SITE-SPECIFIC IRRIGATION OF COTTON ON THE TEXAS HIGH PLAINS

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Abstract

Cotton production might benefit from planned-variable distribution of irrigation as a function of soil water holding capacity (SWHC) and topography leading to better utilization of both rain and irrigation in water short regions of the Texas High Plains. Spans 5, 6, 7 and 8 of an 8-tower LEPA center pivot system were modified to deliver variable-rate (VR) irrigation within areas no larger than 400 m^2. Applicators were modified to provide relative flow rates of 2x, 3x, and 4x thus allowing stepwise increases in irrigation discharge of 20% of a base irrigation quantity. A control system opened solenoid valves relative to field location, thereby controlling irrigation quantities at specific sites.

Field experiments were conducted in 2001 and 2002 to evaluate equipment and document potential advantages of VR irrigation of cotton over standard practices. Alternating strips of cotton, 20 to 22 rows wide, were irrigated by either VR or uniform-rate (UR) irrigation. In 2001, the VR irrigation strategy attempted to level lint yields by reducing irrigation in areas of high SWHC and increasing irrigation on areas of low SWHC following uniform pre-plant irrigations. Management zones were based on soil texture and slope in a 5-ha area. In 2002, irrigation quantities were increased in areas thought to be "more productive". Soil electrical conductivity (EC) was used to determine the management zones on a 6.2-ha test area for site-specific irrigation.

Evaluations of the VR irrigation system following its construction in 2001 and modification in 2002 resulted in actual applicator flow rates within 5% of achievable flow rates. Errors in pivot positioning were documented. Based on preliminary comparisons with given management zone criteria, VR irrigation of cotton produced no significant increase in total lint yield or total irrigation water use efficiency (WUE) over uniform LEPA application in 2001 or increases in WUE in 2002. Using soil EC to establish management zones for VR irrigation resulted in lint yield increases of 2 to 4 % over uniform irrigation, but at the cost of additional water inputs.

Introduction

More than 20,000 center pivot systems irrigate 1.2 million ha of cropland in the Texas High Plains. However, available irrigation capacity is typically far less than peak evapotranspiration (ET) demand for crops grown in this region. Furthermore, irrigated soils are seldom uniform due to differences in texture and depth, and water availability within a field will differ due to topography and its effect on runoff. Crop production could benefit from the planned, non-uniform distribution of irrigation water based on SWHC and topography, leading to better utilization of both rain and irrigation water in this semi-arid environment.

The "multiple manifold" method of dispersing variable quantities of water with irrigation systems has been used at the Texas Agricultural Experiment Station (TAES) at Halfway in small plot research for many years (Bordovsky, et al., 1992). This method uses manifolds with different size nozzles in combinations to create a stepwise range of rates. The USDA/ARS in South Carolina also uses this method (Omary et al., 1997). Other

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VR irrigation systems use pulsing applicators for time proportional volume control (Farmscan Canlink 3000, VRI Controller, Western Australia) and altering the aperture of nozzles with a pin to achieve multiple flow rates (Sadler et al., 2001).

This paper discusses the construction and initial evaluation of a site-specific LEPA irrigation system and presents preliminary evaluations on criteria for managing variable-rate cotton irrigation in the Texas High Plains.

Materials and Methods

Spans 6, 7 and 8 of an 8-tower Zimmatic™ center pivot irrigation system were modified to provide VR irrigation during the spring and summer of 2001. The pivot was located at the Helms Research Farm, 2 miles south of the TAES Research and Extension Center at Halfway, TX. The hydraulic and control components of the VR system were evaluated in July and August. Field evaluations comparing VR to UR water application on cotton were conducted with water treatments beginning in August 2001. Management zones in 2001 were based on soil texture and slope down the furrow. An additional VR section (span 5) was installed in 2002. Irrigation management zones were created based on soil electrical conductivity (EC) measured by the Veris 3100 system (Veris Technologies, Salina KS).

Irrigation Equipment

The VR irrigation system conveys water from the pivot lateral through pressure regulators and solenoid valves into three separate 16-m long manifold pipes, which comprise the manifold unit. Three manifold units are positioned under each 49-m long pivot span. Hoses are used to direct water from the manifolds to specially designed LEPA irrigation applicators. In 2001, nozzle sizes for each applicator provided relative flow rates of 1x, 2x, and 3x, which, when opened in various combinations, provided six discrete irrigation amounts ranging from 25 to 150% of the base irrigation (BI) rate. In 2002, LEPA applicators were modified to provide relative flow rates of 2x, 3x, and 4x allowing stepwise increases in flow of 20% of BI. With additional water sources in 2002, the base flow rate for the 54-ha pivot was increased to 2270 L/min with equivalent flow rates in the modified spans ranging from a low of zero to a high of 3180 L/min.

