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Compost Effects in 'Rio Red' Grapefruit Production on a Heavy Textured Soil

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ABSTRACT

Citrus is grown primarily in the Lower Rio Grande Valley (LRGV) of South Texas using flood irrigation, with approximately 70% of the citrus raised as 'Rio Red' grapefruit (*Citrus paradisi* Macf.). Supplemental irrigation is necessary in this region as annual precipitation is not sufficient to raise citrus in this semi-arid climate. A potential water-conserving strategy for citrus is compost application underneath the tree canopy. A 5-year field study was initiated in 2003 on mature, flood-irrigated 'Rio Red' grapefruit trees located in Weslaco, Texas. The objective of this study was to evaluate the impacts of bark-chip compost application on soil physical properties, root development, and subsequent citrus production when applied to the heavier soil of the LRGV. Three main treatments were evaluated: unfertilized, non-composted (UNC); fertilized, non-composted (FNC); and fertilized, composted (FC) trees. For this study, compost applications did not significantly alter soil bulk density (BD), however, a trend of decreased soil BD was observed as compost application increased, thus an indication that multiple year organic application can improve the physical properties of heavier soils. Increased compost application did significantly increase soil water retention, suggesting its importance for conserving water under the tree canopy. In 2007, a detailed root density study was performed, comparing: 1) a single 5-cm, 2) a single 10-cm, 3) and annual 5-cm (2003-2007) applications of compost with non-composted trees. Root density with annual compost application was 453% higher than with non-composted trees. The bark-chip compost was a very minor contributor of nitrogen (N) to the soil system due to its low N content, however, the highest average fruit yields from 2004 through 2007 came from FC trees. Grapefruit yields from fertilized trees exceeded that of unfertilized trees.

Keywords: citrus, flood irrigation, organic mulch, root density, water conservation
Abbreviations: BD, bulk density; **EC**, electrical conductivity; **FC**, fertilized composted; **FNC**, fertilized non-composted; **LRGV**, Lower Rio Grande Valley; **SAR**, sodium adsorption ratio; **TAMUK**, Texas A&M University-Kingsville; **UNC**, unfertilized non-composted

INTRODUCTION

Irrigation of citrus in the Lower Rio Grande Valley (LRGV) of South Texas is primarily performed using flood irrigation practices. A network of canals diverts water from the Rio Grande River and irrigation water is allocated to growers by several irrigation districts. This method of irrigation is not an optimal water management practice for the LRGV, and during periods of drought growers face limited water supply from the Rio Grande. In this region growers heavily depend upon the higher quality water of the Rio Grande rather than ground water because of saltwater intrusion from the Gulf of Mexico.

Although growers and irrigation districts do face periodic water shortages in the LRGV, there is little incentive for growers to change from flood irrigation practices to alternative irrigation practices (i.e. drip irrigation) with current low water prices and the irrigation networks designed to supply large quantities of water over short durations (Enciso and Wiedenfeld 2005). Switching from flood irrigation to water-conserving systems, like drip irrigation, requires additional expense and generally additional acreage for creation of small reservoirs to supply water more frequently than with the canal system for flood irrigation.

