Monitoring and Management of Pecan Orchard Irrigation: A Case Study-Part II

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Summary

Pecan (*Carya illinoiensis*) production in the southwest US requires 1.90 m (75 inches) to 2.5 m (98 inches) of irrigation per year depending on soil type. However, for many growers, scheduling irrigation is an inexact science. Currently, there are several options available to growers, and some, such as soil moisture sensors and computerized data-collection devices have become inexpensive. With more growers using computers in their business, there is potential to improve irrigation efficiency using these new soil moisture monitoring tools. The objectives of this project were to introduce 2 low-cost soil monitoring instruments to a group of pecan producers, provide instruction on the use of internet-based irrigation scheduling resources, and provide assistance in utilizing these tools to improve their irrigation scheduling and possibly yield. The Doña Ana County Extension agent selected 5 small to intermediate-scale pecan farmers based on their expressed interest in improving soil moisture monitoring

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and whether they used a computer. Farmers were instructed on the use of the instruments and associated software, and received instruction on the use of climate-based irrigation scheduling resources found on the internet. All participants understood that better management of water inputs may translate into higher yields that could offset instrument costs. Three out of five growers indicated they used either the granular matrix sensors (GMS) or tensiometer to schedule irrigations, but compared to the climate-based irrigation scheduling model, all growers tended to irrigate later than the model's recommendation. Graphical analysis of time-series soil moisture content measured with the GMS showed a decrease in the rate of soil moisture extraction coincident with the model's recommended irrigation dates. These inflection points indicated the depletion of readily available soil moisture in the root zone. The findings support the accuracy of the climate-based model and suggest that the model may be used to calibrate the sensors. Four of the five growers expressed interest in continued use of the tensiometer, but only one expressed a desire to use the GMS in the future. None of the participants expressed interest in using the climate-based irrigation scheduling model. A series of nomographs relating time of years to days between irrigation bas on multiple years of climate and the irrigation scheduling model were then produced to try and simplify the irrigation scheduling process. These nomgraphs are currently be evaluated by a focus group to determine if this solution will overcome the limitations of soil moisture sensors or internet climate based irrigation scheduling The nomograph approach to irrigation scheduling is simpler but information is lost using average weather data than real time climate data. .

Introduction

New Mexico is one of the top three producers of improved variety pecans (*Carya illinoiensis*) in the U.S, . In 2005, New Mexico produced 28.6 million kg (62 million lb) of high quality improved variety pecans that garnered the highest price per pound in the nation (USDA National Agricultural Statistics).

Pecans naturally require large quantities of soil moisture to thrive (Sparks, 2002; Wolstenholme, 1979). In commercial pecan production, irrigation is one of the most important inputs affecting yield, especially in mature orchards (Garrot et al., 1993; Rieger and Daniell, 1988; Sparks, 1986; Stein et al., 1989). With all nutrients in sufficient supply it is ultimately non water-stressed evapotranspiration (ET) that contributes most to carbohydrate production (Andales et al., In press). The amount of irrigation water required to produce a crop of pecans ranges from 1.9 m to 2.5 m per year depending on soil type, with yearly ET measured at 1.31 m (52 inches) (Miyamoto, 1983) to 1.42 m (56 inches)(Sammis et al., 2004). In the interests of water conservation, the goals of growers and the research community have been to maximize irrigation application efficiency through proper design and operation of the irrigation system, and at the same time maximize water use efficiency and profitability through careful irrigation scheduling.

Under dead level flood irrigation farmers let water advance down the bordered plot until the water reaches ¾ of the distance from the end before closing the gate or they let the water reach the end of the border and then switch to the next border. This method typically over-irrigates the trees nearest the gate and may under-irrigate at the end of the run, although, application efficiencies in flood-irrigated orchards in the Mesilla Valley of New Mexico have been reported as high as 89% (Al-Jamal et al., 2001). By using soil moisture sensors in their irrigation program growers can better estimate when to schedule sufficient water to the end of the bordered plot and thereby increase water use efficiency.

