**Limited Irrigation for Biotic and Abiotic Stress Management:
A Precision Farming Approach to Water Conservation**

COMPREHENSIVE REPORT

Texas Agricultural Experiment Station and Texas Cooperative Extension

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Project goal: **The primary goal of this research is to increase production efficiency of a typical Winter Garden cropping system by improving irrigation efficiency in stress environments and identify agronomic practices leading to cost savings and consequently increase profit.**

Introduction:
In 1993, the Texas Legislature placed water restrictions on the farming industry by limiting growers to a maximum use of 2 acre-foot of water per year in the Edwards Aquifer Region. Since then, maximization of agricultural production efficiency has become a high priority for numerous studies in the Winter Garden Area of Texas. Crop canopy temperature has been found to be an effective indicator of plant water stress. Coupled with remote sensing technology, this concept allows collection and analysis of temperature data from crops using infrared thermometers (IRTs). IRTs mounted on irrigation systems or operated from aircraft can detect water or pest stress by recording changes in leaf temperature caused by the alteration of the soil-plant water flow continuum. Therefore, remote sensing equipment and mapping systems provide an excellent potential for producers to decrease production cost by implementing site-specific management practices. From this research we expect that conservation tillage in conjunction with limited irrigation would cut crop production costs significantly. In addition, the Accu-Pulse system can provide adequate spray coverage to control pests of corn, sorghum, spinach and cotton grown under two management systems on a site-specific basis (treating only the areas where treatment is needed) providing additional costs savings.

Objectives: 1) Identify limited irrigation thresholds for each variety grown under conventional and conservation tillage farming practice using PET based irrigation, 2) develop best management practices for reduced tillage systems, 3) determine plant physiological responses (canopy temperature) as affected by different irrigation regimes, tillage practices and biotic stresses, 4) evaluate thoroughness of spray coverage and spray efficacy by comparing spray deposition patterns of a site specific pesticide applicator (Accu-Pulse) to that of ground application equipment by using water-sensitive paper and by sampling insect populations.

Materials and Methods:

A field study was conducted at the Texas A&M University – Agricultural Research and Extension Center in Uvalde. The experiment was divided into two farming systems, one conventional tillage (CT) and reduced-tillage (RT). The CT system consisted of normal tillage practices for the region which includes chiseling, moldboard plowing, disking, bedding, banded herbicides at planting and cultivations for weed control, shredding after harvest and disking to kill corn plants. For the RT system we planted white food corn following a killed spinach crop residue (in the second year of the study corn will be planted in the residue from the previous year row crop). Weed control was provided by herbicides applied by broadcast and hooded sprayers. Insect and disease control was done using a precision chemical applicator provided by Valmont (Accu-Pulse). This system allowed for chemical cost savings by spraying only targeted areas instead of the entire field. Pest populations were monitored periodically during the growing season. When pest populations reached significantly measurable levels, pre- and post- pesticide application counts were made in both Accu-Pulse and ground application equipment-treated plots. The land under the center pivot was farmed in a circle and furrow diked. This reduces runoff and improves irrigation distribution uniformity. Soil samples were taken prior to planting in order to implement non-limiting fertilizer rates. Three commercial spinach processing varieties (DMC 09, ASR 157 and CXF 3665), three white food corn varieties (Asgrow 949, Pioneer 30G54 and Asgrow 953), two sorghum varieties (902 W and Jowar) at three plant populations (50,000, 70,000 and 90,000 plants per acre) and cotton variety Stoneville 4892B/Round-up Ready were planted in twelve row plots. Two weighing lysimeter were planted one with a widely used white food corn variety and the other with spinach and standard agronomic practices were implemented. Data from the lysimeter allowed us to apply different amounts of water based on actual evapotranspiration (ET). Three irrigation regimes were imposed: 100% ET, 75% ET, 50% ET. For the spinach crop the ET value was estimated by multiplying the potential evapotranspiration rates (ETo) by a crop factor estimated by the % leaf canopy area.

