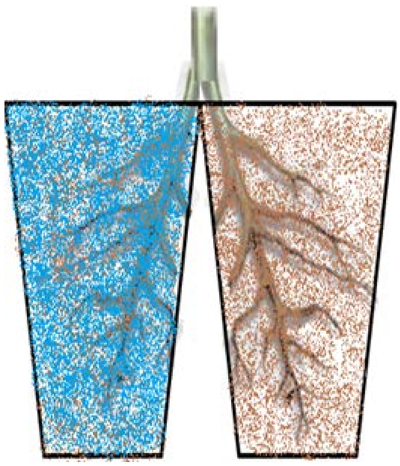
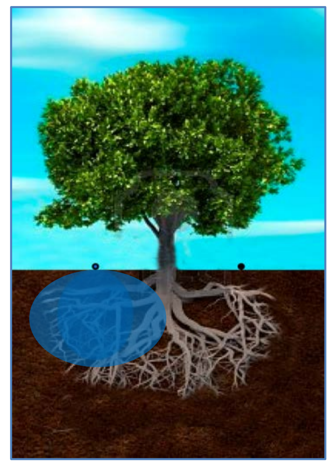
Developing and Promoting Water Saving Irrigation Strategies to Increase Water Use Efficiency in Citrus





Report

by

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Texas Water Development Board

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August 2016

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Report

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Definition of Terms:

Drip:

Irrigation performed using drip emitters where ach drip emitter typically spaced every twelve inches apart. Typically represents one single linear line set along a linear line, and placed approximately 6 inches at the side of the citrus tree trunk.

Dual-line drip:

A drip irrigation system configuration using two main drip lines placed at opposite sides along the citrus tree, used to increase water application system uniformity. Lines are typically placed 1 ½ to 2 feet away from the tree trunk.

Microsprinkler spray:

Irrigation performed using microsprinkler jet spray emitter that rotate 360 degrees, placed on a 12 inch tall riser and. Typically only one microsprinkler spray unit per tree set about one foot away and to the side of the citrus tree trunk. This system is sometimes used by growers to abate freezing during winter months.

Partial rootzone drying:

Partial rootzone drying (PRD) is an irrigation strategy that exposes approximately half of the root system on either side of the tree canopy to drying soil conditions while the other half of the root system is irrigated to full irrigation. This results in a spatial separation of roots under drying conditions, while the other half of the roots are under wet conditions. The system generally requires a dual-line drip system established, where the lines are turned on and off and alternated between irrigation events.

Evapotranspiration:

Water loss from the ground via evaporation, combined with water loss from the leaf surface (transpiration). These two processes of water loss occur simultaneously in the field when crop growth is present.

Texas Water Development Board

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1 Executive summary

Partial rootzone drying (PRD) is an irrigation technique that utilizes the targeting of water to half of the rooting zone of a plant that in turn helps to regulate a reduction in stomatal opening in leaves and lead to enhanced water conservation. Researchers at the Texas A&M University-Kingsville Citrus Center under funding direction by the Texas Water Development Board examined partial rootzone drying impacts on Rio Red grapefruit trees at the greenhouse and field scale in replicated research studies. The results of a greenhouse study focused on partial rootzone drying in tandem with deficit irrigation at varying evapotranspiration regimes found that young citrus trees maintained at 70% evapotranspiration under PRD treatments saved 16 to 36% water and had equivalent growth and development as non-PRD trees watered at 100% ET. A two-year field scale study performed on mature Rio Red grapefruit trees found greater water conservation results as citrus raised under PRD-drip irrigation had 43 to 47% water savings compared to dual-line drip irrigated trees. The potential water saving is substantial when compared to the south Texas standard method of irrigation by large-pan flood irrigation. The before improvements average irrigation water use by conventional flood irrigation is 5.17 acre-feet per acre per year, whereas, PRD-treated trees were able to raise citrus on no more than 0.48 acre-feet per acre of irrigation water per year. The average potential water savings was 4.85 acre-feet per acre per year and water saving percentage of 94% when compared to large-pan flood irrigation practices currently performed throughout the Lower Rio Grande Valley. The PRD study results provide strong evidence that during drought that growers can raise citrus with low quantities of water while sustaining citrus yield and tree health, at least over two consecutive years of extreme drought.

2 Introduction

The objective of this project was to develop and promote a new irrigation strategy to improve water use efficiency in citrus orchard projection in the Lower Rio Grande Valley of south Texas. Citrus orchard irrigation in south Texas is primarily centered upon flood irrigation practices, with less than ten percent of citrus growers using low flow irrigation system, like drip irrigation, that have been employed in water scare regions around the world to grow citrus. The region of south Texas is prone to consecutive years of drought, and it is not uncommon for water supplies to limited during these years. During seasons of extreme drought and heavy water restrictions, this project aimed to evaluate managing water use at the both the bench and field scale to assess the reliability of using partial rootzone drying techniques to grow citrus. A dual-line drip irrigation system was employed at the field level in order to manage irrigation of one half of the citrus root system, while keeping the other half of the tree's root system under drying and water stress conditions. The partial rootzone drying technique was compared to full irrigation of the tree's root system using both dual-line drip and microsprinkler spray irrigation systems.

3 Project summary

This report summarizes the project activities as divided into three main components:

- Developing a demonstration field experiment
- Assessing the effectiveness of the treatments
- Promoting and dissemination of results

3.1 Developing a demonstration field experiment

A two-acre field demonstration site consisting of mature 'Rio Red' grapefruit trees was established in summer 2012 at the Texas A&M University-Kingsville Citrus Center South Farm with several replicated plots of microsprinkler spray and dual-line drip irrigation treatments (Figure 1-1). The demonstration site had three irrigation treatments: micro-jet sprinkler spray irrigation, normal dual-line drip irrigation, and partial rootzone drying (PRD) irrigation using a dual-line drip system. A graduate student, Ms. Beatriz Contreras, and research technician, Ms. Ayako Kusakabe, were selected to work on this partial rootzone drying experimental demonstration project. The irrigation system was retrofitted during summer and early fall 2012 months to the new irrigation systems, whereas, trees were flood irrigated at this site for several years up through December 2012 harvest. Starting January 2013, Beatriz Contreras initiated the drip, microsprinkler and drip partial rootzone drying treatments. These system changes were necessary to evaluate impact on the 2013 harvest.