'Rio Red' grapefruit (*Citrus paradisi* Macf.) is the major perennial fruit crop raised in the LRGV and comprises over 70% of the Texas citrus industry. The United States is the leading producer of grapefruit worldwide as total production exceeded 43.5% in the early 1990s (Davies and Albrigo 2003). The majority of Citrus grape-fruit produced in the United States occurs primarily in four states: California, Florida, Texas and Arizona, with 75% of all sales as the pink- and red-fleshed varieties (da Graca *et al*. 2004). The deep red-fleshed 'Rio Red' grapefruit originates from the LRGV and its high quality and sweet flavor of red-fleshed grapefruit cultivars in Texas makes the 'Rio Red' grapefruit variety a sought after commodity even though Florida has higher total grapefruit production. It is currently the major grapefruit variety grown in Mexico with increased plantings found in Argentina, Cyprus, South Africa, Israel, Spain and Turkey (da Graca *et al.* 2004). In South Texas, the 'Rio Red' grapefruit is generally grafted onto sour orange (*Citrus aurantium* Linn.) rootstock, which improves the hardiness of the tree against the semiarid climate and high pH (calcareous) soils in this region. Average annual rainfall in this region of the U.S. is almost always insufficient to adequately meet the water requirements of perennial crops like citrus; therefore, supplemental irrigation is required (Uckoo *et al.* 2005). Furthermore, precipitation patterns are either sporadic throughout the LRGV or rain commonly falls in large quantities at only certain times of the year, thus leading to extended growing periods needing supplemental watering to maintain adequate citrus crop production.

Application of compost to agricultural soils has been shown to limit water loss from soils in arid and semiarid regions and in some cases improve yields in perennial crops (Moran and Schupp 2003). Organic compost mulch additions to soil can improve soil water retention and increase

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Table 1 Chemical characteristics of the indigenous soil and bark-chip compost (values on dry matter basis).

Constituent	pH	E.C. ($dS\ m^{-1}$)	Org. C (%)	NO_3-N	P	K	Ca	Mg	S	Na
				($mg\ kg^{-1}$)						
Soil	8.3	0.45	1.8	4.3	45	496	9530	526	49	281
Compost	7.5	0.23	12.6	41.0	580	860	12150	504	76	206

soil organic matter (Chantigny *et al.* 2002) so that more water can be conserved over the growing season. In addition, mulching of soils can lead to improved soil physical properties (Martens and Frankenberger 1992; Frageria 2002), such as lowering soil compaction and bulk density (Khaleel *et al.* 1981), in turn directly improving soil tilth through increased soil porosity and water holding capacity (Gregoriou and Rajkumar 1984). However, organic mulch applications can indirectly have negative effects on crop production as composts containing high carbon (C) and low nitrogen (N) contents (high C:N ratio) can lead to immobilization of soil N reserves and applied N fertilizers (Chantigny *et al.* 2002). This tie up of N by soil microbes to breakdown the C within the organic mulch compost can result in N deficiency in the crop and decreased fruit development and lead to lower crop yields. The objective of this study was to evaluate the impact of compost application amount and duration on soil physical properties, root development, and ‘Rio Red’ grapefruit crop yield in heavier textured soils and assess the value of compost application as a potential water conserving practice.

MATERIALS AND METHODS

A field experiment was conducted from 2003 to 2007, located at the Texas A&M University-Kingsville (TAMUK) Citrus Center South Farm in Hidalgo County, Texas (26° 08' N, 97° 57' W), and initiated on 17-year old, mature ‘Rio Red’ grapefruit trees grafted onto sour orange root stock. These trees were grown in heavy clay-type textured soils under continuous flood irrigation practices for several growing seasons prior to initiation of this study. Trees were spaced 4.6 m within row by 7.2 m between rows with a planting density of 287 trees ha^{-1}. The soil type at this site is primarily calcareous and moderately alkaline Cameron silty clay (clayey over loamy, mixed, hyperthermic Vertic Haplustoll). However, soil within the upper 30 cm contains 47% clay, 20% silt and 33% sand, more indicative of a clay soil type where the majority of feeder roots are located for water and nutrient uptake.

The field site was selected to evaluate citrus production with and without compost application under flood irrigation (the conventional irrigation system used for citrus production in the LRGV). Prior to changes in fertility or initiation of compost treatments for 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 $tree^{-1}$ yr^{-1} in March 2002 and flood-irrigated throughout the 2002 harvest season. This was done to provide a base-line assessment of grapefruit production (2002 data not shown) to ensure that fruit production was similar from all trees prior to establishing trials using compost treatments starting in 2003.

