Deficit subsurface drip irrigation of cotton

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Summary

An experiment in arid west Texas, United States of America, grew cotton with subsurface drip irrigation providing four basic levels of water resource and three row widths (1.02 m, 0.76 m, and approximately 0.38 m). The former two row-width treatments contained three planting configurations (a full pattern and two skip patterns). In all, there were seven row-width-pattern configurations, each of which had four water levels, for a total of 28 treatments. Where farmers do not have enough water with which to irrigate their crops, they may choose: (1) to reduce their planted area and apply more water (up to the full water requirement) on this portion of their land; or (2) plant the entire area, whereby they apply a quantity of irrigation water that only partially meets consumptive use requirements. The purpose of this study was to develop mathematical characterizations for yield as a function of water resource for various popular row width/patterns, and then to use these equations in crop budget models to determine economically optimum scenarios for local cotton growers. The full cotton production budgets were based on a 405-ha farm. The assumed water resource varied from scarcely any to enough, with proper management, to supply the majority of crop water needs. In almost all scenarios, it was economically sound to stretch the water resource over the entire farm, rather than to try to maximize yield on portions of the farm. A break-even economic water resource between covering the entire farm irrigating only portions of it was about 2.0 mm/day. Ultra-narrow-row treatments significantly exceeded the treatments with traditional row widths at all four water levels. The highest yield of lint was 1 833 kg/ha. Applying large portions of the moisture requirement as pre-planting irrigation enabled yields of 600 - 900 kg/ha of lint for the full pattern width treatments on the smallest water treatment, which applied 36 mm of in-season irrigation. The skip-row patterns did not yield as much as the full-row patterns.

Materials and methods

Experimental design

The trial lasted three years starting in 1997 in St. Lawrence, Texas, United States of America, which grows 33 000 ha of cotton annually, 30 percent of which irrigated with subsurface drip irrigation (SDI). The region is semi-arid and receives less than 400 mm/year of rainfall. This lack of precipitation makes dryland cotton production risky. Farmers usually adapt a skip-row configuration that allows the cotton plants to mine water from the unplanted rows.

The small groundwater resources in the region, although rechargeable, supply 250-500 mm of irrigation water during the 6½-month pumping season; nearly half of this amount is pre-plant irrigation that is stored in the soil. The soil in the experiment was a Reakor silty clay loam, which possesses good moisture storage ability. The experiment included two basic row widths (1.02 m and 0.76 m), each of which had three separate row patterns: (1) no row skips; (2) every other row skipped; and (3) every third row skipped. Local cotton growers term these "Every Row" "1-and-1" and "2-and-1", respectively. These six configurations were accompanied by a seventh, ultra-narrow row (UNR), treatment. The UNR width was 0.25 m in 1997 and 0.38 m during the other two years. All full-planting patterns (i.e., the 1.02-m Every Row, the 0.76-m Every Row, and the UNR) were irrigated using one of four water resource amounts, equivalent to 0.6, 1.2, 2.4, and 4.7 mm/d. The experiment used water resource amounts instead of percentages of evapotranspiration (ET) because employing percent of ET to initiate a treatment leads to a curtailing of early-season pumping as ET levels are low. In reality, farmers with smaller water resources are likely to pump water continuously during this period, building a reservoir. The skip-row patterns also had four water levels, but were proportionately less than the full-row patterns based on the amount of skips in the pattern. All water levels used in the test were well below the peak water use level for cotton in this region (9 mm/d).

The management of the experiment was based on operating the irrigation system in a "common sense" method. For example, as an SDI system enables local farmers to begin pre-irrigation in December, the systems in the experiment were operated in a similar manner, and the soil profiles were filled where possible. Thus, for the full-row patterns, the soil profile was fully recharged prior to planting in all cases, except for the smallest water treatment, with which the profile was generally half full prior to planting. The patterns with skip row would have received smaller amounts of pre-irrigation.

