EFFECT OF ROW PATTERN AND SPACING ON WATER USE EFFICIENCY FOR SUBSURFACE DRIP IRRIGATED COTTON

J. Enciso-Medina, B.L. Unruh, J. C. Henggeler, and W. L. Multer.[1]

ABSTRACT

Cotton production is an important economic base for Far West Texas; however, the region has erratic and limited rainfall and is dependent on limited groundwater supplies. Maximizing water use efficiency (WUE) for cotton lint yield is therefore a strategic goal in conserving limited water resources. In this study different plant row patterns, row spacings and irrigation levels were evaluated to investigate water use efficiency for cotton under subsurface drip irrigation (SDI). An experiment with three row-spacings, two plant row patterns, and four water levels was conducted during three years in Far West Texas. The row spacing treatments were ultra-narrow rows (UNR), 0.76 and 1.02-m rows. The row patterns for the 0.76 and 1.02 m row spacings were every row planted, one planted and one skipped, and two rows planted and one skipped. The UNR cotton was solid-planted in 0.25-m rows in 1997 and 0.38-m rows in 1998 and 1999. The drip lines were placed beneath each planted row, except in the case of the UNR rows where the rows were planted over the 0.76-m drip line spacing. The UNR and the 0.76-m row spacing resulted in higher WUE than the 1.02-m row spacing for the highest water level in 1997, and the lowest water level in 1998 for the every row pattern. When the three years of data were combined for analysis, it was observed that for the lowest water treatment (0.6-mm/d in-season irrigation), the UNR spacing produced a higher WUE (0.258 kg/m^3) than the 0.76 and

---

[1] The authors are: J. Enciso-Medina, Assistant Professor and Irrigation Specialist, Biological and Agricultural Engineering Department, Texas A&M University. B. L. Unruh, Research and Demonstration Manager, The Samuel Roberts Noble Foundation, Inc., Ardmore, OK; formerly Assistant Professor and Agronomy Specialist, Texas A&M University System, J. C. Henggler, State Irrigation Specialist. University of Missouri System, W. L. Multer, Integrated Pest Management Specialist, Texas A&M Extension Service.

1.02-m row spacings (0.198 kg/m^3). The average WUE of the UNR spacing for three years of the experiment was 11.7 and 21.3% higher than the 0.76-m and 1.02-m row spacing respectively. Although, the 0.76-m and 1.02-m row spacing were not significantly different, the WUE of 0.76-m row spacing was 10.5% higher than the 1.02-m row spacing. Therefore, we conclude under our conditions row spacing can have a moderate impact on WUE for SDI systems. The narrower cotton spacing exhibited trends toward higher WUE. When the row planting patterns were analyzed by combining three years of data, it was found that row pattern did not have an influence on WUE for the 0.76-m and 1.02-m row spacings.

Keywords: Subsurface drip irrigation, cotton, row spacing, water management, water use efficiency.

INTRODUCTION

Most arid areas of the world face the problem that their water resources are limited and there is not enough water to fully irrigate their crops. The Great Plains of the United States is one of the areas where declining water supplies have induced the practice of deficit irrigation. Within this region the southern part of the Texas High Plains is a farming area with very limited water supplies and where farmers pump the limited water recharged during the previous year. To increase management efficiency and to enhance the sustainability of irrigated cotton, it is common to have several small wells interconnected to collect sufficient water, and to irrigate more frequently with subsurface drip irrigation (SDI) and Low Energy Precision Application Systems (Bordovsky et al., 1992 and 1998; Lamm and Trooien, 1998). To deal with limited water supplies, farmers have adopted management practices such as: (1) practicing preseason irrigation to store water in the profile and (2) to use different row widths and patterns. SDI is an excellent irrigation method under arid conditions and low well capacities. It is effective in applying small depths of water uniformly (Camp et al., 1997; Phene et al., 1992; Bucks et al., 1982) and may achieve application efficiencies that exceed 90% when it is properly designed and managed.

Hanson et al. (2000) and Camp et al. (2000) reported that there has been a significant conversion from furrow to drip irrigated cotton in the states of California, Arizona, and Texas. Interest in converting irrigation systems can be related to water savings and yield improvements. SDI systems can also increase profits due to reduced water, fertilizer, and cultural costs and can have a life expectancy of up to ten years when they are properly maintained (Camp, 1998, Hanson et al., 2000; Tollefson, 1985a,b). Although SDI systems can reduce water losses in cotton crops, farmers still have some pressure to increase production per unit of water applied. One option to improve efficiency is to consider different row spacing and planting row patterns to possibly reduce water loss through evaporation and perhaps enhance rainfall utilization. In southwest Texas, cotton rows are commonly spaced between 0.75 to 1 m. Soil water evaporation can be reduced due to additional shading of the soil by decreasing the spacing between rows to about 0.25 to 0.5 m. Cotton that is grown in rows of 0.35 m or less is called ultra-narrow-row (UNR) cotton. The change from traditional spacing to UNR requires changing and adopting new management practices (Howell et al., 1986). A plant population density above 20 plants per m^2 is recommended. A plant height of 45 to 60 cm is desirable to avoid excessive trash during stripper harvesting. Narrower spacing has been studied with short run furrows and drip irrigation by Howell et al., (1986). They obtained WUE of 0.265 kg/m^3 in 1981 and 0.292 kg/m^3 in 1982 for full and limited irrigation with short furrows and drip irrigation. WUE was defined as total lint yield divided by total water applied, which included pre-plant irrigation, seasonal irrigation, and rainfall. Fangmeier et al. (1989) studied WUE (yield divided by just the water applied) for cotton drip irrigated two to three times weekly using buried perforated tubing under each row. They obtained WUEs of 0.51, 0.55, and 0.48 kg/m^3 in 1984, and 0.39, 0.43, and 0.40 kg/m^3 in 1985 for water application rates of 0.6, 1.0 and 1.3 of estimated consumptive use (CU). They obtained the highest WUE for the 1.0 CU treatment. Bordovsky and Lyle (1998) studied the influence of Low Energy Precision Application (LEPA) and SDI systems on WUE with irrigation delivery rates of 2.5, 5.0, and 7.6 mm/day. WUE were significantly higher for SDI (0.275 kg/ m^3) than LEPA (0.249 kg/ m^3) treatments with differences attributed to higher soil evaporation of the LEPA system. They obtained higher water use efficiencies as the irrigation delivery rate increased in the LEPA system. The highest WUE for the SDI system was obtained with the 2.5 mm/day irrigation delivery rate. WUE depends on many factors such as fertility, variety, pest management, sowing date, soil water content at planting, plant density and row spacing (Howell, 2000). The objectives of this study were to determine the effect of row spacing and planting pattern on WUE and to derive relevant cotton production functions to assist growers in the region in making decisions concerning cotton row pattern and spacing given available water and land area.

