Tree and Forestry Science and Biotechnology ©2009 Global Science Books

Impact of Compost Application on Citrus Production under Drip and Microjet Spray Irrigation Systems

Ram Mohan Uckoo[1] • Juan M. Enciso[2] • Irama Wesselman[3] • Kim Jones[3] • Shad D. Nelson[1,4*]

[1] Texas A&M University-Kingsville Citrus Center, 312 N. International Blvd., Weslaco, TX 78596, USA
[2] Texas A&M AgriLIFE Research and Extension Station, 2415 E. Hwy 83, Weslaco, TX 78596, USA
[3] Texas A&M University-Kingsville, Dept. of Environmental Engineering, 700 University Blvd., MSC 213, Kingsville, TX 78363, USA
[4] Texas A&M University-Kingsville, Dept. of Agronomy & Resource Sciences, 700 University Blvd., Kleberg Ag Bldg. Room 117, MSC 228, Kingsville, TX 78363, USA

Corresponding author: * **shad.nelson@tamuk.edu**

ABSTRACT

Texas is the third largest citrus producing state in the USA, after Florida and California. The majority of citrus in the Lower Rio Grande Valley (LRGV) of south Texas is grown under flood irrigation. Due to rapid urban development, periodic droughts and dependence upon irrigation water flows along the Rio Grande River, the semi arid conditions of South Texas commonly results in rapid decline in irrigation water supplies. Perennial crops in the LRGV, like citrus, have an annual evapotranspiration demand that far exceeds annual precipitation in this semi-arid climate. Due to limited water supplies, alternative irrigation and cultural practices are being sought to increase the irrigation use efficiency, enhance plant growth and sustain citrus crop production. A field experiment was conducted from 2003 to 2006 at the Texas A&M University-Kingsville, Citrus Center located in Weslaco, Texas. In this study, 20 year old Rio Red grapefruit trees (*Citrus paradisi* Macf.) received compost and non-compost treatments and were compared using drip and micro-jet spray irrigation systems. The objectives of this study were to evaluate whether annual compost and fertilization application would positively impact citrus root development, growth, and crop production under low-flow irrigation systems, drip and microjet spray. After one year of compost application, a trend of higher crop production was observed in three consecutive harvest years in composted trees compared to non-composted trees under both irrigation systems. Root density was found to be higher under composted than non-composted tree canopies, and a more uniform root growth proliferation was observed under microjet spray than drip irrigated systems. Furthermore, soil moisture sensing equipment continually showed higher soil moisture content under composted vs non-composted trees, suggesting that annual compost application under low water use systems may be ideal for improving water conservation in citrus production for south Texas.

Keywords: irrigation use efficiency, mulch, water conservation
Abbreviations: BD, bulk density; **dS**, deci-Siemens; **EC**, electrical conductivity; **ET**, evapotranspiration; **ETc**, crop evapotranspiration; **ET ref**, reference evapotranspiration; **FC**, fertilizer composted trees; **FNC**, fertilized non-composted trees; **IUE**, irrigation use efficiency; **K**, potassium; **Kc**, crop coefficient; **kPA**, kilopascals; **LRGV**, Lower Rio Grande Valley; **N**, nitrogen; **P**, phosphorus; **UNC**, unfertilized non-composted trees

INTRODUCTION

Citrus is grown in approximately 27,000 acres in the Lower Rio Grande Valley (LRGV) region of South Texas, with approximately 70% as the Rio Red grapefruit (*Citrus paradisi* Macfad.) variety. The majority of the citrus growers in the LRGV flood irrigate their orchards (Sweitlik 1992) using water originating from the Rio Grande River. Rapid urban development along the Texas-Mexico border, combined with reduced water flows from the Rio Grande River are creating increased emphasis on alternative water conserving practices to sustain crop production in this region. Perennial crops, like citrus, require supplemental irrigation year round as annual precipitation in south Texas does not meet the high evapotranspiration (ET) demand of this semi-arid climate. Without supplemental irrigation during the summer months, when ET demand is the highest, crop yields suffer due to water stress (Enciso *et al.* 2005). Another factor hindering optimal citrus production is the use of flood irrigation on high clay soils that are common in this region, where short-term anaerobic soil conditions can occur. This can lead to water logged soil conditions that can be unfavorable for efficient root growth and nutrient uptake. Concerns over limited water supplies in the LRGV for irrigation and the need for improved soil physical properties in orchards with predominantly clay soil textural properties (Uckoo *et al.* 2005) led to this study on alternative irrigation and cultural practices using compost to increase the irrigation use efficiency (IUE) and to sustain citrus production in heavy south Texas clay soils. Thus, the objectives of this study are to determine the impact of compost application on Rio Red grapefruit yield and IUE under low water use irrigation systems, specifically using drip (Drip) and microjet spray (Spray) irrigation technologies.

