Subtropical Plant Science 65:15-23.2013

Alternative Flood Irrigation Strategies That Improve Water Conservation in Citrus

Shad D. Nelson[1], Juan M. Enciso[2], Hugo Perea[2], Mamoudou Sétamou[3], Lhou Beniken [4], Mac Young[5] and Clinton F. Williams[6]

[1]*Department of Agriculture, Agribusiness & Environmental Sciences, Texas A&M University-Kingsville, MSC 228, Kingsville, TX 78363. *Corresponding author: shad.nelson@tamuk.edu; Ph :+1 (361)593-3953*

[2]*Texas A&M University, Texas Agricultural Experiment Station, Weslaco, TX 78596. J-enciso@tamu.edu, hperea@ag.tamu.edu*

[3]*Texas A&M University-Kingsville Citrus Center, 312 International Blvd., Weslaco, TX 78596. Mamoudou.setamou@tamuk.edu*

[4] *N.E. Borlaug Fellow Visiting Scientist, Institut National De La Researche Agronomique (INRA), Kenitra, Morocco. Beniken_lhou@yahoo.fr*

[5]*Texas A&M University, Texas Agricultural Experiment Station, Corpus Christi, TX 78410. amyoung@ag.tamu.edu*

[6] *USDA-ARS, Irrigation & Water Quality Research Lab, Maricopa, AZ 85238. Clinton.williams@ars.usda.gov*

ABSTRACT

Citrus production in Texas is concentrated in the Lower Rio Grande Valley (LRGV). This area is well known for its high quality horticultural crops due to the close proximity to the Rio Grande River and climate. The majority of citrus groves are irrigated in this region using traditional flood (TFd) irrigation practices. The purpose of this study was to compare an alternative form of flood irrigation practice called border flood (BFd) that channels water faster down the tree row. In this research study, water was metered to evaluate total water applied in a replicated field study comparing TFd water use to that of BFd. The water savings results observed in this research study were very similar to on-farm demonstration investigations of water use comparing TFd and BFd irrigators. It was found that using BFd irrigation method saved about 36% of water compared to TFd irrigation practices. This amount of water savings is nearly equivalent to the amount of water saved by current growers using more expensive drip and microjet sprinkers systems. The results of this study suggest that citrus growers can implement modest changes to their cultural practices by raising berms between rows and, in turn, save water.

Additional index words: water use efficiency, water savings, irrigation, best management practices, cultural practices, water conservation.

Citrus production in Texas is primarily confined to three southernmost counties, Hidalgo (ca. 80%), Cameron (ca. 15%), and Willacy (ca. 5%) (Sauls 2008a) located in the Lower Rio Grande Valley (LRGV). Crop production in this region of the state is well known for its high quality horticultural and agricultural crops due to the close proximity to water supplies stemming from the Rio Grande. The majority of horticultural crops require supplemental irrigation, because South Texas is considered a semi-arid climate as defined by UNESCO (1977), despite having a relative high 80% year-round humidity and an average annual precipitation of 56 cm (Enciso and Wiedenfeld, 2005). Rainfall patterns vary yearly, however, it is not uncommon for heavy, sporadic precipitation to occur in September and late October during citrus fruit growth and development (Enciso and Wiedenfeld, 2005). Because south Texas has a high heat index from March through late October, crop production occurs in an environment of high evapotranspiration demand. The infrequent rainfall and seasonal patterns lead to supplemental irrigation to grow crops in the area. Furthermore, drought is a continual concern for this region, as it is not uncommon to have consecutive years with below average to almost no effective rainfall.

Growers utilize irrigation waters supplied from two reservoirs (Amistad and Falcon), which allocate water to the U.S. and Mexico municipalities and farmers along the Rio Grande. Population growth in the LRGV is one of the highest in the U.S. (Census Bureau Reports. 2012) which also increases water use and allocations to municipal supplies from the two reservoirs. Texas experienced its most severe drought on record in 2011 (Allen, 2013), that has extended through 2012 and into 2013. The watershed region along the Rio Grande is often prone to consecutive years of drought, and when water supplies become limited within the two reservoirs, water use restrictions are placed on growers irrigating crops. The most recent occurrence of water restrictions to Texas growers occurred in late 2012 and is continued in 2013 after three consecutive years of region wide drought in 2010 -2012. Consecutive years of 'La Niña' events have steered storm patterns away from South Texas leading to severe water depletions in the two afore-mentioned reservoirs (Guido, 2012). When growers are under water restrictions, they generally have to decrease the acreage of productive cropland.