After the 2002 harvest, each tree received a granular broadcast application of 0.454 kg N $tree^{-1}$ yr^{-1} applied as urea 46-0-0, unless designated as a control treatment that received no fertilizer. The experimental design at this flood-irrigated site was an unbalanced randomized block design with three treatments consisting of: 1) fertilized, composted (FC); 2) fertilized, non-composted (FNC); and 3) unfertilized, non-composted (UNC) control trees. Treatments were arranged such that a greater number of compost and fertilized treatments were included in each block than the control (unfertilized). Each block consisted of 7 rows of trees, with 5 trees within each row. The middle tree (experiment unit) in each row was used for data analysis. For rows containing either FC or FNC treatments, all 5 trees per row received fertilizer; whereas trees in rows containing UNC treatment did not receive any fertilizer. A total of 3 FC, 3 FNC, and 1 UNC treatments were randomized within the 7 rows of trees per block. The treatments were randomized within each block and among blocks. There were 3 replicated block areas (land areas separated by berms for flood irrigation and sufficiently large to house the 7 rows of trees), thus providing a total of 9 FC, 9 FNC, and 3 UNC treatments evaluated.

The study was conducted from 2003 to 2007 where fertilizer and compost treatments were applied annually on 15 March 2003, 15 February 2004, 19 February 2005, 14 December 2005, and 15 January 2007. For the FC treatments, from 2003-2007 annual compost application at a rate of 45.76 kg $tree^{-1}$ yr^{-1} dry weight was applied to the middle tree of each row. This was accomplished by applying three 18.93-L buckets of bark-chip compost (**Table 1**) and spreading it out by hand underneath and within the drip line of the tree canopy without incorporating it into the soil. Trees receiving compost application did not receive a substantial amount of additional N as the source of compost originated from bark wood chips which contributed a minor 0.002 kg N $tree^{-1}$ yr^{-1} based on the 45.7 kg $tree^{-1}$ yr^{-1} rate of compost applied underneath the tree canopy each year prior to inorganic fertilizer applications. The bark-chip compost source originated from the Brownsville Texas municipal yard waste recycling facility and was delivered on-site in one large pile in February 2003. This same pile of compost was used throughout the five years detailed in this study and stored under outdoor conditions. A routine maintenance schedule was performed with annual insecticide spraying and herbicide applications.

A secondary investigation to evaluate the impact of varying compost levels on citrus root development and growth was performed in the 2007 harvest season. One row of trees per block where annual compost application had been applied previously to the middle tree through 2006 harvest, was selected at random for additional compost treatments in 2007. Four of the five trees within each row were used as experimental units in this study, with 3 replications (blocks) per unit. The original tree receiving annual compost application was used, along with new compost treatments to the adjacent trees, with one of the outer trees in the row used as a contol. Recall that trees in this orchard are spaced 4.57 m × 7.2 m apart at a planting density of 287 trees ha^{-1} and compost was applied in a 2.29 m radius from the tree trunk out to the drip line of the tree. The secondary treatments consisted of varying rates of compost applied over varying lengths of time, thus providing the following treatments: 1) no compost applied, 2) 3 buckets of compost (18.93-L buckets used) as a single application in 2007, 3) 6 buckets of compost as a single application in 2007, and 4) 3 buckets of compost applied annually from 2003 through 2007. Therefore, the rates of the four respective secondary compost treatments during the 2007 were: 0, 28, 56 and 140 Mg compost ha^{-1} to further evaluate of the effect of compost amendments on citrus root density. With regards to the depth of the compost layer applied for these treatments, this would represent: 1) 0-cm compost applied, 2) a single 5-cm, 3) a single 10-cm, and 4) annual 5-cm yr^{-1} over five years (2003-2007), respectively.

Rainfall was measured and recorded throughout the 2003-2007 growing seasons. Total average annual rainfall received on-site was 560 mm and ranged from 436 to 733 mm. Flood irrigation was performed periodically and as needed in 15-cm depth irrigation events.

