FINAL REPORT
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On Farm Irrigation Strategies for Water Conservation in the Lower Rio Grande Valley

Final Report

2016 Agricultural Water Conservation Grant

Texas Water Development Board

PI: Juan Enciso, Ph.D., P.E.

Email: Juan.Enciso@ag.tamu.edu

Award 1613581997

TWDB Contract Managers: Kyla Peterson and Cameron G. Turner

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Acronyms

ASA	American Society of Agronomy
ASABE	American Society of Biological and Agricultural Engineers
CSSA	Crop Science Society of America
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
LRGV	Lower Rio Grande Valley
NIFA	National Institute of Food and Agriculture
NRCS	Natural Resource Conservation Service
SSSA	Soil Science Society of America
SWCS	Soil Water Conservation Society
TCEQ	Texas Commission of Environmental Quality
TWDB	Texas Water Development Board
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicles
USDA	United States Department of Agriculture

On Farm Irrigation Strategies for Water Conservation in the Lower Rio Grande Valley

Introduction

The primary source of water for the Lower Rio Grande Valley (LRGV) comes from Mexican Rivers, and the delivery of its water is dependent on the 1944 treaty between the US and Mexico. The agreement requires Mexico to deliver 350,000 minimum average annual acre-feet on a five-year cycle. This water planning region expects more than a 106% increase in population from 2020 to 2070, consequently increasing its water demands, which will increase from a projected 311,591 acre-ft/year in 2020 to 612,127 acre-ft/year in 2070. According to our most recent Region M Water Plan, irrigation water use needs to decrease 240,000 ac-ft/year from 2020 to 2070 to meet this demand. Even if the entire water amount from the agreement from Mexico could be available for agriculture, it may be necessary to conserve water from agriculture to meet water demands. Some of the agricultural irrigation strategies described in the 2016 Region M Water Plan (2016 regional water plan, http://www.riograndewaterplan.org/downloads/2016RWP/RWP_V1_Chapter5.pdf) to conserve water are irrigation district and on-farm conservation. On-farm water conservation measures can be grouped into the following categories: water use management practices (irrigation scheduling), land management systems (land leveling), on-farm water delivery systems (surface irrigation systems, drip, sprinkler irrigation systems, micro-irrigation, etc.), water district delivery systems (earth ditches, pipe systems, canals, etc) and tailwater recovery systems.
One of the leading conservation strategies identified for on-farm water conservation is irrigation scheduling. There are two main methods to schedule irrigation: (1) by replacing crop evapotranspiration (ETc) fractions according to a soil water balance, or (2) by triggering irrigation according to water content status of the soil and allowable depletion levels (Hanson et al., 2000). The first method, which is the method used in this proposal, requires the use of a weather station and a computer program to follow the soil water balance. Significant water savings can be achieved for a variety of crops by scheduling irrigation, which consists of determining the amount and timing of irrigation applications (Martin et al., 1990).
This project will educate farmers on measuring crop water-use and monitoring it with soil moisture sensors. It was predicted that this project would conserve at least 70,400 acre-ft/year by developing irrigation guidelines based on estimated evapotranspiration. Region M recognized that one of the limitations of using irrigation scheduling methods depends on the ability of irrigation districts to deliver water (it may take up to 5 to 7 days to provide this water) and some variability of the reading of the sensors due to soil heterogeneity. Even under drought and in water allocations program, farmers may lack the knowledge in what critical stages of the crop irrigation should be applied. Most farmers don't know how many irrigation events are needed per crop, consequently over-irrigating or irrigating at crop growth stages where water is not required.

The conservation practice proposed in this project was to use weather station networks and an internet-based program (http://southtexasweather.tamu.edu/) to develop irrigation schedules and guidelines for different crops and demonstrate its use among farmers. Besides, this project aims to establish irrigation guidelines to orient farmers when to irrigate in case of limited water supplies.

This project was conducted in the LRGV region, comprised of Starr, Hidalgo, Cameron, and Willacy counties in South Texas. This area is part of the Rio Grande Regional Water Planning Group (Region M) (Fig. 1). The demonstrations and the training of farmers, water users, and irrigation district personnel were conducted with the collaborations of Rio Farms Inc, Wonderful Citrus, Texas International Produce Association, Delta Lake, the Harlingen Irrigation District. The irrigation districts partnered in establishing field demonstrations to educate water users with hands-on experience.

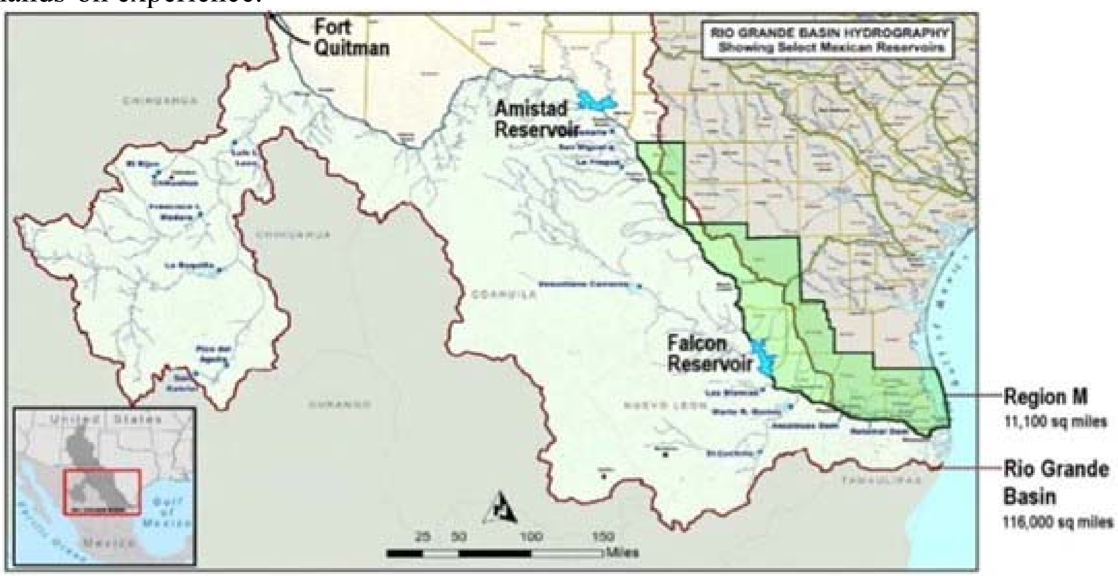


Figure 1. Lower Rio Grande Basin, Texas.

Objectives:

The specific objectives of this project were:

1. Develop an internet web-based tool with a network of weather stations to estimate crop evapotranspiration, develop a water balance to schedule irrigation to conserve water for the main crops of the region (citrus, sugarcane, corn sorghum, cotton, onions, cabbage, and watermelons).
2. Develop irrigation for the sorghum, corn, and cotton to use limited water supplies.
3. To establish field demonstrations to promote the adoption of these irrigation practices.
4. To develop educational programs for farmers and irrigation district personnel.

Results

The outcomes of the project were divided into the following tasks:

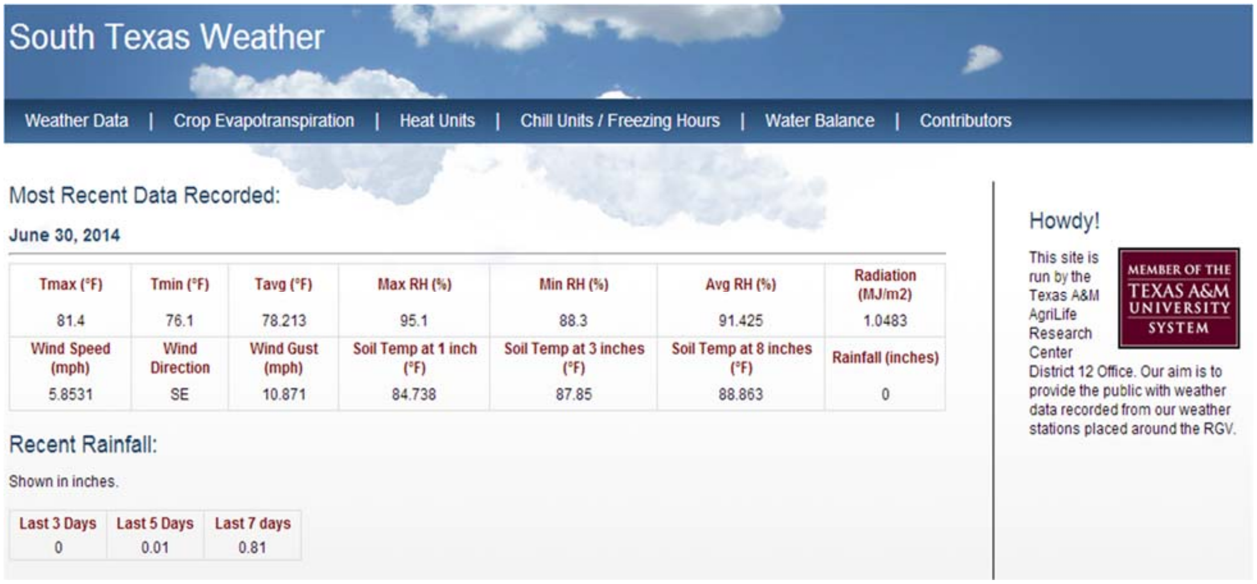
Task 1: Extending the weather network

Three weather stations were installed within selected sites suggested by our partners (Delta Lake irrigation district, Harlingen Irrigation District, Cameron County Irrigation District No 2., And Rio Farms). The weather stations were connected to the website http://southtexasweather.tamu.edu/

The network consists of five weather stations located in Weslaco (center), Mercedes (Annex), Rio Grande City, Elsa (Rio Farms) and Edinburg (Paramount), (Fig 1). The weather stations are operating and collecting data hourly and daily. The stations are being serviced, and the information is provided to our users (farmers, private consultants, NRCS, TCEQ, Texas Farm Bureau, farmer organizations such as Rio Farms, Paramount, and several Irrigation Districts). The weather network provides water requirements for the main crops of the Lower Rio Grande, heat units, freezing hours, and chilling units. It also provides irrigation guidelines. Some features of the program are:

- Graphs monthly and daily climatic variables such as solar radiation, average temperature, rainfall, minimum and maximum relative humidity, maximum and minimum temperature, minimum and maximum temperature, soil temperatures are 1, 3, and 8 inches.
- Graphs of cumulative rainfall and crop ET for the main crops of the LRGV.
- A water balance calculates irrigation depths, irrigation efficiency, runoff, and deep percolation.

There is a front-page in which the station can be selected and the irrigation guidelines for the main crops (Fig. 2). The program also allows downloading historical data (Fig. 3). The crop evapotranspiration is calculated multiplying the FAO-56-Penman Monteith reference evapotranspiration equation (Walter et al., 2000) with FAO crop coefficients (Allen et al., 1998), (Fig. 4) and Table 1.


South Texas Weather

Weather Data | Crop Evapotranspiration | Heat Units | Chill Units / Freezing Hours | Water Balance | Contributors

Most Recent Data Recorded:

June 30, 2014

Tmax (°F)	Tmin (°F)	Tavg (°F)	Max RH (%)	Min RH (%)	Avg RH (%)	Radiation (MJ/m2)
81.4	76.1	78.213	95.1	88.3	91.425	1.0483
Wind Speed (mph)	Wind Direction	Wind Gust (mph)	Soil Temp at 1 inch (°F)	Soil Temp at 3 inches (°F)	Soil Temp at 8 inches (°F)	Rainfall (inches)
5.8531	SE	10.871	84.738	87.85	88.863	0

Recent Rainfall:

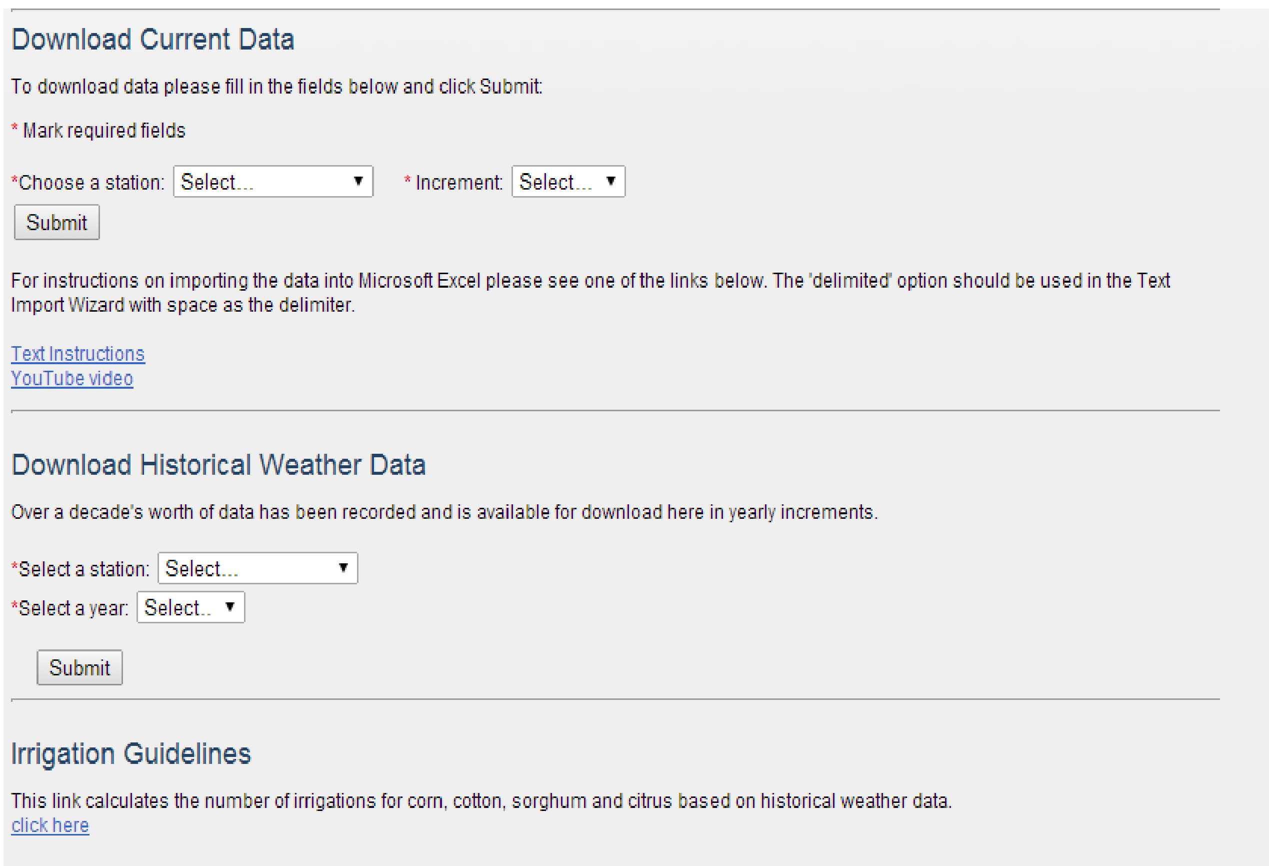
Shown in inches.

