in 2000 was about 60 mm and only 1.4 mm of rainfall occurred in May. In contrast, precipitation during the growing period in 2001 was 241 mm, of which 176 mm was received in May. No rainfall occurred in 2000 and 2001 during the summer months (June–August). Mean air temperature was about 25 °C during the cropping period (May–October) in both

Table 1
Soil properties at experimental site

Texture	Clay
Clay (g kg ⁻¹)	468 ± 9
Silt (g kg ⁻¹)	374 ± 7
Sand (g kg ⁻¹)	159 ± 3
Organic matter (g kg ⁻¹)	11.1 ± 0.2
Total nitrogen (g kg ⁻¹)	0.67 ± 0.034
Available phosphate P (mg g ⁻¹)	9.08 ± 0.454
Available potassium K (mg g ⁻¹)	274 ± 4
CaCO ₃ (g kg ⁻¹)	270 ± 7
Soil pH	7.5 ± 0.2
Saturation (%)	66.0 ± 1.2
Electrical conductivity in 1:5 soil:water (dS m ⁻¹)	1.49 ± 0.025
Bulk density (g cm ⁻³)	1.2 ± 0.01
Infiltration rate (mm h ⁻¹)	4.80 ± 0.11
Soil order	Vertisol

years. The mean relative humidity was around 50 and 54% during growing periods in 2000 and 2001, respectively.

Table 2
Monthly minimum, maximum and mean air temperatures (°C), precipitation (mm) and relative humidity (%) at Hatay State Farm during the growing period, 2000–2001

Year	May	June	July	August	September	October	Total/average
Mean air temperature (°C)							
2000	21.2	26.7	29.2	28.1	25.3	19.8	18.0
2001	20.9	26.6	28.3	28.7	25.4	20.5	18.6
12-year average	21.2	25.7	28.6	27.7	25.3	22.6	18.5
Minimum air temperature (°C)							
2000	13.6	18.1	16.0	14.4	13.8	7.0	8.8
2001	10.0	15.6	19.4	18.2	16.4	8.4	–3.0
12-year average	11.3	17.0	21.0	22.2	15.9	12.2	9.9
Maximum air temperature (°C)							
2000	40.3	37.9	42.0	40.2	37.8	34.2	31.7
2001	37.2	41.6	37.8	37.8	37.6	35.2	41.6
12-year average	33.6	34.9	35.1	35.2	36.4	32.3	27.9
Precipitation (mm)							
2000	1.4	–	–	–	4.3	58.5	518.6
2001	175.6	–	–	–	3.3	62.1	721.1
12-year average	33.3	7.7	–	–	7.8	38.9	46.4
Relative humidity (%)							
2000	50.0	39.0	51.1	52.0	58.0	62.7	52.8
2001	60.8	40.0	53.2	55.7	59.9	54.1	59.7
12-year average	62.0	59.8	65.1	66.0	63.8	59.8	65.3

2.2. Field tillage procedures and experimental design

Cotton was the previous crop at the experimental site in both years. Before the beginning of the experiment, previous cotton stalk and residues were shredded using a rotary cutter. Chiseling to 25 cm depth was done as primary tillage on 15 November 2000 and 17 November 2001. Seedbed preparation for conventional tillage plots corresponded to typical practices in the Eastern Mediterranean region of Turkey. These included a fall chisel plowing followed by disk harrowing twice to 10 cm depth in April each year, finally bedding with a culti-packer. The RT system consisted of a modified lister and ridge culti-packer. The ridge lister is used to form the initial ridges (at approximately 12 cm height and 31 cm width at the base) and rebuilding of the ridges. The ridges were re-formed in April of each year and then pressed with ridge scrubber.

The experimental design was split-plot with three replications. The two tillage systems, conventional tillage (CT) and ridge tillage (RT), were allocated to the main plots and four intra-row spacings (13, 17, 21 and 25 cm) to subplots. Each subplot was comprised of four 0.76 m wide rows, which were 38.0 m long. Cotton cv. Sure Grow 125 (standard cotton variety for the region) was sown using pneumatic seed drill on 7 May 2000 and 21 May 2001. The seed had been acid-delinted and commercially treated with a combination of endosulfan (493.5 g ai 100 kg cotton seed⁻¹ of 6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepine 3-oxide) + carboxin (375 g ai 100 kg cotton seed⁻¹ of 5,6-dihydro-2-methyl-1,4-oxathi-ine-3-carboxanilide). The seeds were sown at around 1 cm intra-row spacing to avoid crusting of the soil surface risk from heavy rainfall after planting and then, subplots were thinned to 13, 17, 21 and 25 cm at the third to fourth true-leaf stage in both years.

