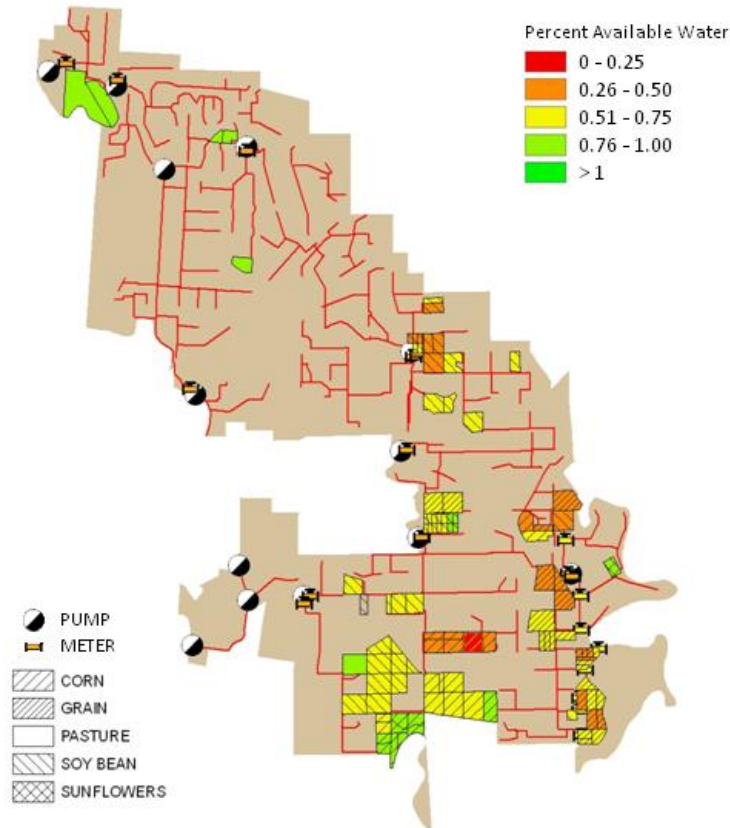# Evaluation of the CRITERIA Irrigation Scheme Soil Water Balance Model in Texas
Rio Grande Basin Initiative

By
Gabriele Bonaiti, Guy Fipps, P.E.
Texas AgriLife Extension Service
College Station, Texas

December 2011

Evaluation of the CRITERIA Irrigation Scheme Soil Water Balance Model in Texas

Rio Grande Basin Initiative
Irrigation Technology Center
Texas AgriLife Extension Service

Evaluation of the CRITERIA Irrigation Scheme Soil Water Balance Model in Texas – Initial Results

December 21, 2011

By

Gabriele Bonaiti
Extension Associate

Guy Fipps, P.E.
Professor and Extension Agricultural Engineer

Texas AgriLife Extension Service
Irrigation Technology Center
Biological and Agricultural Engineering
2117 TAMU
College Station, TX 77843-2117
979-845-3977; http://idea.tamu.edu

EXECUTIVE SUMMARY

The CRITERIA model was created in the 1990s in Italy, and is based on the soil water balance computation procedures developed at the Wageningen University in the Netherlands in the 1980s. CRITERIA has been used as an analysis and regional water planning tool (e.g seasonal crop yield and water use predictions, impact of climate change scenarios), and is currently used in Northern Italy to update the regional water balance on a weekly base. The model can handle a multilayered soils and computes daily average values related to the soil water balance (actual evaporation and transpiration, water flow between layers, deep percolation, surface runoff, and subsurface runoff). Automatic algorithms allow for calculation and scaling of data which may not be available such as detailed meteorological data and soil-water properties. Outputs can be readily used in a Geographic Information System (GIS). The required inputs are precipitation, air temperature, soil texture, and crop management data (planting and harvesting dates, irrigation method and applied volumes). The model allows for input of additional data such as actual ET, soil conductivity, and soil-water characteristics. If this data is not available, the model can estimate them. The model requires calibration using a combination of measured soil moisture and actual ET.