The drip lines were installed at a depth of approximately 0.35 m. A delivery manifold connected lateral lines with a flushing manifold on the distill end. The lines were placed directly beneath the planted rows, except in the case of UNR where the spacing was 0.76 m. The same delivery manifold tied in all three row patterns for the 1.02-m row width. As there was one drip lateral per planted row of cotton, the resultant relative deliveries of water to the various pattern treatments on an aerial basis were 1.00, 0.67, and 0.50 for the Every Row, 2-and-1, and 1-and-1 patterns, respectively. The ranges of water amounts received by the different patterns were: Every Row from 0.6 to 4.8 mm/d, 2-and-1 from 0.4 to 3.2 mm/d, and 1-and-1 from 0.3 to 2.4 mm/d. As local growers with large-capacity wells tended to plant Every Row, and farmers with smaller water resources tended to use row skips, the range of water amounts tested for each pattern tended to be appropriate.

The ultimate goal of the research was to develop mathematical equations of yield as a function of available groundwater resources for the various patterns that could be used in economic analyses. The three row patterns of the 0.76-m group had a similar set-up, but ran for approximately 33 percent less time to compensate for the closer lateral spacings. This made all water application amounts between the two row-width groups similar. The UNR plots were tied into the 0.76-m lateral.

The drip lateral had emitters spaced 0.6-m apart with a nominal discharge of 4 litres/h. The emitters were impregnated with Treflan® to inhibit root intrusion. The plot length was 17.1 m. Treatments were replicated three times. Blocks were irrigated twice per week using an electric timer with appropriate run times to give the desired application depths. Water meters were tied into each delivery manifold to ensure accuracy. A cotton variety genetically modified with Bt traits (Deltapine NuCOTN 33B) was used to limit insect predation and its possible influence on the results. Planting dates were 23, 12 and 19 May for the years 1997, 1998 and 1999, respectively. Urea (32-0-0) was injected into the drip system from around first bloom, at an amount proportional to the water resource, in three chemigation events approximately two weeks apart. The average amounts of nitrogen applied for the three years were 43, 65, 93 and 145 kg/ha for the full-pattern treatments. The skip patterns received proportionately less.

The location for the experiment was on the farm of a local cotton grower, who performed most of the operations. The 1.02-m treatments were planted in beds, with all other treatments planted flat. The UNR treatment was planted with a grain drill (width = 0.25 m) the first year; during the final two years a planter with a row-width setting of 0.38 m was used. Harvest data were gathered by hand-picking two row lengths of 3.0 m, except in the case of the UNR, where an area of 0.8 m_2 was picked.

Third-order polynomial equations of yield as a function of water resource amount were developed for the seven various patterns. Equations were also developed for a separate pattern, 4-and-1, by averaging the yield results of Every Row and 2-and-1 for equivalent amounts of water. The equations were in the form of:

$$Y = a + bW + cW^{½} + dW^{2} \quad (1)$$

where: Y =yield (kg/ha)
W= water resource available (mm/d)
a, *b*, *c*, and *d* are constants

Economic analyses

Economic analyses determined the net total returns for each pattern/spacing under a wide range of water resources. These analyses also investigated the benefits of installing SDI over the entire farm (405 ha) versus installing it only on various fractions, which would increase allocations of water (and thus SDI yield) to those portions, but would dictate that the omitted area produced dryland yield levels.

Yields for the different row patterns/spacings were determined under conditions of varying water resource amounts using Equation (1). All yields were reduced 5 percent to account for possible differences between machine-stripping and the hand-picking. A fixed cost of about US$100/ha was assumed for the machinery of the farm, irrespective of the percentage of land in SDI. The quantity of water and the amount of SDI installed were used to directly calculate yields, as well as several variable costs (fertilizer, pumping and ginning) and fixed costs (land and SDI annual costs). Thus, 100 percent of all returns and about 75 percent of all costs in the cotton budget were self-generated. Costs of pesticides, fuel, etc. that made up the other portion of the cotton budget were based on the authors' estimates. Dryland net returns were assumed at about US$80/ha based on extension service information that did not include the fixed costs captured under the SDI portion of the overall farm budgets.

