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Irrigation and Fertilizer Efficiency in South Texas Grapefruit Production

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ABSTRACT

On-farm management strategies to conserve water in the Lower Rio Grande Valley (LRGV) are of interest due to reduced water available for irrigation during periods of drought and increased demand by rapid population growth in South Texas. This study was performed in South Texas to assess the impact of drip, micro-jet spray and flood irrigation systems on yield and irrigation use efficiency (IUE) of Rio-Red grapefruit (*Citrus paradisi Macfad.*). Mature grapefruit trees previously flood irrigated were converted to drip and micro-jet spray irrigation. By the second year of production after adaptation to low-water use systems, the grapefruit trees under micro-jet spray irrigation out produced flood and drip irrigated trees. Overall IUE was greater by both drip and microjet spray than flood irrigated trees. Also, an organic-based fertilizer of biosolid origin called Xtend® was compared to two inorganic-based fertilizer sources to determine their effect on crop productivity. Results showed that fertilization with Xtend® provided statistically equivalent grapefruit production as 21-0-0 or 13-13-13 fertilizers. This suggests that long-term use of this organic-based fertilizer may provide similar crop productivity while providing slight additions of carbon over time to the soils of South Texas that are natively low in organic carbon.

RESUMEN

La disponibilidad reducida de agua para irrigación durante los períodos de sequía y la demanda creciente de agua para la población en el Sur de Texas, ha creado interés en las estrategias del manejo de agua a nivel de campo en el Valle Bajo del Rio Grande. Este estudio fue conducido en el Sur de Texas para evaluar el impacto de la irrigación por goteo, microasperción, y riego por inundación en el rendimiento y la eficiencia del uso de irrigación (EUI) en el cultivo de la toronja Rio-Red (*Citrus paradisi* Macfad.). Arboles de toronja en edad productiva fueron convertidos de irrigación por inundación a la irrigación por goteo y microasperción. Para el segundo añio de producción y adaptación a los nuevos sistemas de irrigacion, los árboles de toronja bajo el riego de microasperción produjeron mas que los árboles de toronja en los sistemas de irrigacion por goteo he inundacion. En general el EUI fue mas grande en la irrigación por goteo y micro asperción que con la irrigacion por inundación. Tambien se compararon dos tipos de fertigación, uno de base orgánica conocido como Xtend® y otros de base inorgánica, esto con el fin de determinar su efecto en la productividad del cultivo. Los resultados de esta variable indicaron que Xtend® promueve producción estadisticamente igual que los fertilizantes inorganicos 21-0-0 y el 13-13-13. Esto sugiere que el uso a largo plazo del fertilizante orgánico puede dar rendimientos comparables a los fertilizantes inorgánicos, ademas de proveer carbón orgánico a los suelos del Sur de Texas los que son normalmente bajos en este compuesto.

Additional index words: water conservation, drip irrigation, water use efficiency.
Abbreviations: AS, ammonium sulfate; IUE, irrigation use efficiency; LRGV, Lower Rio GrandeValley

Texas citrus production is concentrated in the Lower Rio Grande Valley (LRGV), at the southern region of the state. There are approximately 27,000 acres of citrus grown in Texas, almost 70% of which is grapefruit (*Citrus paradisi Macfad.)* and predominately the Rio Red variety. Due to the semi-arid conditions and low annual rainfall conditions in LRGV (UNESCO, 1977; Enciso and Wiedenfeld, 2005), citrus cultivation requires supplement irrigation for sustainable production (Cruse et al., 1982). The ground water in LRGV is brackish (Schmandt, 2002) as the gulf coast impacts ground water quality, hence the LRGV farmers rely on the Rio Grande River (called the Rio Bravo in Mexico) for their irrigation needs and accounts for approximately 85% of the available water (Gianessi et al., 2002). Agricultural production and urbanization in Mexico near the Rio Grande River has led to rapid decline in irrigation waters flowing into the U.S from the Rio Grande. As water resources become scarce, efficient water management strategies become vital for future sustainability of agriculture. Innovative irrigation techniques and efficient management practices are required to increase the cost-effectiveness of crop production while maximizing crop water use

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efficiency. According to Karasov (1982), the greatest challenge for agriculture is to develop the technology for improving water use efficiency (WUE).