The VR equipment evaluation began in July 2001. Original LEPA application devices were extensively modified to accommodate high water volumes without causing runoff. The final LEPA applicator consisted of a group of four nozzles, three were individually connected to one of the three manifolds of a VR manifold unit, and the fourth connected to the pivot mainline and sized at the BI flow rate. The entire nozzle assembly was inserted into a custom made “sock” with the lower portion of the open-ended sock dragging the ground and dispensing water between pairs of crop rows. All irrigated crops were planted in circular rows. The fourth nozzle was valved so that its flow would be off when the VR system was in use.

Applicator flow rates were determined by volumetric catchments from individual LEPA applicators for each of the manifold units during irrigation events from July through August in 2001, and in June and July in 2002. Water pressure taps were positioned at strategic locations throughout the manifold units to determine pressure losses and help improve water distribution. The two wells supplying water to the VR pivot were equipped with Cycle Stop® (Cycle Stop Valves, Lubbock, TX) pressure regulating valves to stabilize pressure at 200 kPa as changes in pivot flow rates occurred.

An electronic control system was installed to activate solenoid valves at each manifold unit relative to field location, thereby controlling irrigation quantities at specific sites. A SNAP-LCSX-PLUS industrial controller (Opto 22, Temecula, CA), two remote terminal units (SNAP-B3000), software, and related accessories were installed for this purpose. The control system was programmed to provide four control signals to each manifold unit (3 signals for 3 water manifold solenoids and an additional signal for a future chemigation actuator). Programming further allowed changes in solenoid status every 3° around the 360° perimeter of the pivot. Therefore, the largest control area under this VR pivot was < 400 m^2 (16-m manifold unit length by 22-m maximum 3° arc) resulting in more than 2000 potential water/chemical control cells under the 54-ha pivot. A standard incremental encoder (Dynapar™ Series E15, Danaher Controls, Gurnee, IL) was used to provide input signals to the controller to determine pivot location. A Microsoft Excel™ program was written to create coded map files from desired irrigation application maps. The application sequence was then loaded into the VR controller with a laptop computer.

Crop Response to VR Irrigation

2001 growing season. Field experiments were conducted to explore potential advantages of VR irrigation compared to standard uniform LEPA irrigation of cotton on the High Plains. The 2001 experiment was conducted in a 5-ha area irrigated by the VR system. This portion of the field contained the greatest elevation changes and the most notable differences in surface soil texture. The 60° arc was divided into 9 strips with each strip either 20 or 22 rows wide and falling beneath one of the 9 VR manifold units. Alternating strips were irrigated by either VR or UR irrigation. Comparisons of crop responses from these areas were used to evaluate VR irrigation. Figure 1 shows the position of the 5-ha area relative to the pivot and the locations of the nine VR and UR treatment strips in the 2001 experiment.

Past research at Halfway and the AgCares research site at Lamesa had shown variability in cotton lint yield correlated with factors associated with crop water use such as slope, elevation, soil texture, and seasonal irrigation (Bordovsky and Keeling, 2000; Li et al., 2001). At the Helms site, profile elevations and soil texture at 64 locations within the area were used to determine different irrigation zones in the VR strips. Differences in elevation and row direction were used to determine furrow slope at each of 64 referenced sites (Figure 2). Soil texture below 0.4-m depth had not been determined prior to initial VR irrigation on 2 August, therefore, the only textural data used in the initial decision on water placement in VR strips was clay content in the top 0.4 m (Figure 3). The general VR irrigation strategy was to level lint yields by reducing irrigation in areas of high SWHC and adding water to areas of low SWHC. A decision was made to divide the area into three zones. The low-rate zone was irrigated at a rate equal to 75% of the UR in the area where furrow slope was 0% and clay content in the top 0.4 m was > 40%. This zone contained soils with high SWHC and limited risk of rain runoff. The medium-rate zone was irrigated at 100% of UR and included the area of furrow slope from 0.0 to 0.5% and clay content of < 40%. The high-rate zone was irrigated at 125% of the UR where slope was > 0.5%. The high-rate zone had the highest risk of rain losses. Previously defined sampling sites also affected decisions on irrigation boundary positions since yield analysis required representative numbers of sites per zone. Boundaries between zones of different irrigation levels are shown in Figures 1, 2, and 3.