This field demonstration site was selected due to close proximity to an established cistern to hold water for continual irrigation throughout the year, regardless of drought conditions, and a pump house equipped with a sand filtration system to clean up the water prior to moving the water into and through drip and microsprinkler lines to prevent emitter pugging. Trees at this site were established in the late 1980s and are fully mature 'Rio Red' grapefruit planted on sour orange rootstock. The site was established with three irrigation system treatments: 1) Drip using dual-line drip, with irrigation events occurring in both lines (Figure 2-1); 2) Drip using dual-line drip where one irrigation line was turned off with the other irrigation line was turned on during irrigation events lines (Figure 2-2); and 3) Microsprinkler spray irrigation equipped with 360 degree rotating spray (Figure 2-3).

This Citrus Center 'South Farm' demonstration field site was located less than 3 miles south of the Texas A&M University-Kingsville Citrus Center, and established as a randomized block design (Figure 3-1). It was hoped and originally planned to have another nearby demonstration site to be located in a 50-acre farm in Monte Alto, TX, only 18 miles north of the TAMUK Citrus Center in Weslaco, TX (Figure 4-1). However, due to extensive drought in the Delta Lakes irrigation district during 2012-2014, intense water restrictions did not allow for irrigation water to be allocated to this site during the evaluation period. The Monte Alto site (Figure 5-1) was not equipped with an on-site long-term water storage facility, like the cistern located at the South Farm site. This illustrates the importance of a water holding facility, like a cistern, to serve as a mean to retain water for irrigation during times of extreme drought conditions. Thus, no data was collected during this period from the Monte Alto farm site as originally planned in the proposal. Regardless, the results of partial rootzone drying studies at the South Farm site in Weslaco are very positive and emphasize the goals and achievement hoped for when the authors proposed this research project.

A third demonstration site was originally planned with a private citrus company to evaluate PRD under flood irrigation practices (including flood partial rootzone drying, narrow border flood, and traditional flood irrigation). However, due to unavoidable complications this project objective had to be abandoned for the following reasons: a) In 2013, the designated demonstration site was selected and soil preparation to assess mature grapefruit trees under flood irrigation, but severe water restrictions in 2013 at the site prevented use of the site for irrigation in years 2013 and 2014; b) then above average annual rainfall fell throughout the 2015 growing season that prevented the need for irrigation, thus an on-farm irrigation assessment for a 'drought-related' study using partial rootzone drying methods was not possible.

Thus, the on-farm findings of this grant are confined to the replicated research/ demonstration site located at the Citrus Center. The results obtained in 2013 and 2014 during cropping seasons at the Citrus Center provided sufficient drought-stress with excellent data and results to provide us with a strong indication of the potential use and success of partial rootzone drying in citrus production during normal and drought-prone rainfall years. Once normal or above average rainfall patterns return as that of 2015, the need for a partial rootzone drying system is only useful when supplementary irrigation is necessary to sustain tree health and yield.

Additional greenhouse studies were performed by a graduate student, where the focus of this research was to explore the water uptake and distribution of water in young citrus trees in pots. Water application could be quantified, and impacts of water stress could be evaluated.

3.2 Assessing the effectiveness of the treatments

Preliminary investigations into the viability of partial rootzone drying techniques on young Rio Red citrus trees was first performed in a greenhouse setting to acquire preliminary data. Partial rootzone drying employs a technique of tricking the plant into thinking that water is limiting and the plant in turn sends a signal plant hormone called abscisic acid (ABA) to close or partially close leaf stomata (Figure 6-1). The aim of these studies was to evaluate whether splitting the root system of young trees and placing half of the root system into separate pots would lead to decreased water loss (Figure 7-1). Results from the greenhouse partial rootzone drying studies showed that young trees with split rooting systems under deficit-partial rootzone drying treatment with 30% available soil water depletion exhibited water use efficiency equivalent to trees irrigated at 100% evapotranspiration. Although stem dry weight was reduced in 30% available soil water depletion deficit-partial rootzone drying trees, the total tree growth and root length in all partial rootzone drying -treated trees remained the same. Furthermore, all partial rootzone drying-treated trees saved between 16 to 36% water compared to control trees maintained at 100% evapotranspiration. These results were accepted for publication and will be printed in Contreras-Barragan, et al. 2015 publication in the Acta Horticulturae journal. The results of this work demonstrated the potential for a replicated field trial where partial rootzone drying irrigation techniques could be evaluated during years of extreme drought and low rainfall. Below average rainfall years in South Texas were experienced in the year 2013 and 2014 where a field level evaluation of partial rootzone drying was evaluated.

The plot site located at the Citrus Center South Farm includes trees under dual-line drip irrigation with the innovative strategy suggested in this project, namely partial rootzone drying (PRD Drip), where trees are irrigated using regular dual-line drip irrigation (Drip), and Microsprinkler spray irrigated trees. Data was collected on citrus yield and fruit quality parameters for the second year harvest in December 2014 so that comparisons could be made to results in the first year harvest of December 2013.

Rio Red grapefruit yield as shown in Table 1-1 was not significantly different at the end of the first harvest season (ranging from 143-159 kg tree^{-1} or 315-351 lb tree^{-1} in 2013); however, significantly different yields among irrigation treatments were evident in the second year 2014 as evidenced by total overall yield highest in partial rootzone drying drip irrigated trees, followed by Drip, then Microsprinkler spray (163, 132, and 107 kg tree^{-1} or 359, 291, and 236 lb tree^{-1}, respectfully). This provided evidence that during years of consecutively low rainfall that the employment of partial rootzone drying drip irrigated trees could result in 23% and 53% higher grapefruit citrus yield than Drip and Microsprinkler spray irrigated trees, respectfully.

Based on the total irrigation water applied over the two-year experiment, mature grapefruit trees under Partial Rootzone Drying Drip (PRD Drip) irrigation saved 1.72 inches (in 2013) and 4.29 inches (in 2014) of irrigation water per tree, when compared to a typical drip Dual-line Drip irrigation system (Table 2-1). The amount of water saved each year is dependent upon variance in total rainfall and how well the partial rootzone drying drip is managed year to year. The water saving was 47% in 2013 and 42% in 2014 when comparing partial rootzone drying drip to dual-line drip irrigated trees.