Agronomists evaluate the productivity of water through WUE, the ratio of yield to water consumed (kg m^{-3}) by the crop through evapotranspiration at the field scale (Doorenbos and Kassam, 1979) or as the ratio of yield per unit area to volume of water used to produce yield (kg ha^{-1} mm^{-1}) (Gregory et al., 2000) as irrigation use efficiency (IUE), the ratio of yield to supplemental irrigation applied during the cropping season (Iglesias and Minguez, 1997). Efficient irrigation method and scheduling is the key to maximizing water and fertilizer use efficiency. The choice of the irrigation system has a significant influence on how economically productive varying water management strategies will be. High irrigation efficiency results can be obtained by optimum application of irrigation water and decreasing the movement of water beyond the crop rooting zone.

Flood irrigation is the traditional method of irrigating citrus orchards in the LRGV (Swietlik, 1992). The flood irrigation system applies a high volume of water in a short duration of time, which can lead to water and nutrient loss by runoff or leaching. These losses along with evaporative water loss contribute to a low watering efficiency system of irrigation.

There is a high interest as to which irrigation method is the best to use for a particular crop based on its efficiency. Each irrigation system has its own advantages and disadvantages. As water resources become scarce low water use systems, like microjet spray and drip irrigation, are gaining popularity because of their watering efficiency compared to flood irrigation. Drip irrigation is among the most efficient forms of irrigation since it applies small amounts of water, limits evaporation and decreases weed growth between rows (Cruse et al., 1982). Low water use systems allow flexibility and control of irrigation water applications which offer the possibility to use high frequency fertigation with fluid N materials and decrease leaching loss (Thomas et al., 1999). Citrus responds readily to N fertilization, however excessive application affects not only fruit size and quality, but is also associated with problems of water contamination. Hence, it is essential to evaluate the effect of fertilization and N fertilizer source (He et al., 2003). The objectives of this study is to: 1) determine the IUE of Rio Red grapefruit production when converting flood irrigated trees to drip and microjet spray, and 2) evaluate the impact of fertilizer source on grapefruit yield, with particular focus on an organic-based fertilizer of sewage-waste origin compared to inorganic fertilizers.

Three fertilizers were used in this study to evaluate the impact that different fertilizer sources might have on Rio red grapefruit production. This research focused on a new organic-based fertilizer (Xtend®) that is composed of a biosolid made from sewage sludge wastes and re-impregnated with ammonium sulfate (AS) in a dried, pelletelized form. This fertilizer is of interest because it has both an organic component and inorganic fertilizer composition. The organic matter from Xtend® may be of benefit to soils in the Lower Rio Grande Valley that are traditionally low in organic carbon, commonly below 1% soil organic matter. However, the carbon in the Xtend® fertilizer may be a means by which soil microbes tie up the N making it unavailable for crop growth for a period of time until the microbial population dies off and releases the N to the soil later on in the growing season. As Xtend's N source originates from AS, it is high in sulfate and of similar elemental composition to inorganic AS fertilizer. These two fertilizers were compared to no fertilizer application (control) and 13-13-13 to evaluate the effect of P and K on grapefruit production under an equivalent N application rate.

