ROW AND PLANT SPACING EFFECTS ON GROWTH AND YIELD OF DRYLAND COTTON WHERE GROWING SEASON DURATION IS LIMITED

R. Louis Baumhardt
Robert Schwartz
Gary Marek
USDA-ARS Conservation & Production Research Laboratory
Bushland, TX
Jourdan M. Bell
Texas A&M AgriLife Research and Extension
Amarillo, TX

Abstract

Irrigation water availability is decreasing in the Southern Great Plains due to continued pumping from the Ogallala aquifer. Cotton (*Gossypium hirsutum* L.) is a profitable alternative crop suited to sustainable dryland production. However, the growing season of the Texas Panhandle and southwestern Kansas is often energy limited, which may increase the production risk by limiting fiber maturation and yield. We hypothesized that marginal cotton yield produced from earlier bolls could be offset by increasing plant population using narrower row or plant spacing. Our objectives were to quantify (i) row width and (ii) plant spacing effects on the growth, yield, and fiber quality of dryland cotton. Field tests comparing planting row widths from 0.25 to 0.76 -m and plant spacing of 0.075, 0.10, and 0.15 – m for populations of 8.8 – 26.7 plants m^{-2} were conducted from 1999 to 2005 on a nearly level Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) managed in a wheat (*Triticum aestivum* L.), cotton, fallow (W-Ctn-F) rotation. Drought conditions prevented crop establishment in 2002 and in 2005 the crop was destroyed by hail. Plant height, boll number and lint yield increased significantly during most years as the space between rows but not plants increased. This wider row spacing benefit was observed for the short season cultivar more frequently than for full season cultivars. Our data also show that planting semiarid dryland cotton in narrow rows to increase plant population often reduced fiber quality and market value compared with conventional 0.76 m rows.

Introduction

Crop irrigation in the Southern Great Plains exceeds groundwater recharge, resulting in the declining saturated thickness of the Ogallala Aquifer (McGuire, 2017). Dryland cropping systems are a sustainable alternative to irrigated production, but profitability must be increased to preserve southern Great Plains agriculture. Cotton is a profitable alternative crop that is suited for dryland conditions, but the growing season for western Kansas and the northern Texas High Plains may be too short for optimum cotton yield. Nevertheless, mean long term energy for this region is sufficient to mature enough earlier cotton bolls to yield from <500 kg ha^{-1} to 1000 kg ha^{-1} lint (Gowda et al., 2007). Cultivar earliness contributes to determining management practices for improving crop productivity during a thermally limited growing season. Cotton production that emphasizes early set bolls may address the short growing season concerns of risk-averse producers, but maintaining yield necessitates increased boll numbers through higher plant population using narrow row or plant spacing.

Gerick et al. (1998) demonstrated that narrow, 0.19 and 0.38 m, rows increased plant populations and the corresponding rain fed lint yields from 21 % to 37% over wider, 0.76 m, rows in subhumid central Texas. By contrast, narrow rows reduced plant height and lint yield under drier growing conditions (Boquet, 2005; Gwathmey et al., 2010). The potential problem of water availability is clearly illustrated in the Texas High Plains where cotton yield was not affected by plant spacing if irrigated (Bednarz et al., 2000) compared with recommended dryland plant spacing that ranges from 75 to 150 – mm depending seasonal rain (Bilbro, 1981). It is unclear if the restricted growing season duration or limited available water will have greater impact in determining the potential cotton lint yield and fiber quality.

We hypothesize that lint yield from the partial crop of early bolls can be enhanced by higher populations resulting from narrow row or plant spacing despite the potential short growing season of southwestern Kansas and the Texas Panhandle. Our objective was to quantify (i) row width and (ii) plant spacing effects on the growth, yield, and fiber quality of dryland cotton.