Results

Table 1 shows irrigation amounts applied both pre-plant and in-season for the Every Row treatments (2-and-1 and 1-and-1 received 67 and 50 percent of the irrigation amounts, respectively). The pre-season applications contributed 45-81 percent to total irrigation amounts. On average, the lowest full pattern treatment received a total of only 325 mm (irrigation plus rainfall), whereas the highest treatment received 650 mm. Unruh *et al.* (1999) showed that yields were higher in years with more in-season rainfall.

Table 1
Average amount of irrigation and in-season rainfall for the Every Row treatments, 1997-99

	Irrigation supplied at treatment capacity of:			
	0.6 mm/d	1.2 mm/d	2.5 mm/d	4.8 mm/d
	------------ (mm) ------------			
Pre-season	154	223	223	229
In-season irrigation	36	75	149	286
Total irrigation	190	298	375	516
In-season rainfall	135	135	135	135
Total water	325	432	510	650
	------------- (%) ------------			
Fraction of irrigation applied pre-season	81	75	60	45

Yield results

Yields were similar from year to year. UNR provided the highest lint yields for all water levels, followed by the 0.76-m treatment (Table 2). Due to hydraulics of the system, the 0.76-m patterns, which included the UNR treatment, received approximately 4 percent more water than the 1.02-m treatments.

Table 2
Average yields, 1997-99

Treatment	Yield with treatment capacity of			
	0.6 mm/d	1.2 mm/d	2.5 mm/d	4.8 mm/d
	------------- (kg/ha) -----------			
Every (1.02 m)	596	837	1 083	1 308
4-and-1 (1.02 m)	549	751	966	1 149
2-and-1 (1.02 m)	500	671	843	998
1-and-1 (1.02 m)	427	556	695	785
Every (0.76 m)	658	993	1 302	1 570
4-and-1 (0.76 m)	633	890	1 149	1 348
2-and-1 (0.76 m)	605	798	984	1 139
1-and-1 (0.76 m)	429	582	723	842
Ultra-narrow row	880	1 224	1 553	1 833

The yield response curves show that the UNR treatment responded most strongly, followed by the 0.76-m treatments (Figures 1 and 2). The 1.02-m treat-ments (the row spacing generally used by local farmers) had the lowest yields. Normal yields for the area are 560 and 224 kg/ha for furrow-irrigated and dryland conditions, respectively. Table 3 shows the values for the constants in Equation (1).