Growers of annual crops are able to modify and accommodate water restriction periods by not planting. However, growers investing in perennial crops, such as citrus groves, do not have this option. Citrus production in the LRGV requires approximately 110 cm of water annually to raise a crop and maintain good tree health and yield. To keep trees alive and generate profits, South Texas citrus growers cannot avoid irrigating trees. Thus, growers typically will plant trees and wait 7-8 years after setting the grove to produce profitable crops. Moreover, depending on yields and total initial capital outlay, a 9-10 year period may be required to recover all establishment costs. Citrus production is a long investment operation, because citrus trees need to mature to a specific size and age before adequate fruit production occurs. The challenge for citrus growers during periods of drought is maintaining tree survival while managing the number of irrigation events during restrictive watering periods.

The majority of crops in the LRGV, especially citrus groves, are irrigated using traditional flood irrigation practices (Swietlik, 1992; Enciso et al., 2008). Water is allocated to fields through a series of canals from nearby irrigation districts that lift water from the Rio Grande River to canals (Sauls, 2008b). This water delivery system provides relatively low cost water, as pumping costs are very low to lift the water from the river a few feet into the canal head. Water is, then, gravity fed through a canal series to large irrigation pipes (Nelson et al., 2008). Because the cost of water is relatively cheap (ranging between $18 to 45 U.S. per acre-ft [325,851 gallons or 1233.5 m^3]), the incentive to change to a more water-conserving irrigation practice other than traditional large-pan flood irrigation that would save water is not attractive among growers. Changing to an irrigation system design that has the potential to save water, such as drip or microjet spray sprinkler systems, is not currently economically practical according to growers, because the relatively high cost for system installation can range from $1,500 to 2,000 per acre (0.404 hectare) (Enciso et al. 2005). Furthermore, because the irrigation delivery system is built on a canal delivery system, water is only allocated when ordered by a grower and the canal is full. For citrus growers to have a constant water supply for a drip or microjet spray system, they need to take additional land area out of production and build a cistern or small reservoir, where water can be stored and pumped. Irrigation districts often have to charge more for water delivery to micro-irrigation growers, as these farms require more water in the canals than flood irrigators' water needs. This further increases growers' up-front costs and is a disincentive for growers to invest in these systems. Thus, for the majority of growers in South Texas, modifying flood irrigation practices is not currently an option.

The question for citrus producers in South Texas is how to better address irrigation practices using flood irrigation principles to preserve crop production while saving water supplies. Several methods have been used to improve higher irrigation efficiencies with surface methods (Pereira et al., 2002), such as proposed deficit-irrigation for citrus orchards (Tejero et al., 2011). Surge furrow irrigation has been used in cherry orchards achieving applications efficiencies higher than 80% in Washington State (Evans et al., 1990). Irrigation of alternate furrows also conserves water. Alternate furrows partially wet the soil surface and the soil profile, providing additional storage for rainfall. This strategy is best suited for fine textured soils. The use of this strategy reduces water use by 33% in Pullman clay loam soil (Musick and Dusek, 1974) and by 20% in Richfield clay loam (Stone et al, 1982). Traditional flood (TFd) irrigation of citrus covers a large land section at one time by blocking off 3-5 tree rows (Fig. 1). A single TFd irrigation event involves 15 cm of watering covering the ground underneath tree canopies and also the area between tree rows. The area between tree rows is commonly maintained and cultivated throughout the growing season for weed control. The evapotranspiration from the soil surface or weed growth results in field water loss. An alternative flood irrigation practice used by South Texas citrus growers is Border Flood (BFd) irrigation. This method implements raised berms between each citrus tree row, where the berm width ranges from 90-150 cm (Fig. 2). The objective of BFd is to better channel water underneath the tree canopy to tree feeder roots to minimize water loss between tree rows. Irrigation water supplies can be saved using BFd rather than TFd, because the berms located on each side of the citrus tree row will advance water faster down the row.

Nelson et al.(2011) evaluated five years (2005-2009) of grapefruit yield from several growers across the Rio Grande Valley and found that BFd had on average 8.7 Mg ha^{-1} higher yield than TFd irrigators. More importantly, BFd irrigation led to 5.7% more grapefruit classified for the fresh market than the juice market compared to TFd, with the majority going into the 'fancy' fruit class resulting in the greatest profits. The average net farm cash income based on the yields from these five years led to BFd growers receiving \$4,270 yr^{-1} compared to \$2,030 yr-1 from TFd growers (Nelson et al. 2011, Young et al., 2010). Fresh market 'fancy' fruit class brought in \$309/ton and \$103/ton, when compared to only \$12/ton for juice market fruit. Thus, even a small 5.7% fancy class total yield increase can have tremendous financial gains for Rio Grande Valley grapefruit citrus growers after crop raising expenses are subtracted or the additional costs to raise berms between tree rows for BFd irrigation are considered (Nelson et al., 2011).