For growers using computers for their operations there is potential to improve water use efficiency. Growers connected to the internet have access to real-time, relatively local scale climate information and can apply it with relative ease to estimate crop ET and soil moisture depletion using a climate-based irrigation scheduling model found on the New Mexico Climate Center website (http://weather.nmsu.edu). In recent years soil moisture sensors and automated data-collection devices have become inexpensive and accessible. Use of granular matrix sensors (GMS) has become a popular method for measuring soil water potential. Using a computer with both climate-based and soil-based scheduling tools, irrigations can be timed according to crop consumptive use, and site-specific water status.

Nomographs to schedule days between irrigations based on crop and soil type and local long term average climate conditions have been used successfully but information is lost when using average climate conditions (Henggeler 2006) .

The objectives of this project were to introduce two low-cost (< $250 for both) soil monitoring instruments, provide instruction on the use of internet-based irrigation scheduling resources, and assist a group of small to intermediate scale producers in utilizing these tools to facilitate more efficient irrigation scheduling. At the end of the growing season we would assess the performance of the sensors and determine if the farmers would adopt the technology. A second objective was to develop a simpler approach to irrigation scheduling by developing an irrigation nomograph.

Materials and methods

PARTICIPANT SELECTION AND STUDY LOCATION. The Doña Ana County Extension Agent selected five small to intermediate-scale pecan farmers based on their expressed interest in improving soil moisture monitoring, and whether they operated a computer as part of their farming operation. In February 2005, instruments were installed in each grower's orchard located in the Mesilla Valley from Vado, N.M., to north of Doña Ana, N.M.

INSTALLATION OF SOIL-BASED INSTRUMENTS. Each grower received two GMS sensors (Watermark, Irrometer Inc., Riverside Calif.), four data loggers (HOBO H08-002-02, Onset Computer, Bourne Mass.), and datalogger software (Boxcar 3.7, Onset Computer, Bourne Mass.). The extra data loggers pair remained dormant until launched and swapped with the field loggers as they were collected for downloading. Since these HOBO data loggers record a voltage signal, the input cable lead connected to the GMS (2.5 Stereo Cable, Onset Computer, Bourne Mass.) was modified by adding a large resistor to reduce the voltage drop across the sensor and minimize data logger battery drainage. A 10-kiloohm, 1/4 W, 0.1% tolerance metal film resistor (Mouser Electronics, Mansfield Texas) was soldered to the cable leads as described by Allen (1999).

The GMS sensors were buried according to the manufacturer's recommendations at approximately the middle of the root zone, 40 to 45 cm (16 to 18 inches) depth at two locations in each orchard. To assess the unevenness of the irrigations in a single bordered plot one GMS was installed between the first and second tree in a row closest to the irrigation turnout, and the other at the end of the plot between the last and second last tree in the same row. Interior rows were chosen to avoid edge effects. The sensors were placed equal distance between trees, approximately 4.6 m (15 feet) from the trunk.

Each grower also received one 45 cm (18 inch) tensiometer (Model R or LT, Irrometer Inc., Riverside Calif.), which was placed approximately 1 m (39 inches) from the GMS sensor at the end of the plot furthest from the turnout. Growers were given an estimated target soil moisture tension approximating 50 to 60% of field capacity (FC) based on the manufacturer's recommendations for soil texture, and on literature references (Curtis and Tyson, 1998; Paramasivam et al., 2000; Sammis, 1996a).

GMS DATA CONVERSIONS. The derivation of volumetric soil moisture from the data logger output requires three mathematical conversions: converting voltage to resistance, converting resistance to soil matric potential, and converting matric potential to volumetric soil moisture using pedotransfer functions (PTF) specific to soil texture classifications. The resistance of the GMS was calculated using equation 1:

$$R = 10 \times V/(2.5 - V) \qquad [1]$$

where R is the resistance produced by the GMS (kiloohms), and V is the voltage recorded by the HOBO data logger (volts).

The resistance of the GMS was converted to soil matric potential (kilopascals) using equation 2, developed by Shock et al. (1998):

$$\Psi_m = (4.093 + 3.213 \times R)/(1 - 0.009733 \times R - 0.01205 \times T) \qquad [2]$$

where Ψ_m is matric potential (kilopascals), R is the resistance of the GMS (kiloohms), and T is the average soil temperature (°C). We assumed that the soil temperature was approximately 20°C (68° F) for this region during the summer.