Figure 1
Average yield data for the 1.02-m patterns and UNR, 1997-99

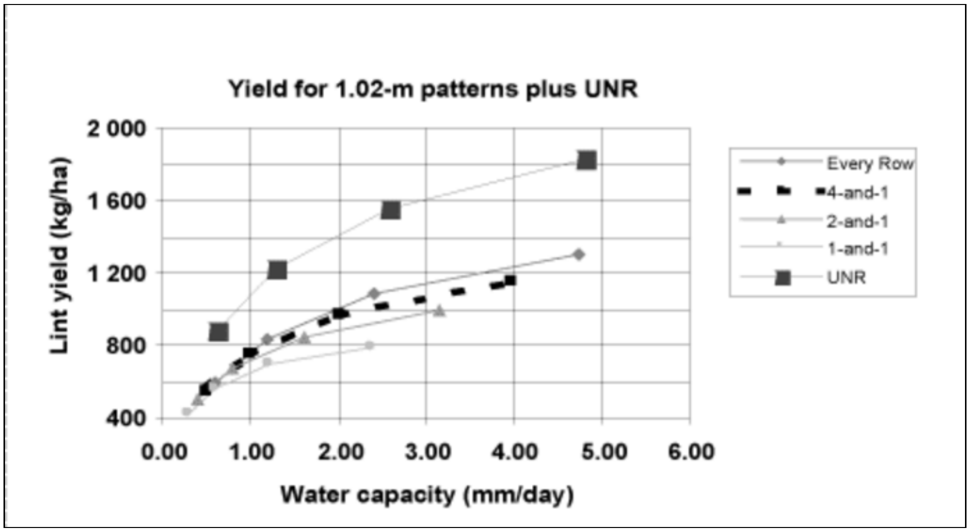


Figure 2
Average yield data for the 0.76-m patterns and UNR, 1997-99

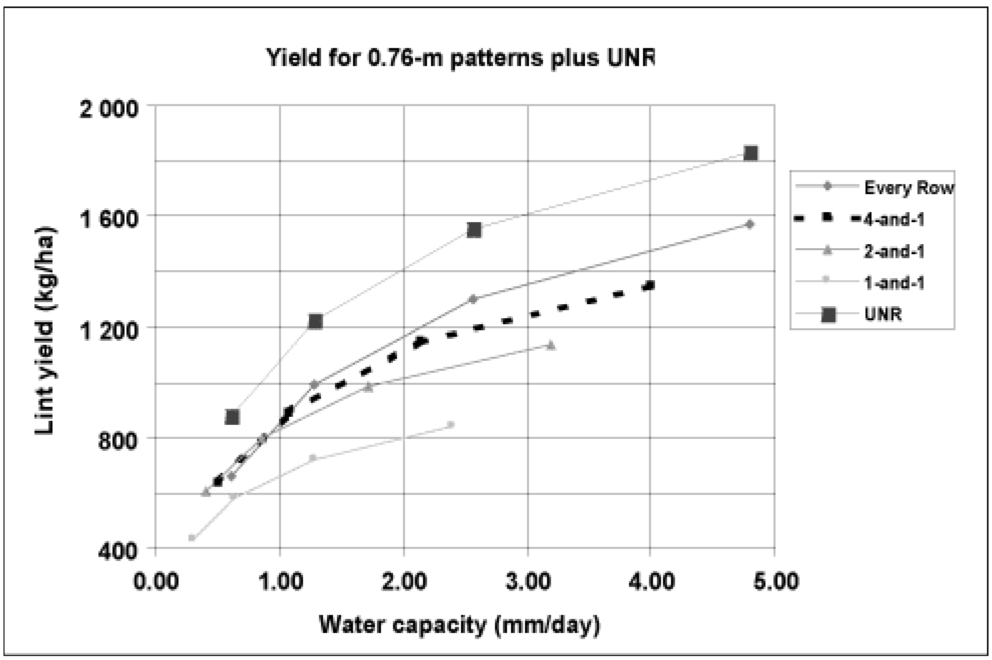


Table 3
Values for constants in Equation (1)

Treatment	Constant			
	a	***b***	***c***	***d***
Every (1.02 m)	-263	-378	1 401	14.0
4-and-1 (1.02 m)	-154	-336	1 230	11.9
2-and-1 (1.02 m)	-60.9	-311	1 086	10.8
1-and-1 (1.02 m)	-76.4	-462	1 168	28.4
Every (0.76 m)	-597	-619	2 067	26.7
4-and-1 (0.76 m)	-253	-426	1 530	15.3
2-and-1 (0.76 m)	-69.6	-434	1 322	22.8
1-and-1 (0.76 m)	-77.5	-405	1 132	23.6
Ultra-narrow row	-376	-587	2 044	24.2

Economic analyses

Figures 3 and 4 show the net profits for a 405-ha farm with limited water resources (0.3 mm/day) (UNR data included for comparison). The UNR had the highest net returns (about US$15 000). This optimum return for UNR occurred when the irrigation system was configured for 1.0 mm/day. For a 405-ha farm with an available water resource of 0.3 mm/day, this would mean 121 ha of SDI [(0.3/1.0) x 405] and 284 ha of dryland. All the other treatments in Figures 3 and 4 showed net losses at all points.