Cotton (Paymaster 2326RR) was planted in the test area on 24 May 2001 and the crop maintained using normal cultural practices. Nutrients were applied based on aggregate soil sampling and pests were treated at recommended thresholds. Irrigation was initiated on 26 May and continued through 30 August. Due to the dry growing season and limited pumping capacity, irrigations in UR treatments were less than the planned 80% of estimated ET. Irrigation amounts of 142 mm were uniformly applied across the test area from 26 May to 27

July. From 2 through 30 August, irrigations totaled 100, 130, and 160 mm in the VR strips of the low-, medium-, and high-irrigated zones, respectively. Therefore, the difference in total irrigation quantity between the low and high irrigation zones within the VR treatments was 60 mm.

2002 growing season. Soil EC was used as the criterion to determine the general productivity of a 6.2-ha area for site-specific irrigation of cotton in 2002. Soil EC measurements of the top 1-m of the soil profile were recorded using the Veris system in 2001 (Figure 4). The VR irrigation strategy followed the general hypothesis that, when resources are limited, the highest overall production will result from applying available resources to the more productive areas of the field (Lascano, 2002). The 2002 research area had been planted to corn in 2001 and, in 2002, was divided into strips irrigated by individual manifold units with alternating strips managed as either VR or UR (Figure 5). Areas with 1-m soil EC measurements > 35 dS/m were assumed "more productive" and received 120% of the base irrigation quantity within VR strips. All UR strips and the VR areas of soil EC < 35 dS/m received 100% BI. Evaluations of VR vs. UR application were based on total irrigation WUE.

Cotton (Stoneville 2454RR) was planted in the test area on 7 May 2002 and the crop maintained using normal cultural practices. Seasonal irrigation was initiated on 17 May and continued through 28 August. Rain, from the day of planting until 28 August, totaled 36 mm. Irrigations in UR treatments were ~80% of estimated ET. Seasonal irrigation amounts of 94 mm were uniformly applied on the test area from 17 June to 16 July. From 16 July through 28 August, irrigations totaled 216 and 260 mm in the VR strips of the "low" and "high" productive areas, respectively.

Results

Equipment Evaluation

The mechanical evaluation of the VR system included tests of the hydraulic and positioning systems. Figure 6 displays hydraulic performance data of the VR system on 4 August 2001 and, again, following several modifications on 30 August 2001. These charts show comparisons of desired, achievable, and measured flow rates of applicators within each of nine manifold units of spans 6, 7 and 8. Flow rates of individual manifold systems were offset from adjacent manifolds due to programmed differences in flow rates relative to field position. Data from the initial date indicated that measured applicator flow rates were somewhat higher and more scattered than the achievable flow rates. System improvements were made by increasing and stabilizing inlet water pressure at the pivot, renozzling the VR applicators, modifying plumbing components to prevent flow restrictions, and eliminating low-pressure drain valves. Hydraulic performance tests were conducted in 2002 following additional VR manifold installation on span 5 and redesign of stepwise flow rates of all manifolds. Measured applicator flow rates were within 5% of achievable flow rates when VR experiments began in 2002.

To date, the controller, remote terminal units, and solenoid valves have functioned flawlessly; however, the positioning system used to activate valves at appropriate locations in the field failed to perform as precisely as desired. An evaluation was conducted comparing measured pivot location to the pivot location sensor outputs of both the VR positioning sensor and the pivot manufactures sensor. Output data were systematically recorded as the pivot rotated around the field in both clockwise and counter-clockwise directions. Comparisons of pivot and VR sensor response to measured position are shown in Figure 7. The pivot and VR sensors showed deviations of up to 6° from the measured field location at 0/360° (north). This represents a positioning error at the outer edge of the pivot of ~40 m. As the pivot rotated through the 120 to 200° arc, the output signals of both sensors were consistently within a few degrees of the actual pivot position. Position data were generally similar in both pivot directions after multiple revolutions. The systematic difference between pivot and VR outputs indicated possible mechanical problems with the rack portion of the rack and pinion sensor mechanisms. This error was reduced by replacing pivot parts and reprogramming the count sequence within the VR controller. Error of up to 2° may be acceptable for most irrigation or chemical applications in this setting.