MATERIAL AND METHODS

A field experiment was conducted to determine the effect of plant spacing and population on yield per unit of water applied with SDI. The system was installed in a cotton field located in St. Lawrence, Texas during the spring of 1997. The area is semi-arid and receives less than 400 mm of rainfall per year. The rainfall received during the growing season for the three years is presented in Table 1. Low annual precipitation makes dryland cotton production in this area marginal. Dryland cotton that is planted here is usually done using "skip row" pattern, which allows water collected from rainfall from the unplanted rows to be used. A genetically modified cotton variety with Bt traits (*Gossypium hirsutum L.*, c.v. Deltapine's Nucotton 33B) was used to limit insect damage and its influence on the experiment. The soil at the field site was a Reagan silty clay loam (fine-silty, mixed, thermic Ustolic Calciorthids) soil with moderate permeability on a 1% slope. Planting dates and dates for initiation and termination of irrigation and fertilizer applications are shown in Table 1.

The experiment consisted of three row-spacings, three planting row patterns, and four water levels during each of three years. The row spacing treatments were UNR (0.25-m in 1997 and 0.36-m in 1998 and 1999), 0.76, and 1.02 m. The planting patterns for the 0.76 and 1.0 m rows were: every row planted (solid), one row planted and one skipped (every other row or 1-and-1), two rows planted and one skipped (2-and-1). Practicality dictated that UNR rows were planted only every row and thus did not have skip patterns. The experiment was planned to supply four water levels to the solid planted treatments at rates of 0.6, 1.2, 2.4, and 4.7 mm/d. Treatments with the skip row patterns have proportionally less water based on their planted row/skip row ratios. The 2-and-1 pattern had 0.4, 0.8, 1.6, and 3.2 mm/d; and the 1-and-1 pattern 0.3, 0.6, 1.2 and 2.4 mm/d. Since local farms in the region with large irrigation capacities (above 4 mm/d) tend to plant every row, and farms with smaller water resources (0.6 mm/d) tend to use skip rows, the range of water amounts evaluated for each pattern were considered appropriate. Table 2 includes the in-season irrigation applications of the 28 treatment combinations, which were replicated three times. The four water level treatments were randomized within each block. The various irrigation water levels were envisioned as resource constraints and were supplied as constant resource amounts in-season instead of set percentages of evapotranspiration (ET). This is due to the fact that producers with limited water tend to keep their systems on even during low ET periods in order to increase water reserves. Plot length was 17.1 m, and there were 8 rows per treatment (every row, 1-and-1 pattern, 2-and-1 pattern, and UNR) of the 0.76-m row width; and 6, 8, and 12 rows per treatment of the 1-and-1, 2-and-1, and every row patterns of the 1.02 m-row width. A drip-line (Geoflow, Inc [□]) with emitters spaced 0.6 m apart with a nominal discharge of 4 L/h was used in the experiment. The drip-lines were installed at approximately

---

[□] Trade names are used for clarity and do not imply endorsement by the Texas A&M University or the University of Missouri.

0.35 m depth. The emitters were constructed of plastic impregnated with Trifluralin to inhibit root intrusion. Blocks were irrigated twice per week using electric timers. A flushing manifold was placed on the end of the lines. The lines were placed beneath the planted row, except in the case of the UNR cotton where the drip-line spacing was 0.76 m. For the UNR cotton, there were two to three rows of cotton for each row of driplines. The UNR cotton was planted with a grain drill at 0.25 m row spacing in 1997 and with a planter capable of being set to a row width of 0.38 m in 1998 and 1999. The plant populations obtained for each row spacing and planting pattern are shown in Table 3.

Liquid nitrogen (N) was injected through the irrigation system beginning the first week of July with 2 subsequent injections following at approximately 14 day intervals (Table 1). The total N was applied in three split applications, 75% of the total N was applied in the first (37.5%) and second (37.5%) injections, and 25% in the third injection. Table 4 shows the total N applied to each water level. Urea ammonium nitrate (UAN) was the N source, where 32% N was used in 1997 and 1999 and 28% was used in 1999. No other fertilizer was applied to the site. Note that the N rates shown for the 2-and-1 and 1-and-1 row patterns represent reductions in N relative to the solid pattern because there were fewer drip-lines per unit area not because a different N rate was sought.

Soil water moisture was determined gravimetrically during 1999 at the beginning and at the end of the growing season in one out of three replications of all the 0.76 and 1.02-m row spacing treatments. Bulk density was determined with a core sampler. Water meters were connected to each delivery manifold to ensure accuracy and measure irrigation water applied.

Rainfall and other climatological data were measured by an automatic weather station (Campbell Scientific, Logan, UT[□]) located at the site. Harvest data were gathered from within each plot by hand picking two 3.04-m sections of row, except in the case of the UNR rows where an area of 2 m^2 was picked from each plot. Yield was calculated on a unit area basis by using the average row width for each planting pattern. For example, the average row width for 0.76-m 2-and-1 and 1-and-1 planting pattern would be 1.14 and 1.52-m, respectively. Seed cotton was weighed for each replication, and a portion (about 600 g) was ginned at the Texas A&M Agricultural Research and Extension Center in Lubbock, TX. Lint was analyzed for fiber quality at the International Textile Center of Lubbock. The data were analyzed with a general linear model (GLM) with mean separation by the Duncan's multiple range test (SAS Institute, 1991). The water used and yield from the three replications of each treatment were fitted to a polynomial model using the sequential sums of squares procedure outlined by Littell et al. (1991). In selecting the polynomial model the goal was to obtain the model with the fewest terms in the model.