In both years, the cotton was grown under irrigated conditions with other cultural inputs applied consistent with local agronomic practices. The pre-sowing herbicide, *trifluralin* (960 g ai ha⁻¹ of trifluoro-2,6 dinitro-*N,N*-dipropyl-*p*-toluidine), was sprayed at the rate of 2000 ml ha⁻¹ before planting. Plots were fertilized with 60 kg N, P, K/ha before planting using a 15-15-15 fertilizer, and an additional nitrogen (as

urea) dose of 60 kg/ha was side-dressed at the square stage. Hoeing was done three times by using of a rotary hoe. Six furrow irrigations were applied at about 14 days intervals from the beginning of square stage to the bolls during the growing season each year. Sufficient water was applied to saturate 120 cm of soil profile in each irrigation.

2.3. Yield, earliness, fiber quality measurements and statistical analysis

Percentage of total crop yield harvested in the first of two harvests (percent first-pick) has been the most frequently used measurement of earliness in cotton (Howard et al., 1999; Bourland et al., 2001). Therefore, percent first-pick was used as a measure of earliness in this study. Seed cotton was hand-picked twice in the middle two rows of each subplot in both years. The first-picking started, when the cotton bolls were approximately 60% open, and the second harvest was 17 days later in both years. The harvested seed cotton was weighed and then roller-ginned to measure lint percentage. The lint and seed were weighed immediately after ginning. Lint percentage was multiplied by seed cotton yield to estimate lint yield. Earliness (percent first-pick) was calculated by dividing first harvest mass by total mass. Fiber properties of each sample were determined in high volume instruments: (a) fiber length in millimeters measured as the average length of the longer one-half of the fibers (upper half mean length); (b) fiber strength as force (g/tex) necessary to break the fiber bundle (a tex unit is equal to the weight in grams of 1000 m of fibers); (c) micronaire reading (mic) as fineness of the fiber expressed in standard micronaire units (micronaire is actually equal to the average weight of the fiber in micrograms).

All data were subjected to analysis of variance (SAS Institute Inc., 1990), followed by the least significant difference (LSD) mean separation when *F*-tests were significant.

3. Results and discussion

3.1. Lint yield

The mean lint yield differed significantly among years (Table 3). The highest lint yield was obtained

Table 3

The effects of tillage systems and intra-row spacings on lint yield, earliness and lint quality in 2000 and 2001

Treatments	Lint yield (kg ha ⁻¹)			Earliness (%)			Fiber length (mm)			Fiber strength (g/tex)			Micronaire reading (mic)		
	2000	2001	Mean	2000	2001	Mean	2000	2001	Mean	2000	2001	Mean	2000	2001	Mean
Tillage systems (T)															
Conventional	2082	1800	1941	56.6	56.4	56.5	29.3	27.9	28.6	22.9	20.8	21.8	4.70	4.98	4.84
Ridge	2058	2043	2050	59.3	66.0	62.7	28.6	26.9	27.8	22.1	19.8	20.9	4.62	5.27	4.95
S.E. ^a	50.89	51.96	47.00	1.29	0.43	0.39	1.88	0.61	0.29	0.94	1.04	0.72	0.24	0.25	0.25
LSD ^b ($P < 0.05$)	NS ^c	223	NS	NS	1.86	2.38	NS	NS	NS	NS	NS	NS	NS	NS	NS
Intra-row spacings (I) (cm)															
13	2109	2015	2062	62.9	67.3	65.1	28.9	27.9	28.4	22.2	20.5	21.3	4.78	5.23	5.01
17	2281	2148	2215	59.4	63.0	61.2	28.7	26.5	27.6	23.5	20.2	21.8	4.50	5.36	4.93
21	2020	1899	1959	57.5	59.0	58.3	28.9	27.8	28.3	22.7	19.9	21.3	4.65	5.18	4.92
25	1869	1624	1767	52.1	55.5	53.8	29.0	27.4	28.2	21.7	20.6	21.1	4.70	5.21	4.96
S.E.	53.78	57.58	30.00	0.91	0.77	0.31	1.49	0.81	0.71	1.74	0.51	1.36	0.24	0.21	0.23
LSD ($P < 0.05$)	114	122	65	3.13	1.64	1.07	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions (T × I)															
S.E.	189.8	238.1	189.4	2.46	2.29	2.17	1.69	0.83	0.09	1.51	0.88	1.23	0.21	0.18	0.17
LSD ($P < 0.05$)	NS	NS	NS	NS	6.88	6.51	NS	NS	NS	NS	NS	NS	NS	NS	NS
Annual mean	2070	1922		57.9	61.2		28.9	27.4		22.5	20.3		4.66	5.13	

^a Standard error.^b Least significant difference.^c Non-significant.