Farm soil texture classifications, on which water holding capacity and PTF were based, were determined by the growers, and verified using the Doña Ana County Soil Survey (Bulloch and Neher, 1980). However, typical of layered alluvial soils, considerable soil texture spatial variability, both vertically and horizontally, was observed within the plots at all locations. Soil pedotransfer functions were developed in the form described by van Genuchten (1980)

TECHNOLOGY TRANSFER. The growers were given oral instruction during demonstration, and a manual describing the steps to activate the data loggers, and to retrieve and import data logger text file information into a spreadsheet program that included the pedotransfer functions (Excel, Microsoft, Redmond Wash.). The manual also described the steps to enter the data logger information in the spreadsheet for converting the sensor voltage output into soil matric potential and soil moisture content. The manual contained blank worksheets for collecting tensiometer data, and listed contact information for the manufacturers of the equipment. The growers then received oral instruction, and demonstrations on how this file was to be used as a source in graphing soil moisture depletion through time, and how the HOBO voltage data was to be appended to the cumulative file by the grower as the data was collected over the season. The graph would allow the grower to extrapolate a future time when the soil moisture would reach a target of 50 to 60% of field capacity, and schedule the next irrigation. Growers were given the target volumetric soil moisture based on PTF for their soil texture.

The growers also received written instructions, and in some cases, a demonstration on their computer, on how to extract estimated pecan ET from the New Mexico Climate Center web site. Daily ET values listed on this site are computed from a climate-based model using Penman's reference ET, an empirically derived crop coefficient for pecan, and regional weather data (Sammis, 1996b; Sammis et al., 2004). Using modeled ET along with a texture-based estimate of soil water holding capacity within a root zone of 1 to 1.2 m (3 to 4 feet), growers could compute an estimated amount of soil moisture lost to ET each day, or since their last irrigation.

POST-SEASON DATA ANALYSIS. Irrigation dates were deduced from time-series GMS data sets from three of the five growers for which we had complete season-long information. The actual irrigation dates were entered in the climate-based irrigation scheduling model and compared with the model's predicted the irrigation dates. Model inputs and parameters were set to include soil water-holding capacity based on soil texture, root zone depth of 1.2 m (4 ft) , an estimated 11.9 cm (4.7 inches) of water applied at each irrigation, and a maximum allowable soil moisture depletion (MAD) of 45%. The model also had a soil moisture stress function that linearly decreased ET when the MAD was less than 45% (Andales et al., In press; Garrot et al.,1993). The cumulative difference between non-stressed ET and stressed ET was determined for each data set for the season and converted to yield loss using a water production function ($2.48 kg.ha^{-1}.mm^{-1}$) (Sammis et al., 2004), and revenue loss based on an average in-shell price of \$0.49/kg (\$1.08/lb).

To assess the calibration of the GMS sensors, the maximum measured soil moisture content at each irrigation was compared to the predicted FC moisture content based on the PTF for that particular soil texture. In addition, the GMS-measured soil moisture at the model-predicted irrigation dates were checked for consistency across irrigation cycles, and correspondence to the predicted moisture content at the 45% MAD. The GMS data used in the analysis was taken from sensors located at the end of the border, furthest from the irrigation gate. Data from sensors nearest the irrigation gate were not included since the gates tended to leak, resulting in perpetually high moisture levels and peaks corresponding to irrigation in adjacent borders.

Results and Discussion

TECHNOLOGY TRANSFER. The farmer participants in this study had diverse backgrounds, computer skills, and farming objectives. They owned and operated pecan orchards ranging from 4 to 112 ha (10 to 278 acres), providing up to 100% of their income (Table 1). Their average age was 48.5 years, and all had some college education. Most considered themselves proficient on the computer However, the degree to which they utilized computers to perform and track farm business activities varied and did not correlate with age or farm size. Most did not log inputs, such as irrigation dates or fertilizer applications with their computer.

Grower number	Age (yr)	Farming experience (yr)	Farm size (ha^z in pecan)	Farm revenue ($ x 1000)	Percent of personal income from pecan sales	Education level
1	48	27	64.8	> 100	100	Some college
2	22	7	4.9	10-30	<1	BS
3	54	20	24.3	>100	10-50	BA
4	55	5	4.2	10-30	25	BS, some grad.
5	64	35	112	>100	30	BSME

Table 1. Pecan farming experience, farm scale, and personal information of study participants.