MATERIALS AND METHODS

Experimental design. Two adjacent field sites located at the Texas A&M University-Kingsville, Citrus Center South Farm in Weslaco, Texas were selected to evaluate citrus production under varying irrigation practices and using different sources of nitrogen fertilizer in harvest years 2003 and 2004. Both fields contained 17 year old mature Rio Red grapefruit trees (*Citrus paradisi* Macfad cv. rio red) and were separated in distance by a farm road approximately 10 m. Trees were spaced 4.6m x 7.3m with a planting density of approximately 300 trees ha^{-1}. Soil texture within the upper 30 cm was heavy at both locations with 33% sand, 20% silt and 47% clay, indicative of a clay soil type as soils in this region are clayey over loamy, mixed, calcareous, hyperthermic Vertic Haplustolls and moderately alkaline. Prior to irrigation and fertility trials in this study all trees at both sites were broadcast fertilized with 21-0-0 at a rate of 0.454 kg N $tree^{-1}$ y^{-1} in March 2002 and flood irrigated throughout the 2002 harvest season. This was done to condition trees and to determine if fruit production at each site was similar prior to establishing trials using different fertilizers starting in 2003. Average grapefruit yields in 2002, for designated flood, microjet spray and drip irrigated trees (30.5, 39.8 and 42.4 kg x 1000 ha^{-1}, respectively) were not statistically different ($P>0.05$).

After harvest year 2002, the east field site was designated for flood irrigation, and the west field site was designated for microjet spray and drip irrigation to compare three main-plot irrigation treatments. The main plot treatments, flood, spray and drip, were replicated in three blocks per field site. The west field had 6 rows of trees with 21 trees per row and drip and spray irrigation treatments were randomized among rows. The east field site had 4 bordered sections each with 5 rows of trees running east-to-west with 35 trees in each section for ease of flood irrigating.

Fertilizer treatments. The mainplot blocks were further divided into seven subplots per block with 3 trees per subplot. Four fertility treatments 21-0-0, Xtend, 13-13-13, and control [no fertilizer]) were randomized throughout the blocks, with one control treatment per block and each fertilizer treatment included twice in each block. Each tree within the fertilized subplots received a granular broadcast application of 0.454 kg N $tree^{-1}$ y^{-1}, unless designated as a control treatment that received no fertilizer application. The total amount of P and K applied in the Triple 13 fertilized trees was 0.20 and 0.38 kg $tree^{-1}$ y^{-1}, respectively. Subplot fertilizer treatments were applied 15 March 2003 and repeated again 15 February 2004.

Irrigation scheduling. A single main irrigation line was placed under each row of trees in the drip and spray treatments. Six water meters were used so that total water volume could be measured during each irrigation period, and one meter was attached to the initial starting point of each of the irrigation lines in each row of the drip and spray treatments. The irrigation systems for the drip and microjet spray plots were designed to deliver at the rate of 26.5 L h^{-1} per tree. In the spray plots, a single 360º microjet spray emitter was placed at the base of each tree that delivered the rate of 26.5 L h^{-1}. To match this same irrigation rate within the drip plots, seven 3.8 L h^{-1} drip emitters were placed along the main irrigation line and under the canopy of each tree for a total combined rate of 26.5 L h^{-1} per tree. Whereas, each irrigation event in the flood plots was measured at a 15 cm water depth (6 inch irrigation event). In the flood plots a total of 4 flood events (61.0 cm total irrigation water) were applied within the 2003 growing season and 4 flood events (76.2 cm total irrigation water) applied over the 2004 growing season. Rainfall was measured and recorded throughout the 2003 and 2004 growing seasons. Citrus evapotranspiration (ET) (ETc for citrus = ET reference * Kc) was calculated using reference ET and crop coefficients recommended by Enciso et al. (2005) (Table 1). Soil moisture was monitored throughout the harvest years 2003-2004 by using Watermark® soil moisture sensors along with WatchDog® data loggers (Spectrum® Technologies, Inc. Plainfield, IL). The total amount of irrigation water applied to the drip, spray, and flood mainplot treatments was done to correlate as best as possible to citrus crop ET demand over the growing season and water loss from the soil profile between rainfall and irrigation events. Also, a single 15cm flood irrigation event was applied to drip and microjet spray plots each year (Jan 2003 and May 2004) to help the tree roots adjust to a new irrigation method.