Materials and Methods

A three year rotation of wheat followed by cotton with intervening 10-month fallow periods was established on a 510 m long by 110 m wide nearly level Pullman clay loam at Bushland, TX (35° 11’ N, 102° 6’ W). All rotation phases appeared each year in three 36 m wide strips from 1999 to 2005, beginning with uniformly cropped wheat that was drilled in October at 200 seeds m^{-2} in rows 0.3-m apart and fertilized as needed for 2-3 Mg ha^{-1} grain yields. No soil active herbicides were used to control growing season weeds because of potential residual effects on sensitive rotation crops, but spring broadleaf weeds were controlled as necessary by applying 0.56 kg a.i. ha^{-1} 2,4-D [(2,4-dichlorophenoxy) acetic acid] before 1 May. Wheat was machine harvested in July and fields remained fallow for ~10 months until the cotton phase.

Short and full –season cotton, PM-183 and HS-26 (Cargill Research, Plainview, TX), was planted in 1999 and 2000 using a John Deer 750 no-till drill (Deere & Co., Moline, IL). Four 170-m long and 9-m wide randomly assigned variety by 0.50 m and 0.76 m row width main plots were replicated three times. Each of those main plots were subdivided into three 56-m long split plots with randomly assigned 0.15, 0.10, and 0.075 –m plant spacing treatments for a total of 36 (9×56 m) plots. Growing season weeds were controlled with a pre-plant application of trifluralin [2,6-dinitro-N,N-dipropyl-4- (trifluoromethyl) benzenamine] at 0.7 kg a.i. ha^{-1}. Beginning 2001, we planted short and full -season glyphosate tolerant cotton cultivars, PM-2145RR and PM-2326RR (Cargill Research) to simplify seasonal weed control with on demand applications of 0.56 kg a.i. ha^{-1} glyphosate [N-(phosphonomethyl) glycine]. Subsequently, the higher population 0.076 m in-row spacing was discontinued in 2002 and replaced with a 0.25 m ultra-narrow row width. Cotton was seeded using a Monosem NG Plus planter (Edwardsville, KS) in triplicate 170m × 9m main plots of four randomly assigned variety by 0.15 m and 0.10 m plant spacing main plots. Plots were subdivided into three equal split plots with randomly assigned 0.25, 0.5, and 0.76 –m row widths. Cotton was harvested at maturity in November then followed by a ~10-month fallow phase when the rotation repeats with wheat planting in late September or early October.

Daily precipitation plus the minimum and maximum air temperature were obtained from the official location weather station (0.75 km away). Soil water was determined in 0.3 m increments from duplicate gravimetric soil cores taken to 1.8 m depth that were converted to volumetric soil water using previously measured soil bulk density. The sum of rain and the seasonal change in soil water was considered crop water use, assuming negligible runon, runoff, or drainage during the summer growing season (Baumhardt et al., 2017). Our measurements included plant height, number of open bolls, and the estimated lint yield determined at maturity from 13.95 m^2 hand samples harvested from 9.1 m long rows centered in each plot. Bur cotton samples were ginned at Texas A&M AgriLife, Lubbock, TX. for routine fiber quality analysis by a high volume instrument at the Fiber and Biopolymer Research Institute in Lubbock.

We compared cotton growth factors, yield, and fiber quality in response to plant and row spacing fixed effects according to a randomized complete block split plot design (Milliken and Johnson, 2009) using SAS mixed linear model ANOVA procedures (SAS Institute, 2012). Random effects were block and block×(row-spacing) for row width main plots initially then block and block×(plant-spacing) for plant spacing main plots, after 2002. We analyzed treatment effects on all dependent parameters within years because of annually variable growing season conditions including air temperature and precipitation distribution and amount.

Results and Discussion

Dryland crops depend exclusively on precipitation and soil water for establishment and growth. Cumulative precipitation totaling 26 mm during the 15 May to 30 June cotton establishment period (Figure 1) in 2002 resulted in a crop failure. Of the five remaining growing seasons that produced cotton, only the 1999 monthly precipitation totaling 410 mm exceeded the long-term average. As a result of cooler cloudy conditions during the 1999 growing season, the cumulative thermal energy of 940 $GDD_{15.5}$ was below average. Precipitation in 2000, 2001, and 2003 approached the May + June 130 mm average then became drier, ranging from 140 mm in 2000 up to 210 mm in 2003 with thermal energy of 1240 $GDD_{15.5}$ and 1110$GDD_{15.5}$, respectively. Only the 2004 growing season came close to the long-term seasonal average of 310 mm, although July and August were drier. These data suggest that dryland cotton had adequate thermal energy with yield limiting water stress.