All of the participants in this study had their own wells and could irrigate as needed, but when surface water was available there could be a delay of a few days from the time of placing an order with the irrigation district to the time of delivery. Previously, the growers had used calendar day, soil probe, and “moisture by feel” to schedule irrigations (Table 2). Some had previous experience using tensiometers, but none had used the climate-based model for estimating ET, even though it has been promoted and demonstrated at the Western Pecan Growers Conference held annually in Las Cruces, New Mexico and has been available on-line for more than four years.

Table 2. Pecan grower response to pre-season questions regarding irrigation scheduling and prior soil moisture monitoring instrument use, and post-season evaluation of the irrigation scheduling project.

Question	Response by grower				
	1	2	3	4	5
How have you previously scheduled irrigations?	Calendar, soil probe	Calendar	Calendar, moisture by feel	Calendar, soil probe	Calendar, soil probe
Had you ever used a tensiometer to measure soil moisture before?	No	No	Yes	Yes	No
Had you ever used the climate-based irrigation scheduling model before?	No	No	No	No	No

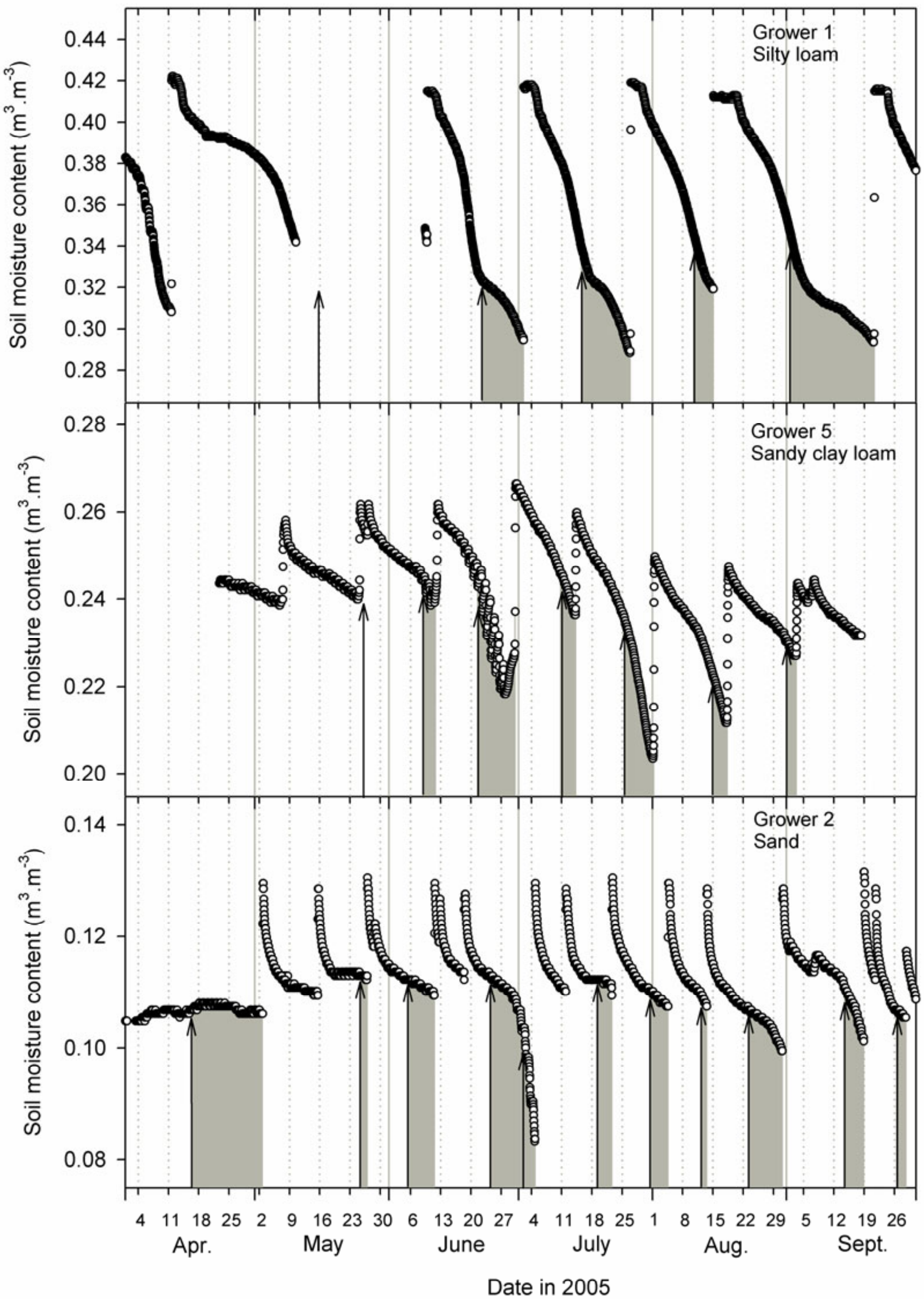
Did you use the GMS sensors with the datalogger to monitor soil moisture?	Initially	No	No	Yes	No
Did you use tensiometer to schedule irrigations?	Yes	Yes	No	Yes	No
Did you keep a record of the tensiometer readings?	Initially	No	No	No	No
Did you use the climate-based irrigation scheduling model?	Once	No	No	No	No
Did the person making the scheduling decisions also collect and analyze the soil moisture data?	Yes	Yes	No	No	Yes
Which instrument was most useful?	Tensio-meter & GMS	Tensio-meter	None	Tensio-meter	None[z]
Will you use any of these methods to schedule irrigations in the future?	Yes	Yes	No	Yes	Maybe
Were you satisfied with the training you received on operating the soil moisture monitoring equipment?	Yes	Yes	Yes	Yes	Yes
How much would you be willing to spend on soil moisture sensing equipment on an annual basis?	$200-800	$275	$0	$600	$500