Last 3 Days	Last 5 Days	Last 7 days
0	0.01	0.81

Howdy!

This site is run by the Texas A&M AgriLife Research Center District 12 Office. Our aim is to provide the public with weather data recorded from our weather stations placed around the RGV.

Figure 2. Program front page of the internet weather site.


Download Current Data

To download data please fill in the fields below and click Submit:

* Mark required fields

*Choose a station: Select... * Increment: Select...

Submit

For instructions on importing the data into Microsoft Excel please see one of the links below. The 'delimited' option should be used in the Text Import Wizard with space as the delimiter.

Text Instructions
YouTube video

Download Historical Weather Data

Over a decade's worth of data has been recorded and is available for download here in yearly increments.

*Select a station: Select...
*Select a year: Select..

Submit

Irrigation Guidelines

This link calculates the number of irrigations for corn, cotton, sorghum and citrus based on historical weather data.
click here

Figure 3. Data download option of the internet site.

Select a crop: Corn

Select a Station: Annex (Mercedes)

Planting Date: 06/26/2014 mm/dd/yyyy

Begin Calculation from: 06/26/2014 mm/dd/yyyy

End Calculation on: 07/02/2014 mm/dd/yyyy

Units: Metric (mm) English (in.)

Calculate

Annex Crop Evapotransporation Data

Original Planting Date: 06/26/2014
Beginning ET Calculations at: 06/26/2014
End ET Calculations at: 07/02/2014
All values are represented in inches.

Total ETc - Total Rainfall: 0.394 inches

Date	Days since Planting	ETo	Kc	ETc	Total ETc	Total Rainfall	Total ETc - Total Rainfall
06/26/2014	0	0.178	0.3	0.053	0.053	0.01	0.043
06/27/2014	1	0.217	0.3	0.065	0.119	0.01	0.109
06/28/2014	2	0.248	0.3	0.074	0.193	0.01	0.183
06/29/2014	3	0.228	0.3	0.069	0.261	0.01	0.251
06/30/2014	4	0.222	0.3	0.067	0.328	0.01	0.318
07/01/2014	5	0.233	0.3	0.07	0.398	0.01	0.388
07/02/2014	6	0.021	0.3	0.006	0.404	0.01	0.394
Date	Days since Planting	ETo	Kc	ETc	Total ETc	Total Rainfall	Total ETc - Total Rainfall

Figure 4. Crop evapotranspiration calculation screen.

Table 1. Crops, planting and harvesting dates, ET and effective rainfall for the main crops grown in the Lower Rio Grande Valley, TX.

Crop		Planting date	Harvest date	Growing days	Crop Evapo-transpiration (mm)	Effective Average Rainfall (mm)	Water Deficit (mm)
Field Crops							
	Sorghum	Feb-20	Jun-29	125	557	167	389
	Cotton	Mar-5	Aug-31	179	902	271	631
	Corn (W)	Aug-15	Dec-17	124	402	296	106
	Corn (S)	Feb-20	Jul-9	139	628	184	444
	Soybean	Aug-1	Dec-27	148	535	204	331
Vegetables							
	Watermelon	Feb-1	May-21	120	398	102	296
	Cantaloupes	Feb-1	May-31	110	394	113	281
	Onions	Oct-15	Apr-13	120	559	156	403
	Carrots	Sep-19	Feb-16	110	444	199	245
	Cabbage	Aug-15	Jan-27	90	539	306	234
	Potatoes	Jan-6	Apr-30	100	404	84	321
Citrus							
	Without grass cover						
	70 Canopy	Jan-1	Dec-31	365	1105	560	545
	50 Canopy	Jan-1	Dec-31	365	1024	560	464
	20 Canopy	Jan-1	Dec-31	365	781	560	221
	With grass cover						
	70 Canopy	Jan-1	Dec-31	365	1188	560	628
	50 Canopy	Jan-1	Dec-31	365	1328	560	768
	20 Canopy	Jan-1	Dec-31	365	1411	560	851
	Sugarcane	Jan-1	Feb-28	365	1969	575	1394

The program was used to estimate crop evapotranspiration (ETc), effective rainfall (Table 2). This table also shows the average estimated yield for each crop, revenue and costs, and net return per unit of water.

Table 2. Crop water productivity (kgs/m3) and net return per unit of water (NR/$) for the most important crops of the Lower Rio Grande Valley, TX.

Crop	Total yield (kg/ha)	Revenues ($)	Costs ($)	Crop ET_c (mm)	Effective Rainfall (mm)	Water productivity without rainfall (kg/m3)	Water productivity with effective rainfall (kg/m3)	Net Return ($/m^3)
Cabbage	42032	5250	182	539	306	7.79	7.79	9.4
Cantaloupes	22417	3200	231	172	113	13.03	13.03	17.3
Onions	50438	6300	185	372	156	13.56	13.56	16.4
Watermelon	50438	8100	232	197	102	25.63	25.63	40.0
Corn (Winter)	6277	380	168	402	106	1.56	1.56	0.5
Corn (Spring)	8000	485	168	628	296	1.27	1.27	0.5
Cotton	1401	788	231	561	184	0.25	0.25	1.0
Sorghum	2242	320	67	385	167	0.58	0.58	0.7
Soybeans	1681	270	156	535	204	0.23	0.31	0.2
Oranges	40351	2880	379	587	560	6.88	6.88	4.3
Grapefruit	51559	2760	379	587	560	8.79	8.79	4.1
Sugarcane (First planting)	98000	1313	145	1293	560	0.91	7.58	0.9
Sugarcane (Ratoon)	75000	998	135	1194	560	0.75	6.28	0.7

Task 2: Modification of the water balance program and development of irrigation guidelines.

The irrigation networks have been used successfully to determine irrigation guidelines, such as the number of irrigations to apply for different crops. The irrigation guidelines are based on average years using a water balance equation. Unknowingly farmers over irrigate frequently late in the growing season when irrigating will not be improving yields, consequently wasting water or irrigating very often when the plant does not need the water. A water balance subroutine of the programs was modified to use information from the weather station to calculate the number of irrigations required for the main crops (Fig. 5).

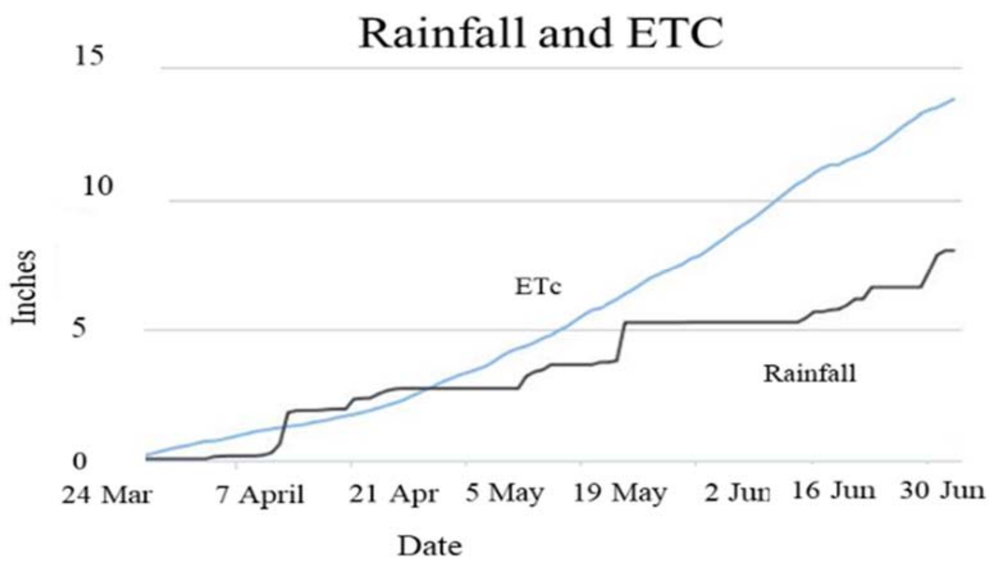


Figure 5. Water Balance Subroutine for the Internet-Weather Based Program.

The following extension publication was prepared as outcome of this task:

- Juan Enciso, Charles Hillyer, Dana Porter, and Guy Fipps. Irrigation Timing during Drought Corn, Cotton, and Sorghum Furrow Systems. Texas A&M AgriLife Research. EBN-015. 3/16

This publication was distributed among 250 farmers that attended our workshops and visited our center. The publication is presented in the appendix. Additionally, we estimated the number of irrigations required for each crop based on historical weather data (Table 3).

Table 3. Number of irrigations in the different soil classes for the Lower Rio Grande Valley, Texas.

Crops	Sandy Loam	Loam	Silt Loam	Silt	Silty Clay Loam	Silty Clay	Clay	Find Sandy Loam	Clay Loam	Peat Mucks	Sandy Clay Loam
Cantaloupes	3	2	1	2	1	2	2	2	1	1	2
Corn	6	4	4	4	4	4	5	5	4	4	5
Cotton	5	3	3	3	3	3	4	4	3	3	4
Onions	15	10	8	10	8	11	11	12	8	8	11
Sorghum	4	3	2	3	2	3	3	3	2	2	3
Watermelons	4	2	2	2	2	3	3	3	2	2	3
Honeydews	3	2	1	2	1	2	2	2	1	1	2
Oranges	9	5	4	5	4	6	6	7	4	4	6
Grapefruit	9	5	4	5	4	6	6	7	4	4	6
Sugarcane (First Planting)	9	6	5	6	5	6	7	7	5	5	7
Sugarcane (Ratoon)	8	6	5	6	5	6	6	7	5	5	6

It is essential to point out from Table 3 that the onions should be watered with drip irrigation instead of surface irrigation due to the shallow root system. The water conserved from the crops evaluated during the demonstrations by irrigation type is shown in Table 4. The use of subsurface drip irrigation can save approximately 3 inches per acre (Table 4), and the production can be increased considerably. One of the main problems in onions and cotton is germinating the seed uniformly and establishing a good stand. The citrus crop conserves more water than other crops (1.89 and 1.91 ac-ft/ ac-ft per acre of land area). Drip irrigated onions can save approximately 1.12 ac-ft of water per acre of land compared to furrow irrigation.

In comparison, watermelons with drip and plastic mulch can save 1.31 ac-ft of water. It has shown in several demonstrations that furrow uses much more water than drip irrigation systems (Table 4). This Table also shows that it is necessary to only have furrow irrigation in deep soils with medium to a heavy texture that can store enough water in the soil profile. Vegetables should be grown with drip irrigation systems.

Table 4. Estimated water conserved (ac-ft/acre) with drip and micro-sprinkler irrigation compared to flood irrigation.

Crop	Drip (subsurface or surface irrigation)	Micro-sprinkler irrigation
Cotton	0.25	----
Citrus	1.89	1.91
Onions	1.12	----
Watermelons	1.31	-----

Task 3: Educational programs.

We organized several educational workshops to train farmers in irrigation scheduling. In these workshop farmers, we informed farmers about the Region M current water situations, weather forecasts, and other agricultural practices to conserve water quality and quantity and increase productivity per unit water. These programs were complemented with conferences in current agricultural topics of interest for the farmers, such as main pests, new varieties, soil and water analysis, and fertilizer campaigns, etc.

Workshops and Conferences

The following workshops and conferences were organized in different counties:

1. **Soil Health and Irrigation Management workshop.** A 6.5-hour workshop was offered in Soil Health and Irrigation Management. The objective of the workshop was to train farmers about the use of the internet-based weather program and irrigation scheduling strategies, and to present results of the watermelon and cotton demonstrations (Fig 6). August 24, 2016. About 50 persons attended the seminar. The flyer is attached in the appendix.