The purpose of the study was to:
- Evaluate the performances of CRITERIA in predicting soil water moisture
- Evaluate its potential for predicting crop water requirement in real time within irrigation schemes using minimal input data

We calibrated the model for two (2) sites: the Texas High Plains with conditions representative of the southern Great Plains, and the semi-tropical Lower Rio Grande Valley (LRGV). Additionally, we evaluated the model without calibration for use at the irrigation district level, by simultaneously simulating many fields with different crops and water management strategies.

In the Texas High Plains, the model was calibrated and compared to lysimetric data for soybean production at the USDA-ARS Laboratory, Bushland, on soybean, over a two year period (2002 and 2003). In the LRGV, data was collected from a 27-ha sugarcane field within the Delta Lake Irrigation District, over a three years period (2007-2009). As sugar cane was not present in the CRITERIA database, we used one of the available crops (Actinidia) and we modified the default values for some parameters. Data on ETo and soil-water characteristics were not available, therefore we estimated them with the model. We also measured soil-water characteristics in laboratory from undisturbed soil cores collected in the field, and compared them to the values estimated with CRITERIA, and the Soil Water Characteristics Calculator (SWCC), an easy to use tool by USDA and Washington State University. The developed district scale evaluation was carried out at the Brownsville Irrigation District (BID) over a season's worth of data (year 2010) for approximately 170 individual fields.

Soil moisture prediction at the Bushland and Delta Lake sites was in good agreement with measured data (R^2 of correlations ranged between 0.7 and 0.8). At the Bushland site, the root growth model did not describe well the actual soybean growth below 30 cm of depth, probably

due to the existence of the thick clay layer at 30 cm of depth which caused an atypical shaped root zone.

When applied at district scale, CRITERIA accurately predicted changes in soil moisture with estimated input data such as crop planting and harvesting dates, and actual irrigation volumes. One product of this study was a soil moisture status map that could be updated on a daily base.

CRITERIA needs additional improvements for application at field level in Texas conditions, particularly the crop management component (e.g. add crops and irrigation methods, improve root growth model). In order to apply the model as real time decision support system at regional scale, additional improvements are needed, including in the scaling algorithms and the automation of data and GIS output. Finally, further evaluation should be carried out to evaluate model algorithms currently used to estimate soil water properties.

CONTENTS

LIST OF FIGURES

INTRODUCTION

Water management in irrigation schemes (or irrigation districts) is challenging due to the large number of fields, crops, planting dates, yield goals and water management strategies. For growers, decisions on the day and volume of irrigation are often difficult. Lack of planning and rotation of water deliveries to individual fields can cause a decrease in operational efficiency and an increase in water losses from water distribution networks (canals and pipelines). Often both farmers and district personnel make decisions based on past experience, not science-based methods.

CRITERIA was develop to address these problems by tracking and updating the water balance at the field level and predicting the soil moisture at various soil depths considering such factors as rainfall, ET and irrigation. CRITERIA is a water balance model created for applications at the regional scale in the low plains of the Po River basin, in Northern Italy (Marletto and Zinoni, 1996; Tomei et al., 2007). The model was created at the Environmental Protection Agency of Emilia Romagna (ARPA-ER), Italy, and is based on the soil water balance computation procedures developed at the Wageningen University in the Netherlands in the 1980s. In 2001, ARPA-ER integrated the crop growth simulation routines of WOFOST (1994) into the model. CRITERIA is interesting because is a easy to use model, with automatic algorithms allowing for calculation of most missing data, and because the outputs can be readily used in a Geographic Information System (GIS).

In this paper, we report the results of an evaluation of the model for use in Texas. We calibrated the model by comparing predicted to experimental data collected in the Texas High Plains and the Lower Rio Grande Valley. We also applied the model to an irrigation district to evaluate its performance in simultaneously simulating multiple fields and multiple crops.