[□] Trade names are used for clarity and do not imply endorsement by the Texas A&M University or the University of Missouri.

RESULTS AND DISCUSSIONS

The effects of row spacing and planting pattern on WUE were evaluated. WUE was defined as cotton lint yield divided by the water used. The total water used was calculated as the sum of pre-season and in-season irrigation, in-season rainfall, and the difference in soil water status (post-season – pre-season). The final term, or soil water difference, was assumed zero. This assumption was based on soil water measurements taken during 1999, that indicated that the volumetric water content (10-12%) was well below the permanent wilting point (20%) of the measured treatments. This assumption was also justified due to the fact that during the 1996-1999 seasons only 40% of the planted dry-land cotton crop in the county was harvested due to drought (NASS, 2002). The pre-season and in-season irrigation depths are shown in Table 5.

During the first two years of this study the amount of N applied was proportional to the water level, following the recommendations of Morrow and Krieg (1990). They suggested a constant ratio of 0.2 kg N ha^{-1} mm^{-1} of water. Considering that total seasonal water was unknown at the time of N application (the beginning of the season), and that N rates are generally based on a realistic yield goal and the N requirement of the crop to produce that yield (Dahnke and Johnson, 1990), in 1999 the N fertilizer rate was adjusted slightly based on the previous two-year lint yields using a ratio of 0.15 kg N per kg of lint produced (Unruh and Silvertooth, 1996). Table 4 shows that the total N applied to all water levels was increased in 1999 based on this approach, especially for the treatments 2, 3 and 4. No consistent trends in lint yield are apparent among years that would suggest differences due to total N application. In general, the 1997 yields were highest. The yields in 1999 tended to be higher than 1998 yields for all the 1.02-m row patterns and the 0.76 m 1-and-1 pattern. The opposite was true (1998 greater than 1999 yields) for the 2-and-1 and solid 0.76-m row patterns and UNR.

Effect of row spacing on water use efficiency

The effects of lateral spacing on WUE and yield were evaluated for the UNR and for the 0.76 and 1.02-m spacing. A summary table of cotton lint yields is presented in Table 6. The WUE results for the every row spacing treatments are presented in Table 7. Each water level presented in Table 7 represents the average of three replications. It was observed that for the year 1997, the WUE of the UNR spacing for water level 4 (4.6 mm/d) was significantly higher ($P<0.05$) with an efficiency of 0.273 kg/m^3 relative to the 0.76-m and 1.02-m row spacings with efficiencies of 0.191 and 0.196 kg/m^3, respectively. The 0.76-m and 1.02-m row spacings were not significantly different. There was no statistical difference between water levels 1, 2, and 3 (0.6, 1.2 and 2.4 mm/d) on WUE. However, the WUE of the UNR was, in general, numerically higher than either the 0.76 or 1.02-m row spacings. The relation between total water (defined as total of pre-season irrigation, in-season irrigation, and rainfall) and lint yield is given in Fig. 1 for the year 1997. All regressions presented in Fig. 1 were significant. Each crop production function was fitted from 12 observations, representing four water levels replicated three times. For this year the best fit was a quadratic polynomial equation.

For 1998 and water level 1, the WUE of the UNR (0.317 kg/ m^3) was statistically higher than those of the 0.76-m and 1.02-m row spacing with efficiencies of 0.239, and 0.246 kg/m^3, respectively. The WUE for the 0.76-m row and 1.02-m row spacing were not different. There was no statistical difference in WUE between the three row spacings for water levels 2, 3, and 4. The crop production functions for the UNR, 0.76 and 1.02-m row spacings were linear (Fig. 2).

A regression analysis indicated that the relation between water applied and cotton lint yield was significant for the three row spacings.

In 1999, there were no statistical differences in WUE between row spacing treatments. However, from the production functions (Fig. 3), it can be visually observed that there was a trend toward numerically higher WUE with UNR at a water depth of less than 450 mm. The crop production functions for 1999 were best fitted with linear equations.

When the three years of data were combined for a statistical analysis for the solid row plantings, it was found that the effect of row spacing on WUE was significant for the lowest water level (0.6 mm/d). The WUE of the UNR spacing (0.258 kg/m^3) was significantly higher from the 0.76 m and 1.02-m row spacing with WUE's of 0.198 kg/ m^3. Similar results were obtained by Bordovsky and Lyle (1998). The WUE's obtained in this experiment are slightly lower than those reported by Howell, et al. (1986), and Bordosky and Lyle (1998). Howell, et al. (1986) obtained average WUE's between 0.265 and 0.295 kg/ m^3 under irrigation conditions in California, and Bordovsky and Lyle (1998) obtained an average WUE of 0.275 kg/ m^3 for a SDI system. The crop production functions for row spacing were fitted with linear models (Fig. 4). The regressions were significant for all the spacings, and their coefficient of determination was higher than 71%. From Fig. 4 it can be observed that the UNR crop production function lies over the 0.76-m row spacing crop production function, and the 0.76-m row spacing lies over the 1.02-m row spacing, indicating higher WUEs for narrower row spacing. The quadratic response observed during 1997 could be a consequence of being the wettest year, plus higher water amounts were applied during that year. The total water applied for the highest water level (in-season irrigation of 4.6 mm/d) during the growing season was over 650 mm. The yield response to water was linear during 1998 and 1999, and the total water applied for the highest water level was below 650 mm. During recent years, observations have been that farmers generally apply between 250 and 325 mm during in-season irrigations. They also start irrigating in February or March to fill the soil profile, and apply between 200 and 300 mm prior to planting. This situation is similar to what we did in some treatment combinations in this experiment.