2. **Advances in Vegetable Irrigation Workshop**. 4-hr workshop was organized in Weslaco, TX, for Small acreage producers. Presented the conference **"Advances in Valley Vegetable Production and Irrigation."** About 50 persons attended the workshop. March 6, 2018.

3. **Irrigation tour in 2018.** A 3-hr program was held at the Weslaco research station. The program included the topics of production planning and irrigation. It included a one-hour conference and a 2-hour tour to demonstrate technologies such as fertigation and irrigation scheduling with soil water sensors. About 35 producers attended the workshop. Weslaco, TX. March 29, 2018.

4. **Vegetable Field Day.** December 4, 2018. Presented for the table Irrigation Programs during the Field tour. Weslaco, TX. About 60 persons attended the tour. May 22, 2018.

5. **Texas 4-H Water Ambassadors Visit LRGV.** We prepared a workshop and a tour of Water Programs in South Texas. A group of about 15-20 students led by David Smith was attended. July 30, 2019 (Fig. 7).

6. **Irrigation and Management Workshop.** 5hr workshop held in San Benito, Cameron County. Twenty-five persons attended the meeting. September 25, 2019. The flyer is attached in the appendix.

7. **Irrigation Extension and Research Projects in the Texas A&M AgriLife Research Center.** Workshop organized by Texas A&M AgriLife Research. Weslaco, TX. September 20, 2019. Forty persons producers and students attended the workshop.

8. **Irrigation and Management Workshop.** 5 hr. workshop held in Edinburgh, Hidalgo County. Fifty-three persons attended the meeting. The workshops were organized in coordination with Dr. Lucas Gregory. September 26, 2019. The flyer is attached in the appendix.

Field days

Several field days and farm training programs were organized in the field demonstrations (explained in the next task) to promote the adoption of sustainable production practices and technologies among farmers.

The Texas A&M Research and Extension Center in Weslaco serves as a demonstration site for this program. The Center facilities and experimental fields are used to provide hands-on experience to limited-resource producers. Also, several demonstrations plots have been established at the Texas A&M Research and Extension Center based on requests and observed needs of our target audience. Field visits provide farmers with new ideas and will expose them to innovative and sustainable production practices. Some of these field demonstrations and field days conducted were:

Figure 6. The results of the watermelon (left) and cotton irrigation demonstration (right) were presented during the Soil Health and Irrigation Management Workshop held in Weslaco, TX.

Figure 7. Irrigation, Workshop and Field Demonstration, Weslaco, TX. A field day was organized for 4-H visitors from College Station and Weslaco, where the students were trained in agricultural water management. The picture shows Dr. Juan Enciso during the presentation.

Presentation in national and state meetings.

The results of the demonstrations and the internet weather program supported by the TWDB were presented in several professional forums and farmer-oriented conferences. Some of these presentations are:

- "Validation and Evaluation of an Internet ET Weather Program". J. Enciso, S. Elsayed-Farag, S. Zapata, L Ribera. Poster presented at the 2017 Annual Conference of the Soil and Water Conservation Society. Madison, Wisconsin. July 30- Aug 2, 2017.

- "Irrigation Guidelines for Managing Irrigation with Limited Water Supplies". Conference presented in 2018. This was an invited presentation for the Soil and Water Conference Board in Albuquerque, NM. July 31, 2018.

- New high yield energy cane germplasm and its yield prediction using unmanned aerial system. Uriel Cholula, Jorge A. da Silva, Thiago Marconi, Juan Enciso, Jorge Solorzano. 2019. 2019 ASA-CSSA-SSSA International Annual Meeting, San Antonio, TX November 10th to November 13th , 2019.

- Phenotyping, BMPs and Irrigation Management of Vegetables using Remote Sensing. Juan Enciso (Associate Professor), Carlos Avila (Assistant Professor), Juan Anciso (Professor) – Texas A&M AgriLife Research, Weslaco, TX. Jinha Jung (Assistant Professor), AJ Chang (Postdoctoral Research Associate) – Corpus Christi, Corpus Christi, TX. 29th Annual Texas Plant Protection Conference "Weathering Uncertainties in Texas Agriculture through Science, Technology and Policy".

Leverage to obtain other grants:

The field demonstrations and the economic support was helpful to complement and leverage other grants such as:

- Satellite and UAS Imagery Use to Implement Timely Irrigation Strategies. 2019. PI: Juan Enciso. Foundation for Food and Agriculture Research. $16,650. 02/01/2019 to 01/31/2020.

- Diversifying the Water Portfolio for Agriculture in the Rio Grande Basin. USDA-Texas Water Resource Institute. Amount requested: $4,997,257.00. PI: John Tracy. Co-Pi: Juan Enciso. My contribution of the project ($287,900). This year I received $130,427.00

- A Comprehensive Educational Program for Socially Disadvantaged, Small Producers. USDA-NIFA. Amount $200,000. My contribution of the project ($40,261). 09/29/2108 to 09/29/2019. PIs: Samuel Zapata, Juan Enciso, Juan Anciso.

Peer Reviewed, Refereed Journal Articles.

The weather data obtained from the internet weather network, and the demonstrations were used to publish the following journal articles and abstract papers:

- Garza, Blanca N.; Ancona, Veronica; Enciso, Juan; Perotto-Baldivieso, Humberto L.; Kunta, Madhurababu; Simpson, Catherine. 2020. Quantifying Citrus Tree Health Using True Color UAV Images. Remote Sens. 12, no. 1: 170.

- Jose Carlos Chavez, Juan Enciso, G. Ganjegunte, N. Rajan, J. Jifon, V. P. Singh. 2019. Growth Response and Productivity of Sorghum for Bionergy Production in Texas. Transactions of the ASABE. Vol 62(5)1207-1218. ISSN 2151-0032 https://doi.org/10.13031/trans.13317

- Juan Enciso, Jose C. Chavez, Girisha Ganjegunte and Samuel D. Zapata. 2019. Energy Sorghum Production under Arid and Semi-Arid Environments of Texas. *Water*, *11*(7), 1344; https://doi.org/10.3390/w11071344 (registering DOI).

- Chavez, J. C., J. Enciso, M. Meki, J. Jeong, and V. Singh. 2017. Simulation of energy sorghum under limited water levels using the EPIC model. *Trans. ASABE* . Transactions of the ASABE. (in press). (doi: 10.13031/trans.12470) @2017

- Corina Fuentes, Juan Enciso, Shad D. Nelson, Juan Anciso, Mamoudou Setamou, and Sheren Elsayed-Farag. 2018. Yield Production and Water Use Efficiency under Furrow and Drip Irrigation Systems for Watermelon in South Texas. Subtropical Agriculture and Environments journal. 69:1-6

Abstracts and Papers

- Juan Enciso. Developing Irrigation Management Strategies under Drought Conditions in Texas. 2016. Poster 69-3A75-13-082. 71st SWCS International annual conference. June 24-27, 2016. Louisville, KY

- Juan Enciso. Irrigation Management Strategies Under Drought Conditions. 2016. Juan Enciso, Texas A&M AgriLife Research. ASA/SSSA/CSSA. Phoenix, AZ. Nov 8.

- Juan Enciso, Murilo Maeda, Juan Landivar, Carlos Avila, Jinha Jung, Anjin Chang. Unmanned aerial system (UAS) for Precision Agriculture and Management Decisions. 2016 ASABE Annual International Meeting 162428013. (doi:10.13031/aim.20162428013)

- J. Enciso, S. Elsayed-Farag, S. Zapata, L. Ribera. 2017. Validation and Evaluation of an Internet ET weather program. Soil Water Conservation Society. 72nd International Annual Conference. July 30-August 2, Madison, WI

- Sheren Elsayed-Farag, Catherine Simpson, Uriel Cholula1, Juan Enciso. 2017. Using leaf turgor pressure sensors as an indicator to monitor water stress under deficit irrigation strategies in South Texas Citrus trees. 71st Annual Meeting of the Subtropical Agriculture and Environments Society.

- Effect of planting date and plastic mulch on tomato production in South Texas. Elsayed-Farag S., Anciso J., Marconi C, Avila C., Rodriguez A., Badillo-Vergas I.E., Cholula U., Enciso J. 2017 Subtropical Plant Science Society.

- Allen Berthold, Juan Enciso, Alexander Fernald,4, Hatim Geli,4, Charles Hillyer, Robert Sabie, ZohrabSamani, and QingwuXue. Assessing Technology and Tools to Improve Water Management within the Rio Grande Basin. Rio Grande Symposium at UTEP. Jan 8, 2018. El Paso, TX.

- George Thomas III, Juan Enciso, Veronica Ancona, Mamoudou Setamou, Catherine Simpson. 2019. Comparing Root Distribution in Two Orange Groves with Different Floor Management and Irrigation Practices. HORTSCIENCE 54 (9), S241-S242.

- Uriel Cholula, Jorge A. da Silva, Thiago Marconi, Juan Enciso, Jorge Solorzano. 2019. New high yield energy cane germplasm and its yield prediction using unmanned aerial system. 2019 ASA-CSSA-SSSA International Annual Meeting, San Antonio, TX November 10th to November 13, 2019.

Popular press articles

We promoted the workshops that we organized using local media in which we informed Texas farmers about the importance of our educational programs and demonstrations.

- Soil and Irrigation Conservation Workshop slated for Aug. 24. The Monitor. 8/24/2016. Rod Santana, Juan Enciso http://www.themonitor.com/news/business/soil-and-irrigation-conservation-workshop-slated-for-aug/article_b263a62a-64fe-11e6-bd71-873620e6f881.html

Training of Students:

The following students were advised or co-advised using field demonstrations supported by this grant:

Graduate students:

- Blanca Garza. 2019. Thesis: Quantifying citrus tree health using true color UAV. Defended her thesis on April 14, 2019. Master student Texas A&M University-Kingsville. Main professor: Dr. Catherine Simpson.

- George Thomas III. 2019 (graduated). Thesis: Impact Of Grove Floor Management And Irrigation Practices. On Citrus Root Distribution. August 2019. Master student Texas A&M University-Kingsville. Main professor: Dr. Catherine Simpson.

- Jose Carlos Chavez. Ph.D. Student (Main advisor: Dr. Vijay Singh). BAEN. Texas A&M University. Published two manuscript in 2019 in the Transactions of the ASABE. Jose will present his pre-doctoral and defend his thesis in 2020.

- Uriel Cholula. Water Management and Hydrological Science. Texas A&M University. He has completed 3 semesters. Uriel is working on his thesis.

- Julian Gonzalez. M.S. Texas A&M University-Kingsville. Agricultural Program. Thesis: Sustainable Management Techniques To Improve Root Distribution And Turnover In Texas Citrus. December 2017. Main professor: Dr. Catherine Simpson.

Graduate student internships:

- Enrique Adame. UAAAN. Saltillo, Coahuila, Mexico
- Inez Vela. Student from University of Texas-Pan American

Undergraduate student internships:

- Mariana Peduti Vicentini SabJason Carmona. Texas A&M-Kingsville. From 08-25-2017 to 11-10-2018. Graduanda em Engenharia Agronômica - FCA Unesp Botucatu, Brazil.
- Micah Cantu. Student from University of Texas-Pan American
- Emmanuel Zapata. Student from University of Texas-Pan American
- Jason Carmona graduated from Texas A&M Kingsville in mathematics and computer sciences.

- Emmanuel Zapata, student in Computer Sciences from UT Rio Grande Valley are helping me with the weather station network.

Awards related to this project:

The quality of the project was recognized by the following award:

2017 Texas Environmental Excellence Award. Presented to Karen Ford; Tom McLemore, Jimmy Pawlik, Catherine R Simpson, Mamoudou Setamou; Juan Enciso, and Mac Young from the TAMUK Citrus Center, Texas A&M AgriLife Corpus, and Weslaco, and Harlingen Irrigation District. This award is a combined team award for our collaborator work with citrus growers on water-conserving practices in the Lower Rio Grande Valley. Texas Commission of Environmental Quality. It is essential to point out that this study was an extension work from this previously TWDB funded project.

Other outcomes:

We expect to enhance the sustainability of the projects beyond the life of this grant. We fully expect these behavior changes to have a future impact on the increase of water-use-efficiency and reduction of wasteful water attitudes. In addition to the direct training of farmers and the development of education materials, we also expect that participant producers and irrigation districts will serve other farmers as influence leaders by providing mentoring, showcasing successful cases with technical tours.

<u>Task 4: Agricultural demonstrations.</u>

Demonstrations with key commodity farmers and coordinated with our partners were established to document water savings and to evaluate the performance of the water balance program. Some of the most outstanding demonstrations are presented in this report.

Three Citrus Demonstrations in Wonderful Citrus (2016-2017).

We initiated demonstrations in citrus because this industry is the second-largest consumer of agricultural water, and the LRGV must develop an accepted industry consensus on how to effectively and efficiently irrigate Texas citrus. This industry was proposing the use of a pressure chamber to schedule irrigation following the recommendation from Wonderful Citrus' headquarters in California.