Though the effect of compost on citrus grapefruit yield has not been adequately studied, composting in general has been shown to be highly beneficial to growth and production of many crops. For example, compost addition to crops such as apple (Moran and Schupp 2003), tomato and squash (Hampton *et al.* 1994), and wheat (Tejada and Gonzalez 2003) increased crop growth and yield. Compost application to soils has the capacity to increase soil organic matter (Chantigny *et al.* 2002), improves soil structure, texture, aeration, and can absorb large quantities of water for plant use, thereby increasing soil water-holding capacity (Gregoriou and Rajkumar1984). Compost keeps the soil moist for longer periods of time and enables the plant roots to absorb more water and avoid stress conditions. Compost applications can decrease soil bulk density (BD), suppress weed growth (Frageria 2002), improve soil aggregate stability (Cox *et al.* 2001) and water infiltration (Martens *et al.* 1992), and reduce runoff and soil erosion. Additional compost ap-

Received: 9 July, 2008. Accepted: 5 September, 2008.

Original Research Paper

plication to soil has also helped to reduce the incidence and severity of some soil borne disease causing pathogens (Widmer *et al.* 1998; Liebman and Davis 2000). In our study, the following factors were compared for trees mulched with compost and non-composted trees: soil physical properties, root density, soil water content, leaf nutrient status, crop yield and IUE.

MATERIALS AND METHODS

A field experiment was conducted from 2003 to 2006, located at the Texas A&M University-Kingsville, Citrus Center South Farm in Weslaco, Texas using mature 20-year old Rio Red grapefruit trees (*Citrus paradisi* Macf.) grafted onto sour orange root stock. These trees were grown in heavy clay textured soils under continuous flood irrigation practices for several growing seasons prior to initiation of this study. Trees were spaced 4.6 m × 7.3 m with a planting density of approximately 300 trees ha^{-1}. The soil texture within the upper 30 cm was heavy with 47% clay, 20% silt and 33% sand, indicative of a clay soil type (clayey over loamy, mixed, calcareous and moderately alkaline, hyperthermic Vertic Haplustolls).

This field site was selected to evaluate citrus production under drip and microjet spray irrigation systems in combination with and without compost application. Prior to this study, all trees were broadcast fertilized with 21-0-0 (N-P_2O_5-K_2O) ammonium sulfate fertilizer 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 prior to establishing trials using compost treatment starting in 2003.

After harvest year 2002, microjet spray and drip irrigation systems were installed in three randomized replicated blocks with each irrigation system consisting of three rows of trees containing twenty one trees per row. The experiment was arranged in a randomized split plot design with two main drip and microjet spray irrigation treatments, and three subplot treatments consisting of: 1) fertilized composted (FC); 2) fertilized, non-composted (FNC); and 3) unfertilized, non-composted (UNC) control trees. Each row containing 21 trees was split into the 3 subplot treatments consisting of 3 trees per subplot, with a total of 3 FC subplot replicates, 3 FNC replicates, and 1 UNC subplot treatment per row. Thus, for each of the mainplot irrigation treatments (Drip and Spray), there were 9 FC, 9 FNC, and 3 UNC subplot treatments evaluated. A routine maintenance schedule was performed with annual insecticide spraying, herbicide application and weekly walking of drip and microjet lines to replace plugged or malfunctioning emitters.

Each row of trees was further divided into seven subplots per block with three trees per subplot. The subplots were arranged such that three trees were fertilized per subplot treatment with the center tree in each subplot area used for collecting data. Each tree within the fertilized subplots received a granular broadcast application of 0.454 kg nitrogen (N) $tree^{-1}$ y^{-1}, unless designated as a control treatment that received no fertilizer. Subplot fertilizer treatments were applied annually on 15 March 2003, 15 February 2004, 19 February 2005 and 14 December 2005. The subplot treatments consisted of three fertility treatments, (FC) compost + 0.454 kg of N, (FNC) non-compost + 0.454 kg of N, and (UNC) control [no fertilizer and compost], were randomized within each row with one control and six fertilizer treatments (composted vs non-composted) in each row. Trees receiving N applications were fertilized with urea (46-0-0), and rate based on the recommended amount of 0.454 kg (1 lb.) N per tree per year for citrus in the LRGV (Sauls 2008). Trees receiving compost application did not receive a significant amount of additional N as the source of compost originated from bark wood chips. Thus, the compost contributed a minor 0.002 kg N $tree^{-1}$ y^{-1}, based on the 45.7 kg $tree^{-1}$ y^{-1} rate of compost applied underneath the tree canopy each year prior to inorganic fertilizer applications. Compost applications were repeated each year on the same date as fertilizer applications mentioned previously. Annual applications consisted of three 5-gallon (18.9 L) buckets filled with compost placed underneath and within the dripline of the tree canopy to an equivalent depth of 2.5-5.0 cm. The elemental composition of the compost is shown in **Table 1**, and the bark chip compost was obtained from the Brownsville, Texas city municipal waste management facility.

Table 1 Elemental constituents and physical properties of compost applied[Z].