The purpose of the study is to:
- Evaluate the ability of CRITERIA to accurately predict soil water status over the growing season
- Evaluate CRITERIA potential for irrigation scheduling within irrigation schemes using minimal input data

MATERIALS AND METHODS

The model

The primary inputs required are rainfall, temperature, drainage layout, crop data (such as planting date, tillage, irrigation and harvesting, and irrigation volumes and methods), soil texture, and soil organic matter content. Based on these data, the model has algorithms to estimate water balance, the soil-water retention curve, and crop growth on a daily time step.

Various options are given to the user, which are described below. The model allows for the input of measured data, such as soil-water characteristics retention values, conductivity, and evapotranspiration, and for the modification of the default values for most of the used parameters. A geographical component of the model allows for interpolation of input spatial data (such as rainfall and water table depth), and the output data is in SHP format, therefore readable by GIS software.

In this chapter we describe the components of the model examined in our study.

Water balance

The water balance components that we examined are:

- Infiltration and redistribution (Numerical and Analytic method)
- Upward flux (Numerical and Analytic method)
- Surface and subsurface runoff
- Deep percolation
- Potential evapotranspiration (Hargreaves and Samani and Penman-Monteith equation)
- Evaporation and transpiration
- Water balance error checking (alarms based on thresholds)

The Numerical method for the water infiltration and movement uses the finite differential method (Richard equation), and is a one-dimensional version of CRITERIA3D (Bittelli et al., 2010). The Analytic method uses successive steady-state calculations, and has the advantage of speed of computation, which allows for applications with GIS or with little input availability. The Analytic method is described below.

Maximum infiltration rate is calculated as suggested by Driessen (1986),

$$I_{Max} = 10 * \frac{A_A}{P_{it}} + 10 * S_O * \left(1 - \frac{\theta}{\theta_{sat}}\right) * \frac{1}{Pit * \left(\frac{Tdp}{Pit}\right)^{0.5}}$$

Where:
I_{Max} = Maximum infiltration rate (mm d^{-1})
A_A = hydraulic conductivity at the wetting front, referring value per texture (cm d^{-1})
Pit = number of integration steps per day, 1 in CRITERIA (-)
S_O = standard sorptivity, referring value per texture (cm d$^{-0.5}$)
θ = volumetric water content of the layer (m^3 m^{-3})
θ_{sat} = volumetric water content of the layer at saturation (m^3 m^{-3})
T_{dp} = days from the last water input (d)

S_O is calculated with no water content, and represents the infiltration due to the only matrix potential. S_O and A_A are available in CRITERIA as tabular data.

The infiltration procedure uses θ, I_{Max}, and field capacity (FC) in the following steps:
- Soil is analyzed by each layer from the bottom
- Initial infiltration is calculated when a layer is found with moisture exceeding the FC
- The moisture exceeding FC moves downward at the I_{Max} rate of the layer, and will try to saturate the underlying layer
- If in the underlying layer FC is exceeded, the movement continues to the next layer
- The movement downward will stop when FC is not exceeded, or if a saturated layer is found
- If a layer has very low I_{Max} a perched water table is created
- A pond phenomena and an eventual surface runoff event are simulated if rainfall exceeds I_{Max} in the soil surface

During irrigation events, layers are brought to FC starting from the surface and without considering the I_{Max} rate. If θ exceeds FC of the entire profile, drainage will occur.

The Hargreaves and Samani equation (1985) was used to calculate ETo in all case studies.

The model offers also a water table recharge component and a customized thickness of the calculation layers. In all our cases we excluded the water table recharge option, and the thickness of the calculation layers was set to 2 cm (default option).

Pedotransfer functions and soil-water retention curve

Van Genuchten (1980) proposed the following equations:

$$\frac{\theta - \theta_{res}}{\theta_{sat} - \theta_{res}} = \left(\frac{1}{1 + (a|h|)^n}\right)^m$$

Where:
θ, θ_{res}, θ_{sat} = water content at tension h, residue, and saturation (m^3 m^{-3})
α, m, n = empirical parameters, with $\alpha>0$, $n>1$, $0<m<1$, and $m=1-1/n$ (-)
h = water potential, with $|h|\geq0$ (cm)

The equation can be written also:

$$h = \frac{(\theta_E^{-\frac{1}{m}}-1)^{\frac{1}{n}}}{\alpha} \qquad \theta_E = \frac{\theta-\theta_{res}}{\theta_{sat}-\theta_{res}}$$
$$\text{with}$$

Pedotransfer functions are obtained as follow. If observed data for the soil-water retention curve are available, the needed input parameters (α, n, θ_{res}, and θ_{sat}) are obtained by a fitting procedure, otherwise CRITERIA will use tabular data based on soil texture.