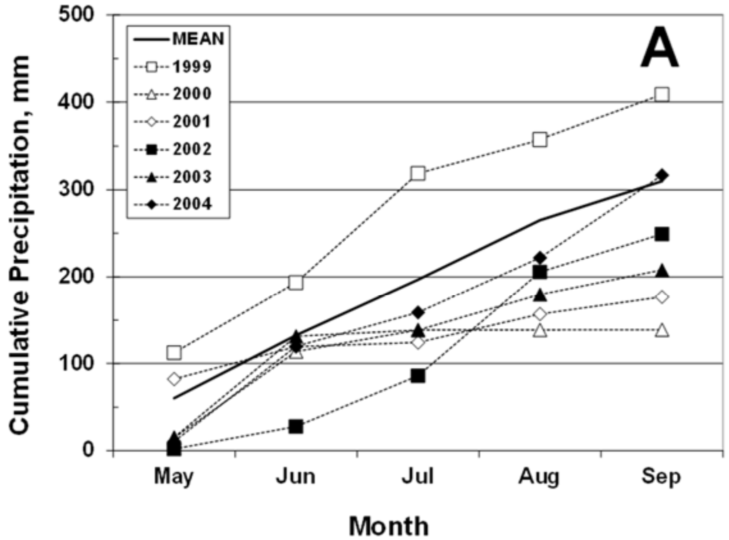

Fig. 1. Growing season, May through September, cumulative mean monthly precipitation for years 1999-2004 and the long-term 1939-2013 average.

Increased plant height at harvest (Table 1) often reflects favorable growing season precipitation and also supports greater boll load, although reduced thermal energy may also reduce height in short season cotton. Plants from the drier 2000 and 2001 growing season were overall shorter probably due to water stress. Decreased row spacing is a way to increase plant population while maintaining plant spacing, but plant height in 0.76 m rows was usually greater than for narrow rows. Wider plant spacing that reduces population and the corresponding competition for soil water often resulted in greater plant heights for the 0.15 m plant spacing compared with 0.075 m spacing. Similar to our results, Gwathmey and Clement (2010) also observed that plant height was typically lower for narrow rows.

Table 1. Mean plant height, m, at harvest of test varieties for each study year in response to row width (RW), m, and plant spacing (PS), m, with the corresponding ANOVA significance levels.

	PM-183		PM-2145RR			HS-26 / PM-2326RR				
EFFECT	1999	2000	2001	2003	2004	1999	2000	2001	2003	2004
Row Width (RW)	Plant Height, m †									
0.25	--	--	--	0.46b	0.48c	–	–	–	0.46b	0.55b
0.50	0.50b	0.47a	0.37b	0.61a	0.67b	0.67a	0.48b	0.39b	0.61a	0.69a
0.76	0.60a	0.49a	0.44a	0.63a	0.78a	0.57a	0.55a	0.45a	0.54ab	0.54b
Plant Spacing (PS)										
0.150	0.59a	0.50a	0.43a	0.60a	0.63a	0.62a	0.54a	0.44a	0.53a	0.60a
0.100	0.53b	0.48a	0.40b	0.53a	0.66a	0.57a	0.52b	0.42ab	0.54a	0.48b
0.075	0.53b	0.46b	0.39c	--	--	0.67a	0.50b	0.41b	–	–
RW × PS										
0.25 x 0.150	--	--	--	0.51ab	0.54c	–	–	–	0.45a	0.58b
0.25 x 0.100	--	--	--	0.41b	0.42d	–	–	–	0.47a	0.53b
0.25 x 0.075	--	--	--	--	--	–	–	–	–	–
0.50 x 0.150	0.51bc	0.49ab	0.39c	0.60ab	0.61c	0.67ab	0.50bc	0.41c	0.60a	0.68a
0.50 x 0.100	0.48c	0.48ab	0.37c	0.62a	0.72b	0.62ab	0.48c	0.39c	0.62a	0.70a
0.50 x 0.075	0.49c	0.46b	0.35c	--	--	0.71a	0.47c	0.38c	–	–
0.76 x 0.150	0.66a	0.50a	0.47a	0.70a	0.73b	0.56ab	0.57a	0.46a	0.53a	0.55b
0.76 x 0.100	0.57b	0.49ab	0.43b	0.55ab	0.83a	0.52b	0.55ab	0.45ab	0.55a	0.53b
0.76 x 0.075	0.57b	0.47b	0.42b	--	--	0.63ab	0.53b	0.43bc	–	–
Significance	P > F					P > F				
Row Width (RW)	0.0163	0.1946	0.0037	0.0052	<.0001	0.0826	0.0114	0.0089	0.0196	<.0001
Plant Spacing (PS)	0.0110	0.0024	<.0001	0.1364	0.1296	0.0569	0.0012	0.0027	0.6687	0.5286
RW x PS	0.0906	0.8599	0.3613	0.1560	<.0001	0.9238	0.4987	0.1790	1.0000	0.0175