Harvest. Fruit was harvested annually, with the 2003 harvest year being harvested in early February 2004 and the 2004 harvest year harvested in late December 2004. All the fruit from the middle tree in each subplot were picked, counted, and sorted using a separator machine, where the fruits were separated according to their fruit diameter size as shown in Table 2. After fruit was sorted according to size class, fruit was weighed with grapefruit sized less than 8.4 cm and greater than 10.6 cm in diameter designated for the juice market and all other sized fruit designated for the fresh market.

Statistical Analysis. Data was analyzed using the General Linear Model (GLM) procedure with the Walter-Duncan K-ratio t-test (SAS, 1997). The analysis of variance diffentiates the treatment means by assigning different letters to the treatment means that are significantly different at the 95% probability level ($P \leq 0.05$).

RESULTS AND DISCUSSION

Irrigation Method. Conversion of a mature stand of Rio Red grapefruit trees to drip and microjet spray irrigation systems had an impact on overall fruit yield. After the first year of having the drip and microjet spray systems in place, total marketable fruit in the flood irrigated trees was significantly greater than drip and spray irrigated trees (Table 3), with flood irrigated trees producing approximately twice the total number of fruit produced by drip irrigated trees in 2003 harvest year. A significantly higher number of fresh market fruit was produced in the flood irrigated trees than the drip and spray irrigated trees. This increased number of fruit going to the fresh market would bring a significantly higher market price than fruit sold to the juice market. In 2003, juice fruit yields were also higher under flood than drip irrigated trees, and higher but not significantly different than spray irrigated trees. In both fruit classes in 2003, spray irrigated trees resulted in higher grapefruit production than drip irrigated trees. The lower fruit production and overall smaller fruit sizes exhibited in the drip and spray plots suggest that it may require time for citrus root systems to adapt to the conversion of a new irrigation strategy. Drip and microjet spray irrigation systems apply a low volume of water in frequent irrigation events commonly irrigating the upper 60 cm soil profile, whereas a single 15 cm flood irrigation event can permeate well beyond a 90 cm soil depth in a clay soil type. It may take time for a mature grapefruit orchard to adjust to the different irrigation scheme under drip and microjet spray irrigation before a high crop production is observed.

Total grapefruit yield in harvest year 2004 did not follow the results of 2003 harvest season. In 2004, the total number of grapefruit in the drip and spray irrigated trees was significantly greater than flood irrigated trees (Table 3). In fact, the total fruit production in the flooded trees declined from 224,800 grapefruit ha^{-1} in 2003 to 130,600 grapefruit ha^{-1} in 2004. Whereas, total fruit numbers increased dramatically from 127,700 and 162,600 fruit ha^{-1} in 2003 to 195,700 and 207,800 fruit ha^{-1} in 2004 in drip and spray irrigated trees, respectively. Total fresh marketable fruit yield from drip and spray irrigated trees were very similar between

Table 1.Total citrus water requirements for drip, microjet spray, and flood irrigated trees during the 2003 and 2004 growing seasons.

	2003	2004
	------------- cm	-------------
ET ref	140	132
Kc (range)	0.6-0.7	0.6-0.7
ETc	96	90
Rain	73	70
Irrigation		
Flood	61	76
Spray	35	35
Drip	30	33
Irrigation + Rain		
Flood	134	147
Spray	109	105
Drip	103	103

Table 2. Fresh and juice marketable grapefruit size classification according to fruit diameter.

Size Class	Fresh Market				Juice Market	
	Small	Medium	Large	X-Large	X-Small	XX-Large
			cm			
Dia Range	8.5 - 9.2	9.3 - 9.5	9.6 - 10.0	10.1 - 10.6	< 8.4	> 10.6

Table 3. Rio Red grapefruit yield for harvest years 2003 and 2004, comparing main plot irrigation treatment effects on fresh and juice marketable fruit.