[z] Deduced, since tensiometers were dry and the activated data loggers had not been downloaded for more than 6 weeks.

At the conclusion of the season growers expressed they had little time or patience to collect and manipulate GMS data on their computers, or to retrieve the estimated ET from the web site. Only one of five collected logged GMS data on a weekly or semi-weekly basis, graphically analyzed it, and used the information; two of five left the activated data loggers in the orchard for several months and never collected the data, even though they read the tensiometer adjacent to the GMS every few days. One of the growers was so frustrated and discouraged with his inability to manipulate data in a spreadsheet that he discontinued the project after 2 months. While three of five growers used the tensiometer information to aid in scheduling irrigations, none recorded the tensiometer readings, plotted the data on graph paper, or used the readings to predict a future date when the soil moisture potential would be at the prescribed target.

Even though the cost of the instruments used in this study was a fraction of the cost of more automatic systems, potential savings apparently did not provide incentive for growers to collect their data and do their own computational and graphical analysis. In cases where the tensiometer readings or GMS data were used, the timing of irrigations was allowed to go longer than the optimal interval predicted by the climate-based irrigation scheduling model (Fig. 1). Grower 1, who only used the tensiometer as an aid to schedule irrigations, was still 2 to 11 d late in scheduling irrigations, except in September when an entire irrigation was missed. The cumulative difference between non-stress ET and stressed ET was 280mm (11.0 inches), which translates to a theoretical yield loss of 694 $kg{\cdot}ha^{-1}$ (619 lb/acre), and revenue loss of \$340/ha (\$840/acre). Grower 2, who also used the tensiometer as an aid, irrigated at an interval consistent with the model during the beginning of the growing season. However, after May he was 4 d late, and appeared to have skipped an irrigation in late June. The cumulative difference in non-stress ET and stressed ET was 84mm (3.3 inches), equivalent to 208 kg·ha^{-1} (186 lb/acre) of lost yield, or \$101/ha (\$250/acre). Grower 5 used neither the tensiometer nor the GMS to schedule irrigations, and irrigated 2 to 8 d late for most of the growing season except in the month of May. The cumulative difference in non-stress ET and stressed ET was 137mm (5.4 inches), equivalent to theoretical lost yield of 340 kg·ha^{-1} (303 lb/acre) or \$166/ha (\$410/acre). Overall, the estimated loss in revenue exceeded by a factor of 4 to 14 the cost of the equipment or hiring a consultant to schedule irrigation at a fee of \$24/ha (\$60/acre).