† Effect means of a year followed by the same letter are not significantly different, P<0.05, according to Tukey significant difference test.

Peak lint yield averaged about 400 kg ha^{-1} regardless of variety during 1999 (Table 2) in response to total water use of 460 mm that combined soil water and > 400 mm rain. In 2000, limited water use of 210 mm from 139 mm rain plus 70 mm available soil water resulted in low yields averaging around 130 kg ha^{-1} for both tested varieties. Row width and plant spacing effects on cotton lint yields were not significant during these unusually wet or dry growing seasons. Lint yield for conventional 0.76 m rows ranged from 15 to 120% larger than for the 0.50 m rows with significant differences in 2001 and 2004 for short season varieties. Our observed yield reduction with narrow rows under dryland conditions differed from observations under irrigated or subhumid rain fed production (Gerik et al., 1998; Gwathmey et al., 2011). Plant spacing did not significantly affect lint yield for either short or full season cotton with one exception for the short season cultivar in 2001. That 2001 growing season began with favorable rain but ended as the second driest of our study years.

Table 2. Mean lint yield of test varieties for each study year in response to row width (RW), m, and plant spacing (PS), m, with the corresponding ANOVA significance levels.

	PM-183		PM-2145RR			HS-26 / PM-2326RR				
EFFECT	1999	2000	2001	2003	2004	1999	2000	2001	2003	2004
Row Width (RW)	Lint Yield, kg ha^{-1}†									
0.25	--	--	--	242.3a	173.0c	--	--	--	247.4a	216.4a
0.50	431.0a	142.8a	222.5b	241.1a	290.5b	396.0a	114.8a	198.3b	274.6a	233.4a
0.76	380.0a	126.6a	350.2a	279.2a	354.1a	419.1a	134.1a	298.2a	292.6a	235.6a
Plant Spacing (PS)										
0.150	403.3a	132.9a	302.3a	251.2a	272.3a	432.8a	132.8a	243.6a	264.5a	237.2a
0.100	424.1a	113.1a	312.8a	257.2a	272.8a	405.2a	116.8a	254.1a	278.5a	219.8a
0.075	389.0a	158.0a	243.8b	--	--	384.6a	123.7a	247.1a	--	--
RW × PS										
0.25 x 0.150	--	--	--	210.4a	140.4c	--	--	--	232.8a	226.5a
0.25 x 0.100	--	--	--	274.2a	205.6c	--	--	--	262.1a	206.3a
0.25 x 0.075	--	--	--	--	--	--	--	--	--	--
0.50 x 0.150	407.9a	159.9a	235.2bc	237.6a	296.7b	412.3a	120.2a	173.9c	267.2a	236.2a
0.50 x 0.100	484.1a	132.7a	255.7b	244.7a	284.3b	403.2a	120.1a	225.4b	282.0a	230.7a
0.50 x 0.075	401.0a	135.7a	176.6c	--	--	372.5a	104.2a	195.5bc	--	--
0.76 x 0.150	398.8a	105.9a	369.5a	305.7a	379.8a	453.3a	145.4a	313.3a	293.7a	248.8a
0.76 x 0.100	364.1a	93.5a	369.9a	252.7a	328.4ab	407.2a	113.5a	282.7ab	291.5a	222.4a
0.76 x 0.075	377.1a	180.4a	311.1a	--	--	396.7a	143.3a	298.6a	--	--
Significance	P > F					P > F				
Row Width (RW)	0.2973	0.4333	0.0126	0.5691	<.0001	0.5829	0.4897	0.0278	0.5736	0.3937
Plant Spacing (PS)	0.7420	0.1485	0.0095	0.9199	0.9708	0.5644	0.6231	0.7960	0.7208	0.2800
RW x PS	0.4423	0.0848	0.8095	0.3786	0.0144	0.9147	0.3905	0.0809	0.9315	0.7668