Irrigation Treatment	Number			Yield		
	Fresh	Juice	Total	Fresh	Juice	Total
	----- # fruit ha^{-1} x 1000-----			-------- kg ha^{-1} x 1000--------		
			2003 Harvest Year			
Flood	123.9 a	100.9 a	224.8 a	42.4 a	28.6 a	71.0 a
Spray	84.4 b	78.2 ab	162.6 b	30.0 b	22.0 b	52.0 b
Drip	71.2 b	56.5 b	127.7 c	28.0 b	15.9 b	43.9 b
			2004 Harvest Year			
Flood	96.7 a	33.8 b	130.6 b	68.0 a	11.5 b	79.5 b
Spray	94.6 a	113.2 a	207.8 a	67.6 a	30.2 a	97.8 a
Drip	70.6 b	125.1 a	195.7 a	48.5 b	31.9 a	80.4 b

Yield data in columns for the same harvest year with different lowercase letter are significantly different at the P = 0.05 level.

2003 and 2004 harvest years, with a slight decline in fresh marketable fruit in the flooded trees from 2003 to 2004. The major decline in total grapefruit numbers in the flooded trees occurred in the juice market class, with 100,900 fruit ha^{-1} in 2003 to 33,800 fruit ha^{-1} in 2004. Both fresh and juice marketable fruit numbers increased from 2003 to 2004 in the drip and spray irrigated trees. The improved fruit production after 2 years irrigating the trees with a different irrigation method suggests that taking a mature stand of citrus trees that has been under flood irrigation for many years and changing them to drip or microjet spray irrigation can still result in a high level of grapefruit production within a couple of growing seasons.

The total weight of fruit within the fresh marketable size class was significantly higher in 2003 for flood than drip and spray irrigated trees (Table 3). This can be of significant advantage to the grower as fruit in the fresh size categories (Table 2) can be sold at a much higher price than juice fruit. By the second year of harvest (2004), the total weight of fresh marketable grapefruit in spray irrigated plots (67,600 kg ha^{-1}) was not significantly different than flood irrigated plots (68,000 kg ha^{-1}), both of which were significantly greater than fresh market grapefruit production in drip irrigated treatments (48,500 kg ha^{-1}). Total weight of grapefruit in 2004 from drip irrigated trees was nearly equivalent to that produced under flood irrigation, suggesting that the extra 20,400 kg ha^{-1} produced by drip over flood in the juice category may be sufficient to make this irrigation method feasible within a few years after installation. When the weight of juice fruit under spray irrigation is taken into consideration for 2004, the total fruit weight was significantly higher for spray (97,800 kg ha^{-1}) than flood (79,500 kg ha^{-1}) or drip (80,400 kg ha^{-1}) irrigation. Under this scenario, the grower would most definitely be able to increase revenue using spray irrigation compared to flood irrigation by the second year after irrigation system conversion. This rebound in marketable fruit production in the drip and spray irrigated plots suggests that converting a mature stand of citrus trees that has been under flood irrigation to drip or microjet spray may take as little as two years before improved crop production is established and equivalent or superior yields are achieved.

Fertility Source. In both harvest years no statistical difference were found among fertilizer treatments (Table 4) for all irrigation systems. However, a trend of lower crop production was observed in unfertilized trees compared to fertilized trees, and this trend became more apparent by the second year of no fertilization. This suggests that continued neglect of an established fertility plan would result in decreased citrus production and lower economic returns over subsequent seasons. Fertilization with the organic-based fertilizer, Xtend®, resulted in similar average yield as that of

Table 4. Total Rio Red grapefruit yield for each irrigation treatment and fertilizer treatments for harvest years 2003 and 2004.