Figure 3
Net profit for farm with a 0.3-mm/d water resource using various row patterns with 1.02-m row width

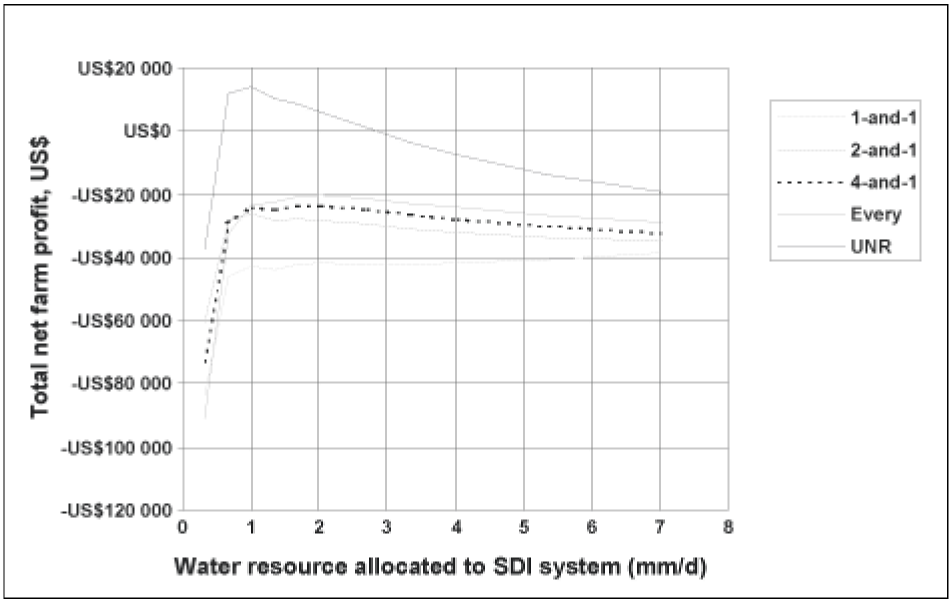
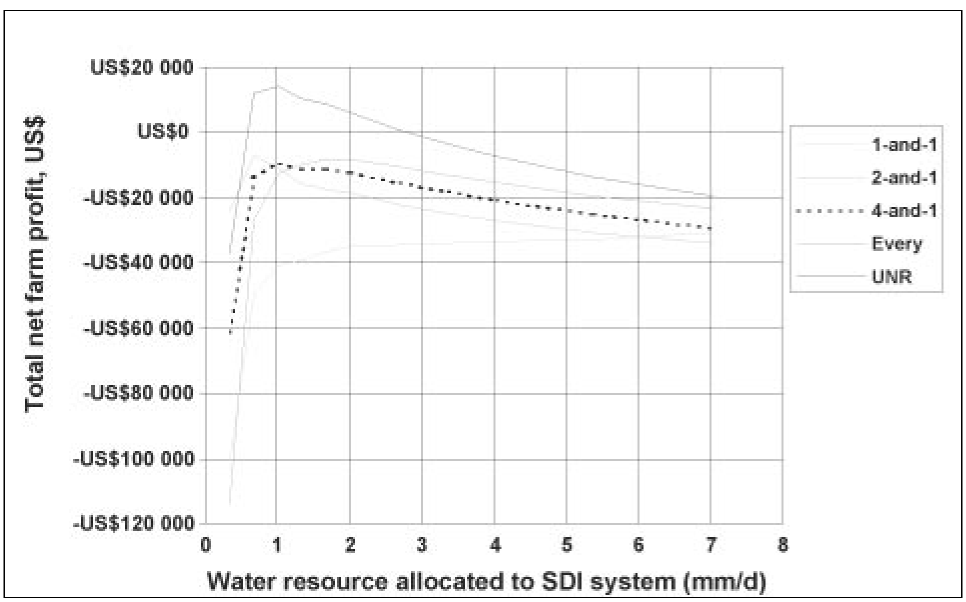


Figure 4
Net profit for farm with a 0.3-mm/d water resource using various row patterns with 0.76-m row width



When the water resource was less than 1.0 mm/d, it was slightly more economic to use the 4-and-1 and the 2-and-1 rather than the Every Row pattern on the 0.76-m patterns, (data not shown). In all other instances, Every Row was more economic than the skip patterns.