Rough estimates from these on-farm demonstration projects comparing water use from different citrus growers' farms have shown BFd to save approximately 23 to 30% of water compared to TFd irrigation (Nelson et al., 2011; TWDB, 2010; Young et al., 2010). However, this five year on-farm demonstration and evaluation study did not quantify the amount of water use through accurate water metering, nor provided a replicated scientific study, but compared results from various farms and growers across the LRGV with different soil types and infiltration rates. The objective of this study was to determine if BFd irrigation conserves water compared to TFd irrigation practices under a replicated scientific study. This research study was done in a single field site of the same soil type, where water meters were used to document the exact amount of water used and treatments were replicated for statistical comparison. The focus of this study was not to evaluate yield assessment, as 5 years of yield data from various growers was examined and published previously (Nelson et al., 2011; Young et al., 2010). Rather, this study was limited to a one year assessment of total water application to determine the extent of water saving potential of BFd irrigation over TFd under replicated irrigation events.

MATERIALS AND METHODS

Experimental design. A research irrigation study was performed in April 2011 at the Texas A&M University-Kingsville Citrus Center in Weslaco, TX, to evaluate the amount of irrigation water used under two flood irrigation strategies, TFd and BFd irrigation. The field site contained 23 year old mature Rio Red grapefruit trees (Citrus x paradisi Macfad cv. 'Rio Red') with a tree spacing of 4.6m x 7.3m and planting density of approximately 300 trees ha^{-1}. The total field area where this study was performed was 1.233 ha (90 m x 137 m). Soil texture in the upper 30 cm was heavy with 33% sand, 20% silt and 47% clay; this is typical of the common clay soil types in this region (clayey over loamy, mixed, calcareous, hyperthermic Vertic Haplustolls, and moderately alkaline).

This field site is typically irrigated using conventional 'large-pan' flood irrigation consisting of irrigating three tree rows simultaneously by focusing each irrigation event within raised berms located between pan sections to divide irrigation sections. Each pan section is irrigated using gravity fed water from the canal through underground cement pipes affixed to a single 30 cm diameter, low-profile cement pipe riser located within each pan section. Water was allocated to each treatment area using a 30-cm diameter flexible polypipe tied to an irrigation valve affixed with a paddle wheel water meter with a calibrated numerical circulating counter mechanism to determine water flow out from the valve (Fig. 3). Water meter readings were taken prior to and after each irrigation treatment. Irrigation was allowed to run until a standing water height of 10 cm was reached within the confined area, which is consistent with typically irrigation practices used by LRGV growers. The standing water was allowed to percolate into the soil. In our study, we simulated this practice and compared the similarity of our replicated results -to farm demonstration projects (TWDB, 2010) previously mentioned in the introduction section of this paper.

In our site comparison, the field site was divided into three main blocks, and the two irrigation treatments (TFd and BFd) followed a completely randomized block design (Fig. 4). Berms with a width of 90 cm and height of 25 cm were raised between treatments, such that TFd treatments had berms located on the edges of an area consisting of three tree rows. The BFd treatments had berms located on each side of the single tree row. Irrigation water was confined within each irrigation treatment area by having berms raised at the North and South ends of the field site. The field site had a 1% slope grading from North to South (water pipe outlets were located on the North end of the field, see Fig. 4). Each block was irrigated in succession, first block I, second block II, and finally block III. Because the soil at this research site was a heavy clay and the berm width was 90 cm separating each treatment, we assumed that lateral water movement between treatment areas would not significantly alter total irrigation quantity applied among TFd and BFd treated areas. Two separate water meters, calibrated prior to running the experiment, were used to measure water in the TFd and BFd treatments We recorded the total time necessary for each plot to be completely covered in water and at a level height of 10-cm of water.

Data Analysis. Data was analyzed as a randomized complete block design with a random block effect and a fixed irrigation effect to test the effects of irrigation water quantity over equivalent area. The statistical analysis was carried out using PROC MIXED in SAS (SAS, 2008) with statistical significance among treatment values at α=0.05.

Fig.1. Traditional Large-Pan Flood (TFd) irrigation is practiced in over 80% of south Texas citrus production.