Fertilizer Treatment	2003 Harvest Year			2004 Harvest Year		
	Drip	Spray	Flood	Drip	Spray	Flood
	-------------------------------- kg ha^{-1} x 1000 -------------------------------					
Control	34.6 a	46.4 a	71.1 a	64.3 a	52.7 b	61.0 a
$(NH_4)_2SO_4$	42.5 a	59.5 a	72.2 a	85.2 a	106.0 a	78.4 a
Xtend	52.1 a	47.1 a	69.9 a	78.0 a	109.9 a	83.1 a
Triple 13	41.7 a	52.6 a	72.7 a	86.1 a	100.1 a	86.3 a

Yield data in the same column and followed by a different lowercase letter are significantly different at the P = 0.05 level.

AS; this may be due to the fact that Xtend® is made with AS during its processing. Regardless, the performance of Xtend® towards grapefruit production was comparable to other inorganic-based fertility sources. The extra addition of P and K from 13-13-13 did not significantly enhance crop production in this study, most likely because the soils had adequate P and K reserves for citrus growth.

Irrigation Use Efficiency. Rainfall was measured and recorded throughout the 2003 and 2004 growing seasons with 69.1 and 70.5 cm cumulative precipitation, respectively. Reference ET was higher than the annual rainfall received during all the months of the year (Table 1). Periodic irrigation was needed to provide sufficient water to citrus trees in order to keep up with citrus ET rate during periods of low rainfall. The volume of water applied under the drip and microjet spray plots was regulated to match as best as possible to daily crop ET for citrus (Fig 1). A total cumulative amount of 61.0 cm (2003) and 76.2 cm (2004) irrigation water was applied to flooded trees, while approximately half this volume was applied to drip (29.1 and 34.8 cm water) and microjet spray (26.9 and 33.0 cm water) irrigated trees during the growing seasons 2003 and 2004 (Figs 1 and 2). This was accomplished for drip and spray irrigated trees with total water use (irrigation + precipitation) resulting in ±3% of annual crop water demand. Each flood application was a 15 cm irrigation event that resulted in water use approximately twice that estimated to meet crop ET (Figs 1 and 2). Therefore, excess water application ranging from 34 to 43 cm per year occurred in flood irrigated trees, resulting in lower irrigation use efficiency for flood than non-flood irrigated trees (Fig. 3). The low IUE values from drip and spray irrigated trees during the 2003 harvest season was due to lower average yields, as the mature trees required time to adapt to a new irrigation method. By the end of the second growing season, the IUE for drip and spray irrigation was more than double that of flood irrigated trees.

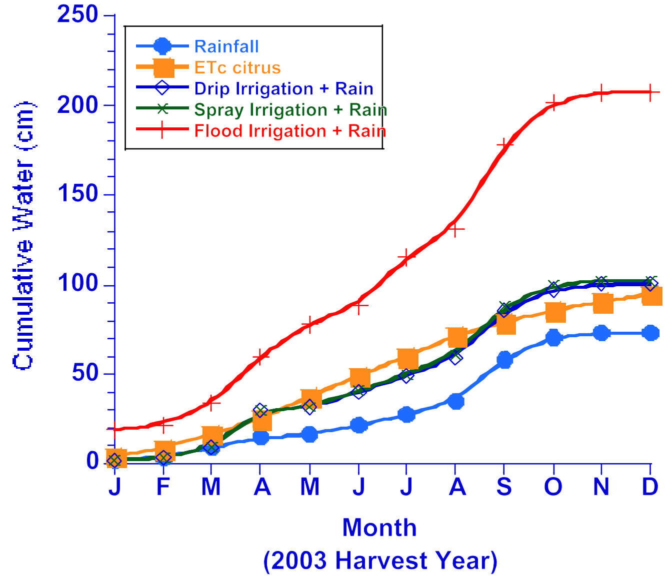

Figure 1. Cumulative monthly rainfall (precipitation) and crop evapotranspiration for citrus (ETc), and the amount of rainfall plus irrigation water applied to drip, microjet spray, and flood irrigated trees in the 2003 harvest year.