The partial rootzone drying drip treated trees resulted in statistically similar yield in both years compared to the dual-line drip trees, whereas the Microsprinkler spray treated trees were statistically lower in yield for the second season in 2014. The comparison of crop water use efficiency (WUE_{crop}; Table 1-1) among different irrigation treatments clearly showed that the partial rootzone drying drip irrigation was the most effective strategy during both years, while the dual-line drip and microsprinkler spray irrigation methods had similar crop water use efficiency. Full detailed results of this study will be found in Kusakabe, et al. (2016) publication in Ag Water Management Journal.

More importantly, the results from the field partial rootzone drying study not only showed improved water savings in total irrigation water applied in years 2013 and 2014 compared to the other irrigation treatments, but results also showed that partial rootzone drying irrigation did not negatively affect vegetative growth or flowering, which led to improved fruit set over drip and microsprinkler spray irrigated trees which translated into the higher yield observed in 2014.
It should be highlighted that the amount of water amount saved by employing partial rootzone drying using a dual-line drip system at the on-farm field level can be impressive. To put these results into greater water savings perspective, the total amount of water saved employing partial rootzone drying drip during years of extreme drought was equivalent to a water application depth of 1.72 inches water per tree in 2013, and 4.29 inches of water depth per tree in 2014 when

compared to dual line drip irrigation (Table 2-1). These results were calculated based upon the canopy size of a mature Rio Red grapefruit tree having an eight foot radius. Taking the total irrigation applied from Table 1 (L $tree^{-1}$ converted to cm^3 $tree^{-1}$) for each year divided by the tree canopy area (8 foot tree canopy radius converts to an area of $0.187x10^6$ cm^2), then the total amount of irrigation water depth applied can be determined.

Dr. Shad Nelson and Mr. A. Mac Young published results of a multi-year assessment of on-farm irrigation water use in Rio Red grapefruit trees from the Lower Rio Grande Valley (Nelson, S., M. Young, S. Klose, and J. Enciso. Feb. 2013. Narrow-border flood for citrus: Saving water while improving yields and net cash farm income. On-Farm AWEsome FACTS on agricultural water conservation and efficiency, Texas Project for Ag Water Efficiency, TexasAWE.org. Report #OF-02-13). They demonstrated evidence that Dual-line Drip irrigators saved an average of 14 inches of water applied compared to traditional flood irrigators. Although this is significant water savings for the citrus industry, the findings of this Partial Rootzone Drying study are even more illuminating seeing as yields can be sustained in extreme drought years for at least a couple of years until normal rainfall patterns return to the Lower Rio Grande Valley. Nelson et al. (2013) report estimated that it takes 45 inches of water applied via rainfall and irrigation to raise a good citrus crop each year. However, the results of this PRD Drip study show that a good citrus crop can be sustained with substantially lower amounts of water (1.72 to 4.29 inches of water per tree per year; Table 2) if irrigation specifically targets the citrus rootzone and employing partial rootzone drying techniques that capitalize on the citrus trees' physiology to regulate water loss control at the leaf stomatal level. This raises questions as to the long term viability of citrus survivability under such intense water limiting application processes. Such as, how many years can PRD Drip methods are sustained without significant tree and yield declines. Unfortunately, this study is limited to only a two year seasonal window to assess PRD Drip irrigation over consecutive years of drought, because by 2015 the rainfall patterns in the Lower Rio Grande Valley completely changed.

Results from the field experimental site was projected to continue into its 3rd harvest year (2015), however, due to high intensity, and repetitive rain storms throughout much of 2015, the PRD irrigation system was not been functional or needed. By the end of December 2015, over 41 inches of total rainfall had fallen at the Citrus Center in 2015, which is 17 inches above normal average rainfall for South Texas. Thus, the on-farm PRD study was not able to be continued at this site due to extensive rains throughout the growing season. But the results from the first two years have provided sufficient evidence that partial rootzone drying using a dual-line drip system can be very effective during lower rainfall years.

Perhaps the greatest indicator of the potential for partial rootzone drying as a water conserving technique for citrus production is when it is compared to what has already been demonstrated at the field scale in other studies. Nelson et al. (2013) estimated that alternative water saving practices at the on-farm level for mature citrus, such as microjet sprinkler spray, single- and dual-line drip, and narrow-border flood irrigation, would save a calculated 11, 14, and 21 inches of water per acre, respectively, when compared to traditional flood irrigation practices in the Lower Rio Grande Valley. Their estimates concluded in a potential industry wide water savings of 26,000 to 49,000 acre-feet water per year (Table 3-1). However, the partial rootzone drying drip research results performed in this field study on mature Rio Red grapefruit trees target the rootzone very directly, and in two consecutive years the maximum amount of water used was a

5.76 inch water depth over the canopy area of each tree. Citrus growers typically ensure that a total of 45 inches of water is applied to each tree per year to maintain a crop, but partial rootzone drying drip irrigated trees were sustained with less than 6 inches of irrigation water and less than 15 inches of cumulative rainfall during the calendar year. Thus, citrus production during years of intense drought conditions can be achieved, at least over a couple years, using partial rootzone drying methods if growers establish a dual-line irrigation system and intensively manage the water applications throughout the drought period. This current study has shown a reduction in the amount of water applied through intensive irrigation management that specifically targets water application to the rootzone tree canopy area only using either microjet sprinkler or dual-line drip irrigation system methods.

The impactful results of this study are best placed into perspective when compared to previous, yet recent on-farm irrigation water use data by citrus producers in the Lower Rio Grande Valley. Table 3-1 shows the results published from a TexasAWE.org 10-year water conservation demonstration site study comparing three alternative irrigation methods compared to the industry standard 'Large-Pan Flood' irrigation practice. In this on-farm study, it was found that average flood irrigation led to average annual cumulative irrigation depth of 62 inches per acre, equivalent to 5.17 acre-feet per acre per year. For the Lower Rio Grande Valley citrus industry, this **5.17 acre-feet is the average industry 'before improvements volume'** of irrigation water applied per acre per year. Thus, for a 28,000 acre citrus industry where large-pan flood irrigation is by far the norm, this equate to approximately 144,750 acre-feet water per year.