This project partnered with the industries' largest grower and innovator to ensure a real, on-farm perspective that will send a clear message to other industry growers of the importance of becoming better stewards of Texas' most important resource. The demonstrations consisted of:

1. Recording and collecting empirical data on how current irrigation practices affect the soil moisture profile throughout a crop cycle.
2. Developing a Texas citrus specific evapotranspiration crop coefficient. This strategy is an already accepted irrigation-timing tool that can be implemented across the spectrum of growers, from large to small.
3. Exploring the use of pressure chamber technology in Texas citrus groves. Pressure chamber technology is already utilized in various tree crops in California and provides a numerical value for plant moisture stress (PMS).
4. Host an industry grower meeting to share the project's findings and collaborate amongst growers on how to incorporate more efficient irrigation methods into their current programs.

Locations of plots:
The plots were located in Hidalgo County (Fig. 8) and the Coordinates, and Soil types are as follows:
Drip irrigation:

Longitude: 26 º 22' 23.04" N, latitude: 98º 16' 1.40" W
26.373066 N
98.267056 W
Hidalgo Fine Sandy loam soil with 0.1 % slope
Distance between trees 10.2 ft
Distance between rows 22.8 ft
Canopy cover: 20%

Surface irrigation:
longitude 26 º 22' 10.80" N, latitude 98º 15' 30.44" W
26.369667 N
98.258456 W
Brennan Fine Sandy loam soil with 0.1 % slope
Distance between trees 14.3 ft
Distance between rows 21.8 ft
Canopy cover: 31%

Sprinkler irrigation:
longitude 26 º 24' 32.11" N, latitude 98º 13' 30.97" W
26.408919 N
98.225270 W
Brennan Fine Sandy loam with 0.1 % slope
Distance between trees 12.1 ft
Distance between rows 24.8 ft
Canopy cover: 34%

Data collected:
We collected and recorded empirical data such as irrigation, soil water, and plant data from March 25 to December 2 of 2016 from three irrigation demonstrations: drip, micro-sprinkler,

and surface irrigated plots. Two stations with granular matrix sensors (GMS; Watermark1 soil water sensors, Irrometer Co., Riverside, CA) were installed per demonstration. Each station consisted of three GMS installed at 1, 2, and 3 ft soil depth to monitor daily soil water potential (centibars). It was intended to install remote soil water sensors, but none of the sensors have a communication signal. Therefore, the sensors were installed with a datalogger that recorded the soil water content daily. The information was downloaded weekly from the datalogger. However, there was a display in the datalogger that showed instant values of soil water content for all the sensors.

Additionally, the plant water status was measured by sampling ten leaves from several trees per demonstration. The leaves were sampled weekly and taken to the laboratory to measure their water potential in bars (1 bar equals 100 cbs) with a pressure chamber (Model 600 pressure chamber instrument, PMS Instrument Company. Albany, OR). The value of water potential is more negative in the plant than in the soil, which means water will flow from positive to negative water potential (from the soil to the plant). Citrus water use was estimated as ETc using weather data and the Penman–Monteith method (ASCE-EWRI Task Committee Report, January 2005) and using FAO crop coefficients for citrus (0.5, 0.7 and 0.85) as suggested by Allen et al. (1998).

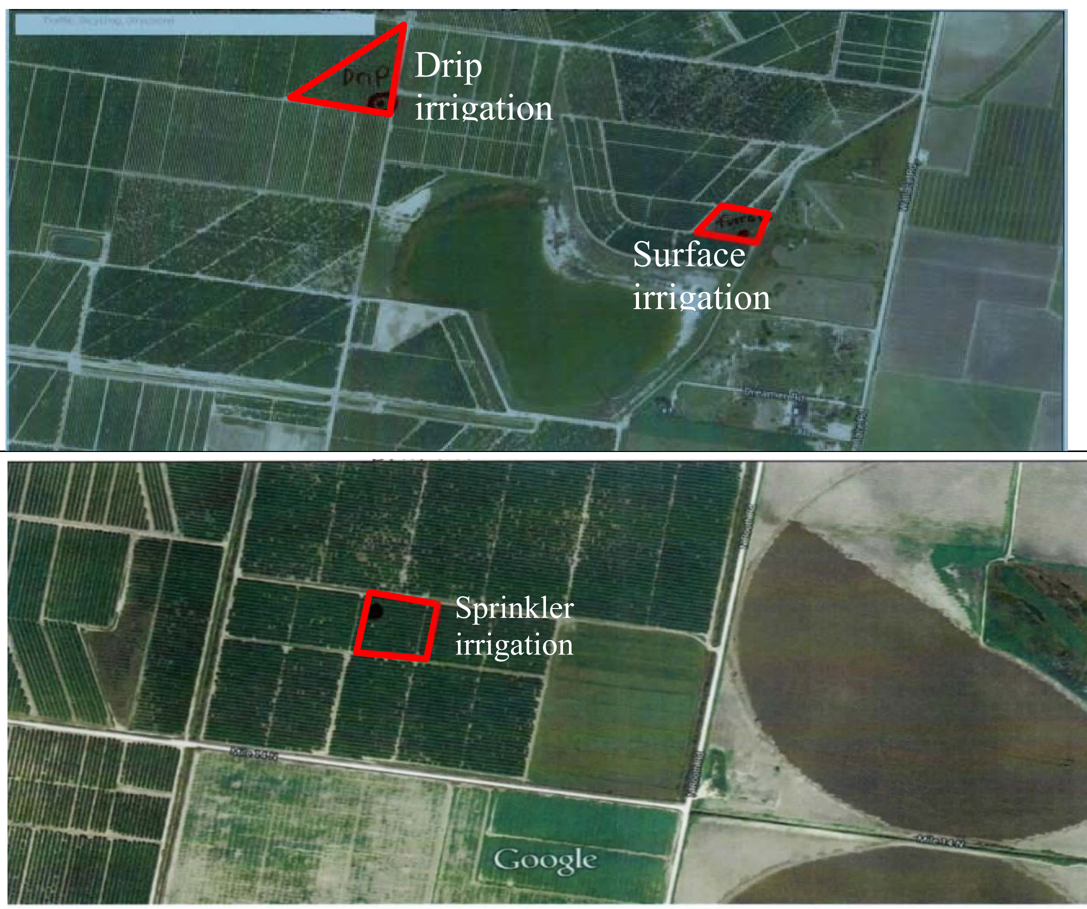


Figure 8. Location of the citrus plots: drip and surface irrigation (top), and sprinkler irrigation (bottom).

Results:
We developed a water balance to schedule irrigation. The internet-based program can be found at http://southtexasweather.tamu.edu/. The water balance use crop coefficients for different canopy covers (70%, 50%, and 20%), and orchards with ground cover and no ground cover. The orchards with no ground cover use herbicides to control weeds, and the ones with ground cover do not control weeds and vegetations between tree rows. The water balance was evaluated to help citrus farmers manage their irrigation applications more efficiently. The relationship between rainfall and citrus evapotranspiration is shown in Fig. 9, and the monitoring of the soil water content in Fig. 10.

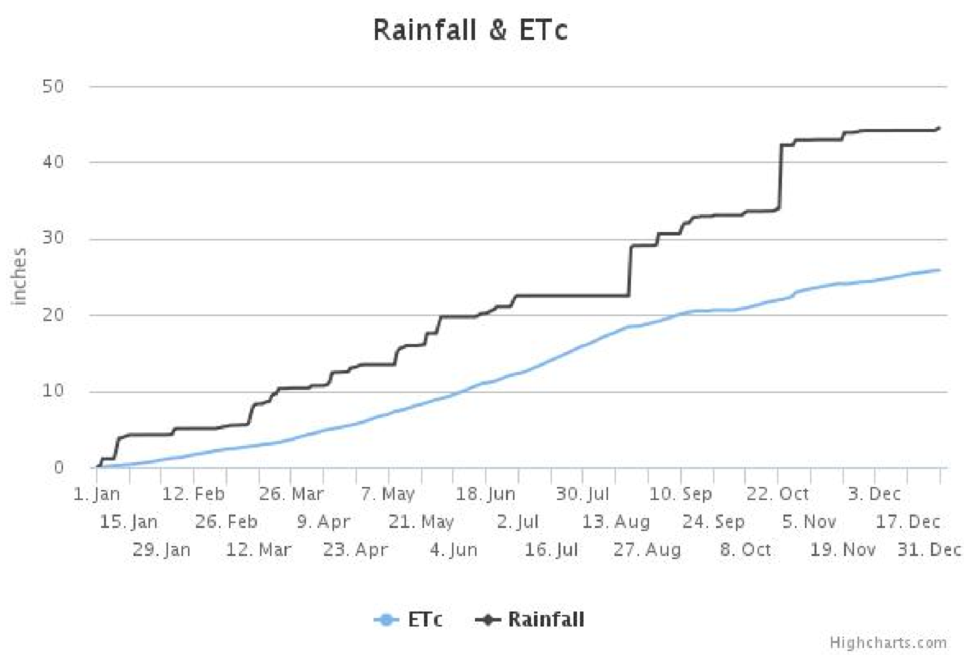


Figure 9. Citrus evapotranspiration and Rainfall

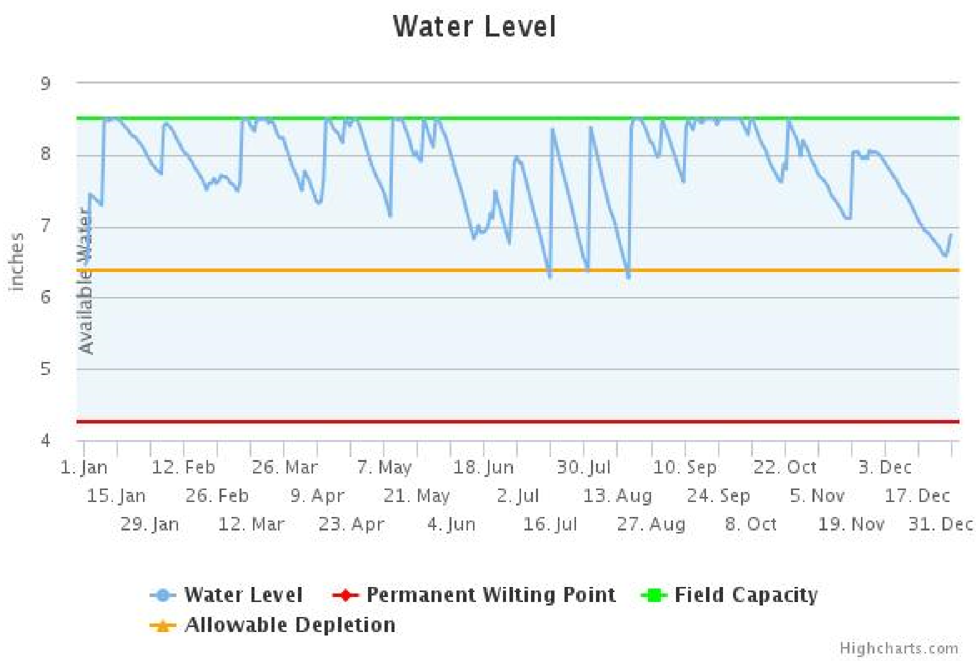


Figure 10. Water balance for citrus crops.

The plant water potential was measured using pressure chambers in young leaves and mature leaves irrigated under drip, micro-sprinkler irrigation, and surface irrigation methods. An average of 10 leaves samples was collected weekly, and the average results are shown in Figs 11 and 12. The water potential of young and old leaves was maintained under 14 bars most of the growing season in all the irrigation systems. Practically, there are no differences in water potential between any of the irrigation methods (drip, micro and surface). There was no relation between soil water stress and water potential of the plants.

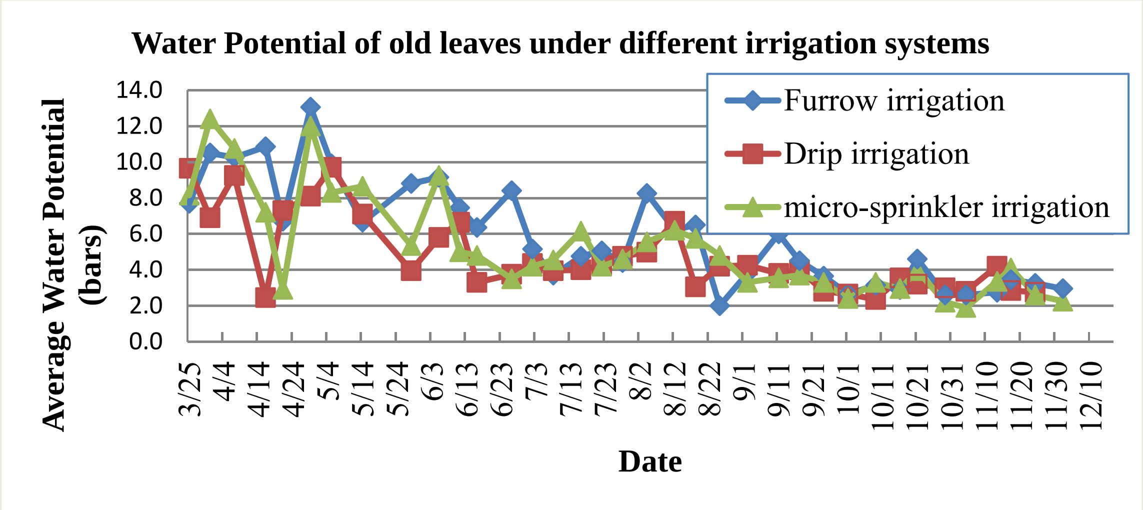


Figure 11. Water potential of old leaves under different irrigation methods.