Thirty Exergen (Irt/c.01-T80F/27C) infrared thermometers (IRTs) were mounted at approximately 15-foot spacing along the pivot length to scan the canopy temperature as the pivot moved. The IRTs recorded canopy temperatures every 10 seconds, and average temperature values every 60 seconds, on a 21X Campbell Scientific datalogger. In addition, canopy temperature differences were determined among treatments using a helicopter equipped with a Mikron 7200 LWIR (Long Wave-length Infrared) infrared camera with infrared band of 8-14 microns.

Results and Discussion

Corn:

Table 1 shows the yield data sorted by irrigation treatments. Under both tillage systems there are no significant differences among varieties except for Asgrow 953 at 75% ETc that yielded significantly less. This yield values are very good in an area where maximum yields do not exceed 150 bu/ac due to early heat stress. Asgrow 953 did not reduce yield when irrigated at 75% and 50% ETc. However, the overall yield was around 100 bu/ac.

Under reduced tillage, there were no yield differences in yield among the three varieties, however overall yield was lower. When the irrigation water was cut to 75% of the full amount all three varieties did not reduce their yield. Furthermore, at 50% ETc Pioneer 30G54 did not significantly reduce their yield.

Table 1: Yield differences (bu/acre $^{-1}$) among three corn varieties.

Variety:	*Conventional Tillage*			*Reduced Tillage*		
	Irrigation Rates (ETc %)					
	100	**75**	**50**	**100**	**75**	**50**
30G54	121 A ab	130 A a	115 A b	111 A a	107 A a	91 A a
ASR-949	124 A a	121 A a	114 A a	121 A a	114 A a	85 A b
ASR-953	133 A a	111 B b	109 A b	117 A a	106 A a	86 A b

Means followed by the same upper case letter within a column are not significantly different.

Means followed by the same lower case letter within a row and within a tillage system are not significantly different.

The statistical comparison between the two tillage systems is shown in table 2. There are no significantly yield differences between conventional (CT) and reduced tillage (RT) at 100% or 75% ETc for each variety except Pioneer 30G54 that had lower yield at 75% ETc reduced tillage. When water is cut to 50% ETc varieties grown under reduced tillage had significantly lower yield then conventional tillage. This field has been under reduced tillage for three seasons and the lower yields can be explained by increased soil compaction.

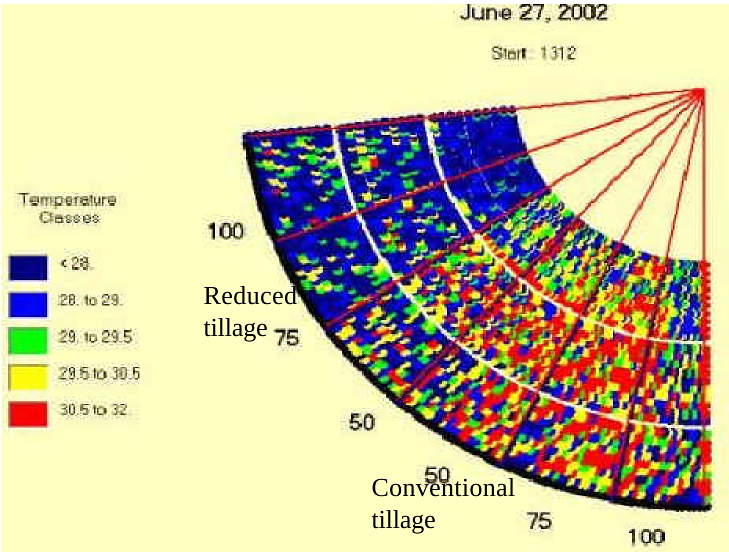
Table 2: Yield comparison (bu/acre $^{-1}$) among three corn varieties grown at three irrigation regimes under conventional (CT) and reduced Tillage (RT)

Variety:	*Irrigation Rates*					
	100% ETc		**75% ETc**		**50% ETc**	
	CT	***RT***	***CT***	***RT***	***CT***	***RT***
30G54	121 a	111 a	130 a	107 b	115 a	91 b
ASR-949	124 a	121 a	121 a	114 a	114 a	85 b
ASR-953	133 a	117 a	111 a	106 a	109 a	86 b

Means followed by the same lower case letter within a row and an irrigation treatment are not significantly different.