EC	NO_3-N	P	K	Ca	Mg	S	Na
dS m^{-1}	-----	-----	----- mg kg^{-1} -----	-----	-----	-----	-----
0.73	41	580	860	12,150	504	76	206
pH	**Fe**	**Zn**	**Mn**	**Co**	**B**	**OM**	**OC**
	-----	-----	----- mg kg^{-1} -----	-----	-----	%	%
7.5	25.3	18.2	9.3	1.7	3.4	24.6	14.3

[Z] Defined abbreviations: EC, electrical conductivity; NO_3-N, nitrate-nitrogen; pH, hydrogen ion potential; OM, organic matter; OC, organic carbon.

Fig. 1 Soil moisture monitoring. (**A**) WaterMark® soil moisture sensors equipped to a Spectrum Technologies, Inc. WatchDog® datalogger were used in the field. (**B**) Sensors were buried under the citrus canopy at 15, 30 and 60 cm depths and data downloaded monthly to a laptop computer.

A single main irrigation line was placed under each row of trees in the drip and spray treatments. A separate water meter was attached to a single irrigation line in each row of the drip and spray treatments. A total of six water meters (one per row of trees) were used to calculate the total water volume dispensed during each irrigation period. 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 360° microjet spray emitter was placed at the base of each tree and delivered at the rate of 26.5 L h^{-1}. To match this irrigation rate, seven 3.8 L h^{-1} drip emitters per tree were placed within the drip plots along the main irrigation line and under the canopy for a total combined rate of 26.5 L h^{-1} per tree. Rainfall was measured and recorded throughout the 2003-2006 growing seasons. Citrus crop evapotranspiration (ETc) was calculated using reference ET and crop coefficient values (ETc = ET reference * Kc) as recommended by Dr. Juan Enciso and based upon work performed by Enciso and Wiendenfeld (2005). The total amount of irrigation water applied to the drip and spray irrigated trees was done to correspond to, as best as possible, the citrus crop ET demand over the growing season and water loss from the soil profile between rainfall and irrigation events. Soil moisture was monitored throughout the harvest years 2003-2006, by using Watermark® soil moisture sensors equipped with WatchDog® data loggers (Spectrum® Technologies, Inc., Plainfield, IL) to improve irrigation scheduling throughout the growing season (**Fig. 1A**). Soil moisture sensors were placed at depths of 15, 30 and 60 cm below the soil surface where the majority of fine citrus roots, that actively take up water, are located. The soil moisture data was downloaded monthly to a laptop computer to assist in irrigation scheduling (**Fig. 1B**).

Fruits were harvested annually, with 2003, 2004, 2005 and 2006 harvest years being harvested in Feb. 2004, Dec. 2004, Dec. 2005, and Feb. 2007, respectively. All fruit from the middle tree in each subplot was picked, sorted into class sizes, counted, and weighed.

In the 2005 harvest year, ten grapefruits were randomly selected at the time of harvest from each treatment tree, washed clean, and juice was extracted using a citrus juice extractor. Each treatment juice solution was analyzed for acidity using a computer-controlled, automated pH titration system (Mettler Toledo DL50 Titrator, Schwerzenbach, Switzerland). The pH electrode (Mettler Toledo DG115 SE, Greifensee, Switzerland) was calibrated with pH buffers: 4.0, 7.0, and 10.0 (Fisher Scientific, Fair Lawn, NJ).

Mature whole leaves were harvested from compost and non-compost treated trees under drip and microjet spray irrigation systems on July 2003 and July 2005. The leaf samples were washed with 1% hydrochloric acid solution, air dried and shipped to Texas A&M University's Soil, Water and Forage Testing Laboratory at College Station, Texas for macro (N, P, K) nutrient analysis.

Soil samples were collected from all compost and non-compost treatment trees at a distance of 60 cm from the tree trunk under drip and microjet spray irrigation systems in September 2005. The soil samples were crushed, air dried, ground, sieved to 2 mm, and sent to the Soil, Water and Forage Testing Laboratory, Texas A&M University, College Station for macro (N, P, K) nutrient analysis.

Soil core samples were taken in February 2006 at a distance of 60 cm from each tree trunk using a hammer driven core sampler that collected a 5.4 cm diameter by 10 cm deep core (Grossman and Reinsch 2002). Three soil cores were taken randomly from underneath three trees per (FC, FNC, UNC) treatment for both irrigation methods. The samples were dried in an oven at 105°C for two days and weighed. Soil dry weight per volume measurements were performed to determine soil BD and the impact of compost on soil physical properties.

Three compost and non compost treatment trees were randomly selected under each irrigation system to assess root growth. Under the canopy of each tree, three 1000 cm^3 (10 cm × 10 cm × 10 cm deep) soil core samples were taken in February 2006 at 60 cm distance from the tree trunk. Roots were placed within a 2 mm sieve and the fibrous roots were separated from the soil by gently massaging the roots in water until the soil was removed. Separated roots were then placed in a 65°C drying chamber for three days, and then weighed for total dry weight mass.