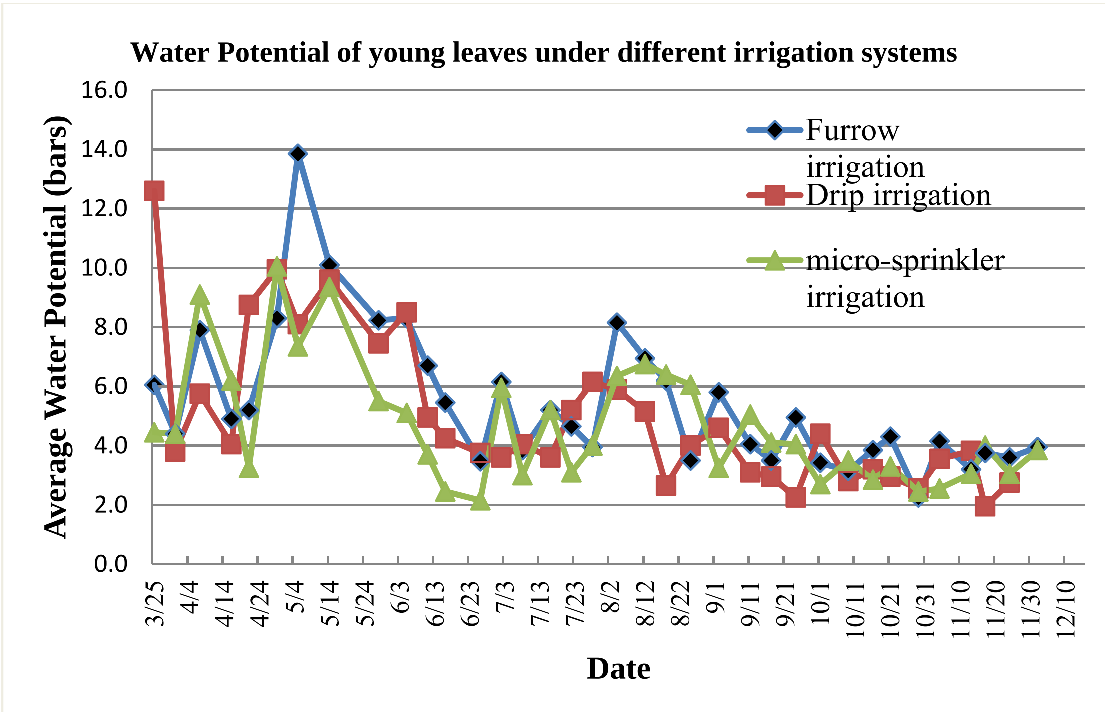


Figure 12. Water potential of young leaves under different irrigation methods.

The surface irrigation system was irrigated less frequently, and the sensors located at 1 and 2 ft reached over 200 cb several times. Once irrigation was applied, the soil water sensor reached 0 cb (Fig. 13). Drip irrigation was irrigated at a higher frequency, maintaining a wet soil profile with a reading of less than 40 cb, except one day around August in which it peaked 50 cb (Fig 14). The micro-irrigation system was kept at a reading of less than 50 cb most of the year (Fig 15). The soil is dry when the soil water content is close to 200 cb and wet when it is closer to 0 cb. For the surface irrigation system, the soil water content reached more than 200 cb several times during the growing season. The soil water sensors indicated higher stress for the surface irrigated system (Fig. 13) than the drip and micro irrigated plots (Fig 14 and 15). The higher soil water fluctuations can be observed at 1 and 2 ft than the 3 ft soil depth. The watermark sensors detected differences between irrigation methods and between irrigation events.

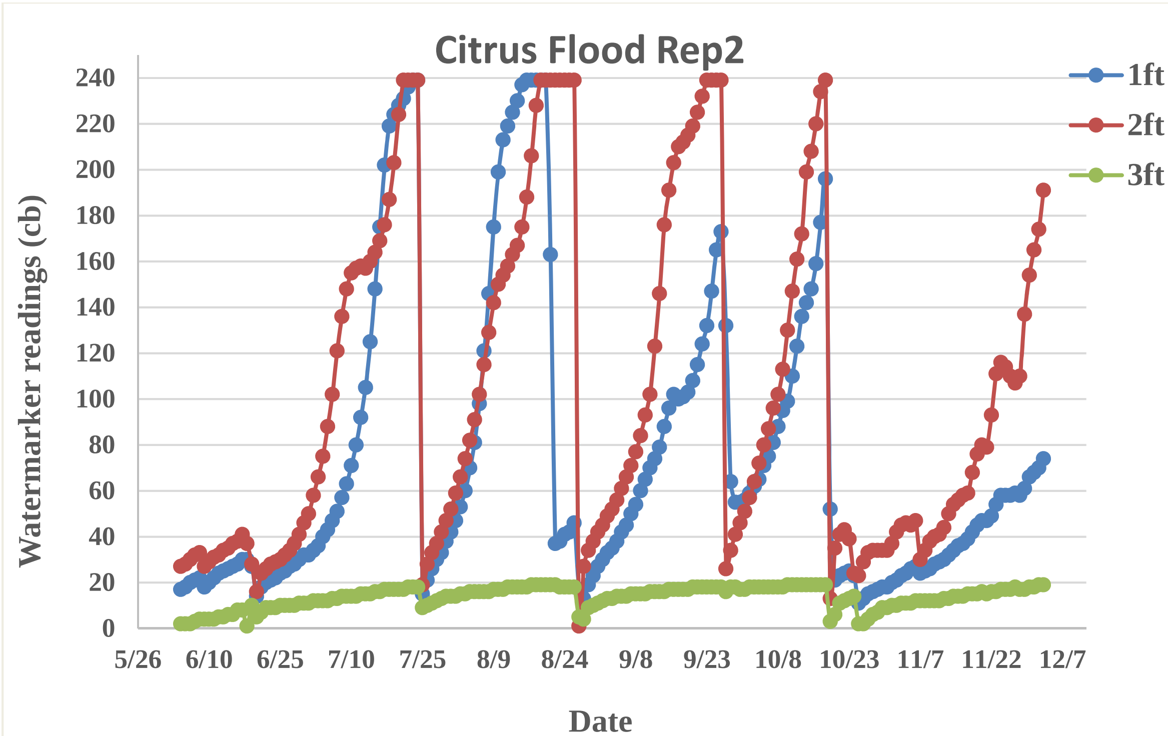


Figure 13. Soil water content measured with the water mark sensors for the surface irrigation system

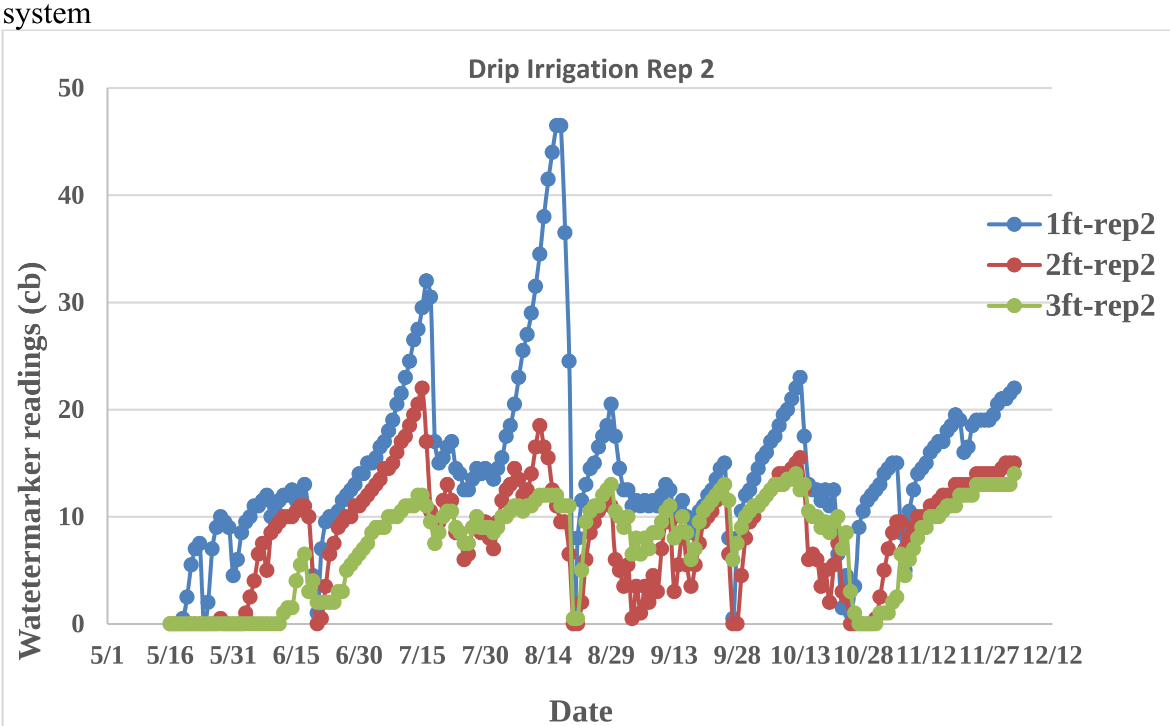


Figure 14. Soil water content measured with the water mark sensors for the drip irrigation system

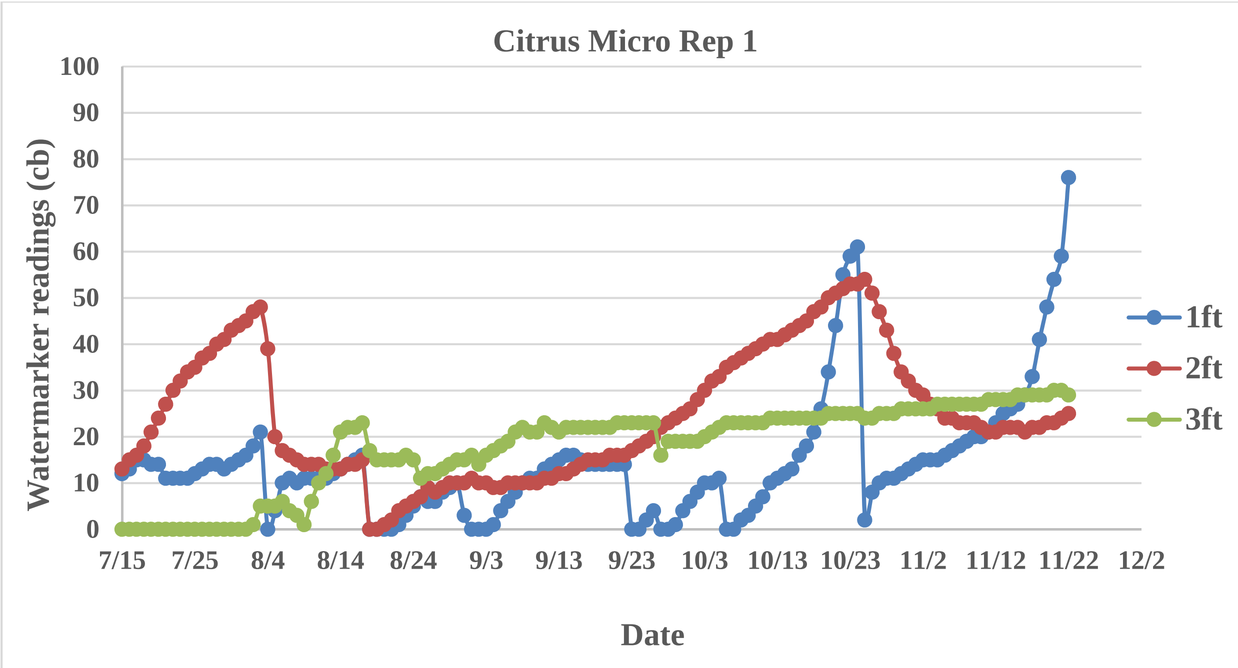


Figure 15. Soil water content measured with the water mark sensors for the micro-sprinkler irrigation system

Discussion from these citrus demonstrations.

Three methods were evaluated in this project to schedule irrigation: the use of soil sensors, the pressure chamber to determine plant water stress, and the use of internet-based weather stations to calculate evapotranspiration. All the evaluated methods present some advantages and disadvantages. We do not recommend the use of pressure chamber technology to schedule irrigation in citrus groves. One of the problems was that it did not detect differences between wetting and drying of the soil. There were also no differences between the irrigation methods using the pressure chamber. The pressure chamber technology is utilized in some places such as California and provides a numerical value for plant moisture stress of the soil (PMS). The values remained below 14 cb even if there was some soil water stress, such as the case of surface irrigation. Therefore, we did not recommend its use, and to my knowledge, Wonderful Citrus' headquarters' in California are not advocating the use of PMS anymore.

Another technology used in this study was the granular matrix sensors (GMS) soil water sensors. Some farmers have used this technology in the LRGV, and most farmers prefer it. The only problem of using this technology is that some fields may have some soil variability, and more than two stations may be needed per plot. However, this technology could be used to determine when to trigger irrigation. In this study, drip irrigation was generally triggered when the GMS reading reached 30 cb, and when micro-irrigation reached 50 cb. We recommend triggering flood irrigation when the sensor located at 1 ft, reaches 50 cb to avoid water stress. However, experiments are needed to learn more when to trigger irrigation and evaluate the yield and quality response to different water amounts. In this demonstration, we did not compare plots, and we did not harvest the fruit.