Table 1. Comparison of three rows of mature citrus trees irrigated by large-pan Traditional Flood (TFd) vs. Border Flood (BFd) Irrigation. Numbers in parenthesis represent ± standard error of the mean.

Flood Irrigation Method	Irrigated 3-row Area (ha)	Time to Irrigate Area (hrs)	Water Applied (m^3)	Water Applied (ha*m) [Z]	Water Applied/ha (ha*m /ha) [Y]	Water Savings (%) [X]
BFd (B)	0.24	0.69(±0.12)	391.5	0.039(±0.009)	0.131 a	35.9
TFd (T)	0.30	1.87(±0.29)	610.5	0.061(±0.011)	0.204 b	0.00
Diff. (T-B)	0.06	1.18 (±stder)	218.9	0.022 (±stder)	0.073	na

Z Note: for BFd 0.013 ha*m water was applied per tree row, thus = 0.039 ha*m total over 3 rows. Calculations for BFd treatments equals sum amounts of 3 treatments between 3 separate irrigated tree rows and the irrigated area between raised berms (borders), and compared to the average of three treatments of three irrigated tree rows using TFd of same area dimension.
Y ha*m/ha, calculated based upon water over equivalent area of 3 rows (TFd 0.30 ha).
Eq = [ha*m /0.30 ha]. Different lower case letters among irrigation treatments for water applied/ha represent statistical difference at the 95% confidence level (P=0.0271).
X Percent water savings, calculated as [(T-B)/T] * 100; using liters.

RESULTS AND DISCUSSION

To better compare total water use between BFd and TFd treated areas, an equivalent number of irrigated tree rows needed to be assessed during the data analysis. Thus, the amount of water used from each of the three BFd treatments was used to comprise three irrigated tree rows, and then compared to the amount of water used in the TFd irrigation of three tree rows. Table 1 shows the total irrigated area (in hectares) for the BFd vs TFd for three irrigated tree rows. It is apparent that BFd irrigation using berms between each row reduced the irrigated areas as much as 19% [(T-B)/T = 0.06 ha/0.30 ha; Table 1]. Raising berms between every tree row for BFd significantly reduced the amount of time needed to allocate water to a constant above the ground height to 10 cm, taking an average time of 0.69 h vs 1.87 h comparing BFd to TFd, respectively (Table 1).The total water applied to all three BFd rows in this study was approximately 391.6 m^3, whereas the average of the three TFd irrigation treatments used 610.5 m^3 of water to cover the area of three tree rows. BFd irrigation was shown to statisti-

Fig.2. Example of Border Flood irrigation where berms are raised between citrus tree rows. This occurs between every tree row to channel water underneath the tree canopy.

cally use less water over equivalent land area when compared to TFd at the 95% confidence level (P=0.027) as shown in Table 1. On average, TFd used 218.9 m^3 more water than BFd to irrigate three tree rows, demonstrating water saving of approximately 36% using BFd over TFd irrigation practices (Table 1). This water savings amount resembles 6 year estimates of on-farm demonstration projects in the LRGV (TWDB, 2010), where water quantity values were estimated based upon a 15-cm irrigation event for TFd vs a 10-cm irrigation event for BFd (most farms did not have water metered unlike our current study).

The reduction in time to irrigate BFd compared to TFd is illustrated in Figs 5 and 6, where irrigation was observed in the field and these figures demonstrate how water movement in citrus groves behaves differently between these two flood irrigation methods. In TFd irrigation (Fig. 5), fields are typically irrigated from a single 30-cm outlet valve to irrigate all three rows of trees simultaneously. However, it was observed that water moved between and down the tree rows first before it eventually moved underneath the citrus trees, because cultivation practices such as weed management (Wright et al., 2003) and harvesting events lead to a lower ground elevation between the tree rows compared to immediately under the trees. In the field, we measured as much as a 7-cm elevation difference from the base of the citrus trees to the center of the rows between trees (data not shown). This is understandable because tractors, cultivation, spraying and harvesting equipment travel between the tree

Fig. 3. Flood irrigation outlet pipe valve attached to polypipe and connected to a 30-cm dia. pipe affixed with water metering device.