In comparison to traditional large-pan flood irrigation practices, south Texas citrus production under using a dual-line drip irrigation partial rootzone drying approach led to the highest water savings of all irrigation methods with an average of 3.8 inches (< 0.32 acre-feet) irrigation water applied per year (Table 3-1). This is a water savings of 58.2 inches (4.85 acre-feet) of irrigation water/acre/year over large-pan flood irrigation practices. For a 28,000 acre citrus industry, this partial rootzone drying **(PRD) technique equates to a water savings of 135,000 acre feet annually** compared to traditional large-pan flood irrigation methods for the South Texas citrus growing region.

The results of this study do not yet support continual, year after year, employment of partial rootzone drying for the long term. But, our findings provide substantial evidence that citrus trees in the Lower Rio Grande Valley can survive on very low water amounts for a least a couple consecutive irrigation years before yield drop off and significant tree decline occurs. Regardless, this may be sufficient time for citrus producers to overcome periods of intense drought and water restriction such that they can keep their investments alive and productive until the rains return and fill up the reservoirs. Lastly, it should be noted that other alternative irrigation designs could potentially be employed that simulate partial rootzone drying, such as establishing microsprinkler irrigation systems to have every other riser down the tree row located on different irrigation lines and alternating irrigation events among lines over time. One of the prohibitive conditions to rapid adoption of partial rootzone drying techniques by citrus producers in the Lower Rio Grande Valley is a limited number of producers currently using drip or microjet sprinkler spray technology across the Valley. The added expense of purchasing the irrigation system, its installation, maintenance and the need for a cistern or land set aside for a water holding pond will hinder rapid adoption as long as the cost of water is relative cheap and the delivery of water is based upon the unpressurized canal-based irrigation system that is prevalent valley wide.

3.3 Promotion and dissemination of results

Ayako Kusakabe, a research associate employed by this project, has been able to finalize two peer-reviewed publications; one from the early greenhouse work looking into the physiological movement of water through young citrus trees under partial rootzone drying with split rooting systems located in separate pots (B. Contreras-Barragan, et al., 2015 entitled: Understanding partial rootzone drying in citrus, accepted for publication in Acta Horticulturae). The results from one pot study where roots were split in two and placed into separate pots, such that one-half of the root system was in one pot receiving water, and the other half was in a pot without water added. The findings provided evidence that water laced with a dye showed the dye moving from the root system in soil with water up and transferring into the root system of the pot without water added. Furthermore, young trees under partial rootzone drying and reduced water application by 30% below normal evapotranspiration requirements showed good tree growth, leaf function, root hydraulic conductivity, with up to 36% water savings compared to trees irrigated at 100% evapotranspiration.

In another publication taken from the thesis of Beatriz Contreras-Barragan that summarizes the field site partial rootzone drying study findings from years 2013 and 2014 (A. Kusakabe, et al.; 2016 entitled: Partial rootzone drying reduces water use efficiency and maintains growth, flowering, yield, and fruit quality in citrus, currently in review for publication in the Journal of Ag Water Management). The results of this work were discussed in detail previously and summarized in Tables 1-1 and 2-1. Ayako Kusakabe worked in concert with Master of Science graduate student Beatriz Contreras-Barragan, in which Beatriz finished her M.S. degree in Plant and Soil Science in December 2014 and Thesis entitled: Evaluation of Water-Saving Irrigation Strategies in Citrus, afterwards she returned to live in Mexico. Ayako Kusakabe has continued on to start a PhD program at the University of Arizona starting September 2016.

Dr. Shad Nelson was invited to present upon the results of this study to several industry representatives, citrus growers and to members of the scientific community over the past several years. The response has been overall positive, and most growers see this method as an alternative during time of extreme drought as a water saving strategy while maintaining tree health and fruit production quality. Citrus growers in regions where drip irrigation is commonly employed and experiencing intense water allocation restrictions like California can readily employ these partial rootzone drying techniques with minimal expense. However, adoption of dual-line drip partial rootzone drying in the Lower Rio Grande Valley of Texas is expected to be slow by growers. The expense of establishing the drip system and having irrigation districts change their delivery systems in order to run water to growers more frequently is a deterrent to employing this technology. Furthermore, for regions like South Texas that rely on delivering a large volume of water over a short period of time in a canal based delivery system, growers will need to invest in a cistern or holding pond to fill up a sufficient amount of water to use at their discretion to drip irrigate their trees.

3.3.1 Promotional citations

Promotional open-access to the results of this work can be found in publications that are listed on the Texas A&M University Citrus Center website http://kcc-weslaco.tamu.edu/publications.html and in a newsletter on the www.TexasAWE.org website.

In the pages that follow, there are a list of accomplishments and presentations provided for public access to disseminate and promote the findings of the partial rootzone drying project as funded by the Texas Water Development Board:

Peer-Review Journal Publications: **Open-access when published to Scientific Community**

Contreras-Barragan, B.A., A. Kusakabe, J.C. Melgar and S.D. Nelson. 2016. Understanding partial rootzone drying in citrus. Acta Horticulturae. 1135:123-130 (http://dx.doi.org/10.17660/ActaHortic.2016.1135.15)

Kusakabe, A, B.A. Contreras-Barragan, C.R. Simpson, J. Enciso, S.D. Nelson, and J.C. Melgar. 2016. Partial rootzone drying reduces water use efficiency and maintains growth, flowering, yield, and fruit quality in citrus. Ag. Water Management. (Paper Submitted 2/1/2016).

Professional Newsletters: **Open to Industry and Public Community**

Dr. Shad Nelson highlighted the PRD water savings work in a Fall 2014 newsletter publication: Texas AWE Reporter, Vol. 2, Issue 2. Partial Root-Zone Drying Augments Water-Savings in Citrus Production. (Newsletter, Fall 2014). http://www.TexasAWE.org (verified active: May 21, 2016) http://90f3eb0b2fdb0c2c614c-cb692d0c0e3f92e6a6ecca747ca56b5c.r16.cf2.rackcdn.com/c7434a6a64ef4c2fa7281a5bdd884db1.pdf

Professional Meeting Abstracts and Presentations: **Open to Industry and Public Community**

Beatriz A. Contreras Barragan. Dec. 2014. Title: Evaluation of Water-Saving Irrigation Strategies in Citrus. December 2014. Thesis Defense. Chair: J.C. Melgar, Co-Chair: S.D. Nelson.

S.D. Nelson, C. Simpson, and M. Young. Oct 1, 2015. On-Farm Orchard Management Strategies the Improve Water Sustainability & Economic Profitability for South Texas. Texas Ag Industries Association, South Texas Regional Meeting, Kingsville, TX. (Invited talk).