Irrigation using the soil water balance requires several computations and can be done using a spreadsheet. The website http://southtexasweather.tamu.edu/ was used in the demonstrations using a crop coefficient of 0.5 and estimated the water requirements very accurately. We believe that with the use of remote sensing and unmanned aerial vehicles, the canopy area could be estimated more accurately, and consequently, the crop coefficients and evapotranspiration.

Farmers comments about the demonstration:

- They mentioned that they preferred the granular matrix sensors (watermarks) to know when to trigger irrigation. However, some of them mentioned that they could not irrigate on time on a few occasions because the irrigation supplied pipes or pumps broke, or maintenance programs of the irrigation district.
- One farmer mentioned that "He was happy using the watermark sensors, and they explained when they should be irrigating."
- Another farmer concluded that while triggering irrigation at 60 cb with the sensor placed at 1 ft was very similar to how he generally irrigates.

Citrus Demonstration in Rio Farms (Detection of water problems due to possible over-irrigation). Demonstration of using unammaned aerial vehicles to detect irrigation problems.

Figure 16. Aerial view of a citrus farm that had over-irrigation problems and some sick trees.

We installed watermark sensors in some citrus fields. In agreement with Andy Scott, we were recommending triggering irrigation at 60 cb. However, in other fields, they presented some problems. Dr. Veronica Ancona from the Citrus Center contacted me to help them diagnose a problem. On this farm, the grower was watering quite often, and he received a heavy rainfall (more than 4 inches) just a few days after irrigation, the water table rose, producing fusarium disease that killed some of the trees (Fig. 16). We realized that the use of unmanned aerial vehicles could be a useful tool to manage irrigation. We installed some wells to monitor the water table, and with the weather stations, we determined the problem. In this demonstration, farmers applied a total of 11 irrigations and one big rainfall equivalent to another heavy irrigation. For this citrus, we estimated that they should be applying nine irrigations. Therefore, they used three extra irrigations of 5 inches each, which is the equivalent of 15 inches of over-irrigation. There are about 28,000 acres of citrus in the lower Rio Grande Valley. If they over-applied 15 inches of water per acre, it is equivalent of over-applying 35,000 ac-ft of water. Farmers comments about this demonstration:

- They realized that over-irrigation could leach out fertilizers and produce more disease. Therefore, this is a strong incentive for not over-irrigating.
- They were interested in conducting studies with unmanned aerial systems to detect plant water stress, considering the significant acreage that they have.
- They were also interested in the use of watermark sensors. (Note: In the past, we installed some sensors. We also advised them not to irrigate that often).
- Drip irrigation can help conserve water and to apply irrigation when it is needed. One incentive for farmers could be to help farmers install drip irrigation systems for citrus if they install flow meters, and they limit their allocations to 40-48 inches per year.

Citrus demonstration for the use of unnamed aerial vehicles versus using weather data in Weslaco, TX.

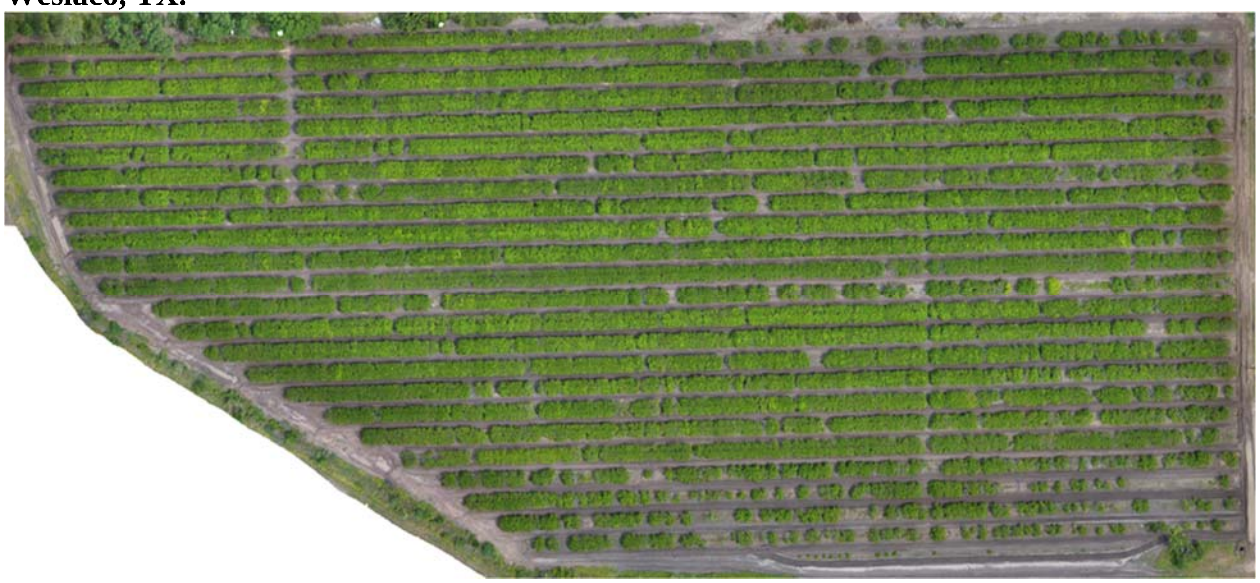


Figure 17. Weslaco Citrus Demonstration in new methods to schedule irrigation.

A paper with the results will be presented at the 2020 ASABE International Annual Meeting. The bottom line is that RGB cameras alone cannot be used to schedule irrigation. It is necessary to install soil water sensors to monitor irrigation. Excess green index (ExG) and triangular greenness index (TGI) were extracted from RGB images and were correlated to volumetric water content (VWC) measured in a citrus orchard. The results indicated that these indices are not correlated to volumetric water content. The RGB camera alone is not detailed enough to determine if the plant stress nor schedule irrigation properly (Fig. 17). In this study, canopy cover was used to determine the crop coefficients and estimate crop evapotranspiration. For scheduling citrus irrigation, it is necessary to monitor soil water content, estimate crop evapotranspiration, and use a water balance of the intended agricultural area to determine irrigation needs. More research is needed to explore the use of unmanned aerial vehicles for irrigation scheduling. Most of the published results used indices derived from hyperspectral and thermal images to detect plant water stress in deficit irrigated experiments, in which the plant already accumulated stress over time, affecting yield quality and production. The results of this demonstration were presented in several seminars during 2019. There is a significant interest of farmers to use new technologies, such as unmanned aerial vehicles and satellites to schedule irrigation.

Watermelon Demonstration in Weslaco.

The main goal of this demonstration was to compare watermelon crop production, fruit quality, and water use efficiency under subsurface drip irrigation with plastic (Drip-Plastic), subsurface drip irrigation without plastic (Drip-Bare) and furrow irrigation. During the field demonstration, a demonstration was conducted on how to use soil sensors (picture below). All the attendees to the exhibit were divided into several small groups.

Figure 18. Demonstration for the irrigation scheduling in vegetable crops. Weslaco, TX.

This study demonstrated that both drip and furrow irrigation systems could provide high watermelon yields when adequately managed. Similar yields were observed with both furrow and drip irrigation systems (Table 5). However, sweeter watermelons were obtained with the drip-irrigated over furrow-irrigated treatments. The °Brix, which measures the sweetness of the watermelons, was similar in the Drip-Plastic and Drip-Bare irrigated treatments. The Drip-Plastic and Drip-Bare irrigation treatments used 46% and 60% less water, respectively, than the furrow irrigated treatment, thus influencing the irrigation and water use efficiencies (Table 6). Drip irrigation may be a good option under water limiting conditions or when fruit quality and, specifically, total soluble solids is an important parameter for the grower. The highest irrigation efficiencies for the watermelons were observed for the drip irrigated treatment with plastic mulch (0.23 lbs/Gal) and for the bare soil (0.19 lbs/Gal). One important note in this study observed watermelon yields that were approximately three times higher than those typically observed in LRGV watermelon production, suggesting that implementation of a water balanced approach to irrigation can lead to greater fruit production and potentially economic gains to growers.

During this demonstration, we applied four irrigations using our program. The guidelines recommended three irrigation. Several farmers applied more than six irrigations. We believe that we could save at least eight ac-inches by saving two irrigations. These reduced number of irrigation events represent savings of 4666 ac-ft in 7000 acres of watermelons in furrow irrigation. This water-conservation savings trend in other vegetable crops such as tomatoes, cabbage, and cantaloupes, can be obtained if irrigation scheduling strategies, such as the use of soil moisture sensors or the irrigation guidelines are adopted.

Table 5. Watermelon yield and average fruit weight.

Irrigation treatment	Yield [mean ± SD ($kg \cdot ha^{-1}$)[z]]	Fruit weight [mean ± SD (kg)[y]]
Furrow	64,960 ± 4747 a[x]	6.9 ± 0.1 c
Drip-plastic	70,096 ± 6738 a	7.4 ± 0.1 b
Drip-bare	65,871 ± 2214 a	8.0 ± 0.2 a
F value	**0.31**	**16.62**
df	**2, 9**	**2, 9**
***P* value**	**0.74**	**<0.0001**

Data represents the average ± standard deviation of each treatment.
[z]1 $kg \cdot ha^{-1}$ = 0.8922 lb/acre.
[y]1 kg = 2.2046 lb.
[x]Different letters indicate significant differences between treatments at $P < 0.001$.

Table 6. Calculation of Evapotranspiration (ET), Water Productivity (WP)[z], and Irrigation Water Productivity (IWP)[y].

Treatment	Irrigation (cm)[x]	Rainfall (cm)[x]	Irrigations (no.)	ET (cm)[x]	WP ($kg \cdot m^{-3}$)[w]	IWP ($kg \cdot m^{-3}$)[w]
Furrow	27.4	13.7	4	39.6	15.8 ± 0.1 b[v]	23.7 ± 0.2 c
Drip-plastic	11.7	13.7	11	39.6	27.6 ± 0.3 a	60.0 ± 0.6 a
Drip-bare	14.7	13.7	13	39.6	23.2 ± 0.1 a	44.7 ± 0.2 b
F-Value					**11.90**	**25.90**
DF					**2, 9**	**2, 9**
p-value					**0.0030**	**0.0002**

Data represents the average ± standard deviation of each treatment.
[z]WP = yield / total water applied (irrigation + rainfall)
[y]IWP = yield / irrigation water applied
[x]1 cm = 0.3937 inch
[w]1 $kg \cdot m^{-3}$ = 1.6856 lb/yard^3
[v]Different letters indicate significant differences among treatments at $P < 0.001$.

Farmers comments about this demonstration:

- Drip irrigation will allow them to control fruit quality and improve yields.
- Drip irrigation can have better control of fertilizer applications.
- When they have plastic mulch, the use of soil water sensors is more efficient than using the internet weather-program as irrigation scheduling technique.

Conclusions

This project promoted irrigation scheduling as a water conservation practice using field demonstrations, an internet based-weather program, and by organizing educational programs for farmers. The use of irrigation scheduling using the weather-based program in citrus can conserve 15 inches of water per acre, equivalent to $35,000 ac-ft of water in the LRGV region. The weather program was evaluated in watermelons irrigated with furrow and drip irrigation, and 8 inches of water were saved as a result of implementing this irrigation scheduling program. The water conserved represent savings of 4,666 ac-ft of water in approximately 7000 acres. The use of drip irrigation and plastic mulch can conserve twice as much water (9,158 ac-ft of water in 7000 acres).

Approximately 240 farmers were educated in irrigation management. Four workshops, one irrigation tour and one field day were organized during the three years of the grant. I was invited to four professional forums and grower meetings to present the project's results to approximately 150 persons. This project was also used for leveraging federal funding for approximately $344,000.

This project also published more than two peer-review publications and one popular press article. An award was received from TCEQ, recognizing the impact of this project. The demonstrations and the internet weather-based program was also used to train four master students and one Ph.D. student.

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APPENDIX

Texas A&M AgriLife Extension

EBN-015
3/16

Irrigation Timing during Drought
Corn, Cotton, and Sorghum Furrow Systems

Juan Enciso, Charles Hillyer, Dana Porter, and Guy Fipps*

When water is limited, farmers must make several difficult decisions about how many times to irrigate, when to apply the water, and how much to apply. They also must accept that their crop may have some deficit, depending on the amount of water available. In districts where water is allocated per irrigation, farmers need to decide how many irrigations to apply and when to apply them.

The guidelines below can help you plan irrigations to minimize yield reductions in corn, cotton, and sorghum.

Reducing the number of irrigations

If the water supply is limited, first determine whether to irrigate part of the field or to practice deficit irrigation on all of it. The type of irrigation system greatly influences this decision:

- **Sprinkler systems** give irrigators better control of the amount and timing of irrigations, enabling the water to be distributed evenly over the entire field according to the irrigation plan.
- **Surface irrigation systems** require that the irrigators depend on their knowledge of and ability to manage the system.