Under limited water availability conservation tillage might be a good alternative to achieve high corn yields in the first two seasons. Early season rainfalls can be more efficiently stored when reduced tillage practices are implemented. This is proven by the higher yields at 50% ETc under reduced tillage compared to conventional tillage in the previous year. Canopy temperature detected with the IRTs in this treatment was lower during the growing season, indicating that the crop was under less stress due to more available soil water (Fig 1).

Fig. 1



Cotton:

Extreme temperatures detected early in crop development were related to the detection of bare soil and moisture availability in the soil by the IRTs. Pivot mounted IRTs were effective in detecting crop canopy temperature differences between the 3 irrigation regimes. Early in the season there were significant differences between all three irrigation regimes; however, at the end of the growing season no significant differences were found between the 100 and 75% ETc regimes (Fig. 2 and 3).

Fig. 2

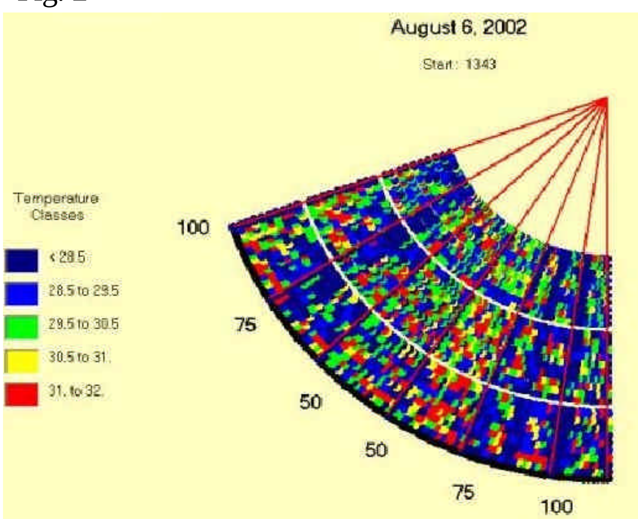
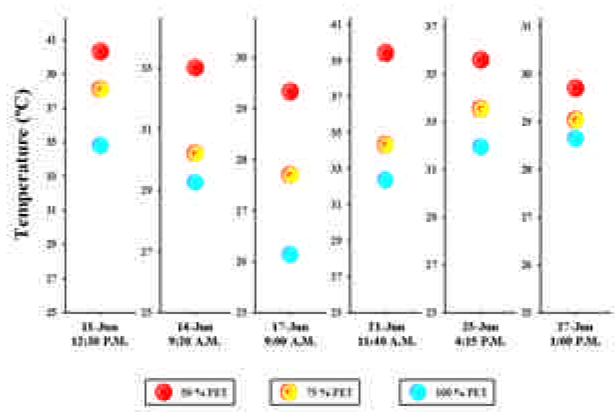


Fig 3



These results are also best explained by yield differences. No significant differences in lint yield were found between the 75% and 100% ETc regimes. Yield from the 50% regime were significantly less than the 75 and 100% ETc regimes. This yield reduction is associated with increased canopy temperatures of this regime. Yields were 1160 lb/acre, 1420 lb/acre, and 1600 lb/acre for the 50%, 75%, and 100% ETc treatments, respectively (Fig. 4).