Fruit were harvested annually, with 2003, 2004, 2005, 2006 and 2007 harvest seasons were Feb. 2004, Dec. 2004, Dec. 2005, Feb. 2007, and Jan. 2008, respectively. All fruit from the center tree in each row was picked, sorted into class sizes, counted, and weighed for yield data collection.

Juice quality was measured annually using a brix: acidity ratio. 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 (Sunkist juice extractor 8R-B97, Overland Park, Kansas, USA). Brix measurements on extracted juice were determined using a hand-held refractometer (BRIX50 model 137531L0, Leico Microsystems Inc., Buffalo, New York). Each treatment juice solution was analyzed for acidity using a compu-

Fig. 1 Compost impact on root density. (**A**) Researchers cut out a 10 cm × 10 cm × 10 cm deep cube of soil below the soil-compost interface to assess root density. (**B**) Example of a 1000 cm^3 cube extracted from below the soil-compost interface and root density determined by quantifying roots within soil cube volume.

Table 2 Total annual 'Rio Red' grapefruit yields comparing fertilized, compost (FC) and non-composted (FNC) to unfertilized, non-composted (UNC) trees.

Main Treatent	Compost[Z] Rate yr^{-1} ($kg\ tree^{-1}$)	Nitrogen[Y] Rate yr^{-1} ($kg\ tree^{-1}$)	Harvest season (kg grapefruit $tree^{-1}$) 2003	2004	2005[X]	2006	2007
UNC	0	0	222 a	199 a	34 b	119 b	126 b
FNC	0	0.454	241 a	245 a	140 a	157 a	190 a
FC	45.76	0.456	228 a	294 a	161 a	172 a	205 a

[Z] Compost application added 0.002 kg NO_3-N $tree^{-1}$ yr^{-1}.
[Y] Nitrogen added as a broadcast application under tree canopy at recommended rate of one pound nitrogen (0.454 kg N) per tree per year applied in early spring. Composted treatments received less than 0.002 kg N $tree^{-1}$ yr^{-1}.
[X] Grapefruit trees were heavily hedged in March 2005, a common practice in citrus orchard management, thus leading to reduced yields.

ter-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, New Jersey, USA). Juice quality was then calculated as the ratio of Brix (%) to acidity (meq mL^{-1}).

Soil and compost samples were collected prior to the study in 2002 and analyzed for nutrient status and organic C content (**Table 1**). Soil was sampled from the upper 30-cm depth at random from 42 locations throughout the field site, air dried, ground and sieved to 2 mm, and sent to the Soil, Water and Forage Testing Laboratory, Texas A&M University, College Station for nutrient and organic matter analysis. Compost was air dried, ground, and sieved similarly to soil, and both soil and compost samples were analyzed for pH and electrical conductivity (EC) using a 1:2 soil: water (or compost: water) extractant. The NO_3^--N was extracted with 1N KCl and concentration in the extractant was determined by cadmium reduction spectrophotometrically; and available P, K, Ca, Mg, S, and Na was extracted with an acidified ammonium acetate + EDTA (ethylene diamine tetraacetic acid) and concentration in the extractant determined using ICP (inductively-coupled plasma) (Texas Cooperative Extension 2005).

Soil dry weight per volume measurements were performed to determine soil bulk density (BD) and impact of compost on soil physical properties. Soil core samples were taken in February 2008 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 per tree were taken at random locations underneath each of the trees containing the varying compost level treatments (0, 28, 56 and 140 Mg compost ha^{-1}). Prior to BD sampling, the compost layer was removed and samples were taken at the soil surface-compost interface and to a depth of 10 cm. The samples were dried in an oven at 105°C for two days and weighed, and BD was calculated based on soil dry weight and volume.