Cotton Lint Yield Response

Cotton lint yields were determined by three methods: 1) using stripper harvested, boll buggy weights from each of the treatment strips under the manifold units; 2) hand harvesting 4 m^2 areas at 64 (2001) and 65 (2002) geo-referenced sites; and 3) harvesting the entire area using a cotton stripper equipped with a yield monitor. No significant statistical differences in total yield or total irrigation WUE were evident between VR and UR treatments in 2001 or differences in WUE were measured between VR and UR treatments in 2002. Table 1 includes weighted irrigation amounts, lint yield based on burr cotton weights (boll buggy), average hand harvested lint weights, and integrated hand harvest lint weights; and total irrigation WUE for VR and UR irrigation treatments for the 2001 crop year. Integrated lint yields were derived from geo-referenced hand-harvested data from either the UR or the VR sites using Surfer® software (Golden Software, Inc., Golden Colorado). Yield based on boll buggy weights were 806 vs. 799 kg/ha for VR vs. UR treatments. Yield based on average hand samples were 1083 kg/ha (1100 kg/ha, integrated) from the VR irrigation treatment compared to 1125 kg/ha (1138 kg/ha, integrated) from the UR treatment. Estimates of WUE were similar for the two treatments. Table 2 gives cotton lint yield by manifold strip and harvest method for the VR and UR treatments for the 2002 experiment. Average lint yields are slightly higher in the VR than UR treatments due, in part, to the larger total water volume applied within the VR plots (409 mm and 387 mm, respectively). VR yields were 2.8, 2.7 and 4.6% higher than UR yields when determined from boll buggy, hand sample, and yield monitor yields, respectively. Table 3 shows WUE of VR and UR treatment areas as a function of harvest method. Although yields were higher in VR than UR strips, WUE was slightly higher in UR than VR areas.

Although average lint yields were similar, spatial distribution of yields were different depending on irrigation treatment. Figure 8 represents the integration of hand harvest data obtained at the 32 sites in the UR treatments as well as VR sites that received the UR irrigation quantity in 2001. This represents the yield response from uniformly irrigating the entire 5-ha area. This map shows two general areas of lower yields, an area with no slope and high clay content (west side) and a sloping area (> 0.5%) with low clay content (southeast corner). For comparison, the VR map shown in Figure 9 is composed of the yield data from the 32 VR sites. This map indicates that shifting water from the west side of the field to the east side reduced lint yield in the low water zone and increased yield in the high water zone. High yields seen on the far west side of the VR map may be due to irrigation from the adjacent field (VR controller not actuating valves at the precise location).

The 2002 spatial distribution of cotton lint yield from VR and UR treatments (hand harvested data) is shown in Figure 10. The UR yield generally shows higher yields in the "more productive" zones (EC > 35 dS/m). Applying additional water to these areas further increased yield in the "more productive" zone on the west (zone 3) as depicted by the darker shades in the VR graph. Integrated yields for this area were 1798 kg/ha for UR vs. 1882 kg/ha for VR irrigation. The potential value of VR irrigation is the prospect of improving irrigation WUE. This did not occur by adding additional water to areas with high EC values in 2002. The spatial distribution of WUE was more uniform with VR rather than UR irrigation (Figure 11); however, the integrated WUE of the UR treatment was slightly higher at 0.46 kg/m^3 compared to the WUE of 0.45 kg/m^3 of the VR treatment in the same area.

The small yield and WUE differences between VR and UR applications in 2001 were not unexpected. Irrigation treatments were started late in the growing season, initial irrigations were being made with VR equipment that had not been fully optimized, data used to base VR irrigation transition zones were limited, and the strategy for creating the zones was based on normal rainfall. In 2002, using 1-m soil EC as the criterion to establish management zones for VR irrigation resulted in higher lint yield with additional water inputs, but lower total irrigation WUE. These preliminary results illustrate that the in-season, site-specific water management of a cotton crop is complex. Further, due to the indeterminate growth habit of cotton in combination with the short growing season in the Texas High Plains strategies to optimize the allocation of finite water resources may need to consider additional factors other than slope and soil water holding capacity.

Acknowledgments

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Table 1. Cotton lint yield and total irrigation water use efficiency from VR and UR irrigation treatments TAES, Helms Farm, 2001.