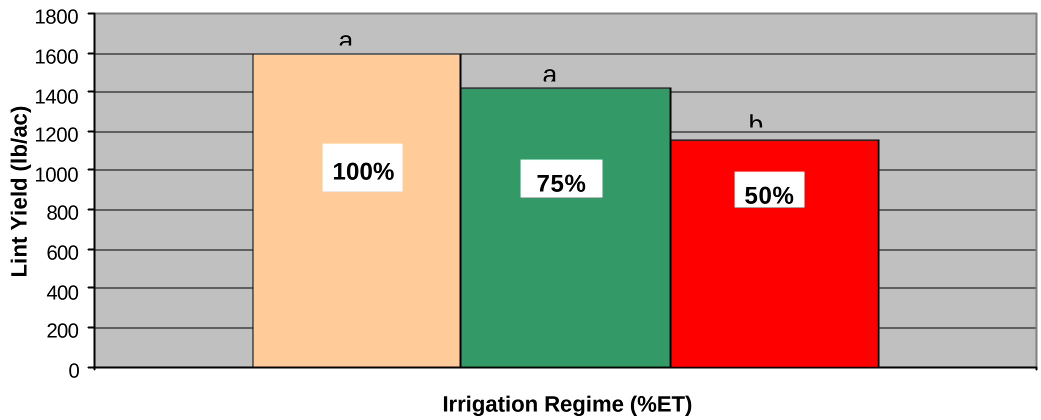
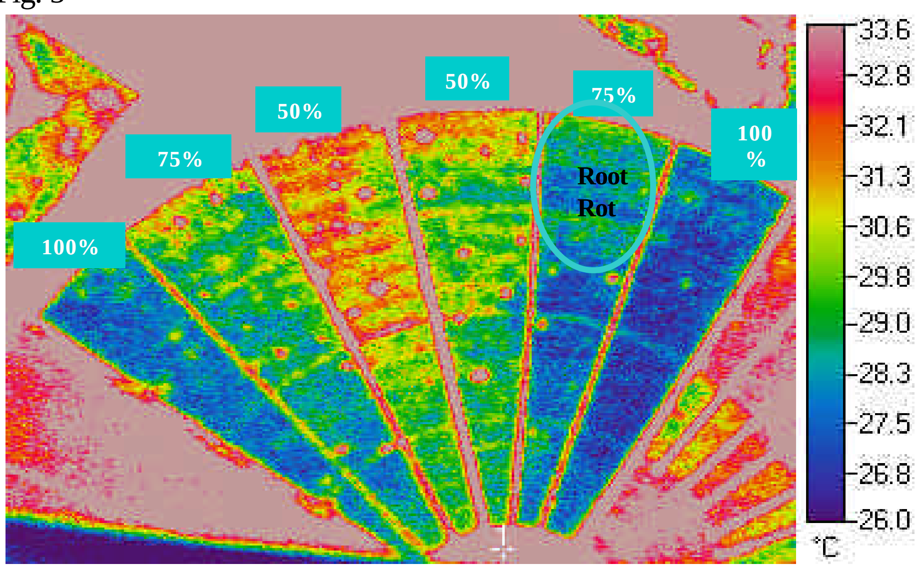


Fig. 4

Abiotic and biotic stress can be differentiated better by the Mikron 7200 than the pivot mounted IRTs because of its increased image scanning resolution. The IR camera was able to detect distinct canopy temperature differences between all 3 irrigation regimes. Biotic stress (root rot) was detected by using the camera before symptoms could be detected visually (Fig. 5 circled area within 75% irrigation regime).

Fig. 5



Pivot mounted IRTs and IR cameras were able to differentiate water stress between the irrigation regimes, but only IR cameras were able to distinguish between abiotic and biotic stress. The Accu-Pulse system has some promise as an alternative pesticide application delivery system for insects and diseases. This system is showing excellent pest control. Comparison data between Spra-coupe and AccuPulse spray coverage are shown in Table 3.

Table 3. Estimates of percent spray coverage based on percent of surface area of water sensitive paper that reacted to the sprays.