Once a farm's water resource reached 2.0 mm/d or greater, the analysis showed that it was best to install SDI over the entire 405 ha. Figures 5 and 6 show net returns for a farm with a water resource of 1.5 mm/d. At this point, optimum economic levels were reached when about 90 percent of the farm was in SDI. Returns for the UNR, 0.76-m Every Row, and the 1.02-m Every Row were approximately US$175 000, 100 000 and 50 000, respectively, for the 1.5-mm/d water resource level. When the farm had a water resource of 3.0 mm/day, the net profits were about US$286 000, 191 000, and 86 000 for the UNR, 0.76 Every Row, and the 1.02-m Every Row treatments, respectively.

Figure 5
Net profit for farm with a 1.5-mm/d water resource using various row patterns with 1.02-m row width

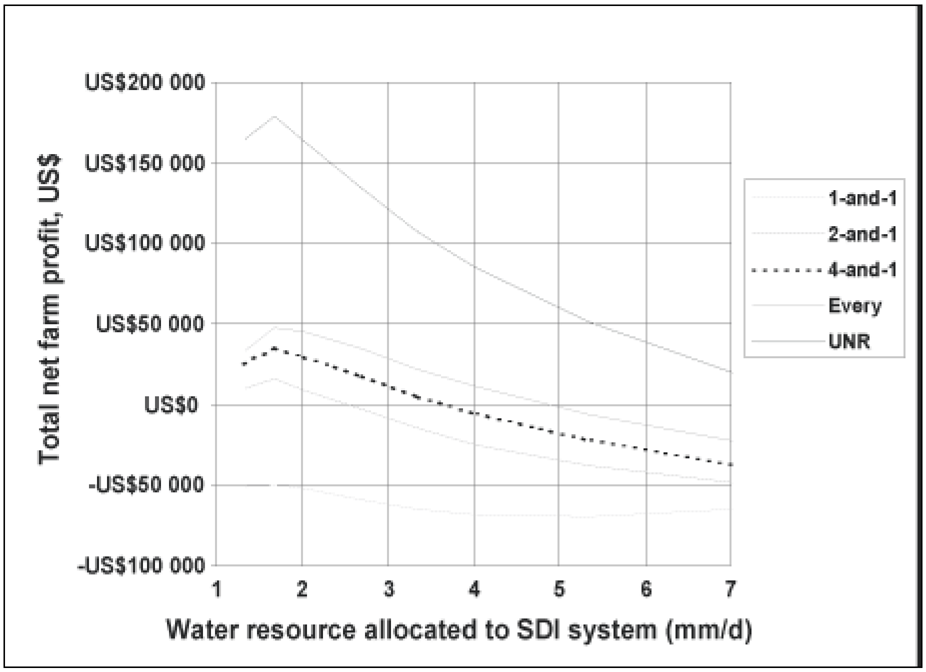


Figure 6
Net profit for farm with a 1.5-mm/d water resource using various row patterns with 0.76-m row width