Effect of row pattern on water use efficiency

Table 8 presents the summary of average WUE's from three replications for the three planting row patterns (solid, 1-and-1, and 2-and-1) of the 0.76-m row spacing. In 1997, it was found that there was no statistical difference between planting row patterns for water levels 2, 3 and 4 of the 0.76-m row spacing, while the water level 1 had statistical difference. The 2-and-1 pattern (0.199 kg/m^3) of water level 1 had higher WUE than both the solid and 1-and-1 planting row patterns with efficiencies of 0.175 and 0.169 kg/m^3. In 1998 and 1999 water level did not have an effect on WUE for the three row patterns analyzed. When the three years of data of the 0.76-m row spacing were combined for statistical analysis, it was found that the row patterns were not statistically different. The crop production function for the solid, 1-and-1 and 2-and-1 planting row pattern of the 0.76-m row spacing is represented in Fig. 5. It can be visually observed that even though differences were not significant, water production functions were generally higher in the solid and 2-and-1 treatments than in the 1-and-1 treatments indicating higher WUE for closer row spacing.

Table 9 presents the average WUEs from three replications of the solid, 2-and-1, and 1-and-1 planting row patterns of the 1.02-m row spacing. In 1997 and 1998 there were not statistical differences between planting row patterns for the four water levels analyzed. In 1999 the 1-and-1 planting row pattern had higher WUE than the solid and 2-and-1 planting pattern for water level 2. There was no statistical difference among planting row patterns for water levels 1, 3, and 4. Just as with the 0.76-m row spacing, when three years of data were combined for analysis, it was found that for the 1.02-m row spacing, significant statistical difference did not exist. The crop production functions of the solid, 1-and-1, and 2-and-1 row patterns of the 1.02-m row spacing are presented in Fig. 6. It can be observed that the solid planting row pattern lies over the 1-and-1 and 2-and-1 planting row patterns, indicating higher water use efficiency with closer row spacings. In summary, when the three years of data were combined for analysis, it was found that the four water levels of the three row patterns (solid, 1-and-1, and 2-and-1) did not have an effect on WUE for the 0.76-m, and 1.02-m row spacings.

CONCLUSIONS

The UNR and the 0.76-m row spacing resulted in higher WUE than the 1.02-m row spacing for the highest water level in 1997, and the lowest water level in 1998 for the every row pattern. When the three years of data were combined for analysis, it was observed that for the lowest water treatment (0.6-mm/d in-season irrigation treatment), the UNR spacing resulted in higher WUE (0.258 kg/m^3) than the 0.76-m and 1.02-m row spacing (0.198 kg/m^3). The average WUE of the UNR spacing for three years of the experiment was 11.7 and 21.3% higher than the 0.76-m and 1.02-m row spacing, respectively. Although, the 0.76-m and 1.02-m row spacing were not significantly different, the WUE of 0.76-m row spacing was 10.5% higher than the 1.02-m row spacing. Therefore, we conclude under our conditions row spacing can have a moderate impact on WUE for SDI systems. The narrower cotton spacing exhibited trends toward higher WUE. When the row planting patterns were analyzed by combining three years of data, it was found that row pattern did not have an influence on WUE for the 0.76-m and 1.02-m row spacings.

ACKNOWLEDGEMENT. This research was funded by Cotton Incorporated Texas State Support Program, under cooperative agreement No. 97-433TX.

REFERENCES

Bordovsky, J.P., W.M. Lyle, R.J. Lascano, and D.R. Upchurch. 1992. Cotton irrigation management with LEPA systems. Transactions of the ASAE 35(3):879-884.

Bordovsky, J.P. and W.M. Lyle. 1998. Cotton irrigation with LEPA and subsurface drip irrigation systems on the Southern High Plains. Beltwide Cotton Conference Proceedings. San Diego California. Jan 5-9, 1998. Pp. 409-417.

Bucks, D.A.,F.S. Nakayama, and A.W. Warrick. 1982. Principles, practices, and potentials of trickle (drip) irrigation. In advances in irrigation, ed D. Hillel, 219-299. New York, N.Y.: Academic Press. 302 p.

Camp, C.R. 1998. Subsurface drip irrigation: A review. Transactions of the ASAE 41(5):1353-1367.

Camp, C.R. F.R. Lamm, R.G. Evans, and C.J.Phene. 2000. Subsurface drip irrigation – past, present, and future. Proceedings of the 4th decennial National Irrigation Symposium. November 14-16, 2000. Phoenix, Arizona. Pp 363-372. St. Joseph, Mich.:ASAE.

Camp, C.R., E.J. Sadler, and W. J. Busscher. 1997. A comparison of uniformity measures for drip irrigation systems. Trans. of the ASAE 40(4):1013-1020.

Dahnke, W.C., and G.V. Johnson. 1990. Testing soils for available nitrogen. P. 127-139. In R.L. Westerman (ed.) Soil testing and plant analysis. 3rd ed. SSA, Madison, WI.

Fangmeier, D.D. D. J. Garrot, Jr., S.H. Husman, and J. Perez. 1989. Cotton water stress under trickle irrigation. Trans. of the ASAE 32(6):1955-1959.

Hanson, B. R. G. Fipps, and E.C. Martin. 2000. Drip irrigation of row crops: what is the state of the art? Proceedings of the 4th decennial National Irrigation Symposium. November 14-16, 2000. Phoenix, Arizona. Pp 391-400. St. Joseph, Mich.:ASAE.

Howell, T.A. 2000. Irrigation's role in enhancing water use efficiency. Proceedings of the 4th decennial National Irrigation Symposium. November 14-16, 2000. Phoenix, Arizona. Pp 66-80. St. Joseph, Mich.:ASAE.

Howell, T.A., M. Meron, K.R. Davis, C.J. Phene and H. Yamada. 1986. Water Management of trickle and furrow irrigated narrow cotton in the San Joaquin Valley. Applied Engineering in Agriculture. Vol. 3(2):222-227.

Lamm, F. R. and T.P. Trooien. 1998. SDI and the declining Ogallala. In Proc., 15th Annual Water and the future of Kansas Conference, Manhattan, KS, March 3, 1998. Pp 12-15.