S.D. Nelson, J. Melgar, B. Contreras-Barragan, A. Kusakabe, M. Young, J. Enciso, C. Simpson, and M. Setamou. Dec. 9, 2015. Strategies for Water Conservation: Overcoming the 'Hydro-illogical Cycle'. Water Workshop and Forum, Santa Cruz Irrigation District #15 in partnership with TAMUK & Texas Dept of Agriculture. Weslaco, TX. (Invited talk).

S.D. Nelson, M. Young, J. Enciso, and T. McLemore. May 19-20, 2015. Irrigation Management Practices in Citrus Groves for Advancing Sustainable Water Supplies for South Texas. LRGV 17th Annual Water Quality Management & Planning Conference. South Padre Island, TX. (Invited talk).

Contreras-Barrangan, B., A. Kusabe, J.C. Melgar, and S.D. Nelson. Partial-Rootzone Drying an Effective Water Saving Strategy in Citrus. Subtropical Agriculture & Environments Society Annual Conference. Feb. 21, 2014. Weslaco, TX. (poster, 1st place winner).

Nelson,S.D., J. Enciso, and M. Young. Proven Irrigation Strategies that Improve Water Conservation in Citrus. Grande Basin Initiative Meeting. April 15-16, 2013. San Antonio, TX (talk).

Professional Meeting Abstracts and Presentations: **Open to Scientific Community**

Contreras-Barragan, B.A., A. Kusakabe, J.C. Melgar, and S.D. Nelson. Nov. 10-14, 2014. Understanding partial rootzone drying in citrus. International Biotechnology Conference. Shizouka, Japan. (poster).

Nelson, S.D., B.A. Contreras-Barragan, A. Kusakabe, and J.C. Melgar. Efficient use of partial rootzone-drying in citrus in semiarid areas. 29th International Horticultural Congress, Brisbane, Australia. Aug. 17-22, 2014 (talk).

Contreras-Barrangan, B., A. Kusabe, J.C. Melgar, and S.D. Nelson. Partial-Rootzone Drying an Effective Water Saving Strategy in Citrus. American Society of Horticultural Science Annual Meeting. July 28-30, 2014. Orlando, FL. (invited talk)

Contreras-Barrangan, B., A. Kusabe, J.C. Melgar, and S.D. Nelson. Partial-Rootzone Drying an Effective Water Saving Strategy in Citrus. Javelina Research Symposium. April 29, 2014. Kingsville, TX. (poster).

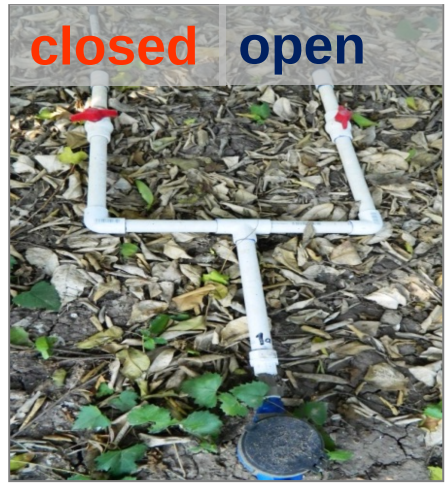
Thesis Publication: **Open-access via Texas A&M University-Kingsville library system**

Thesis: Beatriz A. Contreras Barragan. Dec. 2014. Title: Evaluation of Water-Saving Irrigation Strategies in Citrus. December 2014. Thesis Chair: J.C. Melgar, Co-Chair: S.D. Nelson.

3.4 Figures

Figure 1-1. Map of the Citrus Center South Farm in Weslaco, Texas is where the partial rootzone drying demonstration field site was located.

Dual-line drip



Drip-PRD

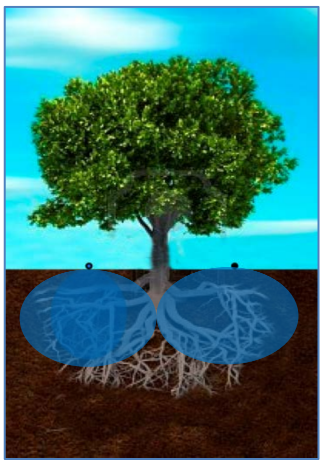


Figure 2-1.

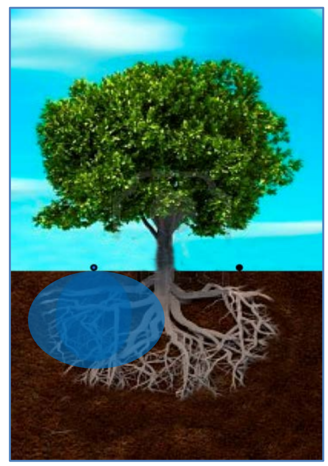


Figure 2-2.

Figures 2-1 and 2-2. Configuration of a dual-line drip irrigation system (Figure 2-1), as compared to dual-line drip irrigation partial rootzone drying (PRD) irrigation system (Figure 2-2). Blue color on roots provide a visual as to the wetted root zone during or after irrigation. Irrigation lines in Drip-PRD trees are alternated to avoid root death.

Microsprinkler spray

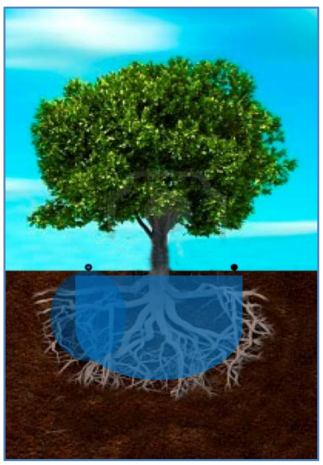


Figure 2-3. Example of a microsprinkler spray irrigation jet with 360 degree rotation. Blue color on roots provide a visual as to the wetted root zone during or after irrigation.