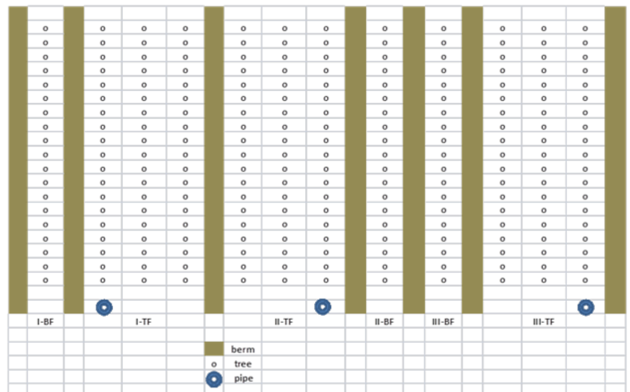

Fig. 4. Field Site Diagram: Field site has three main blocks (I, II, III), and two irrigation treatments, traditional flood (TFd) and border flood (BFd). Water pipe outlets located on north end of field; the field slopes North to South (bottom to top of figure).

Table 2. Amount of excess water applied beyond a 10.2 cm irrigation target depth for traditional flood (TFd) and border flood (BFd) irrigation.

Flood Irrigation Method	Total Water Applied (ha*m) [Z]	Water Applied Per Ha (ha*m/ha) [Y]	Depth Water Applied (cm) [X]	Water Past Target Application (cm) [w]
BFd (B)	0.0392 a	0.131 a	13.1	2.9
TFd (T)	0.0611 b	0.204 b	20.4	10.2

[Z] ha*m; calculated from total water applied as m^3 X 0.0001 = ha*m; where B = 392 m^3 and T = 611 m^3.
[Y] ha*m/m**;** calculated based upon water over equivalent area of three rows under TFd irrigation or 0.30 ha, thus Equation = [ha*m /0.30 ha].
[X] where ha*m/ha = m, then X 100 cm/m to convert to cm water depth.
[W] Excess water past target application equals the total 'depth water applied' minus 10.2 cm. Assuming the desired target amount of water was a 10.2-cm (4-inch) irrigation event.

rows, compacting soil and lowering soil elevation between rows.

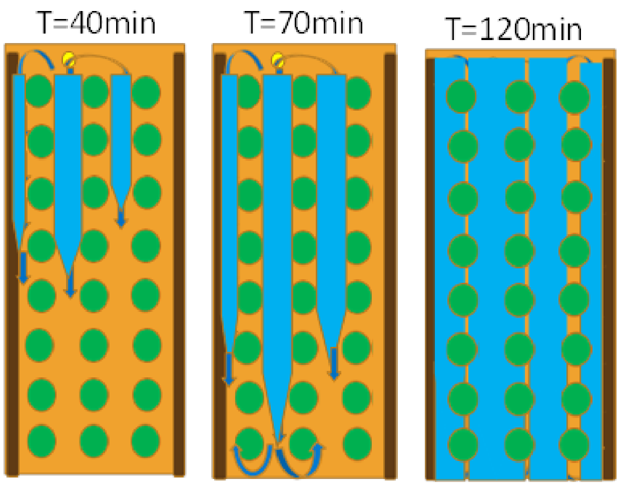

Fig. 5. Simulated overhead view of water movement over time in traditional flood (TFd) irrigated field as observed during this study. Water moved between tree rows and did not move laterally underneath tree canopy until lower soil elevations between tree rows were covered with water.

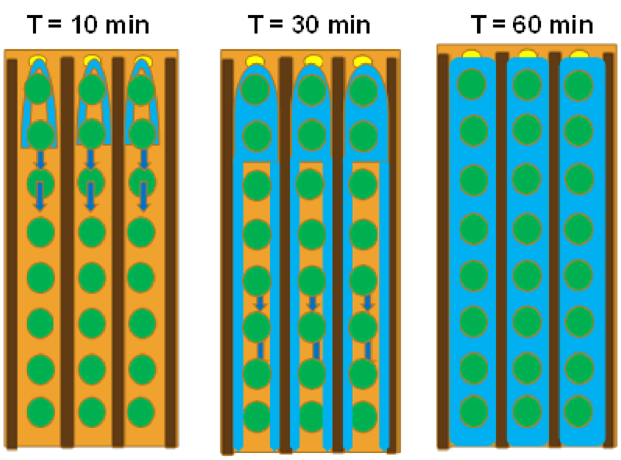

Fig. 6. Simulated overhead view of water movement over time between raised berms over time as observed in border flood (BFd) irrigated rows.