(2070 kg ha⁻¹) in 2000 and the lowest (1922 kg ha⁻¹) in 2001. In 2001, excessive rainfall (175.6 mm) after emergence in May caused waterlogging and cooler temperature during early seedling stage, which reduced lint yield by 7% than in 2000. Tisdall and Hodgson (1990) showed that as soil was waterlogged from 5 to 25 days per growing season, the average yield of lint decreased by 38–19 kg ha⁻¹ day⁻¹. Mean minimum temperature in May 2000 and 2001 was 13.6 and 10.0 °C (Table 2), respectively. In the early phase of cotton growth, the increase in dry weight per plant was mostly due to temperatures above 13 °C (Roussopoulos et al., 1998).

The effect of tillage system on lint yield were found significant only in 2001, while the lint yield was significantly affected by intra-row spacings in both years (Table 3). There were no interactions between tillage systems and intra-row spacing for the lint yield (Table 3). The occasional interactions that did occur were inconsistent over time and not considered a major influence on the results. In 2001, RT-planting system produced about 13.5% higher lint yield than

the CT-planting system. Sowing on ridges reduced detrimental effects of waterlogging during post emergence period in 2001 and seedlings remained above the water level. Moreover, the ridge system probably resulted in warmer top soil temperature under these wet conditions. Tisdall and Hodgson (1990) reported that ridges reduced risks of waterlogging in Vertisols without seriously reducing the amount of water stored. Radke et al. (1993) also found that soil drying started at the peak of the ridges and moved downward, and so, soil temperatures in RT-planting system increased more rapidly, where the soil was driest and evaporation lower than in CT-planting system. Aerated ridges can compensate, at least partially, for the waterlogged subsoil. This probably explains the high yields of cotton grown on aerated ridges in 2001. It is apparent that ridge planting on Vertisols could be a risk-avoidance system during excessively wet years.

Despite the differences in mean lint yield among the years, there were similarities among years in pattern of intra-row spacings. The highest lint yield

was obtained from 17 cm intra-row spacing under both tillage systems in both years. Very high or very low plant population of cotton reduce lint yield, since the inter-plant competition for production inputs increases with closer spacing, while the total number of plants per unit area decreases with wider spacing (Kittock et al., 1986). However, the optimum plant density strongly depends on environmental conditions, cultivars and production systems. Therefore, the optimization of plant density in a unit area is very important to maximizing yield and quality of cotton crop for specific environment or production system. The Sure Grow 125 is an early cultivar with a cluster growth habit. Therefore, it responded well to the closer spacing for lint yield but the closer spacing than 17 cm increased inter-plant competition and reduced lint yield irrespective of tillage systems in both years.

3.2. Earliness of harvesting (percent first-pick)

The RT-planting system improved earliness of harvesting by 3% in 2000 and 10% in 2001, but differences among tillage systems were not statistically significant in 2000 (Table 4). These results indicated that RT-planting systems, especially in a wet season, may enhance earliness by improving soil water and temperature regimes in the root zone during

the first growing period as cotton growth rate in early season was highly related to subsequent early boll set or earliness. Reductions in percent first-pick induced by CT-planting system in this study agree with the findings of Blaise and Ravindran (2003). However, Kennedy and Hutchinson (2001) showed that CT-planting system produced earlier flower buds than RT-planting system leading to earlier boll set. This apparent contradiction regarding the earliness may be explained by different soil properties and weather conditions.