Crop Growth

There are two (2) models implemented in CRITERIA to estimate crop growth: standard and WOFOST. In this study, we used the standard growing model. In the standard model, crop is just an element that contributes to the water balance; no reduction of yield due to water stress is calculated. The crop growth parameters involved are the Leaf Area Index (LAI) and the root growth. The "temperature sum" (heat units) drives these two (2) parameters.

Temperature sum. The standard equation for the temperature sum is:

$$TSum = \frac{T_{min} + T_{max}}{2} - Threshold$$

Where:
TSum = daily temperature sum (°C d)
T_{min}, T_{max} = minimum and maximum air temperature (°C)
Threshold = minimum temperature for crop to begin root and leaf growth (°C)

Computation of TSum begins in January and is set to 0 at the end of December for poliannual crops, while for annual crops it begins on planting day. In the case of sudden temperature change, Tmax is restricted to a threshold temperature, typical of each crop.

<u>LAI</u>. The LAI development is divided in 4 phases (5 for herbaceous crops), with a length typical per each crop:

  0) Plant emergence (only for herbaceous crops)
  1) LAI exponential increase
  2) Linear LAI growth
  3) Reduced speed of LAI increase
  4) LAI decrease (harvest is set at the end of this phase)

The equation used for phases 1-3 is:

$$LAI = \frac{LAI_{max} - LAI_{min}}{1 + e^{(a_{LAI} + b_{LAI} * TSum)}} + LAI_{min}$$

Where:
LAI = leaf area index (-)
LAI_{min}, LAI_{max} = minimum and maximum LAI (-)
a_{LAI}, b_{LAI} = coefficients for the linear regression logLAI-TSum, available on chart (-)
TSum = daily temperature sum (°C d)

In orchards with grass growing underneath, a LAI_{grass} is added to the orchard LAI.

For herbaceous crops, the equation used for phase 4 is:

$$LAI = \frac{LAI_{max} - LAI_{min}}{1 + \left(\dfrac{10 * (TSum - Sphase3)}{phase4 * C4_{LAI}}\right)^{N4_{LAI}}} + LAI_{min}$$

Where:
LAI = leaf area index (-)
LAI_{min}, LAI_{max} = minimum and maximum LAI (-)
Sphase3 = total temperature sum for phases 1-3 (°C d)
Phase4 = temperature sum between phase 3 and 4 (°C d)
$N4_{LAI}$, $C4_{LAI}$ = crop specific coefficients (-)
TSum = daily temperature sum (°C d)

Once the daily temperature sum reaches phase 4 (harvest time), LAI is set equal to LAI_{min}. For orchards, LAI decreases exponentially until it reaches the LAI_{min}.

<u>Root Growth</u>. For annual crops (herbaceous and horticultural), the root depth development is computed with one of the available functions (logarithmic, linear, asymptotic, and exponential) until maximum depth is reached. Root density is calculated per each layer daily, using one of the available density profiles (cylinder, ellipse, ovoid, and cardioid).

For orchards, root depth is maximum all year and the density per each layer is constant according to the chosen density profile (cylinder, ellipse, ovoid, or cardioid).