Associate Professor and Extension Agricultural Engineer; Assistant Professor and Extension Agricultural Engineer; Associate Professor, Extension Program Leader, Biological and Engineering Department; and Professor and Extension Agricultural Engineer, The Texas A&M University System

Because surface irrigation lacks the flexibility of sprinkler systems, those irrigators must consider other strategies for managing drought, such as:

- Delaying the first irrigation of the season
- Reducing the number of irrigations
- Forgoing the last irrigation

The goal of delaying irrigation is to take a chance on rainfall during the waiting period. This strategy requires that you carefully consider weather forecasts and current soil moisture.

At times, farmers must reduce the number of irrigations but carefully control where to apply them. In some growth stages, the crop is more sensitive, and yield losses may be higher.

If the soil has moisture for the crop, the irrigator may be able to avoid the last application. After maturity, rainfall does not affect yield.

Irrigating in critical growing stages

Crops grown with limited water need deep soils that retain moisture well. These include medium to heavy soils with textures such as clay loams and silty clay loams.

If water is limited, plant more drought-tolerant crops such as dry-land sorghum, dry-land cotton, and sunflower.

Irrigation strategies differ by levels of water reduction. Following are plans for corn, cotton, and sorghum.

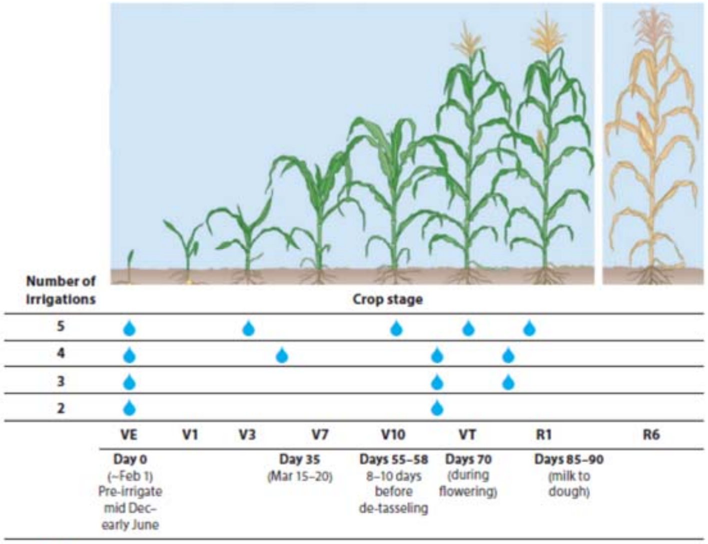

Figure 1. Timing and number of irrigations for corn in drought conditions.

Corn

Maize tolerates water deficits fairly well during its vegetative and ripening periods. Yields drop the most when the deficits occur in the flowering periods (tasseling and silking). Target your irrigation during flowering and, if water is available, during yield formation.

Five irrigations: Apply water according to the first row in Figure 1. In many situations, if soil moisture is good at planting, you may delay irrigation and end it at physiological maturity without affecting crop yields.

Four irrigations: If water is lacking, monitor the soil moisture content and consider the rainfall received during the season. With adequate rainfall, you may be able to delay and even conserve one irrigation.

Three irrigations: If you expect a wet year and decide to irrigate corn, but only three irrigations are available, try to pre-irrigate to establish good moisture for germination. The critical stages for irrigation are before the tasseling and silking stages, when the yield potential is determined.

Two irrigations: Apply water to establish the crop, and apply the second irrigation before tasseling. You will be taking the risk of relying on rainfall to supplement that irrigation.

Cotton

Cotton must have adequate soil water during germination and establishment. An irrigation will be needed if not enough moisture is available to establish the crop and obtain good stand. If water for two additional irrigations is available, apply one irrigation before squaring and the second before peak flowering.

If only two irrigations are available, apply one before or just after planting to obtain a uniform stand. Apply the second irrigation before the first white bloom.

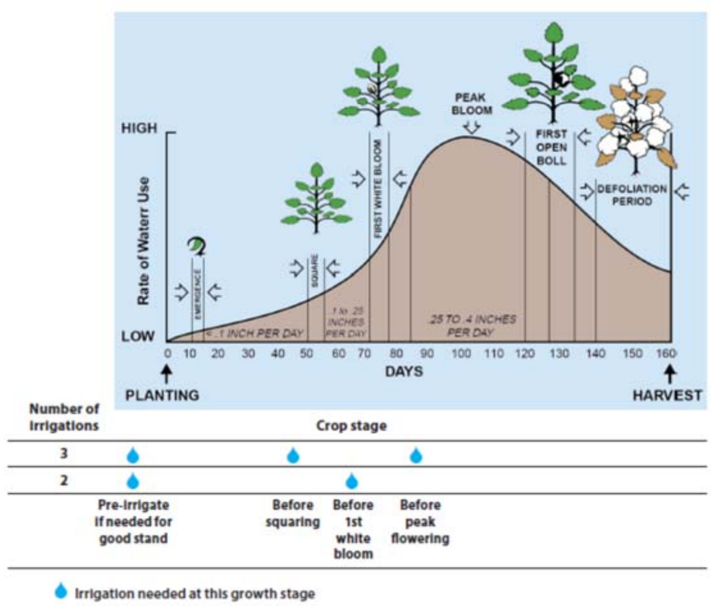

Figure 2. Timing and number of irrigations for cotton in drought conditions

Sorghum

Sorghum requires about 17 to 19 inches of water. Rainfall supplements part of these needs. The growth periods of sorghum are:

1. **Establishment,** from planting to fifth leaf visible (15 to 20 days)
2. **Vegetative,** from fifth leaf visible to head emergence or boot (20 to 30 days); in the boot stage, the head has developed nearly to full size and is enclosed in the flag-leaf sheath
3. **Flowering,** from emergence to seed set (15 to 20 days)
4. **Yield formation,** from seed set to physiological maturity (35 to 40 days)
5. **Ripening,** from physiological maturity to harvest (10 to 15 days) for a total of 92 to 120 days during the season

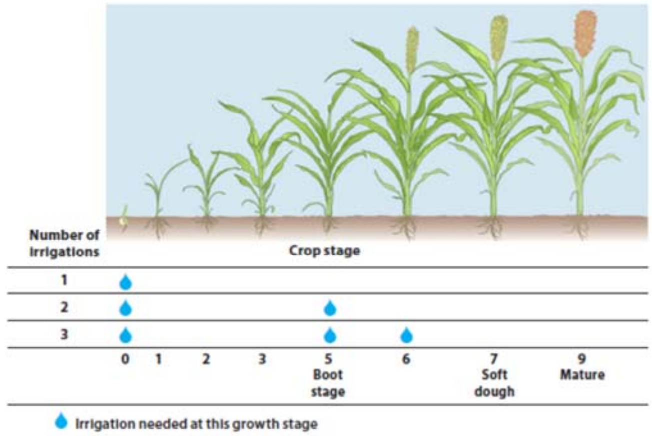

Figure 3. Timing and number of irrigations for sorghum in drought conditions

Sorghum is more drought resistant than are other crops such as corn. Sorghum has an extensive root system that helps the plant recover quickly after periods of water stress.

Sorghum requires from one to four irrigations, depending on climatic conditions, soil type, and tillage operations such as residue management. For optimum production when water is limited, irrigation must be timed appropriately.

If only one irrigation is available and the soil lacks enough moisture to germinate the seed, the best strategy is to apply water at pre-plant or just after planting to germinate the seed.

If only two irrigations are available, it is usually best to apply one at pre-plant and a second during the boot stage. The plant will achieve bigger gains in productivity per unit of water with these two irrigations. After the third irrigation, the productivity per unit of water will start to drop.

If a third irrigation is available, apply it during the filling heading stage. This stage is when the peduncle grows rapidly, extending the head through the flag leaf sheath. About half of the plants in a field are in some stage of bloom and two-thirds of the time from planting to physiological maturity. The plant has produced about half the total dry weight, and grain formation begins. If moisture is limited and the plant is stressed, the heads will fill poorly.

If four irrigations are available, the best strategy is to apply the last one during the soft dough stage, when the grain fills rapidly. About half of the dry weight accumulates in this period.

Other irrigation strategies

Some of the strategies to irrigate furrow irrigation systems are:

- Take advantage of this drought period to level your land if it is not leveled.
- To improve efficiencies, retouch the land already leveled.
- Avoid runoff:
  - Block the furrows at the lower end.
  - Supervise irrigations to avoid spills and runoff.
  - Use pump-back systems to help save runoff water.
- Irrigate using gated and flexible plastic pipes.
- To increase uniformity and reduce deep percolation losses:
  - Irrigate alternate rows.
  - Irrigate the tractor wheel rows.
  - Use surge irrigation.
  - Use packers and smothers on the rows to advance the water faster to the end of the row.
- Have a good flow rate per furrow to advance water as fast as possible in the row without eroding the soil. A low flow rate

will increase percolation at the upstream end, and will lixiviate (separate soluble and insoluble components) the fertilizer.

- To reduce runoff:
  - Shorten the wetting length of the rows.
  - Block the rows at the lower end.
  - Supervise irrigation closely to avoid runoff.

Acknowledgments

This publication was funded by the U.S. Department of Agriculture–Natural Resource Conservation Service as part of the Conservation Innovation Grants Number 69-3A75-1382 and the financial support of the Texas Water Development Board as part of the Agricultural Water Conservation Demonstration Initiative (ADI), also known as the Texas Project for Ag Water Efficiency (AWE).

Reference

Vanderlip, R. L. *How a Sorghum Plant Develops.* Kansas State University. Agricultural Experiment Station and Cooperative Extension Service. 1993.

Texas A&M AgriLife Extension Service

AgriLifeExtension.tamu.edu

More Extension publications can be found at *AgriLifeBookstore.org*

Soil Health & Irrigation Conservation Workshop

Date: August 24, 2016

Location:

Texas A&M AgriLife Research & Extension Center, Hoblitzelle Auditorium

2401 East Business Hwy 83 Weslaco, TX. 78596

8:00 AM– **REGISTRATION**

8:20 AM– **Welcome**

Rolando R. Zamora, Extension Agent-CEP (AgNR)

8:30 AM– **Internet Weather Based Tools for Irrigation Management,**

Dr. Juan Enciso Texas A&M AgriLife Research Associate Professor

Victor Gutierrez, Extension Assistant Texas Water Resources Institute

9:00 AM– **Soil Health for Maximum Productivity**

James Henderson, USDA-NRCS Agronomist

9:30 AM– **USDA-NRCS Programs**

Ray Hinojosa-District Conservationist USDA-NRCS

10:05 AM- **Concepts in Integrated Pest Management**

Dr. Ismael Badillo-Assistant Professor, Texas A&M Agrilife Research

10:30 AM– **Nutrient Management**

Brad Cowan, Texas A&M Agrilife-CEA Hidalgo County

Dr. Enrique Perez, Texas A&M AgriLife-CEA Cameron County

11:00 AM- **USDA-FSA Commodity Programs**

Chris Perez – USDA-FSA County Executive Director, Cameron County

11:20 AM- **Texas State Soil Water Conservation Board**

Ricardo Chapa-Regional Manager, Texas State Soil Water Conservation Board

11:40 AM– **USDA FSA-Farm Loan Programs**

Arnulfo Lerma-Farm Loan Manager USDA-FSA

LUNCH

1:00 PM– **Technical Assistance with FSA Farm Loan Applications**

Vidal Saenz, Extension Agent-CEP (Farm Advisor)

1:30 PM- **Rules, Regulations and Worker Protection Standards (2 hours of CEU'S)**

TDA

Texas A&M AgriLife Extension

Prairie View A&M University College of Agriculture and Human Sciences Cooperative Extension Program

Arroyo Colorado Conservancy

Texas Water Development Board

Texas Water Resources Institute make every drop count

Maverick County Agricultural Irrigation Field Day

Maverick County Junior Livestock Show Meeting Room
2350 East Main, Eagle Pass, TX 78852
September 13th, 2017

Please Register by September 11th at http://twri.tamu.edu/irrigation

Planned Agenda

08:00	**Registration**
08:30	**Welcome and Introductions** Dr. Lucas Gregory, Texas Water Resources Institute
08:40	**Irrigation Technologies and Best Management Practices for Water Conservation** Dr. Askar Karimov, Texas A&M AgriLife Extension Service
09:25	**Irrigation Scheduling and New Technologies** Dr. Juan Enciso, Texas A&M AgriLife Extension Service
10:00	**Economics of Irrigation Water Conservation** Dr. Samuel Zapata, Texas A&M Agricultural Economics
10:35	**Networking Break and Refreshments**
10:50	**Water Quality Issues in Irrigation** Dr. Dana Porter, Texas A&M Biological and Agricultural Engineering
11:30	**Irrigation Considerations for Pecan Production** Larry Stein, Texas A&M AgriLife Extension Service
12:00	**TWDB Water Conservation Program and Assistance Opportunities** Kevin Kluge, Texas Water Development Board
12:15	**NRCS Technical and Financial Assistance Opportunities** Serafin Aguirre, NRCS District Conservationist
12:30	**Program Evaluation and Adjourn**

Irrigation Training Program for LRGV
Address: 2401 E. Business Highway 83, Weslaco, Texas 78596
September 12th, 2017

This free producer program will focus on the practical aspects of implementing water conserving irrigation technologies. This program will also provide perspectives and researchers will convey water conservation, economic issues and other findings on each approach.