Littell, R.C., R.J. Freund, and Spector, J.C. 1991. SAS systems for linear models. Third edition. SAS Institute, Cary, N.C.

Morrow M.R. and D.R. Krieg. 1990. Cotton management strategies for a short growing season environment: water-nitrogen consideration. Agronomy Journal Vol. 82(1):52-56.

NASS, 2002. U.S. Department of Agriculture, National Statistical Service. http://www.nass.usda.gov:81/ipedb/, Washington, D.C.

Phene, C. J., R. Yue, I-Pai Wu, J.E. Ayars, R.A. Schoneman, and B. Meso. 1992. Distribution uniformity of subsurface drip irrigation systems. ASAE Paper No. 92-2569, 14 pp. St. Joseph, Mich.:ASAE.

SAS Institute. 1991. SAS/STAT user's guide. Release 6.03 ed. SAS Institute, Cary, N.C.

Tollefson, S. 1985a. The Arizona system: Drip irrigation design for cotton. In Proc. Third International Drip/Trickle Irrigation Congress 1:401-405. St. Joseph, Mich.:ASAE.

Tollefson, S. 1985b. Subsurface drip irrigation of cotton and small grains. In Proc. Third International Drip/Trickle Irrigation Congress 1:887-895. St. Joseph, Mich.:ASEA.

Unruh B.L. and J.C. Silvertooth. 1996. Comparisons between an upland and pima cotton cultivar: II. Nutrient and uptake partitioning. Agron J. 88:589-595.

USDA. National Agricultural Statistic Service.

Table 1. Average field data, St. Lawrence, Glasscock County, TX. 1997-1999.

Operation	1997	1998	1999
Planting date	May 3	May 12	May 19
First in-season irrigation	July 3	June 15	June 12
First N-injection	July 3	July 7	July 2
Second N-injection	July 15	July 21	July 16
Third N-injection	July 29	August 4	July 30
Last irrigation	September 2	August 25	September 3
Harvest date	October 17	October 8	September 27
Growing season rain (mm)†	193	62	148
Rainfall for the calendar year (mm)	360	220	221
Seasonal Degree-day (15.6°C)†	1316	1593	1454

† Cumulative values from planting until harvest each year.

Table 2. Design parameters regarding water rates for the 28 treatments.

Plant spacing (m)	Planting Pattern	Water level			
		1	2	3	4
		In-season water availability (mm/d)*			
0.76	Every row planted	0.6	1.2	2.4	4.7
	1 planted-1 skipped	0.4	0.8	1.6	3.2
	2 planted-1 skipped	0.3	0.6	1.2	2.4
1.02	Every row planted	0.6	1.2	2.4	4.7
	1 planted-1 skipped	0.4	0.8	1.6	3.2
	2 planted-1 skipped	0.3	0.6	1.2	2.4
UNR	Every row planted	0.6	1.2	2.4	4.7

* The experiment was planned to apply these in-season water amounts in a period of 60 days. Rainfall received during in-season was not considered.

Table 3. Plant populations.

		Plants/m^2			
Spacing (m)	Planting Pattern	1997	1998	1999	Average
1.02	Every row	14.07	9.41	11.94	11.81
0.76	Every row	12.70	7.14	15.10	11.65
UNR	Every row	28.62	21.37	23.95	24.65
1.02	1-and-1	7.03	4.98	6.53	6.18
1.02	2-and-1	8.70	7.76	8.59	8.35
0.76	1-and-1	6.29	4.13	5.50	5.31
0.76	2-and-1	7.32	5.20	5.36	5.96

Table 4. Total N applied to each treatment

Row pattern	Water level			
	1	2	3	4
	Kg N ha^{-1}			
	1997 and 1998			
Every row planted	43	56	84	140
2-and-1	28	37	56	93
1-and-1	21	28	42	70
	1999			
Every row planted	44	83	121	155
2-and-1	29	55	81	103
1-and-1	22	41	60	77

Table 5. Pre-season and in-season irrigation depths applied for each water level, row spacing and planting pattern treatments.

Row Spacing M	Planting Pattern	Year	Water Level							
			1		2		3		4	
			Pre-season	In-season	Pre-season	In-season	Pre-season	In-season	Pre-season	In-season
						mm				
1.02	1-and-1	1997	95	17	99	34	97	69	98	135
		1998	66	20	117	39	119	79	126	154
		1999	63	17	115	34	116	69	117	138
1.02	2-and-1	1997	127	22	132	45	130	92	131	180
		1998	89	27	155	52	158	106	168	205
		1999	84	22	154	46	154	92	156	184
1.02	Solid	1997	190	33	199	68	194	138	197	270
		1998	133	40	233	78	237	158	253	308
		1999	126	34	231	68	232	138	234	276
0.76	1-and-1	1997	105	16	102	35	105	76	100	143
		1998	68	21	120	43	123	83	131	140
		1999	65	17	116	37	117	72	116	149
0.76	2-and-1	1997	139	21	136	47	140	101	134	191
		1998	91	28	160	58	163	109	175	185
		1999	87	23	155	50	156	96	154	198
0.76	Solid	1997	209	32	204	70	210	152	201	287
		1998	135	42	240	86	245	165	261	279
		1999	130	35	232	75	233	145	232	297
Ultra-narrow	Solid	1997	209	32	204	70	210	152	201	287
		1998	135	42	240	86	245	165	261	279
		1999	130	35	232	75	233	145	232	297

Table 6. Summary of cotton lint yields.