		Percent Spray Coverage at Canopy Level		
Spray Method		Top of Canopy	Mid-canopy	Bottom
2001	AccuPulse	**65%**	**37%**	**20%**
	Spra Coupe	**33%**	**6.25%**	**15%**
2002	AccuPulse	**42%**	**27%**	**9.5%**
	Spra Coupe	**12.8%**	**2.65%**	**0.75%**

Some advantages of a center pivot-mounted spraying system: 1) application cost is a fraction of other application methods at approximately $0.50 per acre; 2) applications can be applied when fields are wet and conventional ground application equipment would not be able to travel across the field; 3) applications can be computer controlled so that they may be applied at any time, even when personnel are not present; 4) AccuPulse system utilizes a separate water source and distribution system for chemical application so chemigation label restrictions do not apply; 5) uses existing center pivot as a spray boom.

Sorghum:

Table 4 shows the yield data sorted by irrigation treatments and plant population for the two sorghum varieties. Under both tillage systems there are no significant differences among varieties or plant populations. When irrigation was cut to 50% ETc we did not find a significant difference in yield. This is probably due to the ability of the sorghum crop to compensate for water stress. Furthermore, use of existing PET models and crop coefficients might overestimate plant water needs. Therefore, further investigation on sorghum water needs is necessary.

Table 4

Variety	***902 W***			***JOWAR 1***		
Plant Population	***Irrigation Rates (ETc %)***					
	100	**75**	**50**	**100**	**75**	**50**
50,000	5355 A a	5471 A a	4847 A a	5733 A a	4884 A a	4961 A a
70,000	5579 A a	5182 A a	4930 A a	4822 A a	5330 A a	4728 A a
90,000	5334 A a	5115 A a	5415 A a	5093 A a	5167 A a	4857 A a

Means followed by the same upper case letter within a column are not significantly different.

Means followed by the same lower case letter within a row and within a tillage system are not significantly different.

The statistical comparison between the two tillage systems is shown in table 5. Variety 902 W showed no significant yield differences between conventional (CT) and reduced tillage (RT) at 100% or 75% ETc at 90,000 plants per acre (ppa). When water is cut to 50% ETc reduced tillage had significantly lower yield then conventional tillage. Same trend was found at 50,000 ppa. The overall results of this study showed that conventional tillage is conducive to either higher or similar yield to reduced tillage. Like for the corn study, this field has been under reduced tillage for three seasons and the lower yields can be explained by increased soil compaction.

Table 5

Population	***50,000***			***70,000***			***90,000***		
	Irrigation Rates (ETc %)								
	100	**75**	**50**	**100**	**75**	**50**	**100**	**75**	**50**
Tillage	**902 W**								
Conventional	5355 A	5471 A	4847 A	5579 A	5182 A	4930 A	5334 A	5115 A	5415 A
Reduced	4699 A	4348 B	3420 B	4187 B	4358 B	3978 A	5026 A	4836 A	4110 B
	Jowar 1								
Conventional	5733 A	4884 A	4961 A	4822 A	5330 A	4728 A	5093 A	5617 A	4858 A
Reduced	5178 A	4355 A	3963 A	4918 A	4526 A	3853 A	5000 A	4620 B	3226 B

Spinach:

Methodology

A 6-acre block used in a rotation with corn and fallow under the center pivot system at the TAMU Uvalde Center was used. Raised (6-in high) beds spaced 40 inches apart were made in a circle. Spinach seeds were planted with a commercial vacuum planter with two lines per bed on 12 Nov. 2002. Spacing between the seeds along each line was 1.25 inches (planter set for a theoretical plant density of 250,000 seeds/acre). Three commercial processing varieties were used: DMC 09, ASR 157 and ACX 3665. Pre-plant fertilization was 70N-70P lb/ac, following by an additional 70N application. Three irrigation treatments were imposed under a center pivot system, 100, 75, and 50% crop evapotranspiration rates (ETc). The ETc value was estimated by multiplying the potential evapotranspiration rates (ETo) by a crop factor estimated by the % leaf canopy area. The ETo (expressed in inches/day) was accessible daily from our Uvalde Research Center Weather data web page (http://uvalde.tamu.edu/). A total of 1.5 inches was initially applied to all plots during the seedling establishment period (0.75 inches at planting, following by 0.75 inches after emergence). Thereafter the differential irrigation was applied and adjusted by the rainfall amounts. The three differential irrigations represented a total of 3.69, 2.79 and 1.93 inches for the 100%, 75% and 50% ETc rates. During the growth period total rainfall accumulated to 1.59 inches, which were scattered in 21 rainfall events between 15 Nov. and 16 Feb. 2003. The cumulative water received per treatment (post-plant application + rainfall + irrigation applied) was 6.78 inches for 100% ETc, 5.88 inches for the 75% ETc and 5.02 inches for the 50% ETc.

A protective fungicide (Kocide 101) to control white rust development was applied twice during Dec. and Jan. An insecticide (Ambush) was applied once to control cucumber beetle. White rust was evaluated during early development by sampling a total of 96 leaves per variety in each irrigation plot. Samples were taken at three row cross-section positions (0, 45 and 90 degree angles) and they were rated for % of leaf area with white rust lesions. Each individual plot was harvested on 16 Feb. with a commercial Pixel spinach harvester following the procedures used for Del Monte canning company in the region. After each plot was harvested, a random sample of about 5-8 lbs/plot was taken for grading the spinach according to 'Del Monte' procedures. For each sample, the weight of weeds, roots and/or foreign material, yellow leaves, and excess stem (longer than 4 inches) was recorded and the total % of culls was calculated.

Results:

Spinach varieties had a differential response to irrigation rates since significant interactions were measured for total marketable yield (adjusted after cull weights). There was a differential variety response in leaf quality characteristics (% yellow leaves, % excess stem, % weeds and total culls). Irrigation rates did not affect white rust disease or insect populations in any variety, since leaf evaluations did not show measurable levels of white rust or insect damage (data not shown).

The % of yellow leaves increased significantly for the variety ACX 3665, followed by ASR 157. The variety DMC 09 had the lowest % of yellow leaves. Irrigation rates generally did not affect the % of yellow leaves, with the exception of DMC 09, which showed a higher level with deficit irrigation at 75 and 50% ETc (Fig. 6A). Yellowness was more evident for ACX 3665, which had the most % yellow leaves than DMC 09 and ARS 157. In terms of excess stem, clearly DMC 09 had the lowest % as compared to ARS 157 and ACX 3665 (Fig. 6B). Deficit irrigation did not increase the % stem excess in all varieties.

Marketable yield was calculated by the difference between harvested yield and the % culls (weight basis due to yellowness, excess stem, seed stalk and weeds). There was a significant irrigation and variety interaction. Highest marketable yields were measured for the variety ACX 3665 at 100% ETc, but yield for this variety was significantly reduced with deficit irrigation. Yield for DMC 09 was also significantly reduced at 0.5 ETc compared to 100% ETc rate. Yield for the variety ASR 157 was similar at all irrigation rates (Fig. 6C).

In terms of water use efficiency (herein, the conversion of biomass produced per inch of water received), minimal differences were measured across rates and cultivars (Fig. 6D). Overall, ARS 157 was the most effective at 0.5 ETc rate. Conversely, DMC 09 and ACX 3665 were less efficient than ARS 157 at 50% ETc.

Canopy temperatures taken with infrared thermometers (Exergen, IRT/c.01T80F/27C) at the end of the growing season show that plots with 100 and 75% ETc were cooler than at 0.5 ETc., with no significant differences in temperatures between 100 and 75% ETc. Furthermore, canopy temperature for the variety ASR 157 was cooler than canopies of the varieties ACX 3665 and DMC 09 (Fig. 7).

Conclusions:

- Leaf quality was significantly affected by variety but less by irrigation rate. Leaf yellowness and % stem were higher for ACX 3665.