Because the ground elevation is lower between the tree rows than underneath the tree canopy, water has to fill between the tree rows before it can move laterally and irrigate beneath the trees. The time limiting step to rapid irrigation in TFd is ground elevation and topography where substantial additional time is needed to get water beneath the trees where it can irrigate citrus feeder roots. Whereas the time is reduced significantly if wide berms are raised between citrus tree rows (Fig. 6), as berms eliminate the low elevation problem observed between rows in TFd practices and allow water to be channeled faster between the raised berms. Thus, water is allowed to move laterally quicker and underneath the tree canopy where the feeder roots are located.

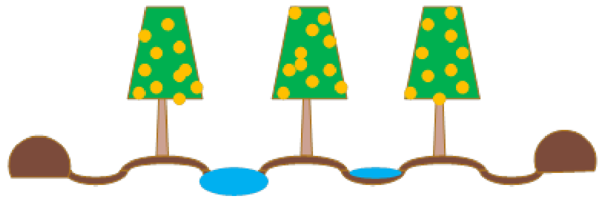

Fig. 7a.

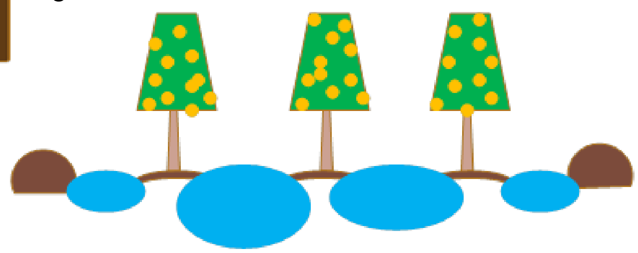

Fig. 7b.

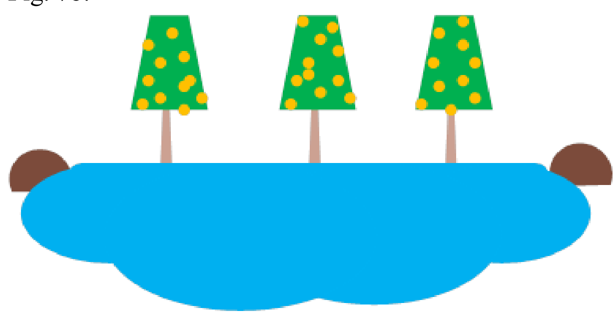

Fig. 7c.

Fig. 7. Traditional flood (TFd) irrigation for citrus irrigates three or more tree rows at the same time confined by outside raised berms (a) but cultivation practices between rows compacts soil at a lower elevation than under the tree canopy. This causes water to move between rows before it fills in under the tree canopies where it is needed (b). Extra time is needed in irrigation to create a 10-cm irrigation event, and as a result often leads to water, fertilizer, and pesticide movement beyond the effective rooting depth of citrus trees (c).

The benefits of BFd over TFd irrigation practices can be further demonstrated through examination of the downward movement of water in the soil as well. As previously discussed, TFd irrigation requires more time to apply water. This leads to water application in regions outside of where the majority of feeder roots are located in the field, thus leading to water loss by weeds and evaporation (Fig. 7a-b). Additionally, the extra time required to maintain a 10-cm water application across the area can lead to excessive water movement beyond the rootzone. This often leads to unanticipated environmental consequences, such as fertilizer (Quinones, et al., 2007) and pesticide (Pimentel et al., 1992) movement into ground water systems (Fig. 7c). Quinones et al. (2007) observed that flood irrigation practices in citrus tree lysimeter studies resulted in increased loss of NO_3-N as N migrated down the soil profile and outside of the effective uptake region by citrus tree roots when compared to other water conserving irrigation practices. Because BFd irrigation lowers the time of application to sustain a 10-cm water application, this can minimize water loss to the non-root zone area of the field and localizes fertilizers and pesticides more effectively in the rooting depth of the tree (Fig. 8a-c). Use of BFd can minimize the loss of fertilizers and soil applied pesticides and lead to improvement in grapefruit pack-out and economic return to the grower, as supported by Young et al. (2010). In their study, BFd irrigators cumulated twice the cash flow of TFd 'Rio Red' grapefruit producers over a ten-year outlook. Young et al., (2010) reported that LRGV BFd citrus growers had higher economic gains and produced better quality fruit with a higher percentage of grapefruit classified for sale to the fresh market when compared to TFd producers.

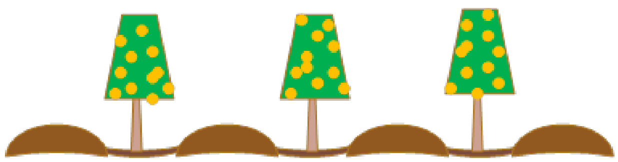

Fig. 8a.