Row Spacing (m)	Planting Pattern	Year	Water Level 1	Water Level 2	Water Level 3	Water Level 4
			Cotton lint yield (kg/ha)			
1.02	1-and-1	1997	565	628	805	891
		1998	311	462	607	757
		1999	444	592	696	785
1.02	2-and-1	1997	694	675	877	1062
		1998	417	528	625	1068
		1999	456	552	611	1016
1.02	Solid	1997	728	851	1126	1304
		1998	577	740	1071	1290
		1999	536	658	892	1399
0.76	1-and-1	1997	535	687	741	1018
		1998	293	556	648	815
		1999	429	563	553	889
0.76	2-and-1	1997	709	835	993	1025
		1998	573	755	1072	1242
		1999	465	569	667	1053
0.76	Solid	1997	765	1086	1191	1309
		1998	572	988	1362	1876
		1999	566	753	932	1502
UNR	Solid	1997	1080	1294	1697	1859
		1998	758	1042	1428	1457
		1999	660	726	973	1460

Table 7. WUE for UNR, 0.76, and 1.02-m solid row patterns.

Year	Row Spacing m	Water Level * 1	2	3	4
		---------------------------- kg/ m^3	--------------------		
1997	UNR	0.248	0.277	0.306	0.273 a
	0.76	0.175	0.231	0.213	0.191 b
	1.02	0.174	0.185	0.213	0.196 b
P > F		0.10	0.14	0.11	0.0006
1998	UNR	0.317 a	0.268	0.302	0.242
	0.76	0.239 b	0.254	0.288	0.312
	1.02	0.246 b	0.198	0.234	0.207
P > F		0.02	0.22	0.20	0.34
1999	UNR	0.211	0.159	0.185	0.216
	0.76	0.181	0.165	0.177	0.222
	1.02	0.174	0.147	0.172	0.212
P > F		0.32	0.42	0.79	0.61
1997 to 1999	UNR 0.76 1.02	0.258 a 0.198 b 0.198b	0.235 0.217 0.177	0.264 0.226 0.207	0.243 0.242 0.205
P > F		0.0035	0.08	0.13	0.22

* Means within a water level and for a given year followed by the same letter are not significantly different according to the Duncan Multiple Range Test (P = 0.05).

Table 8. WUE for different planting row patterns for the 0.76-m plant row patterns.

Year	Planting Pattern	Water Level* 1	2	3	4
		------------------------kg/m^3	--------------------------		
1997	Solid	0.175 b	0.231	0.213	0.191
	2-and-1	0.199 a	0.221	0.227	0.196
	1-and-1	0.169 b	0.207	0.197	0.233
P > F	-	0.02	0.08	0.08	0.08
1998	Solid	0.239	0.254	0.288	0.312
	2-and-1	0.318	0.270	0.319	0.294
	1-and-1	0.195	0.247	0.242	0.245
P > F	-	0.05	0.83	0.29	0.05
1999	Solid	0.181	0.165	0.177	0.222
	2-and-1	0.180	0.161	0.167	0.210
	1-and-1	0.186	0.186	0.164	0.215
P > F	-	0.78	0.20	0.66	0.31
1997	Solid	0.198	0.217	0.226	0.242
to	2-and-1	0.232	0.217	0.238	0.234
1999	1-and-1	0.183	0.214	0.201	0.231
P > F	-	0.11	0.98	0.42	0.89

* Means within a water level and for a given year followed by the same letter are not significantly different according to the Duncan Multiple Range Test (P = 0.05).

Table 9. WUE for lint yield for different planting row patterns for the 1.02-m planting patterns.

Year	Planting Pattern	Water Level * 1	2	3	4
		-----------------------kg/m^3			--------------------------
1997	Solid	0.175	0.185	0.214	0.197
	2-and-1	0.203	0.182	0.211	0.210
	1-and-1	0.185	0.192	0.224	0.209
P > F	-	0.19	0.91	0.81	0.77
1998	Solid	0.246	0.198	0.234	0.207
	2-and-1	0.236	0.196	0.192	0.245
	1-and-1	0.210	0.213	0.234	0.221
P > F	-	0.53	0.74	0.20	0.32
1999	Solid	0.174	0.147 b	0.172	0.212
	2-and-1	0.179	0.159 b	0.155	0.208
	1-and-1	0.195	0.199 a	0.209	0.194
P > F	-	0.39	0.01	0.20	0.05
1997	Solid	0.198	0.177	0.207	0.205
to	2-and-1	0.206	0.179	0.186	0.221
1999	1-and-1	0.196	0.201	0.222	0.208
P > F	-	0.82	0.13	0.08	0.28

* Means within a water level and for a given year followed by the same letter are not significantly different according to the Duncan Multiple Range Test (P = 0.05).

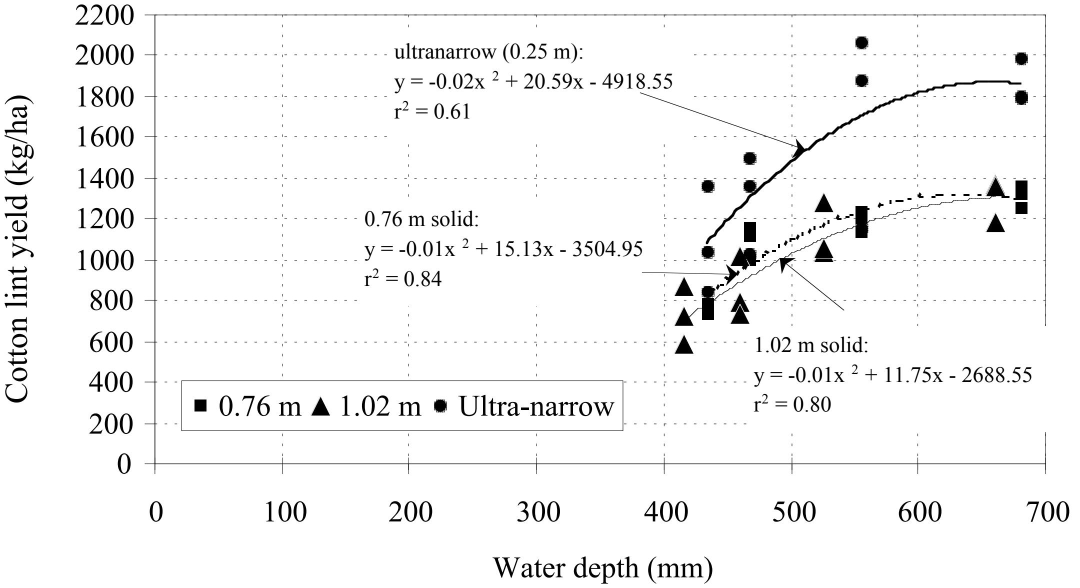

Fig. 1. Relation between cotton lint yield and total water applied for ultra-narrow c
and rows spaced at 0.76 m, and 1.02 m, during 1997 at St. Lawrence, TX.