Differences in earliness caused by intra-row spacing were significant in both years (Table 3). However, trends in earliness were similar across years. The earliness increased when intra-row spacing decreased; 13 cm intra-row spacing caused more earliness compared to wider spacings in both years. The interactions of tillage systems and intra-row spacing were statistically significant for combined analysis in 2001 and data pooled over the 2 years (Table 4). In general, the highest earliness obtained from the interactions between tillage and intra-row spacing was high in 13 or 17 cm intra-row spacing in both 2001 and data pooled over the 2 years. This significant interaction plus the fact that the highest lint yields were obtained at intra-row spacing of 17 cm and sowing on ridges suggests that as intra-row spacing above 17 cm increased both lint yield and declined earliness.

3.3. Fiber quality

Mean fiber length, fiber strength and micronaire values in 2000 and 2001 were 28.9 and 27.4 mm, 22.5 and 20.3 g/tex and 4.66 and 5.13 mic, respectively. In comparison with the 2001 growing season, the 2000 growing period produced strong, fine and long fibers. Overall, however, fiber quality was poor in 2001, because of the environmental factors.

There were no significant differences among tillage systems with respect to fiber quality (fiber length, strength and micronaire readings) in either of the 2 years (Table 3). Mean fiber length, fiber strength and micronaire values in CT and RT systems were 28.6 and 27.8 mm, 21.9 and 20.9 g/tex and 4.84 and 4.95, respectively. These findings are similar to those reported by Hulugalle et al. (2004), who found no differences in fiber length, strength and micronaire readings by tillage systems.

Table 4
Tillage $\times$ intra-row spacing interaction effects on earliness

Intra-row spacings (cm)	Earliness		
	2000	2001	2-year mean
Ridge			
13	62.9	72.3	67.6
17	61.0	68.0	64.5
21	57.6	64.0	60.8
25	56.1	59.7	57.9
Conventional			
13	63.7	62.3	63.0
17	57.8	58.0	57.9
21	57.4	54.0	55.7
25	48.3	51.3	49.8
S.E. ^a	2.46	2.29	2.17
LSD ^b ($P < 0.05$)	NS ^c	6.88	6.51

Tillage systems: ridge and conventional.

^a Standard error.

^b Least significant difference.

^c Non-significant.

Fiber length, fiber strength and micronaire values obtained in 2000 were similar to those in 2001 in relation to intra-row spacing. Contrasting results have been reported in the literature about the effects of spacing on fiber quality. Vories et al. (1999) reported that in 2 out of 3 years, micronaire readings were reduced in ultra narrow row cotton versus conventionally grown cotton, while Jost and Cothren (2001) and Nichols et al. (2003) found no differences in micronaire reading with respect to row spacing. Bridge et al. (1973), Heitholt et al. (1993), and Nichols et al. (2003) reported that fiber length and strength were unaffected by intra-row spacing. Fiber length and strength are largely determined by genotype such that cultivars with the highest length and strength tend to produce larger cellulose molecules with few break points in lint and more cross linkages between fibers (Hake et al., 1996; Jordan, 2001). Collectively, these data suggest that neither tillage systems nor intra-row spacing have a detrimental effect on fiber quality.

4. Conclusion

Tillage systems had no effect on cotton lint yield during the first year (2000). Excessive rainfall occurred immediately after emergence during 2001. Waterlogging and cooler temperature during early seedling stage limited cotton growth and yield. The adverse weather conditions in 2001 had more adverse effect on lint yield under CT-planting system, while RT-planting system maintained productivity in respect to lint yield with acceptable fiber quality. In addition to lint yield, percent first-pick was improved by the RT-planting system during the adverse growing conditions in 2001. Moreover, RT-planting system offers more options in decreasing or shifting the risks from the cold and damp soil conditions, seedling disease stress in early growing period and high insect infestations in late growing period. These results indicate that sowing cotton on ridges is an efficient alternative tillage system for increasing earliness (percent first-pick) and lint yield while maintaining fiber quality in the Mediterranean environments. However, to consistently improve yield and earliness in RT system, other production practices need to be identified and optimized to address this shift in risk from early

season to late season stresses. The intra-row spacings also significantly affected lint yield and earliness, while their effects on fiber quality were not significant in both years. The earliness increased with closer spacing, while the highest lint yield was obtained in 17 cm spacing in both years. Therefore, ridge system with 17 cm intra-row spacing is recommended for the Eastern Mediterranean region of Turkey.

Acknowledgments

This research was financially supported by the Research Fund of Mustafa Kemal University. Field experiments were carried out at the research fields of Ozbugday Seed Inc., Hatay, Turkey. The authors thank Ali Ozbugday and Aykut Ozbugday for their excellent field technical assistance in conducting this research.

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