Root density was further assessed for these secondary compost treated trees to determine compost application impact on root development near the soil surface (**Fig. 1A**). Under the canopy of each tree, three 1000 cm^3 (10 cm × 10 cm × 10 cm depth) soil cube samples (**Fig. 1B**) were taken on February 2008 at 60 cm distance from the tree trunk. Roots visible to the naked eye were separated from the soil by hand, then placed in a 65°C drying chamber for 3 days, and weighed afterwards for total dry weight mass. The remaining soil was air-dried, ground and sieved to 2 mm, and sent for nutrient and organic matter analysis as mentioned previously (Texas Cooperative Extension 2005). The compost was analyzed by ICP for the micronutrients Fe, Zn, Mn, Cu and B as well.

Data were analyzed using the General Linear Model (GLM) procedure of the SAS for Windows software version 9.1 (©2002-03 SAS Institute, Cary, NC, USA). Mean comparisons were made using Duncan's multiple range test with significant differences of means at the 95% confidence level ($P \leq 0.05$).

RESULTS AND DISCUSSION

Initial soil fertility status prior to fertilizer and compost treatments indicated that soils underneath the tree canopy had low NO_3-N, moderate P, and high K levels (**Table 1**) compared to the nutrient requirements for citrus (Enciso *et al*. 2008). Soil pH was indicative of a moderately alkaline soil with low soil salinity (EC), while soil organic C level of 1.8% suggested that continual leaf litter decomposition beneath the tree canopy led to good organic matter content within the upper 30 cm soil depth. Analysis of compost suggests that compost application to trees would further increase soil C residues and nutrients as the bark-chip compost is decomposed because the compost source consisted of 12.6% organic C and in the case of N, P, K, and S somewhat higher macronutrient levels compared to the soil alone (**Table 1**). The compost was also a minor contributor to micronutrients as ICP analysis showed that it consisted of 25.3, 18.2, 9.3, 1.7 and 3.4 mg kg^{-1} Fe, Zn, Mn, Cu, and B,

Table 3 Soil constituent and plant available nutrient analysis[Z] at end of the 2007 harvest season taken from upper 10-cm soil beneath the citrus tree canopy and sampled below the soil-compost interface as appropriate. All trees received annual 0.454 kg N tree^{-1} fertilizer applications from 2002 through 2007.

Compost rate (Mg ha^{-1})	Amount applied Rate × yrs	SAR[Y]	Ca (g kg^{-1})	Mg	Na	S	NO_3-N	P	K	EC (dS m^{-1})	pH
				(mg kg^{-1})							
0	0 × 5 yr	4.2	11.7	680 a	329	63	5.3	45	496	0.45	8.33
28	28 × 1 yr	4.3	11.2	554 b	327	65	2.7	50	484	0.42	8.27
56	56 × 1 yr	4.2	11.1	568 ab	322	61	4.3	54	681	0.45	8.27
140	28 × 5 yr	4.5	10.7	568 ab	335	72	3.7	106	568	0.49	8.23

[Z] Statistical analysis for each soil constituent was performed independent of one another. Different letters within the same column indicate significant differences, at $P \leq 0.05$, as shown for constituent Mg only. Data within the same column for all other constituents that do not have letters assigned indicate no statistical differences at $P \leq 0.05$ level.
[Y] SAR = sodium adsorption ratio; SAR = Na (meq L^{-1}) / (square root [Ca + Mg (meq L^{-1})]).

Table 4 Soil physical constituent analysis[Z] at end of the 2007 harvest season taken from upper 10-cm soil beneath the citrus tree canopy and sampled below the soil-compost interface as appropriate.

Compost rate (Mg ha^{-1})	Years applied Rate × yrs	Soil water content (g H_2O g^{-1})	Bulk density (g cm^{-3})	Soil porosity (%)	Organic matter (%)	Root density (g 1000 cm^{-3})
0	0 × 5 yr	0.16 a	1.38 a	48.07 a	3.09 a	2.25 a
28	28 × 1 yr	0.17 ab	1.38 a	48.06 a	3.17 a	2.96 a
56	56 × 1 yr	0.19 b	1.35 a	49.07 a	3.23 a	3.39 a
140	28 × 5 yr	0.19 b	1.31 a	50.41 a	4.14 b	12.45 b

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

respectively.