Case studies

The model was calibrated for two (2) sites: the Texas High Plains with conditions representative of the southern Great Plains, and the semi-tropical Lower Rio Grande Valley. It was also evaluated for use at irrigation district scale, at the Brownsville Irrigation District (Fig. 1).
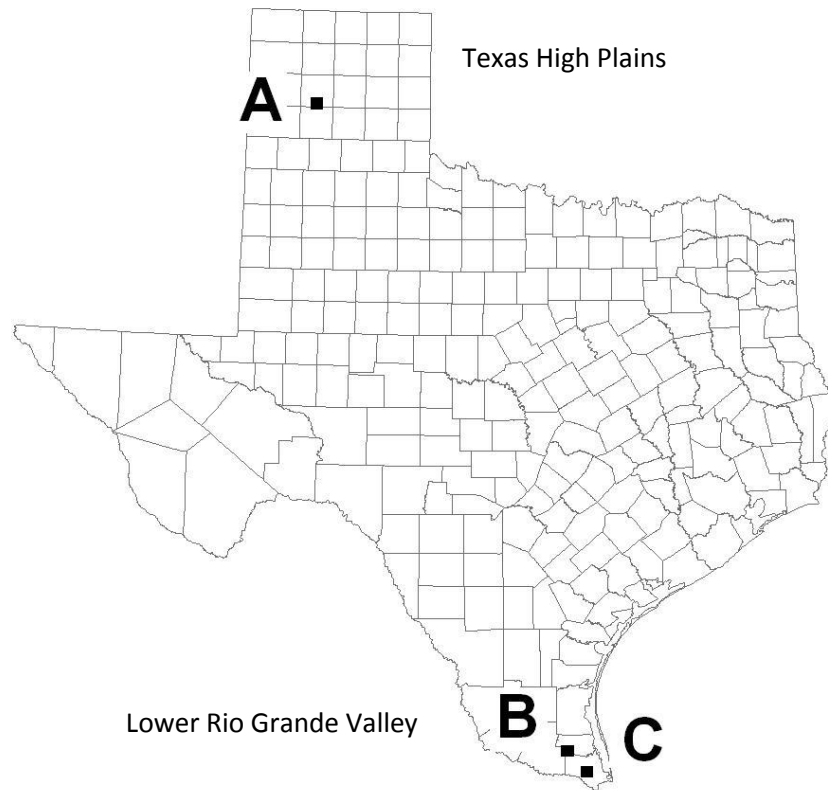

Figure 1. Location of case studies: A = USDA-ARS Laboratory, Bushland (soybean), B = Delta Lake Irrigation District (sugarcane), C = Brownsville Irrigation District (multiple crops)

USDA-ARS Laboratory, Bushland

At the USDA-ARS Laboratory in Bushland, data was collected from a giant weighting lysimeter, for soybean over a two year period (2002 and 2003). The lysimeter is located in the middle of a larger field and is irrigated with a lateral move system equipped with LEPA (Low Energy Precision Application) (Fig. 2). The soil is Pullman clay loam and silty-clay loam, and is characterized by a very shallow root zone due to a thick clay layer at about 50 cm of depth, and by a calcic layer below 135 cm of depth (Evett, 2009).

Various field and laboratory data were measured, including soil moisture every 20 cm from 10 to 190 cm of depth, ET, ETo, soil-water retention curve, and soil saturated hydraulic conductivity. Soil moisture was measured with a neutron probe, before several irrigation and rainfall events.

ETo was calculated using data from an on-site agricultural weather station using the standardized Penman-Monteith equation.