Statistical analysis

Data was subjected to analysis of variance using the General Linear Model (GLM) procedure of SAS (SAS Institute, Cary, N.C.). A randomized split plot design was used, and mainplot (drip/microjet spray) and subplot (control/compost/non-compost) treatment means were separated using Duncan's multiple range test (Freund and Little 1981). Statistical significance was evaluated at the P≤0.05 level.

RESULTS AND DISCUSSION

Annual rainfall of 73, 70, 44 and 49 cm, respectively, was measured during the four growing seasons of the study. Total cumulative reference ET (ET ref) was higher than annual rainfall during all four years (**Table 2**), thus supplemental irrigation was needed to provide sufficient water to citrus trees and to keep up with the crop ET (ETc) demand for good citrus production. The volume of water applied under the drip and microjet spray plots was regulated as best as possible to match the daily ETc for citrus (**Table 2**). The total cumulative irrigation applied under drip was 30, 33, 24 and 54 cm during the 2003-2006 growing seasons. Microjet spray trees received 35, 35, 32 and 67 cm supplemental irrigation during the same growing seasons. Adjusted irrigation scheduling was accomplished for drip and microjet spray irrigated trees with total water use (irrigation + precipitation) resulting in ± 10% of annual crop water demand based on estimated crop coefficients (Kc) for citrus. Total water use in 2003, 2004 and 2006 for both drip and microjet spray irrigated trees slightly exceeded the ETc whereas, in 2005, total water use was slightly lower than ETc throughout the growing season. Scheduling irrigation events to supply sufficient water to match or exceed daily ETc demand in the 2005 and 2006 growing season was more challenging due to extended periods of drought during these two years. Greater irrigation was required in harvest year 2006 because there were 9 consecutive months between 2005 and 2006 of no rainfall. Trees were also heavily stressed due to extensive tree canopy hedging: 50% of the tree canopy was hedged in March 2005 (**Fig. 2A, 2B**), and extra water was necessary to stimulate flushes and improve overall tree health. As the drip and microjet spray systems installed aged, more labor was required to clean or replace clogged emitters in the low flow irrigation systems.

Table 2 Total citrus water requirements[Z] for Drip and microjet Spray irrigated Rio Red grapefruit trees during the 2003-2006 growing seasons in South Texas.

Harvest year	2003	2004	2005	2006
	(cm)			
Cumulative ET ref	140	132	152	156
Kc (range)	0.7	0.7	0.5	0.65
Cumulative ETc	98	92	76	101
Rainfall	73	70	44	49
Irrigation				
Spray	35	35	32	67
Drip	30	33	24	54
Irrigation + Rain				
Spray	109	105	76	116
Drip	103	103	68	103

[Z] Defined abbreviations: ET ref; reference evapotranspiration, Kc, crop coefficient; ETc, citrus crop evapotranspiration, ETc = ETref * Kc.

In the harvest year 2003, non-composted trees had slightly higher fruit yield values than composted trees. This was evidenced in both total fruit number and total fruit yield weight for both drip and microjet spray trees after one year of converting previously flood irrigated trees to low flow irrigation systems (**Table 3**). However by the 2004 harvest, after the second year of compost application, a trend of higher grapefruit yield was observed in composted trees compared to non-composted tress for both irrigation systems. This trend continued into 2005 harvest season, although the total yield numbers decreased relative to the previous 2003 and 2004 harvests due to heavy hedging in the early spring of 2005 (**Fig. 2B**). Yield improved in 2006 compared to 2005, which can be attributed to the rejuvenation of the plants by more frequent and slightly higher irrigation than required. The trend of higher yields in composted over non-composted trees was continued in the 2006 harvest for both drip and microjet spray irrigation systems. These findings suggest that annual compost application (**Fig. 3A**) under these irrigation systems can be ideal for improving grapefruit production over the long term. This may be due to the ability of compost to improve soil physical properties and soil water holding capacity.

In all the harvest years, non-fertilized control trees generally produced highly reduced yields in regards to both total number of fruit and fruit weight relative to fertilized trees, whether compost or non-compost treated (**Table 3**). This further demonstrates the importance of annual N application for citrus trees and a continuous fertility management plan for adequate and sustainable citrus production. Lastly, a general trend of higher average yields was observed under microjet spray irrigation over drip irrigation.

Fig. 2 Citrus canopy hedging. (**A**) Graduate students standing next to mature Rio Red grapefruit trees prior to hedging in 2004 and (**B**) beside the same trees after heavy hedging in 2005, where 50% of the tree canopy was removed and resulted in significant reductions in yield.

Fig. 3 Compost impact on root density. (**A**) Graduate student spreading compost under citrus tree canopy where annual compost application resulted in significant increases in root growth development within the compost layer and below the soil-compost interface. (**B**) Newly formed roots and root density improved in the upper 10 cm soil depth measured below the soil-compost interface.