Grapefruit juice quality was not significantly affected by fertilization and/or compost treatment (P=0.066) in any of the harvest years (data not shown; sample population n=42 per year: 21 experimental units evaluated with two readings per unit per year). This suggests that compost additions will not result in decreased fruit quality. Wiedenfeld and Sauls (2008) furthermore showed that varying the N fertility program did not result in notable differences in fruit quality as measured by the brix: acidity ratio, but annual high N applications can lead to misshaped grapefruit (sheep-nosing), which can result in decreased fruit sales to the fresh market.

Grapefruit yields from FNC in the first growing season (2003) were higher, but not statistically different, than those from FC and UNC trees (**Table 2**). However, by the second growing season and throughout the remaining four consecutive growing seasons (2004-2007) annual application of compost beneath the tree canopy led consistently higher average yields from FC than from FNC trees, but not statistically different. Yields for UNC trees were significantly lower than FNC and FC trees after 2004, providing evidence that continual neglect of a N fertility program will lead to significant economic losses in fruit yield (Sweitlik 1992; Wiedenfeld and Sauls 2008). Similar yield trends were observed under drip and microjet spray irrigated 'Rio Red' grapefruit (Uckoo *et al.* 2008) as yields increased slightly as follows UNC < FNC < FC after years of continual fertilization and compost application. It should be noted that in early spring 2005, the trees received heavy hedging as trees received as much as 40% reduction of the tree canopy, leading to high reductions in yield in 2005 and continued into subsequent years as yields in 2007 were still below that observed in years 2003 and 2004 (**Table 2**). Although tree pruning is a necessary practice in citrus production, it is recommended that instead of heavy hedging every few years annual hedging should be performed periodically removing only a small fraction of the tree canopy to sustain good fruit production year after year.

Results of a secondary investigation looking into the impact of varying compost application amount and duration under grapefruit trees is shown in **Tables 3-4**. Continuously fertilized trees that did not received compost application were compared with trees receiving compost at varying rates and time (1X rate in year 2007, 2X rate in year 2007, and 5X rate [annual 1X rate] from 2003 through 2007). The respective compost treatment rates were 0, 28, 56, and 28 Mg ha^{-1} applied over 5 yr, 1 yr, 1 yr, and 5 yr, respectively, for a final compost amount of 0, 28, 56, and 140 Mg ha^{-1}.

Results of varying compost levels did not significantly affect soil nutrient status, except Mg (**Table 3**). However, even though statistical differences were observed between treatments for Mg^{2+} ions, there was no observable trend correlating compost as a contributing factor for these observed differences. The compost was a good source of P (**Table 1**) and its breakdown and incorporation over the five years of this study led to overall soil P levels more than double that of soil without compost added, although not statistically higher here (**Table 3**). However, it provides evidence that compost use may increase soil P levels and if flood irrigation practices leads to offsite movement of the compost source or from the soil reservoir itself, surface water bodies may have higher P level as an unforeseen consequence. Fortunately, this bark-chip compost did not float or move offsite after flood irrigation and remained in place beneath the tree canopy throughout the study period.

The apprehension to utilize annual applications and increasing levels of compost as it may lead to increased soil salinization was not realized. No statistical differences were observed in EC and sodium adsorption ratio (SAR) among compost and no-compost treated soils (**Table 3**). No statistically significant changes were observed in soil pH as a result of increasing compost application (**Table 3**), but mean soil pH levels were decreasing with increasing compost application which is beneficial for citrus growing in these highly calcareous, heavy clay soils of South Texas. Any rise in soil pH in these elevated pH soils would lead to impaired nutrient availability (Havlin *et al.* 2005), this did not occur in our studies.