For this study, we used the numerical solution for vertical flux computation, and the van Genuchten equation to interpolate the measured soil-water retention values. The soybean root depth development was computed with the logarithmic functions, and root density was calculated using a cardioid density profile. The model was run for a total soil profile of 300 cm. We modified the default values for the following parameters:
- Crop coefficient (K_c) max (increased)
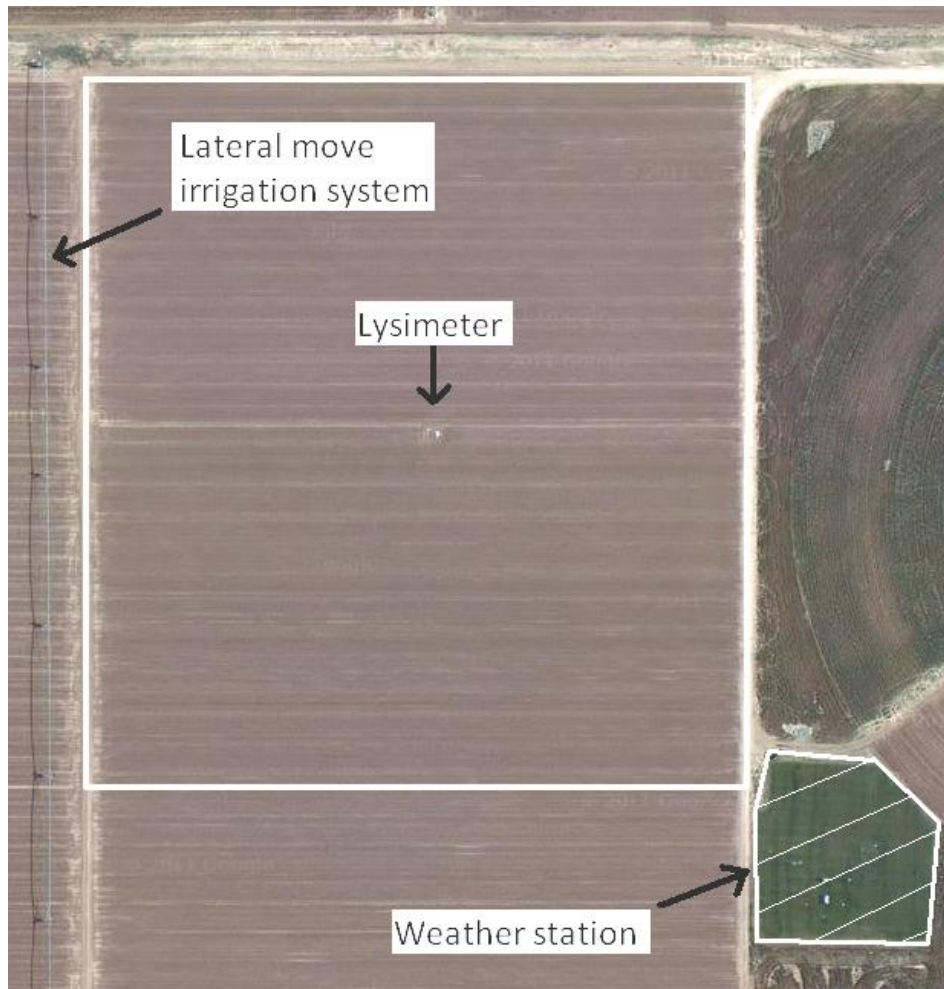- Maximum root depth (reduced)

Figure 2. Bushland: Location of lysimeter, water delivery system, and on-site agricultural weather station

Lower Rio Grande Valley, Delta Lake Irrigation District

At the Delta Lake Irrigation District (Delta Lake ID), data was collected from a 27-ha sugarcane field, over a three years period (2007-2009). The field is located near Monte Alto, Texas, and is furrow-irrigated with water delivery in two points (East side and center) (Fig. 3). Furrow ends are blocked to prevent runoff. Deep percolation is collected by a subsurface drainage system with drainage tubes spaced 30-m apart with a slope of 0.5/1000, ranging from 1.7 to 2 m in depth. Right under these tubes, there is a second drainage system made of larger collecting lines that discharge into storage sumps (Fig. 4). Mobile pumps are used for the discharge of water from these sumps into an outlet ditch. This situation is common with deep drainage systems that are designed for salinity control in arid and semi-arid regions, and when gravity outflow is not possible because of insufficient outlet depth (FAO, 2005). The soils Survey are Racombes sandy clay loam, Delfina fine sandy loam, and Raymondville clay loam (Fig. 5) (USDA, 1977). The soil is characterized by a salty and shallow water table.