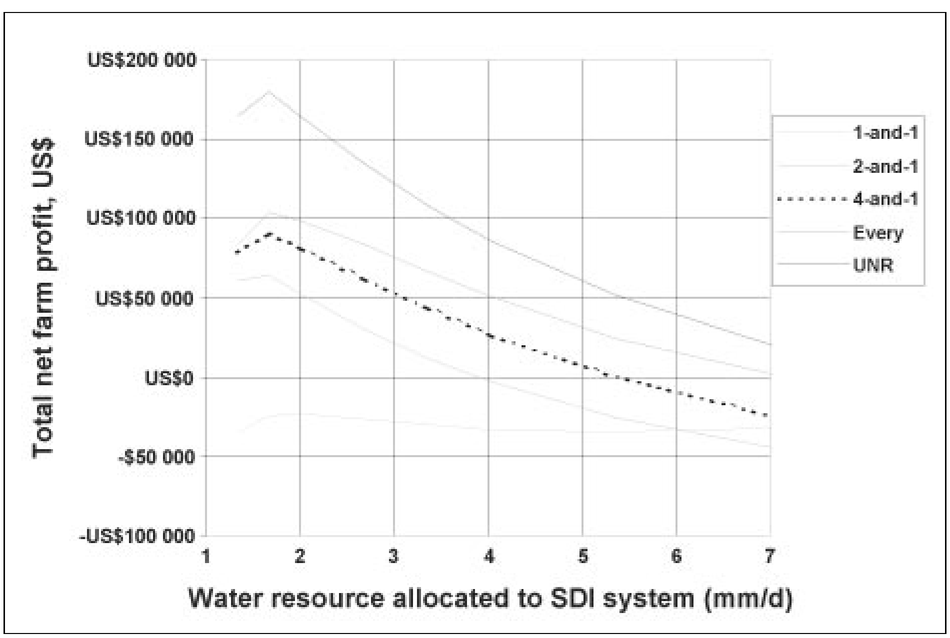
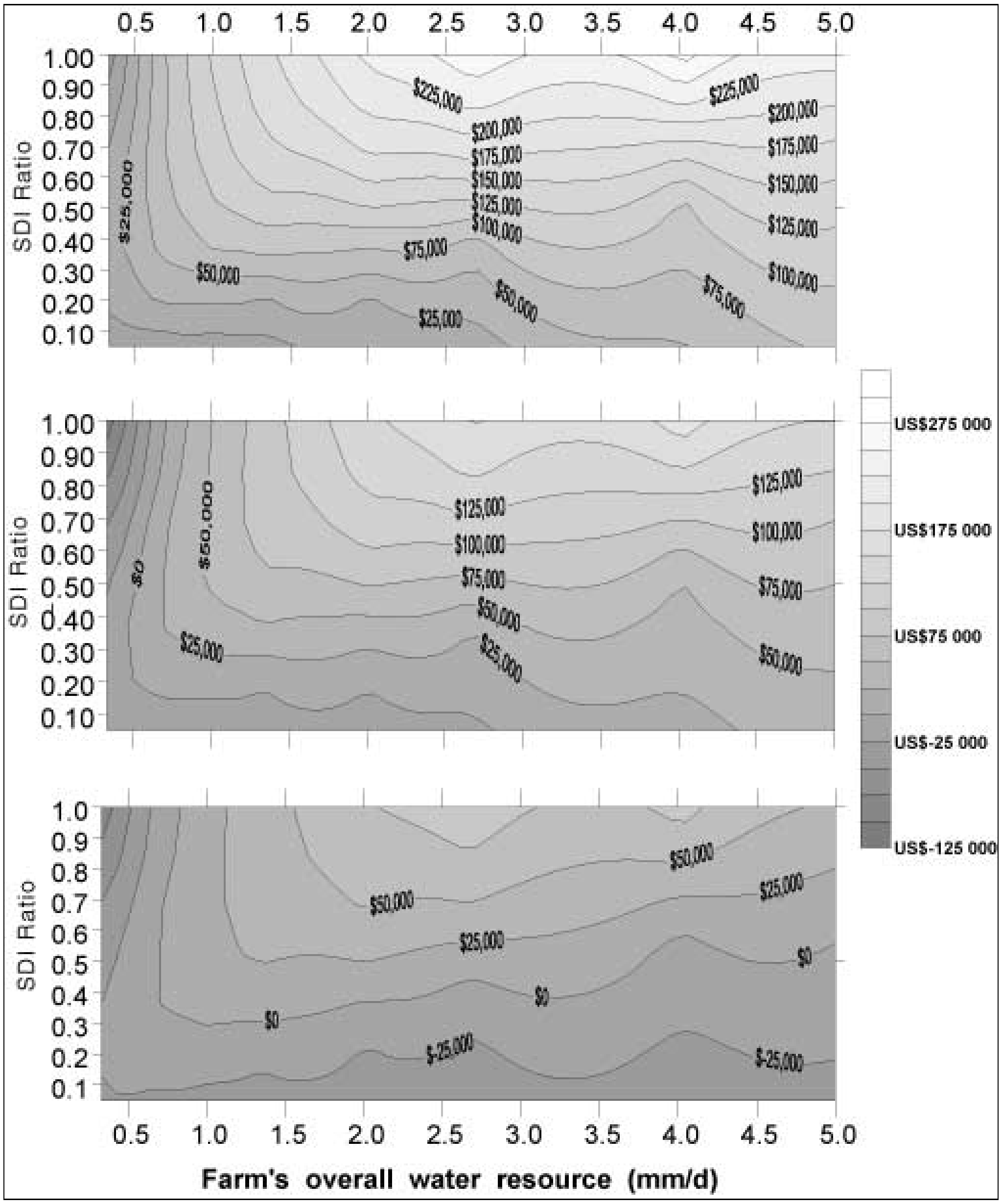