The impact of varying compost rate and duration of compost application on soil physical properties and upper rooting density in the top 10-cm below the soil-compost interface is shown in **Table 4**. Gravimetric soil water content was statistically higher under trees receiving 56 and 140 than receiving 0 Mg ha^{-1} compost, providing supporting evidence increased compost application rate (depth) can result in improved soil water retention. The results demonstrate that it may take several years of continuous compost applications to achieve a significant increase in soil organic matter content as trees receiving 5 consecutive years of compost application had statistically higher organic matter content than other treatments (**Table 4**).

Soil BD and porosity are inversely related soil physical properties and indicators of soil quality. Generally the higher the BD (i.e., lower soil porosity), the poorer the soil quality as the soil is typically more compacted. Improved BD and porosity is an indication of improved soil tilth (Tester 1990) and will typically provide an environment that encourages and improves root growth and development (Gregoriou and Rajkumar 1984). Results from this study did not statistically demonstrate whether increased compost application will decrease BD and increase soil porosity. However, mean BD values were decreasing (**Table 4**) and porosity increasing with increasing compost applications and duration,

Fig. 2 Newly formed roots formed within the compost layer and above the soil-compost interface.

suggesting that long term compost use has the potential for positive changes in soil physical properties.

The results of this secondary study on compost rate and duration of application shows a dramatic impact on improving root development within the upper soil surface and within the compost layer itself (**Fig. 2**). Average root density amount increased with increasing compost application rate, with statistically higher levels of root density from under 5 years of consecutive compost applications than other treatments (**Table 4**). Comparing 5 years of annual compost application vs. 5 years with no-compost treatment, root density was 5.5 times higher in the upper 10-cm depth beneath the soil-compost interface than under tree canopies not receiving compost application. As compost application depth increased from a one year 5-cm, one year 10-cm, and 5 consecutive years 5-cm treatments, rooting density increased 32, 51, and 453% over non-composted trees.

In citrus production, the large majority of feeder roots reside within the upper 45-cm depth, thus any improved root growth and development in this region should have a positive impact on fruit yield and total grapefruit production. This is apparently the case as improved average yields were found between 2004 through 2007 (**Table 2**) in composted vs. non-composted 'Rio Red' grapefruit trees. Root development within the compost layer itself formed very rapidly after application and by the end of one year with compost, fine roots were spread throughout the compost above the soil surface (**Fig. 2**). Thus, enhanced root development above and below the soil surface under composted grapefruit trees can contribute to improved soil physical properties and citrus production over the long-term.

Bark-chip compost has a very high C:N ratio and requires soil microbes to utilize (or immobilize) N from the soil N pool to breakdown this C source. Commonly, it has been shown that immobilization of soil N will dramatically lower crop yields as the N is tied up by the soil microbial activity, thus making the N unavailable for plant growth and fruit development. This may have been the case in this study within the first two growing seasons, because crop yields from FC trees were not significantly different from those of UNC trees (**Table 2**). However, this was not a problem from 2005 to 2007 during which higher yields were obtained from FC and FNC citrus trees than from UNC trees.

The research results from this project suggest that annual applications using a high C:N compost source, like bark-chip amendments, can be beneficial for grapefruit production under a sound fertility management plan. Improved root growth and fruit yield were demonstrated using compost soil amendments applied under the tree canopy of flood irrigated 'Rio Red' grapefruit trees. The overall agronomic importance of this research implies that annual additions of bark-chip compost to the soil surface on clay textured soils can lead to increases in soil organic matter that can modify soil physical properties and improving soil water content. This in turn may lead to citrus trees that can better handle period of droughts or tolerate fewer flood irrigation events when water resources become limited. The positive impacts of compost application to high clay containing soils under Citrus trees shown in this study may warrant further investigations where the compost is incorporate into the soil surface and not just placed on the soil surface.

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