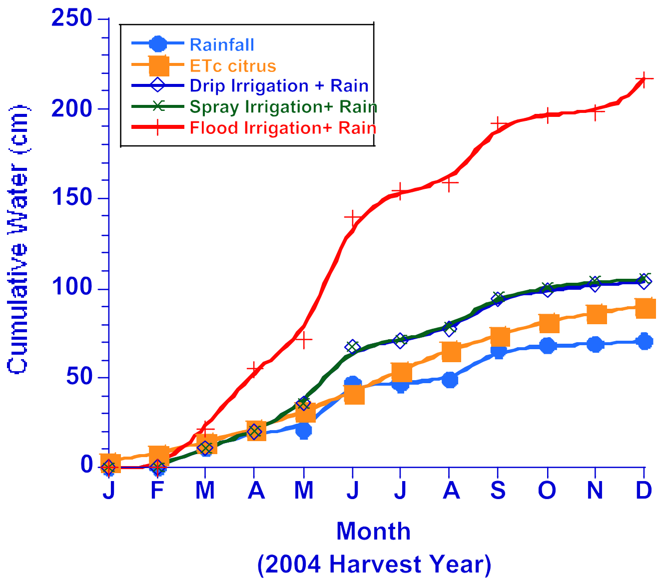

Figure 2. Cumulative monthly rainfall (precipitation) and crop evapotranspiration for citrus (Etc), and the amount of rainfall plus irrigation water applied to drip, microjet spray, and flood irrigated trees in the 2004 harvest year.

CONCLUSIONS

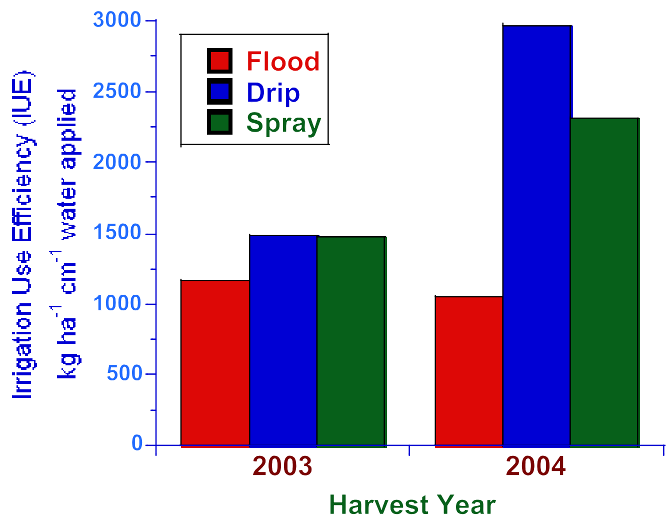

Figure 3. Average irrigation use efficiency (IUE=average yield/amount of irrigation applied) for drip, microjet spray, and flood irrigated trees for the 2003 and 2004 harvest years.

The application of the organic-based fertilizer Xtend® of biosolid origin can provide similar grapefruit yields as inorganic fertilizer sources. This suggests that N source was returned to the soil throughout the growing season and made available for crop production. Further years of evaluation are needed to determine whether substantial carbon buildup in soils can be obtained by continued use of Xtend® year after year. Irrigation of citrus by drip and microjet spray irrigation can provide substantial increase in IUE over traditional flood irrigation. This suggests that when irrigation sources become scarce and/or water costs rise substantially in the LRGV, low water use irrigation systems like drip and microjet spray may be economically viable options for growers to maintain citrus production. However, when converting a mature orchard that has been previously irrigated by flood irrigation to drip or microjet spray irrigation systems, it may take a growing season or two before equivalent yields are obtained. This study demonstrates that significant yield improvements are achievable within the second growing season after converting to a drip or microjet spray irrigation method.

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