		Variable Rate Irrigation						Uniform Rate Irrigation					
Span	Man. Unit	Irr. Amt. mm	Yield Boll Buggy kg/ha	Yield Hand Harvest kg/ha	Yield Int. Hand kg/ha	WUE Boll Buggy kg/m^3	WUE Hand Harvest kg/m^3	Irr. Amt. mm	Yield Boll Buggy kg/ha	Yield Hand Harvest kg/ha	Yield Int. Hand kg/ha	WUE Boll Buggy kg/m^3	WUE Hand Harvest kg/m^3
6	a	258	850	965		0.33	0.37						
	b							273	910	1159		0.33	0.43
	c	267	837	1198		0.31	0.45						
7	a							273	777	1152		0.28	0.42
	b	280	853	1111		0.30	0.40						
	c							273	776	1081		0.28	0.40
8	a	280	785	1054		0.28	0.38						
	b							273	732	1110		0.27	0.41
	c	284	704	1085		0.25	0.38						
Averages		274	806	1083	1100	0.30	0.40	273	799	1125	1138	0.29	0.41

Table 2. Cotton lint yields (kg/ha) and weighted irrigation quantities of areas where variable and uniform irrigation applications occurred, TAES, Helms Farm, 2002.

		Variable Rate				Uniform Rate			
Span	Manifold. Unit	Wt. Irr. Amt. mm	Boll Buggy	Hand Harvest	Yld Monitor	Wt. Irr. Amt. mm	Boll Buggy	Hand Harvest	Yld Monitor
5	a					387	1632	1726	1573
	b	430	1654	2090	1695				
	c					387	1557	1560	1594
6	a	424	1874	1875	1821				
	b					387	1732	1847	1663
	c	402	1647	1816	1728				
7	a					387	1649	1932	1635
	b	395	1613	1622	1717				
	c					387	1686	1802	1725
8	a	393	1648	1761	1751				
	b					387	1539	1899	1788
	c	408	1629	1899	1733				
Average		409	1678	1844	1741	387	1632	1794	1663

Table 3. Total irrigation water use efficiency (kg/m^3) and weighted irrigation quantities of areas where variable and uniform irrigation applications occurred, Helms Farm, 2002.

Span	Manifold Unit	Variable Rate			Uniform Rate		
		Boll Buggy	Hand Harvest	Yld Monitor	Boll Buggy	Hand Harvest	Yld Monitor
5	a				0.42	0.45	0.41
	b	0.38	0.49	0.39			
	c				0.40	0.40	0.41
6	a	0.44	0.44	0.43			
	b				0.45	0.48	0.43
	c	0.41	0.45	0.43			
7	a				0.43	0.50	0.42
	b	0.41	0.41	0.43			
	c				0.44	0.47	0.45
8	a	0.42	0.45	0.44			
	b				0.40	0.49	0.46
	c	0.40	0.46	0.42			
Avg.		0.41	0.45	0.43	0.42	0.46	0.43

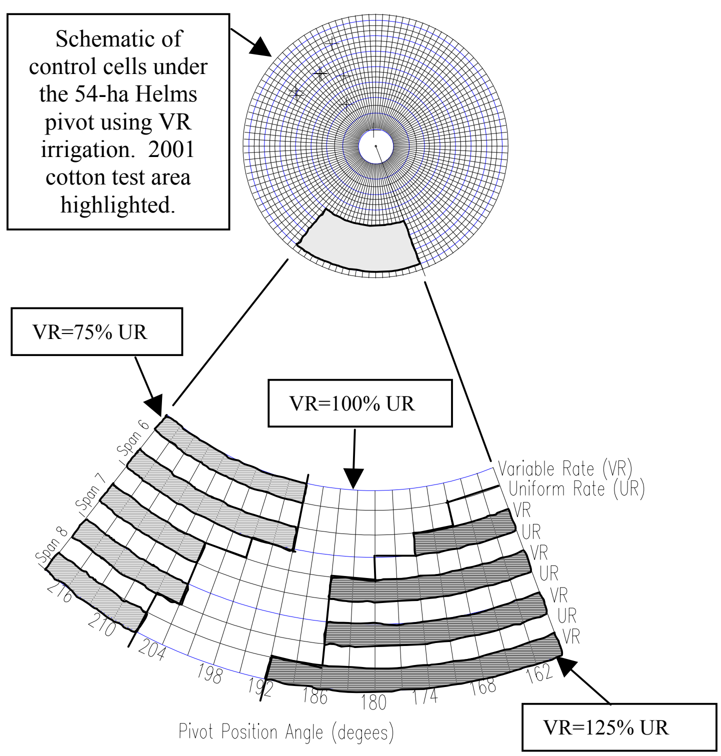

Figure 1. Schematic of the VR control cells under the Helms pivot and the 5-ha area used in the VR irrigation cotton study. In 2001, the control cells were divided into three-target irrigation areas based on slope down the furrow and clay content in the top 15-cm of the profile.