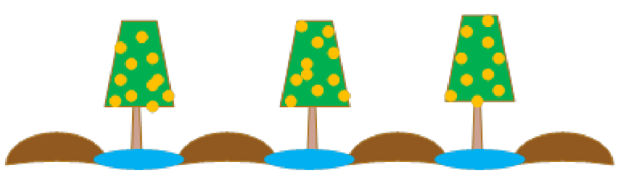

Fig. 8b.

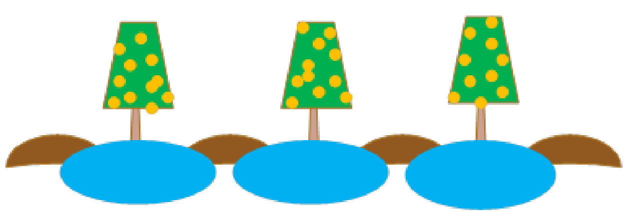

Fig. 8c.

Fig. 8. Raised berms are placed between each tree row in border flood (BFd) irrigation (a). This allows water to be channeled underneath the tree canopy (b). The result allows for a faster allocation of water down the tree rows and minimizes deep percolation of water and chemicals beyond the effective rooting zone (c).

For this study, a 10.2-cm (4-inch) irrigation event was targeted, thus an excess of 2.9 cm and 10.2 cm of water were applied in the BFd and TFd treatments, respectively (Table 2). This excess water would percolate beyond the desired target depth and effective feeder roots of the tree. Thus, changing flood irrigation methods from TFd to BFd could reduce excessive water loss by as much as 7.3 cm (10.2 cm minus 2.9 cm) per irrigation event. More importantly, the potential environmental benefits could be substantial for the LRGV, for water tables tend to be high in this region due to its close proximity to the Gulf of Mexico and high flood irrigation of crops. Sunitha et al. (2012) observed that a single 10 cm irrigation event resulted in significant downward movement of nitrates from fertilizer. As citrus groves in the LRGV are irrigated between 6 to11 times per year, successive flood irrigation events lead to enhanced water movement and increased soil depths over time.

CONCLUSIONS

Citrus growers that change from traditional flood irrigation to border flood irrigation could save a substantial amount of water, as much as 36%. Implementation of this agricultural practice should be highly attractive to both growers and irrigation districts in the LRGV, because it does not require a large start-up cost or change in watering strategies, like microjet spray or drip irrigation systems require. Border flood irrigation can be implemented now, and could help to immediately reduce the amount of total water use needed to irrigate citrus groves. Growers and irrigation districts could increase future water availability for additional acreage.

If all LRGV citrus growers switched to BFd irrigation, then the total potential annual water savings contributed by the Texas citrus industry could be substantial. Over 11,000 ha citrus is grown in the LRGV with the majority using TFd irrigation practices. Switching to BFd irrigation could preserves more water in the reservoirs for future use. Another important aspect of switching to BFd irrigation is the potential benefits to the grower and the environment. The loss of fertilizers and soil applied pesticides moving beyond the rooting depth of trees would be substantially reduced in BFd as compared to current TFd practices. This would minimize environmental contamination, and concurrently retain more fertilizer for citrus roots and lead to improved yields and fruit pack-out.

ACKNOWLEDGMENTS

This project was funded in part by Rio Grande Basin Initiative Task 4 Prime USDA-NIFA Award # 2010-34461-20677; the USDA-NIFA HSI grants program Award # 2009-38422-20111; Texas Water Development Board Agricultural Water Conservation Demonstration Initiative funds, and the Norman E. Borlaug Fellowship Program. We thank the TAMUK Citrus Center farm crew and graduate students for their labor and time in data collection during this study, and statistician Dr. David Wester for statistical data analysis.

LITERATURE CITED

Allen, T. A. 2013. The South Texas drought and the future of groundwater use for hydraulic fracturing in the Eagle Ford shale. St. Mary's Law J. 44:487-527

Census Bureau Reports. 2012. Texas Dominates List of Fastest-Growing Large Cities Since 2010 Census, US Census Bureau Reports. June 28, 2012. http://www.census.gov/newsroom/releases/archives/population/cb12-117.html

Enciso, J.M., J.W. Sauls, R.P. Wiedenfeld and S.D. Nelson. 2005. Irrigation of citrus in Texas-A Review. Subtrop. Plant Sci. 57:16-22.

Enciso, J., and B. Wiedenfeld. 2005. Irrigation guidelines based on historical weather data in the Lower Rio Grande Valley of Texas. Ag. Water Manage. 76:1-7.