Prior to this study in 2002, grapefruit yields from this site averaged 315 and 332 fruit tree^{-1} or 143 and 151 kg fruit tree^{-1}, from the respective areas designated for drip and microjet spray irrigation and started in 2003. Citrus production for mature grapefruit will typically range from 78 to 188 kg tree^{-1}, an indication of fair to very good yields for Rio Red grapefruit (data calculated and modified from Enciso *et al*. 2008). It was observed in the field that the microjet spray system provided a more uniform wetting pattern under the tree canopy and had minimal emitter clogging problems in comparison to the drip irrigated system. This may have led to the slightly higher yields in microjet spray irrigated trees relative to drip irrigated trees.

Juice acidity (pH) is a fruit quality indicator, and analysis of juice acidity in all the treatment trees from 2005 harvest resulted in no statistical differences (P=0.7964) in juice quality. The average juice acidity pH was 1.43 (compost), 1.39 (non-compost) and 1.46 (control) in drip irrigated and 1.38 (compost), 1.39 (non-compost), and 1.41 (control) in microjet spray irrigated trees. These values are slightly lower than published acidity value range of pH 2.0–3.0 for citrus (Smith 2000). Although pH was lower in our findings, our results demonstrate that juice quality was similar in all treatments regardless of treatment, suggesting that composting did not negatively impact grapefruit juice quality.

Table 3 Yields from four consecutive harvest seasons (2003 to 2006)^{Z} for Drip and microjet Spray irrigated Rio Red grapefruit trees that were fertilized and compost (Compost) or non-compost (No-Compost) treated versus unfertilized, non-composted (Control) trees.

Irrigation type	Total fruit (no. tree^{-1})			Yield (kg tree^{-1})		
	Compost	No-Compost	Control	Compost	No-Compost	Control
2003 harvest						
Drip	422 ab	434 ab	352 b	144 ab	153 ab	113 b
Spray	458 ab	620 a	485 ab	150 ab	196 a	150 ab
2004 harvest						
Drip	770 a	603 ab	586 ab	279 ab	275 a	210 bc
Spray	737 a	702 a	433 b	351 a	337 a	172 c
2005^{Y} harvest						
Drip	141 ab	113 ab	95 ab	48 abc	40 abc	29 bc
Spray	197 a	170 ab	52 b	69 a	62 ab	16 c
2006 harvest						
Drip	361 a	304 ab	227 b	141 ab	121 abc	92 c
Spray	365 a	321 ab	269 ab	157 a	123 abc	108 bc

^{Z} Different letters indicate significant differences, at P<0.05. Statistical analysis for each harvest year was analyzed independent of one another.
^{Y} Trees were heavily hedged in March 2005 with 50% canopy reduction, resulting in substantial reduction of yield.

Table 4 Effect of fertilizer application on Rio Red grapefruit leaf macro-nutrient status (% N, P, K) taken from one-year old leaf tissues during 2003 and 2005 harvest seasons[Z]. Treatments were fertilized compost (Compost) and non-compost (No-Compost) treated trees versus unfertilized, non-composted (Control) trees using drip and microjet spray irrigation systems.

Irrigation type	2003 leaf analysis			2005 leaf analysis		
	Compost	No-Compost	Control	Compost	No-Compost	Control
N (% dry wt)						
Drip	2.47 a	2.47 a	2.37 a	2.22 bc	2.19 bc	2.12 c
Spray	2.48 a	2.44 a	2.03 b	2.42 a	2.31 ab	2.09 c
P (% dry wt)						
Drip	0.17 a	0.17 a	0.18 a	0.13 b	0.14 b	0.17 b
Spray	0.16 a	0.16 a	0.16 a	0.13 b	0.13 b	0.31 a
K (% dry wt)						
Drip	1.36 ab	1.30 b	1.56 a	1.29 b	1.31 b	1.22 b
Spray	1.24 b	1.19 b	1.41 ab	1.37 b	1.25 b	1.94 a

[Z] Different letters indicate significant differences, at *P*<0.05. Statistical analysis for each plant nutrient was performed independent of one another.

[Y] Plant leaf nutrient analysis % dry wt (weight) represents g nutrient per g leaf tissue × 100.

Table 5 Soil macro-nutrients (N, P, K) levels taken from the upper 30 cm depth of fertilized compost (Comp) and non-compost (No-Compost) treated trees versus unfertilized, non-composted (Control) trees[Z]. Composted tree sampling was taken below the soil-compost surface interface.

Treatment	N (mg kg^{-1})		P (mg kg^{-1})		K (mg kg^{-1})	
	Drip	Spray	Drip	Spray	Drip	Spray
Control	16.3 ab	8.7 b	58.3 b	58.3 b	457.0 ab	410.0 b
No-Compost	8.7 b	7.7 b	42.0 b	45.0 b	402.0 b	393.0 b
Compost	43.3 a	22.7 a	97.3 a	76.3 a	582.0 a	638.0 a

[Z] Different letters indicate significant differences, at *P*<0.05. Statistical analysis for each soil nutrient was performed independent of one another.