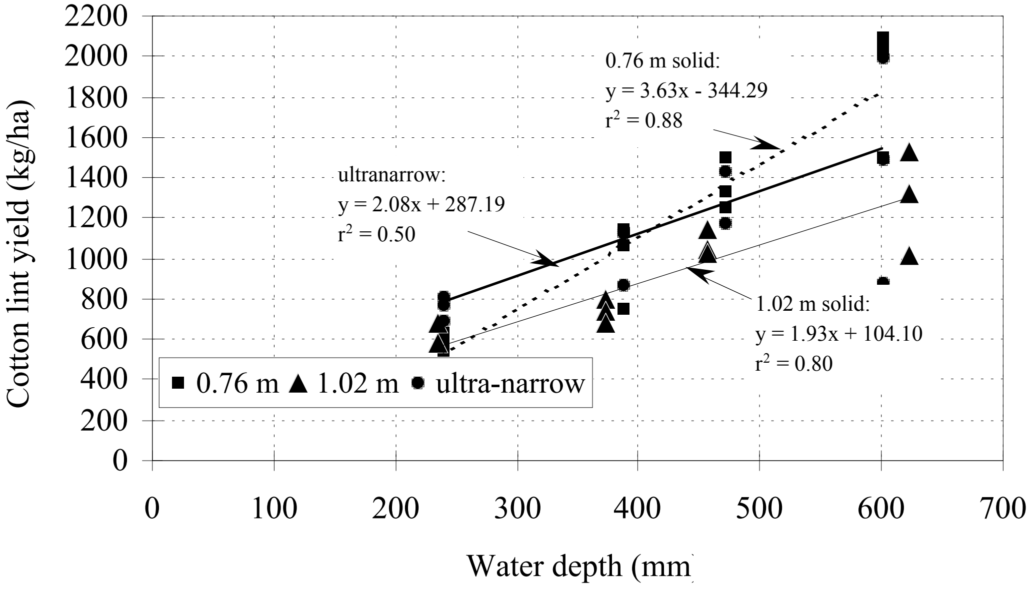

Fig. 2. Relation between cotton lint yield and total water applied for ultra-na
rows and rows spaced at 0.76 m and 1.02 m, during 1998 at St. Lawrence, T

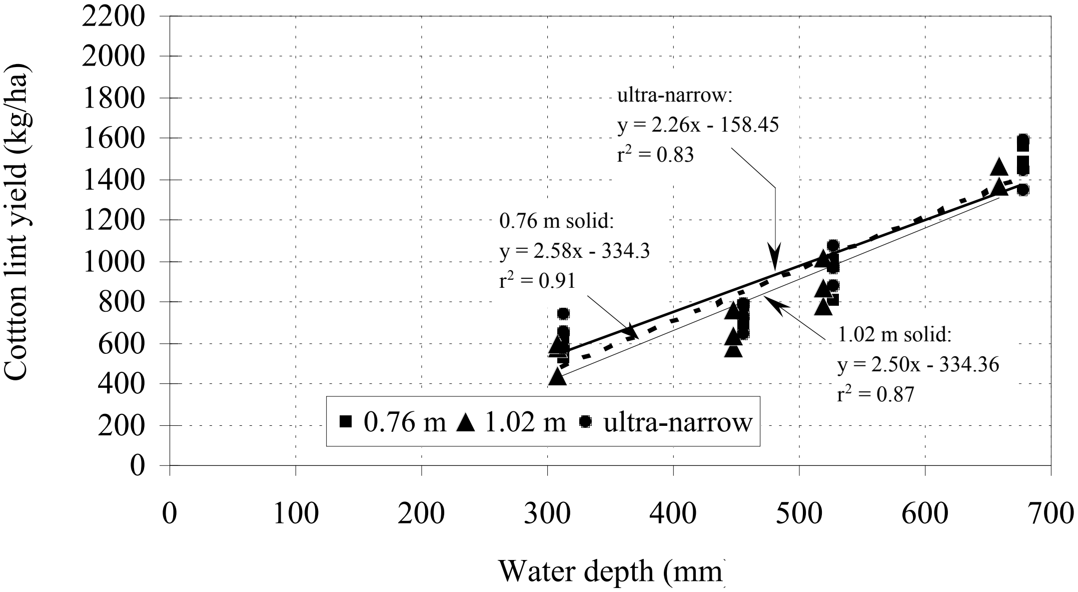

Fig. 3. Relation between cotton lint yield and total water applied for ultra-narrow rows and spaced at 0.76 m, and 1.02 m, during 1999 at St. Lawrence, TX.