Figure 7 shows net farm returns as a function of both farm water resources and fraction of farm in SDI, with data for UNR, 0.76-m Every Row, and the 1.02-m Every Row. The X axis shows the farm's water resource.The Y axis represents the portion of SDI installed on the farm (hectares of SDI/405). As an example, if this farm uses UNR and it has a water capacity of 2.0 mm/d and 300 ha of SDI are installed, then the SDI ratio is 0.74 and net profits should be a little over US$175 000. With all acreage converted to SDI (ratio = 1.0), net profits would be over US$225 000.

Figure 7
Net farm returns for the entire 405-ha farm for UNR (top), 0.76-m Every Row (middle) and 1.02-m Every Row (bottom)



Conclusions

The experiment provided estimates of yields and incomes for a certain region of Texas. Therefore, the data do not necessarily apply to other soil types and weather patterns.UNR had the highest yields and largest farm net returns. However, UNR production practices, specifically in planting and harvesting, are difficult to manage successfully, and local growers not adopted them widely.

The 0.76-m treatments had significantly higher yields and net farm returns than did their 1.02-m counterparts. With a water resource greater than 1.0 mm/d, Every Row was more economic than skip patterns. When the water resource was less than 1.0 mm/d, then 4-and-1 and the 2-and-1 were more economic.

The high proportion of pre-plant irrigation that was beneficially used was important in making the SDI enterprises viable, especially with less water available. Questions remain regarding the skip-row patterns and pre-plant irrigation. As blank rows existed, these treatments, depending on lateral water movement, may store more useable pre-plant irrigation water than do the Every Row patterns. However, as tested, all treatments received the same amount of pre-plant irrigation.

One of the most significant findings was that, in almost all cases, the economic analyses showed that it was better to stretch the water resource over the entire farm, rather than to concentrate it to maximize yields on parts of the farm. The exception to this was where the farm had very little available water (less than 2.0 mm/d), when it was better to decrease installed SDI acreage to ensure that 1.0-1.5 mm/d was available to any SDI that was installed.

Reference

Unruh, B.L., Multer W.L., Sturtz S., Scott R. & Warren J. 1999. *Optimizing row-width patterns when faced with limited water resources*. Result Demonstration Report. Fort Stockton, Texas, United States of America, Texas Agricultural Extension Service.