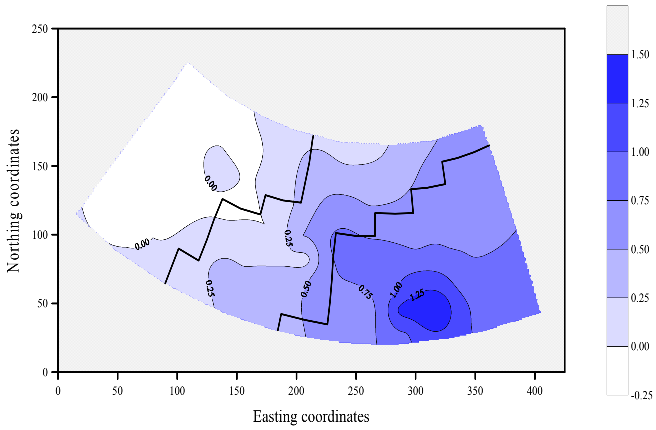

Figure 2. Furrow slope of the 5-ha area used in the VR cotton irrigation study, 2001.

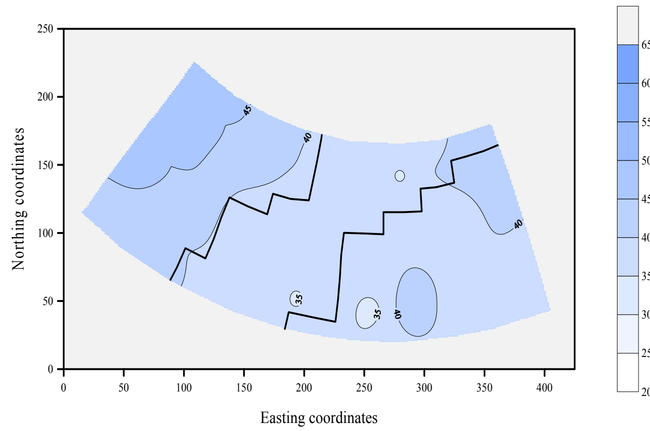

Figure 3. Percent clay in the top 40 cm of the soil profile.

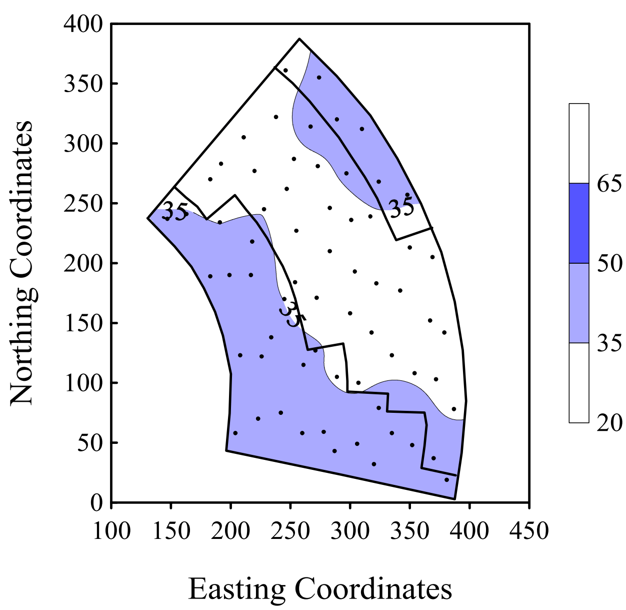

Figure 4. Soil electrical conductivity at one-meter depth used to determine management zones for VR cotton irrigation, 2002.

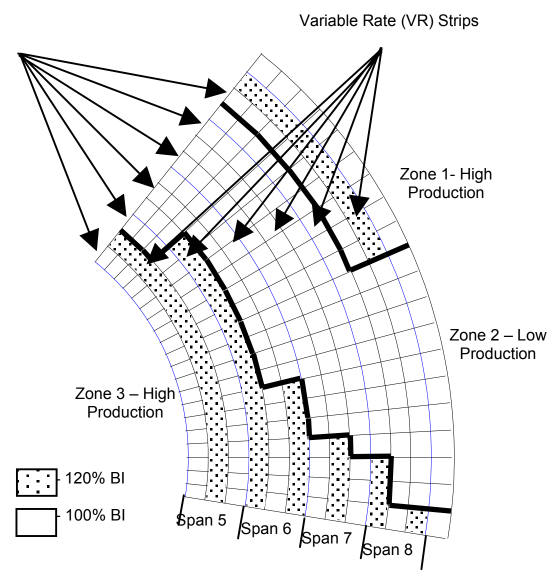

Figure 5. Map of VR and UR irrigation control cells, irrigation quantities, and boundaries between management zones, Helms, 2002.