Figure 1. Time series soil moisture content during the 2005 growing season at three pecan orchards measured with GMS sensors and HOBO data loggers. Open circles represent hourly soil moisture content readings from sensors located near the end of the bordered plot, furthest from the irrigation gate. Arrows indicate the next irrigation predicted by the climate-based irrigation scheduling model. Shaded areas represent periods of potential water-stress when soil moisture was below 45% MAD.


Grower 1
Silty loam
Grower 5
Sandy clay loam
Grower 2
Sand
Soil moisture content (m3.m-3)
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.14
0.12
0.10
0.08
4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19 26
Apr.
May
June
July
Aug.
Sept.
Date in 2005

The reported overall in-shell yields for 2005 were 2595 $kg \cdot ha^{-1}$ (2315 lb/acre) for Grower 1; 1993 $kg \cdot ha^{-1}$ (1778 lb/acre) for Grower 2; 3004 $kg \cdot ha^{-1}$ (2680 lb/acre) for Grower 5. Local yields in mature, well managed, non-stressed orchards typically exceed 3700 $kg \cdot ha^{-1}$ (3300 lb/acre) in an "on" year. However, many factors affect actual yield including: alternate bearing, tree age, tree spacing, pruning regime, prior water or nitrogen stress, and disease. In this study, the yield for the bordered plot at Grower 1's orchard was at only 45% of the overall orchard yield. Trees in this block were over 30 years old, in need of pruning at the top of the canopy, and have recently produced low yields in both "on" and "off" years. Trees at Grower 2's orchard were severely water stressed in 2003 and 2004 to the point of early defoliation and severe branch die-back, and have yet to fully recover. In situations such as these, theoretical yield may not match the actual yield even with sufficient irrigation at optimal timing.

While some frustration with learning how to use the equipment and computer programs was expected, some of the shortcomings of this project were due to poor communication that may stem from a lack of incentive. By the end of the season it was apparent that most of the growers had difficulty with the instruments and spreadsheet manipulations, but during the season only two of the growers communicated any problems to the researcher or the county agent by phone or email. To minimize lost time and resources in future studies we recommend the following criteria for selecting grower participants:

1) Motivation to collect data needs to come from the grower's desire to increase profits, and the percent of personal income dependent on pecan sales should exceed 50%. 2) The person making the irrigation scheduling decisions needs to have demonstrated computer skills in spreadsheet programs. 3) Most importantly, future outreach programs should be less neutral with regards to rewards and expectations. If growers were actually paid a monthly stipend for gathering the data like a technician they would be obliged to record the data and solve the technical problems when they arose. The research community needs to include such stipends in grant proposals.

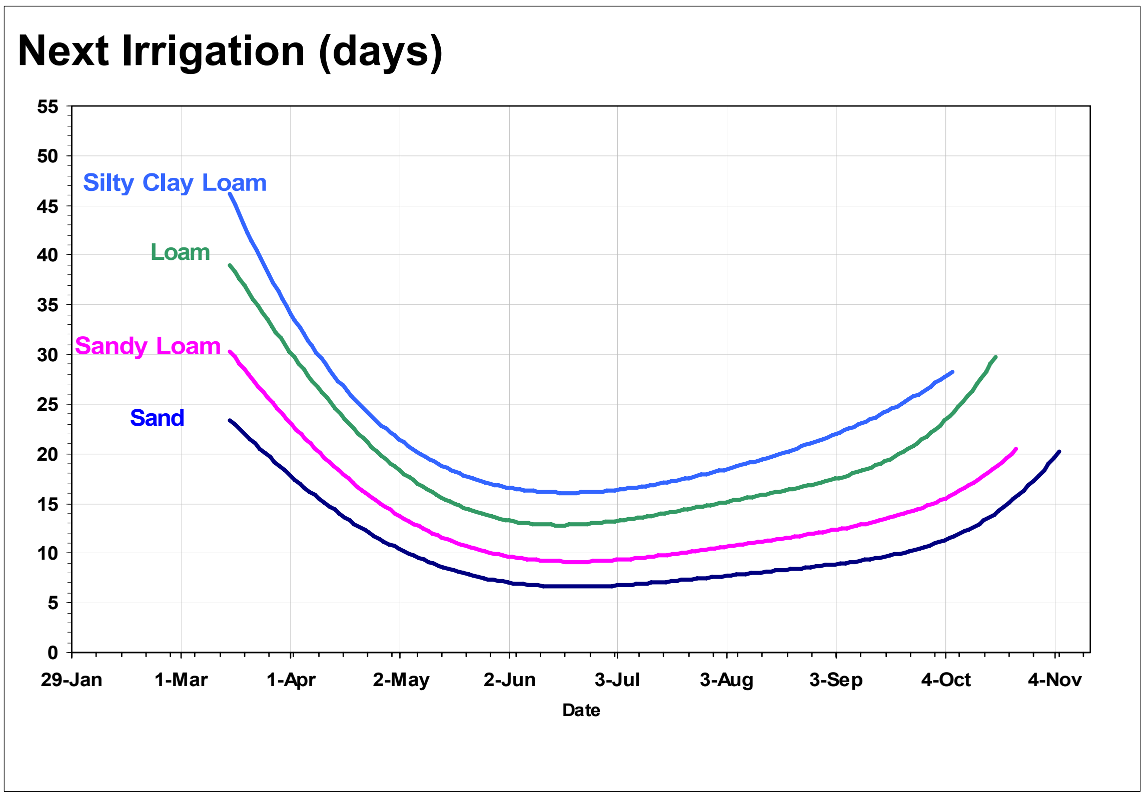
TECHNOLOGY ASSESSMENT.