- High marketable yields were obtained under limited irrigation (5.88 and 5.02 inches at 75 and 50% ETc) for ASR 157, a variety that exhibited the faster growth rate.
- Water use efficiency was slightly higher for ASR 157 at 50% ETc and lowest for ACX 3665 and DMC 09.
- This study shows that deficit irrigation did not reduce leaf quality. Deficit irrigation allows water savings without depleting yields when combined with fast growing cultivars such as ARS 157.

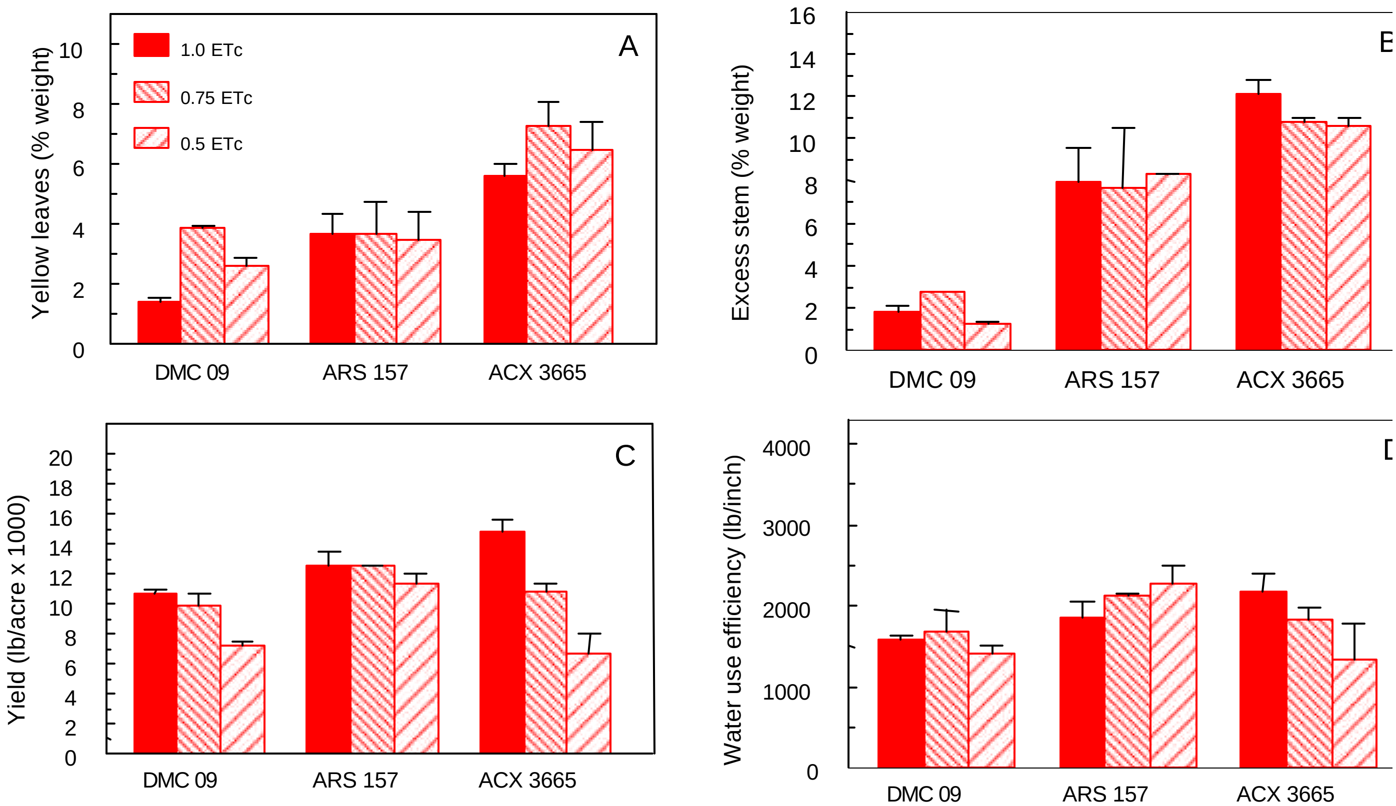
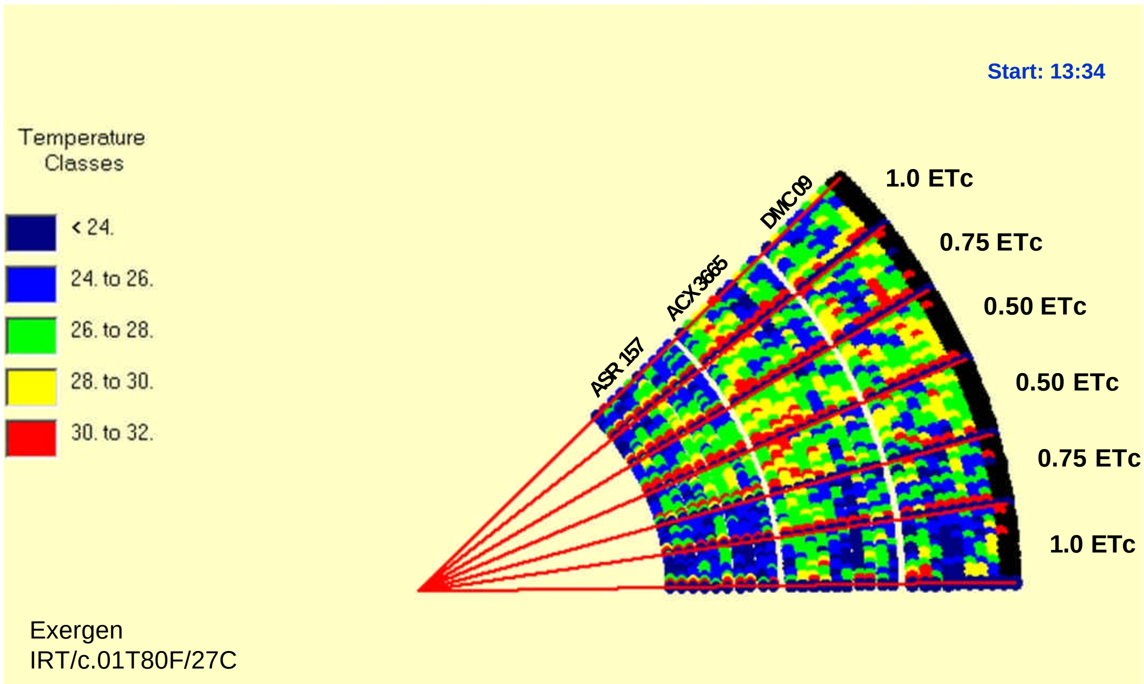


Figure 6. Yellow % (A), Stem % (B), Yield (C) and Water use efficiency (D)

Fig. 7 Spinach canopy temperature



Project Education / technology transfer: Data of this work have been presented to 3 professional society meeting, 2 growers' field days and several meetings with local funding agencies. Furthermore, we have requested matching funds to several agencies and at the present time we were able to obtain funds from the Wintergarden Spinach Producers Board, The San Antonio Water System, The Edwards Aquifer Authority and the Texas Corn Producers Board. Growers in the Edward region are limited to pump no more than 2-acre feet of water per year. With this limitation, the above-mentioned agencies and the local agricultural clientele groups have acknowledge the importance of this study and they are supportive of this research effort.

Project milestone achieved: Based on the first year of the study, preliminary results show tremendous water saving opportunity for crops grown under limited irrigation. Crop temperature mapping shows lower temperature stress under conservation as oppose to conventional tillage, indicating the possibility to reduce irrigation and maintaining profitable yield. Deficit irrigation up to 75% ETc had no impact on yield, indicating that water savings are possible without yield depletion.