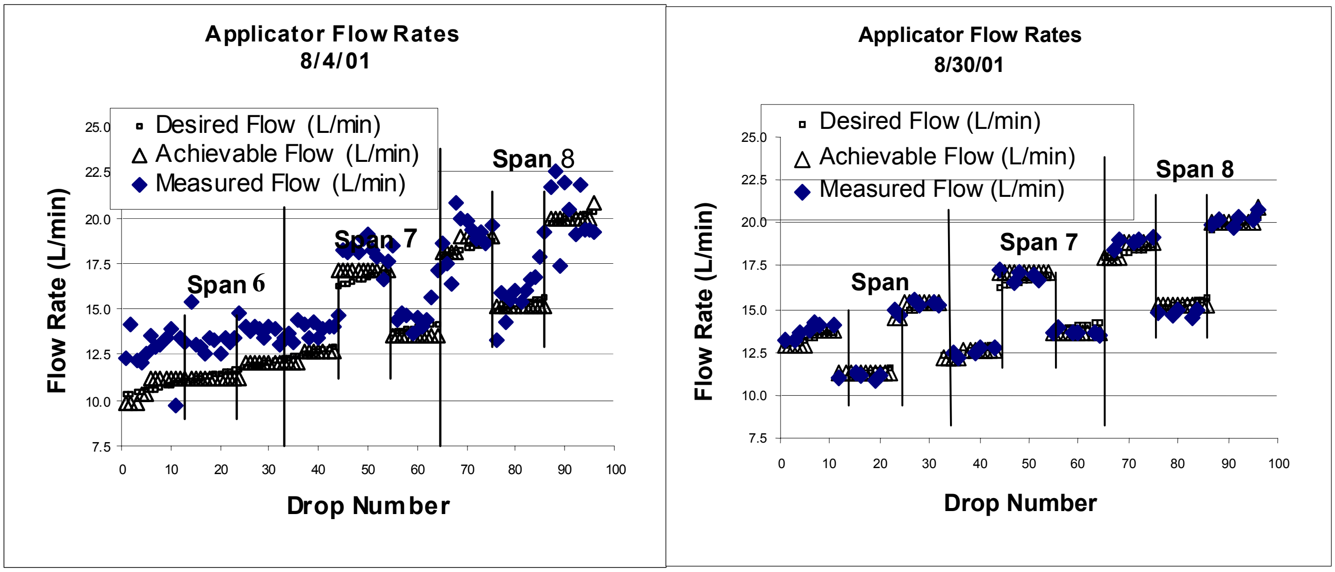

Figure 6. Comparisons of desired, achievable and measured flow rates of applicators within each of the nine manifold units of spans 6, 7, and 8 on 4 August and 30 August 2001.

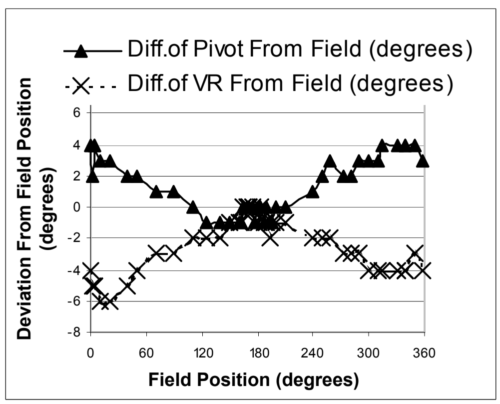

Figure 7. Deviations from actual field position of pivot and VR sensor indicators during one revolution of the Helms pivot.

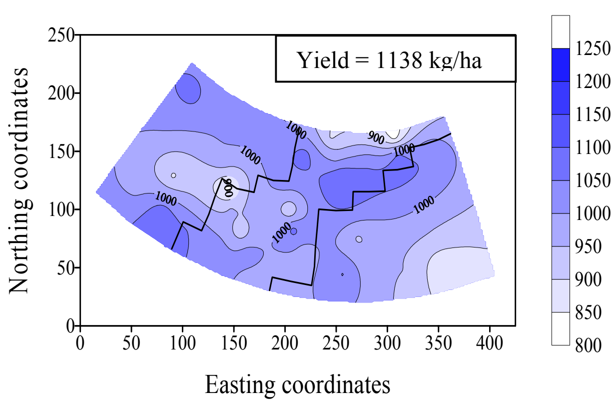

Figure 8. Yield map of hand harvested cotton yields in uniform irrigated areas at Helms, 2001.