8:30 - 9:00 **Registration**

9:00 **Welcome and Introductions**
Dr. Lucas Gregory

9:10 **Economic Issues in Irrigation**
Dr. Luis Ribera or Dr. Samuel Zapata

9:30 **Irrigation Scheduling (Soil Moisture Monitoring)**
Dr. Juan Enciso

9:50 **Irrigation Technologies and Best Management Practices**
Dr. Juan Enciso and Dr. Porter

10:10 **Break**

10:15 **Water Quality Issues in Irrigation**
Dr. Dana Porter

10:30 **TWDB**
Kathleen Jackson (Ag water conservation)

10:50 **NRCS Nutrient management**
NRCS REP

11:10 **TSSWCB Irrigation Conservation Practices**
TSSWCB REP

11:30 **Fertigation/Chemigation**
Danny Sosebee

11:50 **Discussion**

Irrigation Management and Technology Workshop

Cameron County San Benito Annex: Extension Meeting Room
1390 W. Expressway 83, San Benito, TX
September 25th, 2019

This free producer program will highlight current irrigation management techniques and technologies available to growers that have the potential to add efficiency to their operations and conserve water resources. Discussion items will include irrigation scheduling, irrigation management techniques, new technologies available to the grower and salinity management. Economics and value of irrigation water will also be highlighted. Options for chemigation and fertigation discussion will provide **1 hour of CEU credit** for TDA pesticide applicator license holders. Technical and financial assistance opportunities and resources available to producers will also be discussed.

Please Register by September 20th at http://twri.tamu.edu/irrigation

Program Agenda

12:15	**Registration & Light Refreshments**
12:30	**Welcome and Introductions** Dr. Lucas Gregory, Texas Water Resources Institute
12:40	**Irrigation Scheduling Tools and Approaches** Dr. Dana Porter, Texas A&M AgriLife Extension Service, Biological and Agricultural Engineering
1:15	**Irrigation Management and Technologies Panel** Mr. Danny Sosebee, Netafim USA Mr. Jeffery Kleypas, Toro Irrigation Mr. Ken Whitley, Trellis, Inc.
2:00	**Economics and Value of Irrigation Water** Dr. Luis Ribera, Texas A&M Agricultural Economics
2:30	**Networking Break and Refreshments**
2:45	**TWDB TexMesonet Overview** Leyon Greene, Texas Water Development Board
3:00	**NRCS Technical and Financial Assistance Opportunities** TBD, NRCS District Conservationist
3:10	**TSSWCB Technical and Financial Assistance Opportunities** Mr. Ronnie Ramirez, TSSWCB Conservation Planner
3:20	**Salinity Management in Irrigation Water** Dr. Girisha Ganjegunte, Texas A&M Soil and Crop Sciences
4:05	**Chemigation and Fertigation Irrigation Options and Considerations for Growers** Dr. Juan Enciso, Texas A&M AgriLife Research
5:05	**Program Evaluation and Adjourn**

Irrigation Management and Technology Workshop

Echo Hotel and Conference Center: Vista Room
1903 South Closner Blvd. Edinburg, TX
September 26th, 2019

This free producer program will highlight current irrigation management techniques and technologies available to growers that have the potential to add efficiency to their operations and conserve water resources. Discussion items will include irrigation scheduling, irrigation management techniques, new technologies available to the grower and salinity management. Economics and value of irrigation water will also be highlighted. Options for chemigation and fertigation discussion will provide **1 hour of CEU credit** for TDA pesticide applicator license holders. Technical and financial assistance opportunities and resources available to producers will also be discussed.

Please Register by September 20th at http://twri.tamu.edu/irrigation

Program Agenda

07:45	**Registration & Coffee**
08:00	**Welcome and Introductions** Dr. Lucas Gregory, Texas Water Resources Institute
08:10	**Irrigation Scheduling Tools and Approaches** Dr. Dana Porter, Texas A&M AgriLife Extension Service, Biological and Agricultural Engineering
08:45	**Irrigation Management and Technologies Panel** Mr. Danny Sosebee, Netafim USA Mr. Jeffery Kleypas, Toro Irrigation Mr. Ken Whitley, Trellis, Inc.
09:30	**Economics and Value of Irrigation Water** Dr. Luis Ribera, Texas A&M Agricultural Economics
10:00	**Networking Break and Refreshments**
10:15	**TWDB TexMesonet Overview** Leyon Greene, Texas Water Development Board
10:30	**NRCS Technical and Financial Assistance Opportunities** TBD, NRCS District Conservationist
10:40	**TSSWCB Technical and Financial Assistance Opportunities** Mr. Ronnie Ramirez, TSSWCB Conservation Planner
10:50	**Salinity Management in Irrigation Water** Dr. Girisha Ganjegunte, Texas A&M Soil and Crop Sciences
11:35	**Chemigation and Fertigation Irrigation Options and Considerations for Growers** Dr. Juan Enciso, Texas A&M AgriLife Research
12:35	**Program Evaluation and Adjourn**

TEXAS A&M AGRILIFE EXTENSION

5 CEU's Workshop

Friday, February 7, 2020
Hoblitzelle Auditorium, Texas A&M Agrilife Research & Extension Center, Weslaco, TX. 78596
Registration: 8:00-8:45 a.m. Workshop begins at 9:00 a.m.

Fee: $40 for 5-hour workshop or $10 per hour for partial credit
Make checks payable to: Valley Ag Fund
Need an invoice? Call or email Elena@(956) 383-1026 or ealmendarez@ag.tamu.edu
Lunch will be on your own

This training has been approved by TDA for 5 hours of continuing education units

Agenda

9:00 a.m.	**Issues in Cotton and Tomatoes**, Dr. Olufemi Alabi, PhD, Associate Professor and Extension Specialist, Plant Pathology and Microbiology, Texas A&M AgriLife Extension Service
10:00 a.m	**Federal and TDA Recordkeeping,** Dr. Don Renchie, Associate Professor, Extension Program Leader for Pesticide Safety and Education
11:00 a.m.	**Applying Chemicals and Fertilizer Through Irrigation**. Dr. Juan Enciso, Associate Professor, Texas A&M AgriLife Research
12:00 noon	Lunch on your own
1:00 p.m.	**Pesticide Safety for Aerial Applicators** Dr. Mark Matocha, Assistant Professor & Extension Specialist, College Station
2:00 p.m.	**Spray Drift Management for Aerial Applicators** Dr. Dan Martin, Research Engineer, USDA Aerial Application Technology Unit, College Station

(CEU's offered will be 2 General, 1 IPM, 1 Laws & Regs, and 1 Drift)

TEXAS A&M AGRILIFE RESEARCH AND EXTENSION CENTER AT WESLACO

TEXAS A&M AGRILIFE RESEARCH

June 5, 2020

John T. Dupnik,
Deputy Executive Administrator
Water Science and Conservation

Dear Mr. Dupnik,

I appreciate all the comments and suggestions to improve my final report. I addressed all the comments and made corrections accordingly to the final report. I'm also attaching to this letter my response to some suggestions. Please, let me know if any additional modifications are needed.

Regards,

Juan Enciso, Ph.D. P.E.
Associate Professor
Biological and Agricultural Engineering Department
Texas A&M AgriLife Research
2415 E. Business 83
Weslaco, TX. 78595

2415 E. Hwy 83
Weslaco, TX 78596-8344
Tel.: 956.968.5585 | Fax: 956.969.5620
Weslaco.tamu.edu

General:

- Ensure consistency of font type formatting throughout.

I reviewed the formatting and font type.

- Format report according to TWDB accessibility standards.

I corrected some figures to adhere to the TWDB accessibility standards.

- Please add a cover page, table of contents, and list(s) of figures & tables.

I added them.

- Please include a cumulative estimate of the water savings benefits realized through the course of this project and as a direct result of the grant funding.

I added them and added a conclusion as suggested

- Please define all acronyms prior to use.

I defined the acronyms

Page 1: *Corrected*

· Please considering rephrasing, "*Irrigation water use needs to decrease 240,000 ac-ft/year from 2020 to 2070 according to our most recent Region M Water Plan to meet this demand*" to start with the phrase "According to our most recent Region M Water Plan" followed by a comma. *Corrected*

· Please standardized the font formatting for "*This project will educate farmers* ***on measuring water - use with soil moisture sensors***". *Corrected*

· Please consider changing "*using it*" to "irrigating" in last sentence. *Corrected*

· Please consider adding one or two paragraph breaks in the Introduction on page for better readability. *Corrected*

Page 3: *Corrected*

· Change *"farm Bureau"* to "Texas Farm Bureau", if applicable.

Page 9: *Corrected*

· Please elaborate on the findings regarding irrigation system types for the specific crops mentioned. *Corrected*

· Consider including any associated data with these findings in the table or include a separate table with the irrigation savings potential by system type. *Added*

· The paragraph below Table 3 refers to a *"graph"*. Correct this to say "table" or include the appropriate graph, if applicable. *Corrected*

Page 11: *Corrected*

· Please reformat the text and images in Figure 6 to meet accessibility standards.

Page 12: *Modified the picture*

· Please consider adding "*on left*" and "*on right*" for description of Figure 7 for better clarity. *Removed the students' pictures.*

· Please ensure students photographed are 18+ or parental consent forms are included along with the final report submission for Figure 7. *Removed the students' pictures. The students are from College Station and it will take a lot of time to get parental consent forms.*

Page 13: *Corrected*

· Within the citations of the pdf document, 'Juan Enciso' and dates appear to be bolded in some areas, but not in others. Please consider reviewing and standardizing if necessary. *Corrected*

Pages 12–16: *Corrected*

· Consider adding an introductory paragraph to each of the *Presentations, Other Grants, Journal Articles, Papers, Press, Student Training,* and *Awards* sections, similar to those of the *Educational Workshops* and *Field Days* sections, to explain the overall relevance to the project scope of work and benefits to the state. *Added introductory paragraphs*

Page 15: *Corrected*

· Please change "*advice*" to "advised." *Corrected*

Page 16: *Corrected*

· Please rephrase or clarify who *"They"* refers to in the sentence about the Environmental Excellence Award. *Corrected*

· Revise *"...the headquarters in California"* to "...Wonderful Citrus' headquarters in California." *Corrected*

Page 18: *Corrected*

· Please correct "*Additionally, the plant was status was measured by*". *Corrected*

· Please consider adding an extra line between the 4th and 5th line of the text, where there appears to be a paragraph break. *Corrected*

Page 19: *Corrected*

· In the last sentence, change *"relation"* to "relationship". *Corrected*

Page 20: *Corrected*

· Please consider editing Figure 11 to allow the legend to be more legible. *Corrected*

Page 21: *Corrected*

· Include drip and micro-irrigation in the legend on Figure 12. *Corrected*

· Capitalize *"august"*. *Corrected*

· Please consider revising, "*The soil water sensors can be a good indicator of plant stress, considering the differences between the three irrigation methods and between irrigation events, and were very useful to schedule irrigation.*" *Corrected*

Page 23: *Corrected*

· Please consider revising, "*The method that we recommend the less for schedule irrigation it is the use of pressure chamber technology to schedule irrigation in citrus groves*" to "we do not recommend" or "the least efficient method." *Corrected*

· Explain if *"...they are not advocating the use of PMS anymore"* refers to Wonderful Citrus' headquarters in California, or... (?) *Corrected*

· Change *"Some farmer has..."* to "Some farmers have..." *Corrected*

· Please consider adding an extra line between the 11th and 12th line of the text, where there appears to be a paragraph break. *Corrected*

Page 24: *Corrected*

· Please add comma before and after "*consequently*". *Corrected*

· Consider revising this sentence, *"This can cause to delay the irrigation too much or compromise and irrigate earlier." Corrected*

· In the bold text, please change "*possibli*" to "possible" and change "*unammaned aerial problems*" to "unmanned aerial vehicles".

· Capitalize "Citrus Center." *Corrected*

Page 25: *Corrected*

· Please change "*raised*" to "rose." *Corrected*

Page 26: *Corrected*

· Change *"...Citrus orchard"* to "...citrus orchard." *Corrected*

· Please consider revising, "*The RGB camera alone is not enough to determine if the plant is stressed and schedule irrigation*" to "*The use of an RGB camera, alone, is not detailed enough to determine plant stress nor schedule irrigations properly.*" *Corrected*

· Please add comma before "*in which the plant already accumulated*" *Corrected*

· Please add comma before and after "*such as unmanned aerial vehicles and satellites". Corrected*

· Correct spacing issues between pages 26 and 27. *Corrected*

Page 27: *Corrected*

· Please correct, "*During the field demonstration, a field was conducted"* to "...a field day was conducted." *Corrected*

· Revise *"attendants"* to "attendees." *Corrected*

· Change *"watermelon"* to "watermelons", where appropriate. *Corrected*

· Please clarify, *"°Brix was similar for Drip-Plastic and Drip-Bare irrigation systems." Corrected*

· Please define TSS in "*TSS is an important parameter for the grower" Corrected*

· Please add "s" to "irrigation" in final paragraph. *Corrected*

Page 28: *Corrected*

· Include a conclusion paragraph with a brief summary of the project results, including any feedback provided from the producer surveys and an estimate of water savings as a result of the project, according to the scope of work (Task 4).
We added a conclusion part at the end of results