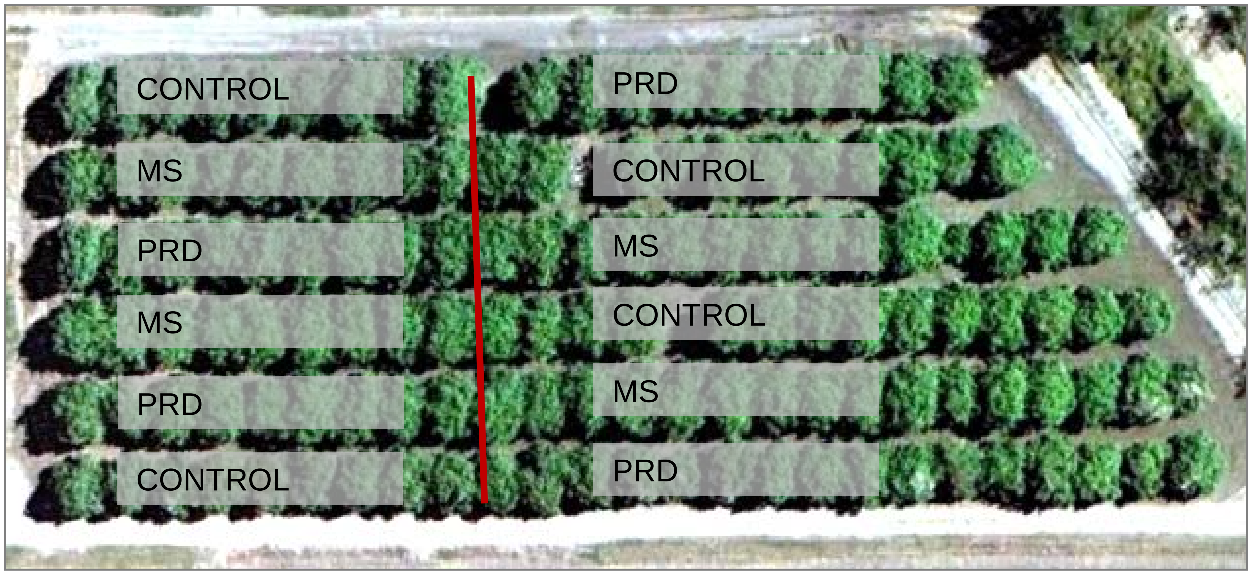


Figure 3-1. **Field site layout design for study, where dual-line Drip (Control), microsprinkler spray (MS), and drip partial rootzone drying (PRD).**

Figure 4-1. **Map of the geographical area where the demonstration field sites were planned for Monte Alto and Weslaco, TX.**

Figure 5-1. **Map of the area Monte Alto Farm, where a second demonstration field site would have been established.**

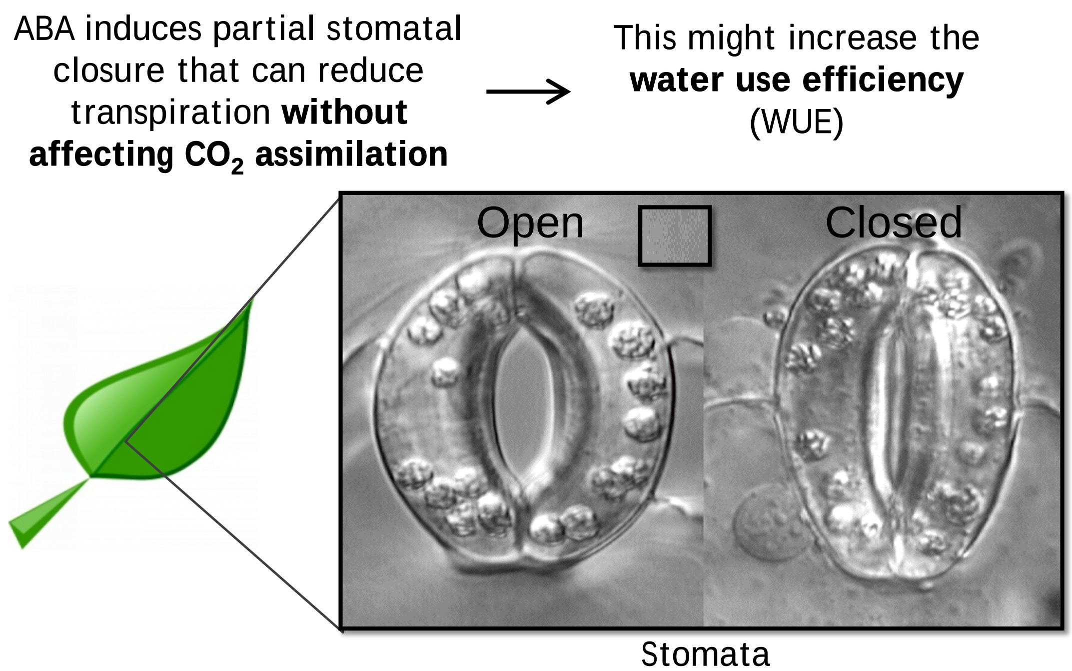


Figure 6-1. **Leaf stomata when completely open compared to stomata when near fully closed. Drought stress will send plant hormone like abscisic acid (ABA) to regulate stomatal closure to prevent further water loss. Partial rootzone drying capitalizes upon this plant physiological response as by drydown of half of the root system sends signals to the plant to close stomata and helps to restrict water loss and in turn increase plant water use efficiency (WUE).**

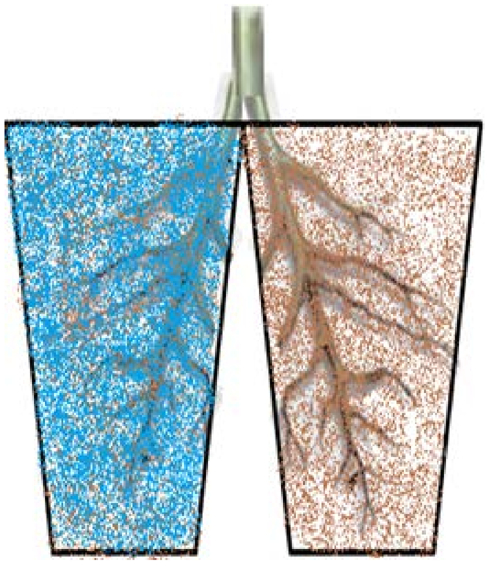


Figure 7-1. **Young citrus tree root system split at separated into different pots so one-half of the root system could be watered, while the other half would be dry. Watering was alternated according to a dry-down schedule to prevent root system from completely dying.**

3.5 Tables

Table 1-1. Effects of the different irrigation treatments (Dual-line Drip; Microsprinkler Spray; and Partial Rootzone Drying Drip [PRD Drip]) on total irrigation water applied (n = 12 ± SE), grapefruit yield (n = 36 ± SE), and crop water use efficiency (WUE_{crop}, n = 12 ± SE).