Enciso, J., J.W. Sauls, R.P. Wiedenfeld, and S.D. Nelson. May 2008. Impacts of irrigation on citrus in the Lower Rio Grande Valley. Texas AgriLIFE Extension Fact Sheet B-6205. pp 14.

Evans, R.G., E.L. Proebsting, M.O. Mahan. 1990. Daily furrow irrigation in orchards. Appl. Eng. Agric. 6:175-179.

Guido, Z.. 2012. The Cost of Dought on the Rio Grande. NOAA Climate.Gov, Sciences and Services for Society. NOAA Climate Portal. Climate Watch Magazine. Nov. 13, 2012. http://www.climatewatch.noaa.gov/article/2012/the-costs-of-drought-on-the-rio-grande

Musick, T.J. and D.A. Dusek. 1974. Alternate furrow irrigation of fine textured soils. Trans. ASAE. 17:289-294.

Nelson, S.D., R.M. Uckoo, H. Esquivel, J.M. Enciso, and K. Jones. 2008. Compost effects in ‘Rio Red’ grapefruit production on a heavy textured soil. Dynamic Soil, Dynamic Plant. 2(Special Issue 1):67-71.

Nelson, S.D., M. Young, J.M. Enciso, S.L. Klose, and M.Setamou. 2011. Impact of irrigation method on water savings and ‘Rio Red’ grapefruit pack-out in South Texas. Subtrop. Plant Sci. 63:14-22.

Pereira, L.S., Oweis, T., Zairi, A., 2002. Irrigation management under water scarcity. Agric. Water Manage. 57:175–206.

Pimentel, D., H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A.D. Horowitz, and M. Amore. 1992. Environmental and human costs of pesticide use. Biosci. 42:750-790.

Quinones, A., B. Martinez-Alcantara, and F. Legaz. 2007. Influence of irrigation system and fertilization management on seasonal distribution of N in the soil profile and on N-uptake by citrus trees. Agric. Ecosys. Environ. 122:399-409.

SAS Institute Inc. 2008. The SAS system for Windows, Release 9.2. The SAS Inst., Cary, N.C.

Sauls, J.W. 2008a. Texas Citrus and Subtropical Fruits. The Texas Citrus Industry. Texas AgriLIFE Extension Service-Texas A&M University (TAES-TAMU). Updated January 2008. http://aggie-horticulture.tamu.edu/citrus/12286.htm (verified March 2013).

Sauls, J.W. 2008b. Texas Citrus and Subtropical Fruits. Citrus Water Management. Texas AgriLIFE Extension Service-Texas A&M University (TAES-TAMU). Updated January 2008. http://aggie-horticulture.tamu.edu/citrus/L2307.htm (verified March 2013).

Stone, J.F., H.E. Reeves and J.E. Garton. 1982. Irrigation water conservation by using wide-spaced furrows. Ag. Water Manage. 5:309-317.

Sunitha, V.V., B., Reddy, and M. Reddy. 2012. Groundwater contamination from agro-chemicals in irrigated environment: field trials. Adv. Appl. Sci. Res. 3:3382-3386.

Swietlik.D. 1992. Yield, growth, and mineral nutrition of young 'Ray Ruby' grapefruit trees under trickle or flood irrigation and various nitrogen rates. J. Amer. Soc. Hort. Sci. 117: 22-27.

Tejero, I.G., V.H.D. Zuazo, J.A.J. Bocanegra, and J.L.M. Fernandez. 2011. Improved water-use efficiency by deficit-irrigation programmes: Implications for saving water in citrus orchards. Scientia Hort. 128:274-282.

Texas Water Development Board. 2010. Agricultural Water Conservation Demonstration Initiative 2010 Annual Progress Report. Harlingen Irrigation District. https://www.twdb.texas.gov/conservation/agriculture/demonstration/doc/ADI_2010.pdf

United Nations Educational, Scientific, and Cultural Organization (UNESCO). 1977. World Map of

Desertification. U.N. Conference on Desertification. Conference 74/2. FAO. Rome, Italy.

Wright, G.C., W.B. McCloskey, and K.C. Taylor. 2003. Managing orchard floor vegetation in flood-irrigated citrus groves. HortTechnol. 13:668-677.

Young, M., S. Nelson, S. Klose, and J. Enciso. 2010. Assessing irrigation methods based on grapefruit pack-out in the Lower Rio Grande Valley. Texas AgriLife Extension. FARM Assistance Focus 2010-4. pp. 1-3.