Significant differences (P=0.0249) in leaf nutrient concentration were observed among the irrigation systems (**Table 4**) for both sampling events in 2003 and 2005. In 2003, the percentage N in the year old citrus leaf tissues was significantly lower (P=0.0494) in the spray irrigated control treatment compared to all other treatments. Because 2003 was the initial treatment year, no significant variation was noticed between compost and non-compost treatments for N, P and K levels. By 2005, continuously unfertilized (control) trees had significantly lower N levels than trees that received fertilizer applications, thus demonstrating the importance of a perpetual fertilization program for citrus. Optimum citrus leaf nutrient ranges reported for N, P and K is 2.5-2.8, 0.12-0.17, and 1.2-1.7%, respectively, with potential nutrient deficiencies occurring below 2.2% N, 0.09% P and 0.7% K (Sauls 2008).

For the spray irrigated compost treated trees, N levels were higher in 2005 than for trees under drip irrigation. For both irrigation systems, compost treated trees had higher average N content in leaf tissues, but it was not statistically greater for the non-composted trees. Although the percentage of P and K were within the optimum level for all treatments, minor differences were evident in control treatments in 2005 and may indicate a stress response due to years without fertilization (**Table 4**).

Drip irrigation did not significantly change soil bulk density (BD) relative to microjet spray systems; however, compost applications did lower soil BD values underneath the tree canopy of both drip and microjet irrigated trees. Composted trees had significantly lower BD values than the control plots in the spray irrigated trees (**Table 6**). Although BD levels were not significantly greater in composted vs. non-composted treatment, there was a very strong trend of decreasing BD values going from control to non-composted to composted soil systems. This indicates that compost application can produce a more favorable rooting environment and promote root growth by maintaining a less compacted soil. This is supported by the observation of higher root density values in composted than non-composted trees (**Table 6**). Agricultural soils research has demonstrated that the incorporation of organic amendments will lead to lower soil bulk density (Tester 2000; Foley and Cooperband 2002), which in turn promotes improved soil water infiltration (Cox *et al.* 2001) and available water to the plant (Giusquiani *et al.* 1995).

Root growth in the upper 10-cm soil surface below the soil-compost interface was found to be greater under composted (**Fig. 3A**) than non-composted trees. Trees receiving compost application under microjet spray irrigation had significantly (P = 0.0493) higher root density (**Fig. 3B**) than non-composted drip irrigated trees (**Table 6**). The increased root density in microjet spray plots indicates that citrus trees can adapt to a low water use system in a few years after converting from flood irrigation practices. The lower root density observed in the drip system was due to the random placement of drip emitters. During sampling events in the field, improved root growth was observed close to the location of the drip emitter and root growth declined substantially at locations further away from the drip emitter. A higher amount of root development in the microjet spray plots was most likely due to a more uniform wetting pattern around the tree base produced by the spray emitters. Increase in root density can improve soil nutrient and water uptake and may have led to the higher average yields in spray over drip irrigated trees (**Table 3**).

No significant differences were observed in soil electrical conductivity (EC) levels for both compost and non-composted treatments under drip and microjet spray irrigation. The unfertilized control treatments did have statistically lower soil salinity levels than fertilized treatments, indicative that salts from annual fertilizer and compost applications contribute to increased soil salinity. Citrus is not known to be a very salt tolerant crop with a threshold salinity level of only 1.6 dS m^{-1} (Sauls 2008), so growers using low flow irrigation systems, like drip and microjet spray, may want monitor their soils annually and flush out excess salt from the soil profile, if soil salinization becomes problematic.

Table 6 Soil characteristics from the upper 10 cm soil underneath grapefruit trees receiving the following treatments: fertilized, composted (Comp) and fertilized, non-composted (No-Comp) versus unfertilized, non-composted (Control) trees sampled February 2006[Z]. Composted tree soil sampling was taken below the soil-compost surface interface.

Treatment	Bulk density (g cm^{-3})		Root density (g 1000 cm^{-3})[Y]		Soil salinity EC (dS m^{-1})		Soil acidity (pH)	
	Drip	Spray	Drip	Spray	Drip	Spray	Drip	Spray
Control	1.28 ab	1.40 a	NA	NA	0.30 b	0.32 b	8.13 ab	8.40 a
NoComp	1.29 ab	1.32 ab	2.11 b	2.96 ab	0.40 ab	0.37 ab	8.27 a	8.07 ab
Compost	1.22 b	1.15 b	2.53 ab	4.21 a	0.49 ab	0.51 a	7.73 b	8.07 ab

[Z] Different letters indicate significant differences, at *P*<0.05. Statistical analysis for each component in table was performed independent of one another.

[Y] Root density measured by taking a 10 cm × 10 cm × 10 cm deep cube (1000 cm^3) beneath the soil surface-compost interface and taking the air dry weight of the roots.

No significant variation in soil pH was noticed between compost and non-compost treatments under microjet spray irrigation. However, under drip irrigation, soil samples collected from compost treated trees had a lower pH than that from the non-composted plots (**Table 6**). For south Texas soils that are naturally high in pH (Jacobs 1981), addition of compost may be a beneficial means of progressively lowering soil pH as compost treated trees had the lowest average pH levels compared to non-composted treatments. Lower soil pH levels where active surface roots are located can potentially allow for improved soil nutrient availability and uptake.