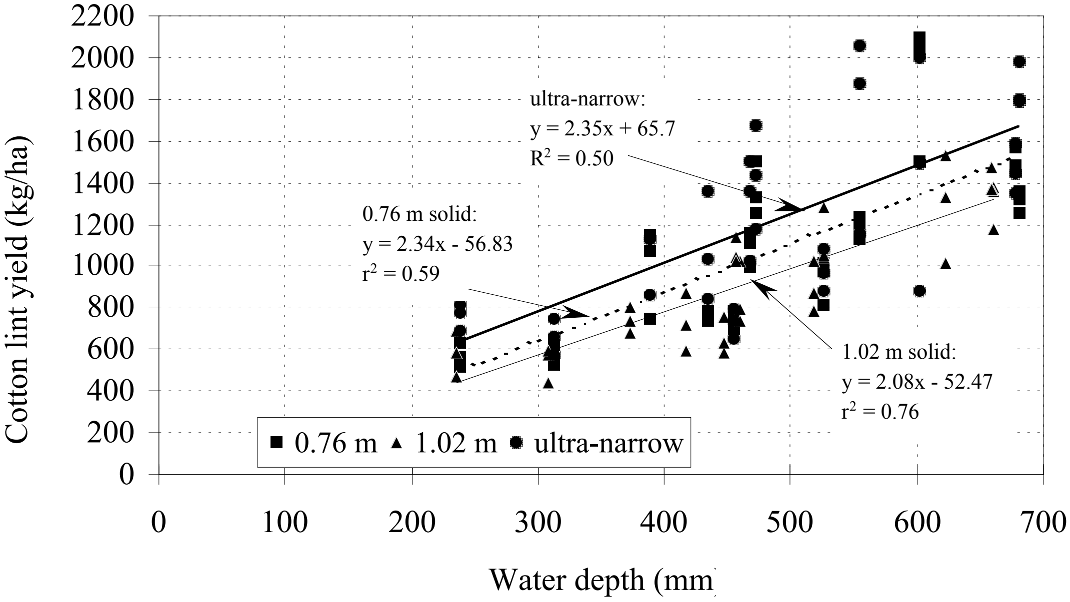

Fig. 4. Relation between average cotton lint yield and total water applied for thre cotton row spacings (UNR, 0.76 m, and 1.02 m), St. Lawrence, TX in 1997-1999

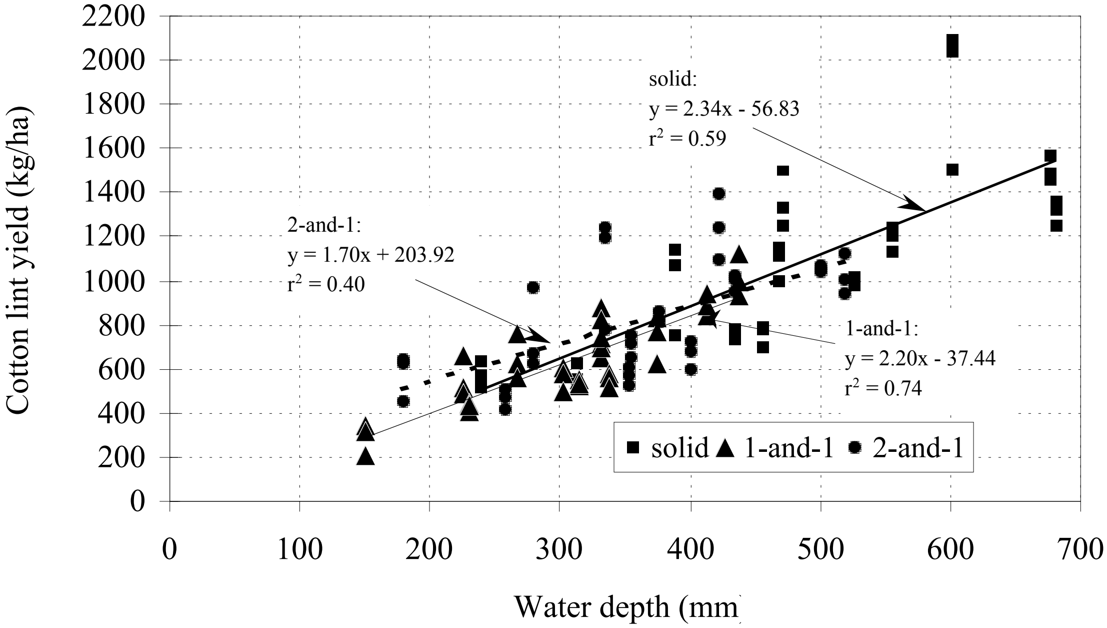

Fig. 5. Relation between average cotton lint yield and total water applied for different planti patterns for the 0.76-m row spacing, St. Lawrence, TX, 1997-1999.

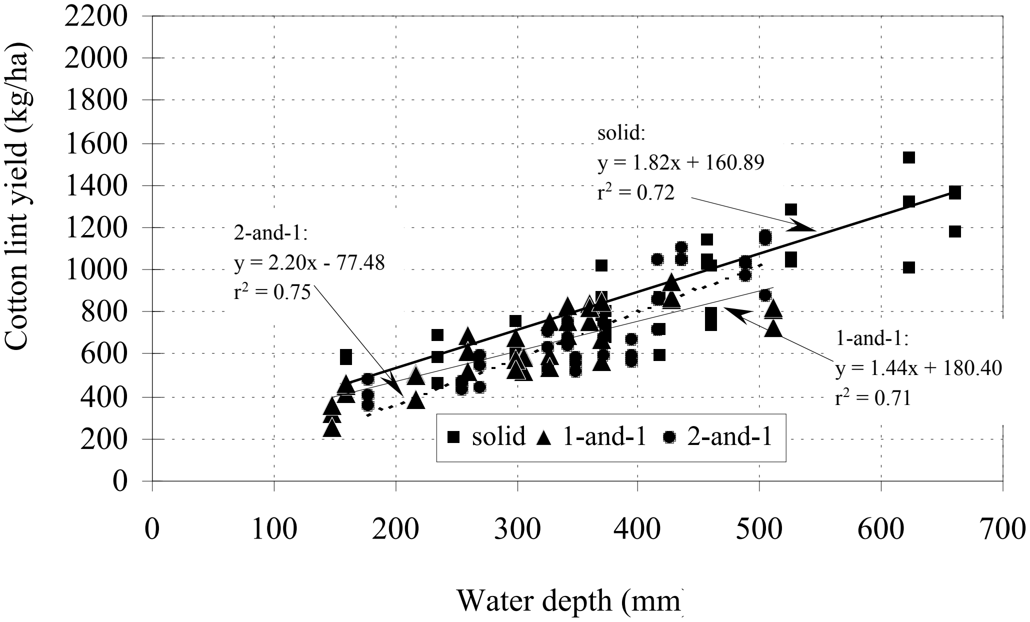

Fig. 6. Relation between average cotton lint yield and total water applied for dif planting row patterns for the 1.02-m row spacing, St. Lawrence, TX, 1997-1999.