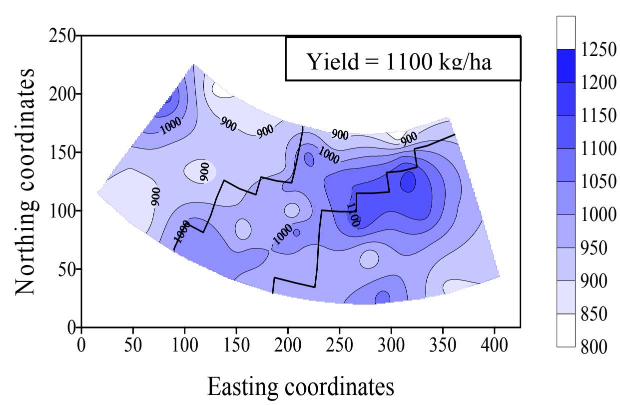

Figure 9. Yield map of hand harvested cotton yields in variable rate irrigated areas at Helms, 2001.

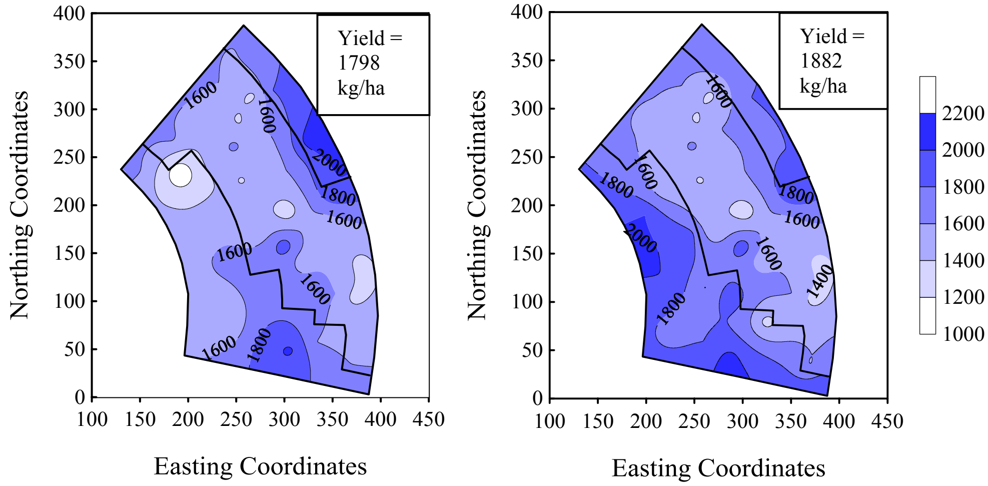

Figure 10. Yield maps of hand-harvested data representing uniform irrigation (left) and variable rate irrigation (right) of an identical area at Helms Farm, 2002.

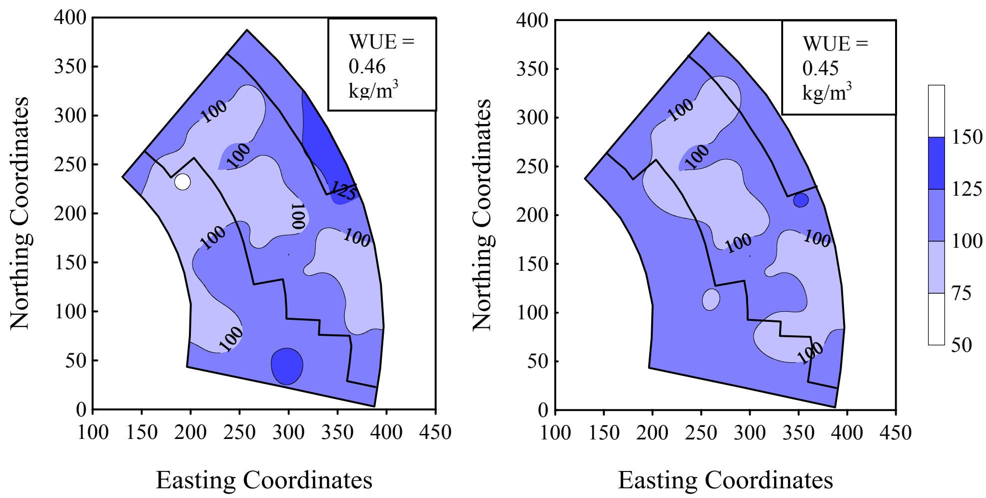

Figure 11. Spatial distribution of total irrigation water use efficiency (WUE) from hand-harvested data representing uniform irrigation (left) and variable rate irrigation (right) of an identical area at Helms Farm, 2002.