† Effect means of a year followed by the same letter are not significantly different, $P<0.05$, according to Tukey significant difference test.

Fiber quality often reflects environmental stressors during the growing season that may limit fiber length or maturation as well as any varietal / genetic contribution. The overall fiber quality premium discounts were 790 and 480 points lower for the full-season variety (Table 3) in 1999 and 2000 when beneficial May rain supported early growth and additional soil water that likely resulted in improved fiber length and micronaire (not shown). Premium differences between the 0.50 and 0.76 m rows were significant in 2003 when planting was delayed until mid-June and followed by a dry July when maturing fibers would require assimilate for improved quality. The premium discount for 0.76 m rows was significantly less than for the ultra-narrow rows in 2003 and 2004 for the short-season cotton and 2003 for the full-season variety. Because seasonal precipitation during 2003 and 2004 were similarly below average through August but improved to normal in September in 2004, the fiber quality premiums may have suffered in both years for the short season variety whereas the longer season variety benefitted from later precipitation in 2004. Plant spacing resulted in no difference in fiber price premiums for the varieties tested during any growing season.

Table 3. Mean lint price premium, $ per 45 kg, based on fiber quality factors of test varieties for each study year in response to row width (RW), m, and plant spacing (PS), m, with the corresponding ANOVA significance levels.

	PM-183		PM-2145RR			HS-26 / PM-2326RR				
EFFECT	1999	2000	2001	2003	2004	1999	2000	2001	2003	2004
Row Width (RW)	Lint Price Premium, $ per 45 kg†					Lint Price Premium, $ per 45 kg†				
0.25	--	--	--	-7.62b	-4.57b	--	--	--	-7.27b	-3.41a
0.50	-14.79a	-13.02a	-14.87a	-6.30b	-3.83ab	-7.30a	-9.01a	-14.48a	-5.68ab	-3.55a
0.76	-14.76a	-12.86a	-12.88a	-2.94a	-3.36a	-6.41a	-7.28a	-15.03a	-3.33a	-3.69a
Plant Spacing (PS)										
0.150	-14.89a	-12.78a	-13.09a	-5.88a	-4.23a	-5.64a	-7.87a	-14.76a	-5.82a	-3.74a
0.100	-14.08a	-12.96a	-14.06a	-5.36a	-3.61a	-7.51a	-8.48a	-15.37a	-5.03a	-3.36a
0.075	-15.36a	-13.08a	-14.48a	--	--	-7.41a	-8.08a	-14.14a	--	--
RW × PS										
0.25 x 0.150	--	--	--	-8.17b	-4.97a	--	--	--	-7.40b	-3.27a
0.25 x 0.100	--	--	--	-7.07b	-4.17a	--	--	--	-7.13b	-3.55a
0.25 x 0.075	--	--	--	--	--	--	--	--	--	--
0.50 x 0.150	-15.32a	-12.97a	-14.82a	-5.75ab	-4.10a	-7.63a	-8.73a	-13.87a	-5.67ab	-3.83a
0.50 x 0.100	-13.63a	-13.07a	-14.83a	-6.85ab	-3.57a	-6.60a	-8.70a	-14.68a	-5.70ab	-3.27a
0.50 x 0.075	-15.42a	-13.02a	-14.97a	--	--	-7.67a	-9.60a	-14.90a	--	--
0.76 x 0.150	-14.47a	-12.58a	-11.37a	-3.72ab	-3.61a	-3.65a	-7.00a	-15.65a	-4.38ab	-4.13a
0.76 x 0.100	-14.52a	-12.85a	-13.28a	-2.17a	-3.10a	-8.42a	-8.27a	-16.05a	-2.27a	-3.25a
0.76 x 0.075	-15.30a	-13.15a	-13.98a	--	--	-7.15a	-6.57a	-13.38a	--	--
Significance	P > F					P > F				
Row Width (RW)	0.9682	0.4599	0.2057	0.0106	0.0474	0.5427	0.1823	0.4763	0.0082	0.7103
Plant Spacing (PS)	0.2853	0.3810	0.5834	0.6529	0.3205	0.4189	0.8424	0.3305	0.457	0.2913
RW x PS	0.5426	0.4868	0.6366	0.5103	0.9158	0.2146	0.5001	0.1237	0.4813	0.2568