Post-season analysis of the time-series GMS data (Fig. 1) indicated that, in many cases, the rate of soil moisture depletion slowed on or near the model recommended irrigation dates. If the actual irrigation was missed or delayed the rate of moisture depletion became more rapid as the moisture content decreased, suggesting that readily available soil moisture in the middle root zone (where the sensor was located) was depleted and the moisture gradient between the middle and lower root zone had increased. This correlation also implied that the model's parameters and assumptions were fairly accurate, which was further supported by the relatively consistent moisture content observed on all modeled irrigation dates. These results support our proposal that the model may be used to calibrate the sensors if the sensors are placed in the middle of the root zone and in a location where the moisture status is representative of the whole plot. However, given the sensitivity of the GMS to soil temperature (Shock et al., 1998) this calibration may need to be reset in the summer months.

Given outcome of this project and the comments from participants any improvement for future implementation of these tools needs to focus on simplicity. We suggest the following: 1) many data manipulation steps can be eliminated by developing template spreadsheets and macro programs that automatically convert logger voltage to volumetric moisture content and graph the time series data. The growers should only need to import, copy, and paste the data logger file into the template. 2) Information obtained from the on-line irrigation scheduling model could be more specialized. It was not clear whether the web site was too difficult to navigate, or growers had an inherent distrust of modeled values. To reduce the amount of information, an irrigation scheduling web page dedicated to Mesilla Valley pecan production using local weather data could be developed with fewer steps and menu options. An alternative way this information could be accessed by the growers is for a regular column to appear in the daily newspaper, written by the county extension office with crop irrigation information based on the irrigation scheduling model. Daily and cumulative ET for a variety of crops along with a recommended interval between irrigations for each crop in a few soil types could be reported in a table.