Irrigation Treatment	2013			2014		
	Irrigation applied[b]	**Yield**	**WUE_{crop}[a]**	**Irrigation applied****	**Yield**	**WUE_{crop}[a]**
	(L $tree^{-1}$)	**(kg $tree^{-1}$)**	**(%)**	**(L $tree^{-1}$)**	**(kg $tree^{-1}$)**	**(%)**
Dual-line Drip	1724 a	159 a	9.4 b	4774 a	132 ab	2.9 b
Microsprinkler	1519 a	143 a	10.2 b	3916 ab	107 b	2.8 b
PRD Drip	908 b	155 a	17.0 a	2735 b	163 a	6.8 a

[a] WUE_{crop} were expressed in percent weight with respect to yield (kg $tree^{-1}$) per unit of water applied (L $tree^{-1}$).
[b] 1 L of water weighs 1 kg.
Note: SE = standard error of the mean. For each year, different lower-case letters within each column indicate significant differences between treatments at Student-Newman-Keuls test ($P < 0.05$). Thus, numbers values showing only the letter ‘a’ compared to numbers having the letter ‘b’ next to them are significantly different from each other; whereas, numbers showing ‘ab’ next to them are not significantly different from numbers having ‘a’ or ‘b’ that reside in the same column.

Table 2-1. [a]**Water depth saved (inches per tree) for irrigation treatments microsprinkler spray and partial rootzone drying drip (PRD Drip) compared to dual-line drip irrigation.**

Irrigation Treatment	2013 Water applied cm $tree^{-1}$	2014 Water applied cm $tree^{-1}$	2013 Water depth inch $tree^{-1}$	2014 Water depth inch $tree^{-1}$	2013 Water saved inch $tree^{-1}$	2014 Water saved inch $tree^{-1}$
Dual-line Drip	9.22	25.53	3.63	10.05	0.0	0.0
Microsprinkler	8.12	20.94	3.20	8.24	0.43	1.81
PRD Drip	4.86	14.63	1.91	5.76	1.72	4.29

[a] Data calculated based on Table 1-1, where water applied (L $tree^{-1}$) was multiplied by 1000 to obtain cm^3 $tree^{-1}$. Then, assuming an 8 foot radius tree canopy and converting into area ($8ft^2 \times \pi = [(243.84cm)^2 \times \pi] = 186{,}995.25\ cm^2$), then dividing water applied (cm^3) by canopy area (cm^2) to obtain total water depth applied (cm $tree^{-1}$). Water depth converted from cm to inches, then the total amount of water saved was determined by subtracting water depth for each irrigation treatment compared to dual-line drip water depth.

Table 3-1. Water savings estimates using alternative irrigation practices in the citrus production.

Irrigation Method	Inches of Water Applied		Water Savings over Large-Pan Flood		
TexasAWE Study [a]	**Min-Max**	**Average**	**Inches/Acre**	**AF/Acre**	**Potential Industry Wide AF/Acre**
Large Pan Flood	60 - 66	62	-	-	-
Microjet Spray	48 - 56	51	11	0.94	26,200
Drip Irrigation	48 - 50	48	14	1.18	33,000
Narrow Border Flood	40 - 44	41	21	1.75	49,000
PRD Study [b]					
Dual-Line Drip	3.6 - 10.1	6.8	54.2	4.52	126,560
Microjet Spray	3.2 - 8.2	5.7	56.3	4.69	131,320
PRD Drip	1.9 - 5.8	3.8	58.2	4.85	135,000

[a] Data taken from 10-year (2004-2013) on-farm demonstration site study evaluating typical irrigation water use in citrus production throughout Lower Rio Grande Valley as funded by Texas Water Development Board and presented in Texas Project for Ag Water Efficiency as presented in TexasAWE.org website (Nelson, et al., 2013) where rainfall average was 24 inches per year (ranging from 12 to 30 inches per year during study period).

[b] Data taken from current Partial Rootzone Drying (PRD) field study with average water use during two consecutive drought years (2013 and 2014) where irrigation applications were intensively managed and average rainfall was less than 15 inches per year.

4 Conclusions

The likelihood of continual utilization of partial rootzone drying techniques at the on-farm level have not yet been verified over the long term. The results of this study and its evaluation are limited to only a couple of two consecutive dry seasons. Regardless of these limitations for long-term drought, the results have shown strong evidence that citrus trees are able to survive on very low water amounts for at least two growing seasons before a significant drop in yield is observed. The field project findings have shown that employing partial rootzone drying techniques can result in equivalent to up to 52% higher over yield when compared to drip and microsprinkler spray irrigated trees. Thus, citrus producers that invest in a dual-line drip irrigation system would be able to overcome periods of intense drought and water restriction and sustain citrus productivity with high quality until the rains return and reservoirs refill. The water saving ranged from 42% to 47% when comparing water use from partial rootzone drying drip irrigated trees to citrus trees irrigated by a dual-line drip system. Furthermore, the results of this study provide evidence that citrus production may be maintained using far less water during times of drought than what is commonly thought by citrus growers in south Texas as total irrigation and rainfall was less than 25 inches per year during two consecutive growing season (2013 and 2014), and yet yield and citrus fruit quality were sustained. More importantly the cumulative impact of this result in regards to water savings potential has shown that the Texas citrus growers could save 4.85 acre-feet per acre or over 135,000 acre-feet of water per year by employing partial rootzone drying dual-line drip irrigation system when compared to conventional large-pan flood irrigation practices, so long as irrigation practices were managed intensively by the entire South Texas citrus industry.

The results of this study evaluating the benefits of partial rootzone drying for citrus are conducive and applicable to only two consecutive years of intense drought. Thus, additional studies are necessary to evaluate long-term drought conditions. However, for the short term of this study, it is safe to say that significant water savings was achieved using partial rootzone drying without significant impacts on yield and fruit quality parameters. In short, we can summarize the water savings potential of this study as follows:

Water savings = Before improvements volume (Flood) – After improvements volume (PRD)

Water savings = 5.17 acre-feet/acre (Flood) – 0.32 acre-feet/acre (PRD) = **4.85 acre-feet/acre**

Water savings percentage = water savings ÷ before improvements volume

Water savings percentage = 4.85 acre-feet/acre ÷ 5.17 acre-feet/acre = 0.938 x 100 = **94%**

5 Acknowledgments

The authors would like to thank Ms. Ayako Kusakabe and Beatriz Contreras who both worked tirelessly on the projects described in this report. Their contribution to the advancing our knowledge of workable solutions for citrus production in extreme drought conditions is highly impactful.