Soils from composted trees under drip and microjet spray irrigation showed significantly higher N, P and K concentrations than non-composted trees (**Table 5**). The lower soil N, P and K concentrations obtained with the microjet spray treatment than under drip irrigated trees may be attributed to a combination of enhanced nutrient uptake by a better developed root system and a soil profile that is more uniformly irrigated. As the total amount of irrigation water applied in both spray and drip irrigated systems (**Table 2**) was relatively similar, the lower soil N levels observed under the spray irrigation system is not likely due to increased leaching relative to drip irrigation.

Higher soil moisture content was observed under composted trees than non-composted trees for both irrigation systems. The use of soil moisture sensing devices assisted in irrigation scheduling. However, the use of WaterMark® matrix sensors can be challenging in the heavy clay textured soils of south Texas as these soils are prone to cracking due to the shrink-swell properties of the clay minerology. When the soil cracks, the soil can separate away from the sensor leading to an inefficient soil moisture monitoring system and restoration of the monitoring system commonly requires a heavy rain or irrigation event to bring the sensor into proper soil contact and working condition. This loss of adequate contact between the soil and the sensor was more common under trees that were not treated with compost. As evident in **Fig. 4**, the non-compost treatment dried out rapidly (high kPA value) and it took a large rain event or irrigation to restore the sensor reading. The rise and fall of kPa values shown in the line representing the 'compost' treatment (**Fig. 4**) demonstrates that the irrigation system was functioning properly and regularly; however, this regularity in the rise and fall of kPa values was less frequent in the 'non compost' treatment. This was not due to a lack of irrigation water, but rather due to the separation of the sensor from the soil matrix. **Fig. 4** also demonstrates that compost application led to higher soil water content (lower kPA values), in comparison to non-composted soils, and this occurred for both the drip and microjet spray irrigation systems at all monitored soil depths (15, 30, and 60 cm; data not shown). The ability of compost to keep the soil moist for longer periods of time relative to non-composted plots enabled the sensors to be in constant contact with the soil, thus enabling better water scheduling and irrigation management.

Our findings have shown that the application of compost to the base of citrus trees can over a very short period of time improve citrus yield. This was accomplished through improved soil physical properties, such as lower soil bulk density, which allowed for enhanced root development and growth near the soil surface, and improved soil water retention by reducing evaporative loss. Amending the soil with compost can indirectly increase soil porosity (Martens *et al.* 1992) by directly reducing soil BD and soil compaction (Khaleel *et al.* 1981). For soil with elevated clay content with high shrink-swell properties, as evident in this study, surface applications of compost may be sufficient without incorporation because the organic matter can work itself below the soil surface and lower soil BD. Furthermore, composting prevented the high clay soil in this study from cracking. In our study, soil moisture sensors did not lose contact with the soil and the upper soil profile did not dry out quickly due to rapid water loss. This study further illustrates the importance of maintaining an active fertilization program for maintaining good citrus production. Of note, reductions of tree canopy by 50% through heavy hedging will severely impact citrus yield and it may take two years before citrus yields are restored. Therefore, it is recommended that along with annual fertilization and compost application, that the citrus tree canopy should not be heavily pruned every few years. It is suggested that more routine pruning practices be adopted, such as a maximum of 25% canopy reduction, in order to sustain high grapefruit yields.

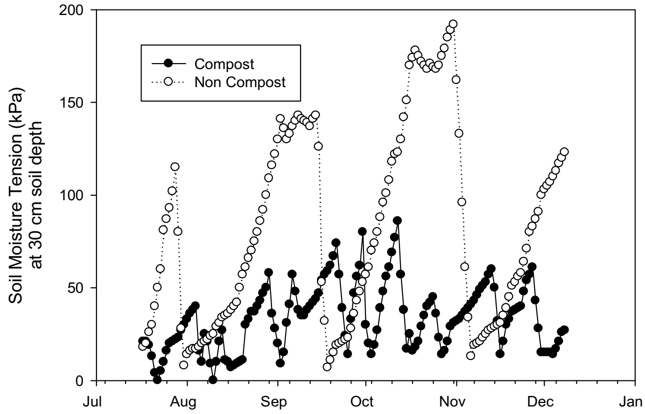

Fig. 4 WaterMark® soil moisture sensor data. An example of soil moisture change in 2004 under compost and non-compost drip irrigated citrus tree canopies from soil sensors located 30 cm below soil surface. Higher soil moisture levels (low kPa, solid line) and improved soil sensor-to-soil contact occurred under composted than non-composted trees (high kPa, dashed line).