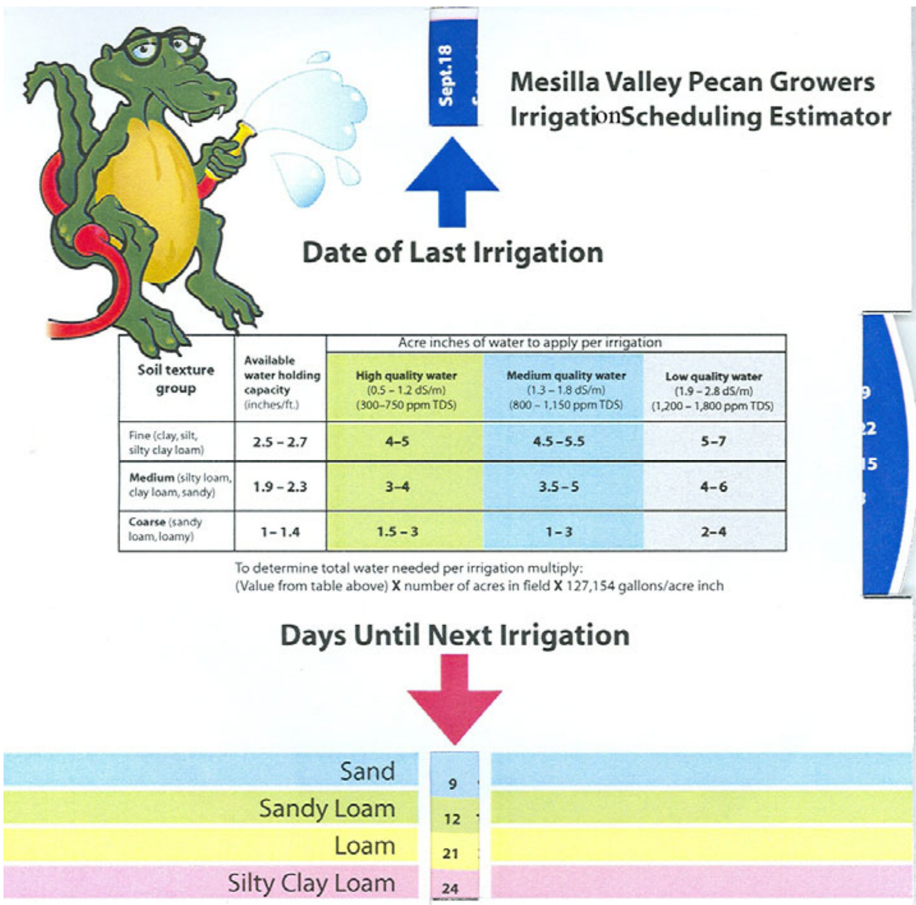
A second approach is to develop a nomograph that use average long term weather data to determine irrigation intervals days between irrigations depending on the soil type and month of the year (Figure 2).

Figure 2. Nomograph of pecan irrigation interval based on soil type and day of the year.



Nomographs can be built to present the data in figure 2 in a circular format like a circular slide rule (Figure 3) or in a standard slide rule format using different configurations. The different formats of the nomograph are currently being evaluated by a series of focus groups to determine the format of the nomograph that is preferred by a group of pecan farmers. The concept is that using the simpler nomograph approach to irrigation scheduling of pecans, information is lost but simplicity gained that will result in the use of the information where as soil moisture monitoring or internet irrigation scheduling approach to managing irrigations was not adapted.

Figure 3. Nomograph of pecan irrigation interval based on soil type and day of the year and presented in a circular nomograph format



Soil texture group	Available water holding capacity (inches/ft.)	Acre inches of water to apply per irrigation		
		High quality water (0.5 – 1.2 dS/m) (300–750 ppm TDS)	Medium quality water (1.3 – 1.8 dS/m) (800 – 1,150 ppm TDS)	Low quality water (1.9 – 2.8 dS/m) (1,200 – 1,800 ppm TDS)
Fine (clay, silt, silty clay loam)	2.5 – 2.7	4–5	4.5 – 5.5	5–7
Medium (silty loam, clay loam, sandy)	1.9 – 2.3	3–4	3.5 – 5	4–6
Coarse (sandy loam, loamy)	1 – 1.4	1.5 – 3	1 – 3	2–4

Conclusions

We had negligible success at transferring these cost-saving soil moisture monitoring technologies to growers because: a) many participants did not have the skills in spreadsheet programs as they had claimed; b) many participants did not have a substantial financial incentive to improve yield; c) most participants needed continued help the through the learning phase but did not communicate this with the research and extension community; d) there were too many steps involved in data procurement and analysis; e) the recommended target moisture content for scheduling irrigation based on PTFs did not agree fully with the GMS sensor output, creating added confusion about data interpretation. All of the growers in this study understood conceptually that better management of water inputs could translate into higher yields. While three out of five growers indicated they had used either a GMS or tensiometer to schedule irrigations, they all irrigated 2 to 11 d late throughout the season based on modeled ET dates. The estimated revenue lost based on theoretical yield exceeded the cost of the equipment or irrigation consultant fees.

A simpler approach to irrigation scheduling is needed and a nomograph although not as accurate as using a soil moisture sensor or internet real time irrigation scheduling may result in some form of irrigation scheduling where as the more sophisticated method will not be used.

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