We would also like to thank the farm crew and research scientists that assisted in data collection, tree and irrigation management. Without the dedication of the staff at the Citrus Center and use of vehicles this project would not have been a success. We especially thank the Citrus Center Director for supporting both graduate student and research assistant positions at the Center.

6 References

Nelson, S., M. Young, S. Klose, and J. Enciso. Feb. 2013. Narrow-border flood for citrus: Saving water while improving yields and net cash farm income. On-Farm AWEsome FACTS on agricultural water conservation and efficiency, Texas Project for Ag Water Efficiency, TexasAWE.org. Report #OF-02-13.

Texas Water Development Board

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March 28, 2016

Mohamed Abdelrahman, Ph.D.
Associate Vice President, Office of Research and Sponsored Programs
Texas A&M University - Kingsville
700 University Blvd. MSC 198
Kingsville, Texas 78363-8202

RE: Agricultural Water Conservation Grant Contract between the Texas Water Development Board (TWDB) and Texas A&M University – Kingsville (TAMUK); TWDB Contract No. 1213581482, Draft Report Comments for "Developing and Promoting Water Saving Irrigation Strategies to Increase Water Use Efficiency in Citrus"

Dear Dr. Abdelrahman:

Staff members of the TWDB have completed a review of the draft report prepared under the above-referenced contract. ATTACHMENT I provides the comments resulting from this review. As stated in the TWDB contract, TAMUK will consider revising the final report in response to comments from the Executive Administrator and other reviewers. In addition, TAMUK will include a copy of the Executive Administrator's draft report comments in the Final Report.

The TWDB looks forward to receiving one (1) electronic copy of the entire Final Report in Portable Document Format (PDF) and six (6) bound double-sided copies. **Please further note, that in compliance with Texas Administrative Code Chapters 206 and 213 (related to Accessibility and Usability of State Web Sites), the digital copy of the final report must comply with the requirements and standards specified in statute. For more information, visit http://www.sos.state.tx.us/tac/index.shtml.** If you have any questions on accessibility, please contact David Carter with the Contract Administration Division at (512) 936-6079 or David.Carter@twdb.texas.gov

TAMUK shall also submit one (1) electronic copy of any computer programs or models, and, if applicable, an operations manual developed under the terms of this Contract.

If you have any questions concerning the contract, please contact Mindy Conyers, the TWDB's designated Contract Manager for this project at (512) 463-5102 or by email at mindy.conyers@twdb.texas.gov.

Sincerely,

Robert E. Mace, Ph.D., P.G.
Deputy Executive Administrator
Water Science and Conservation

Enclosure

c: Mindy Conyers, TWDB

Attachment I

TWDB Comments on Developing and Promoting Water Saving Irrigation Strategies to Increase Water Use Efficiency in Citrus

Texas A&M University – Kingsville (Contractor)

TWDB Agricultural Water Conservation Grant Contract #1213581482

TWDB staff comments on the Draft Final Report submitted February 15, 2016

General Comments:

- Please follow the *Author's report formatting template* and the *Formatting Guidelines for Texas Water Development Board Reports*, online at http://www.twdb.texas.gov/about/contract_admin/index.asp.
- Please include a cover page, table of contents, definition of terms, etc.
- Please avoid the use of acronyms and abbreviations wherever possible (e.g. PRD, MJ, MS, AD, ET, SE, Aug).
- As this report will be posted online as the final deliverable for this project, consider expanding upon it significantly and including pictures from the project throughout.
- Include a cumulative estimate of actual water savings as a result of activities funded through this project. This should be presented as a percentage improvement in overall water use efficiency **and** quantity of water saved (i.e. water savings percentage = water savings volume / before improvements volume).
- Consider including relevant detailed information from the two submitted abstracts / technical papers on the research done through this project in this final report, rather than just a reference to the papers.
- Consider including a map of the geographical area in which the project took place.
- Consider editing throughout for grammatical errors and typos.
- If the departure of Juan Carlos Melgar impacted the project, consider noting that in the report.

Specific Comments:

p. 1: The final report should discuss in detail work done between June 21, 2012, and December 15, 2015 (referred to as the Study Completion Date in the contract).

p. 1 and throughout: Please remove or rephrase any text referencing "this proposal" or referring to activities that "will occur".

p. 1: Please elaborate on the types of irrigation treatments mentioned/studied here and include an analysis of each activity with resulting water use efficiency improvements. For example, the report does not include an explanation of partial rootzone drying, how it works, how it does or doesn't affect fruit quality, and so on.

p. 1 and throughout: Please consider removing the underline from certain terms (e.g. "replicated plots of micro-jet sprinkler spray and dual-line drip irrigation treatments.")

p. 2, third paragraph: "Water application could be quantified, and impacts of water stress could be evaluated." Elaborate here on project results and include appropriate visual aids.

p. 2, fourth full paragraph and elsewhere: "...overall yield was highest in PRD drip irrigated trees, followed by Drip, then Microsprinkler Spray (163, 132, and 107 kg tree^{-1}, respectfully)." Consider using either "Microsprinkler Spray" or "micro-jet sprinkler spray" but not both. Also, "respectfully" should be "respectively" when referring to the order given.

p. 2-3: Consider rephrasing the last/first paragraph to include the actual titles of the soon to be published articles or at least more details from said articles.

p. 3, Table 1: Please explain the terms in the table (e.g. WUE) and what is meant by the "a", "b", and "ab" next to the numbers. Also, the summary below the table includes valuable information that should be included in the main body of the report, not as a caption for the table.

p. 4: Consider rearranging the listed presentations to highlight which ones, if any, were open to the public or had producers in attendance, and elaborate significantly as promotion of these water saving techniques is a key component of the funded project.

p. 5: Consider omitting the "Note:" at the end of this page as it does not contribute necessary information to the reader.

p. 6: The reference to the presentation in Palm Desert, CA, should be formatted like the previous presentations and included within the list on page 5.

p. 6: The last three paragraphs duplicate information reported on page 5 and should be deleted.