† Effect means of a year followed by the same letter are not significantly different, P<0.05, according to Tukey significant difference test.

Conclusions

Although differences were not always significant, plant height and lint yield of cotton grown in narrow, 0.50 m, and ultra-narrow, 0.25 m, rows were usually less than for conventional 0.76 m rows regardless of variety. For both short and full season varieties, plant spacing did not affect yield or fiber quality premiums. Many fiber quality factors did not differ with planting geometry, but pooled fiber quality degradation with narrow row spacing lowered the price premium. We conclude that using narrow row or plant spacing did not improve lint yield or fiber quality of dryland cotton. In lieu of some beneficial yield or fiber quality premium combination, we do not recommend using narrow row or plant spacing under dryland conditions to overcome a thermally limited growing season.

Disclaimer

The U.S. Department of Agriculture (USDA) is an equal opportunity provider and employer.
The use of trade, firm, or corporation names in this article is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the United States Department of Agriculture or the Agricultural Research Service of any product or service to the exclusion of others that may be suitable.

References

Baumhardt, R.L., R.C. Schwartz, O.R. Jones, B.R. Scanlon, R.C. Reedy, G.W Marek. 2017. Long-term conventional and no-tillage effects on field hydrology and yields of a dryland crop rotation. Soil Sci. Soc. Am. J. 81:200–209.

Bednarz, C.W., Bridges, D.C., Brown, S.M., 2000. Analysis of cotton yield stability across population densities. Agron. J. 92, 128–135.

Bilbro, J.D. 1981. Spatial Responses of Contrasting Cotton Cultivars Grown Under Semiarid Conditions. Agron. J. 78:271-277.

Boquet, D.J. 2005. Cotton in ultra-narrow row spacing: Plant density and nitrogen fertilizer rates. Agron. J. 97:279–287.

Gerik, T.J., R.G. Lemon, K.L. Faver, T.A. Hoelewyn, and M. Jungman. 1998. Performance of ultra-narrow row cotton in Central Texas. Proceedings Beltwide Cotton Production Conference, Technical Paper, San Diego, CA. 5–9 Jan. 1998, 1406–1409.

Gowda, P.H., R.L. Baumhardt, A.M. Esparza, T.H. Marek, and T.A. Howell. 2007. Suitability of cotton as an alternative crop in the Ogallala Aquifer Region. Agron. J. 99:1397–1403.

Gwathmey, C.O. and J.D. Clement. 2010. Alteration of cotton source–sink relations with plant population density and mepiquat chloride. Field Crops Res. 116:101-107.

Gwathmey, C.O., L.E. Steckel, J.A. Larson, and D.F. Mooney. 2011 Lower Limits of Cotton Seeding Rates in Alternative Row Widths and Patterns. Agron. J. 103:584-592.

McGuire, V. L. 2017. Water-level and recoverable water in storage changes, High Plains aquifer, predevelopment to 2015 and 2013–15: U.S. Geological Survey Scientific Investigations Rpt. 2017–5040, 14 p., U.S. Geological Survey, Reston, VASAS Inst. Inc. 2004.

Milliken, G.A., and D.E. Johnson. 2009. Analysis of messy data. Vol.1. Designed experiments. 2nd. ed. CRC Press Taylor and Francis Group, Boca Raton, FL.

SAS Institute. 2012. SAS OnlineDoc® 9.3. SAS Inst., Cary, NC.