ACKNOWLEDGEMENTS

This research was funded, in part, by the Cooperative State Research, Education and Extension Service, U.S.D.A under Agreement No. 2005-34461-15661, through the Rio Grande basin Initiative through Texas Water Resources Institute. We appreciate CSREES/USDA through the Hispanic Serving Institutions grant # 2004-38422-14608 that helped fund student labor associated with this research. The authors would like to thank Leeroy Rock, Kishore Shantidas, Heriberto Esquivel and the Agricultural Water Conservation Demonstration Initiative, and the Texas A&M University-Kingsville Citrus Center farm crew for their technical assistance.

REFERENCES

Chantigny MH, Angers DA, Rochette P (2002) Fate of carbon and nitrogen from animal manure and crop residues in wet and cold soils. *Soil Biology and Biochemistry* **34**, 509-517

Cox D, Bezdicek D, Fauci M (2001) Effects of compost, coal ash, and straw amendments on restoring the quality of eroded Palouse soil. *Biology and Fertility of Soils* **33**, 365-372

Enciso JM, Wiedenfeld B (2005) Irrigation guidelines based on historical weather data in the Lower Rio Grande Valley of Texas. *Agricultural Water Management* **76**, 1-7

Enciso J, Sauls JW, Wiedenfeld RP, Nelson SD (2008) *Impacts of Irrigation on Citrus in the Lower Rio Grande Valley*, AgriLIFE Communications and Marketing, Texas A&M University System Extension Publication B-6205, 05-08, 14 pp. Available online: http://AgriLifeBookstore.org

Foley BJ, Cooperband LR (2002) Paper mill residuals and compost effects on soil carbon and physical properties. *Journal of Environmental Quality* **31**, 2086-2095

Frageria NK (2002) Soil quality vs. environmentally-based agricultural management practices. *Communication in Soil Science and Plant Analysis* **33**, 2301-2329

Freund RJ, Little RC (1981) *SAS for Linear Models.* SAS Inst., Cary, N.C.

Gregoriou C, Rajkumar D (1984) Effects of irrigation and mulching on shoot and root growth of avocado (*Persea americana* Mill.) and mango (*Mangifera indica* L.). *Journal of Horticultural Science* **59**, 109-117

Grossman RB, Reinsch TG (2002) Bulk density and linear extensibility. In: Dane JH, Topp EG (Eds) *Methods of Soil Analysis. Part 4. Physical Methods*, Soil Science Society of America Book Series 5. SSSA, Madison, WI, USA, pp 201-228

Giusquiani PL, Pagliai M, Gigliotti G, Businelli D, Benetti A (1995) Urban waste compost: Effects on physical, chemical, and biochemical soil properties. *Journal of Environmental Quality* **24**, 175-182

Hampton MO, Schaffer B, Bryan HH, Hanlon EA (1994) Nutrient concentrations, growth, and yield of tomato and squash in municipal solid-waste-amended soil. *HortScience* **29**, 785-788

Khaleel R, Reddy KR, Overcash MR (1981) Changes in soil physical properties due to organic waste applications: A review. *Journal of Environmental Quality* **10**, 133-141

Jacobs JL (1981) *Soil Survey of Hidalgo County, Texas*, United States Department of Agriculture, Soil Conservation Service in cooperation with the Texas Agricultural Experiment Station, pp 171

Liebman M, Davis AS (2000) Integration of soil, crop and weed management in low-external-input farming systems. *Weed Research* **40**, 27-47

Martens DA, Frankenberger WT Jr. (1992) Modification of infiltration rates in an organic-amended irrigated soil. *Agronomy Journal* **84**, 707-717

Moran RE, Schupp JR (2003) Preplant monoammonium phosphate fertilizer and compost affects the growth of newly planted 'Macoun' apple trees. *HortScience* **38**, 32-35

Sauls JW (2008) Texas Citrus and Subtropical Fruits: Nutrition and Fertilization. Texas AgriLIFE Extension. Available online: http://aggie-horticulture.tamu.edu/citrus/nutrition/L2288.htm

Smith K (2002) Drinks that eat teeth. 21st Century Dental. Available online: http://www.21stcenturydental.com/smith/pH_drinks.htm

Sweitlik D (1992) Yield, growth and Mineral nutrition of young 'Ray Ruby' grapefruit trees under trickle or flood irrigation and various nitrogen rates. *Journal of American Society of Horticultural Science* **117**, 22-27

Tester CF (1990) Organic amendment effects on physical and chemical properties of a sandy soil. *Soil Science Society of America Journal* **54**, 827-831

Tejada M, Gonzalez JL (2003) Effects of the application of a compost originating from crushed cotton gin residues on wheat yield under dry land conditions. *European Journal of Agronomy* **12**, 357-368

Uckoo RM, Nelson SD, Shantidas KJ, Enciso JM (2005) Irrigation and fertilizer efficiency in South Texas grapefruit production. *Subtropical Plant Science, Journal of the Rio Grande Valley Horticultural Society* **57**, 23-28

Widmer TL, Graham JH, Mitchell DJ (1998) Composted municipal waste reduces infection of citrus seedlings by *Phytophthora nicotianae*. *Plant Disease* **82**, 683-688