Rainfall was measured at the South-West corner of the field, and irrigation days and volumes were obtained from the district water tickets database. Number of days with drainage and drained volumes were roughly estimated by the landowner. Bulk density, soil texture and continuous soil moisture measurement were measured at the North-West corner of the field. Soil moisture was measured with four (4) 20-cm long ECH_2O Dielectric Aquameter probes (from Devices, Inc.), connected to a data logger. The probes were installed vertically at the depths of 5-25 cm, 20-40 cm, 50-70 cm, and 80-100 cm, and data were automatically recorded every two (2) hours. Additional measurements of volumetric water content using the gravimetric method were made to calibrate the probe.

This site has much less data available than the research plot at the USDA-ARS lab in Bushland. Thus, vertical water flux was determined using the analytic method. The Hargreaves equation was used to calculate ETo, and the van Genuchten equation to estimate the soil-water retention curve. The model was run for a total soil profile of 300 cm. The sugarcane root density was calculated using a cardioid density profile. As sugar cane was not present in the CRITERIA database, we used one of the available crops (Actinidia with grass growing underneath) and modified the default values for the following parameters:
- Temperature threshold to calculate temperature sum (increased)
- Minimum root depth to calculate available water (reduced)

The model was run with the 2007 data without calibration, and the results were compared to actual data.
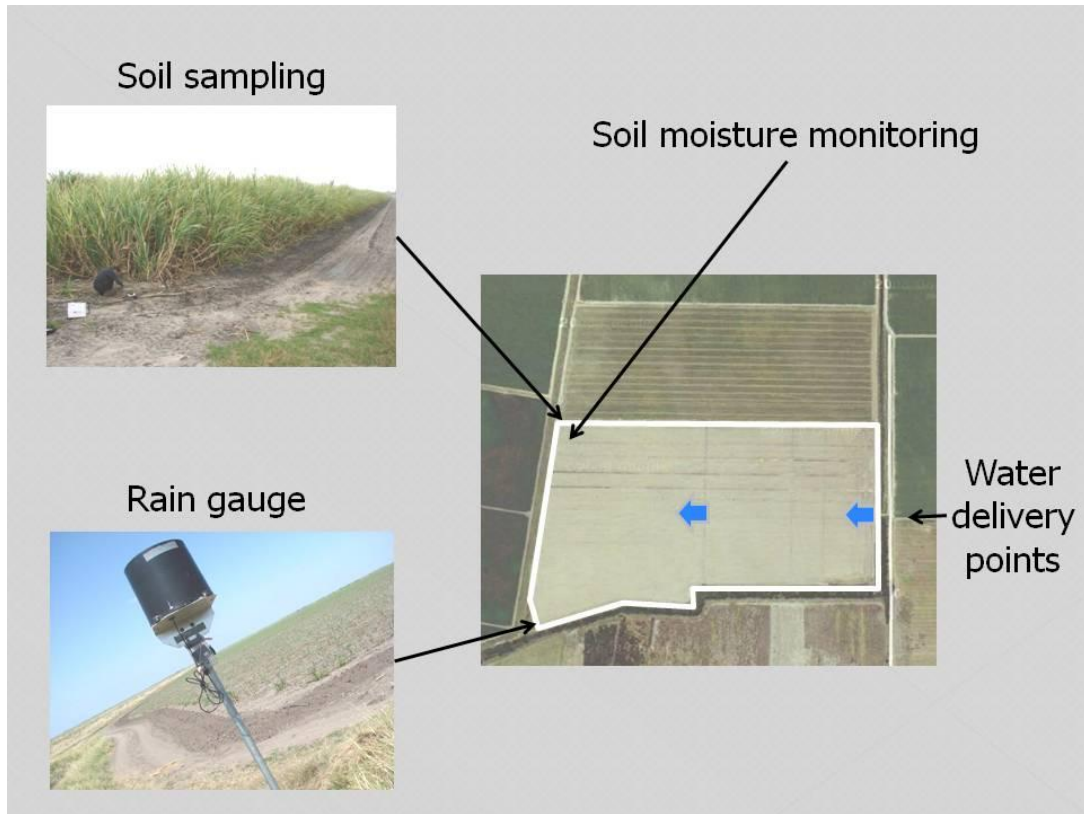
Figure 3. Delta Lake ID: location of monitoring instrumentation, soil sampling, and water delivery points

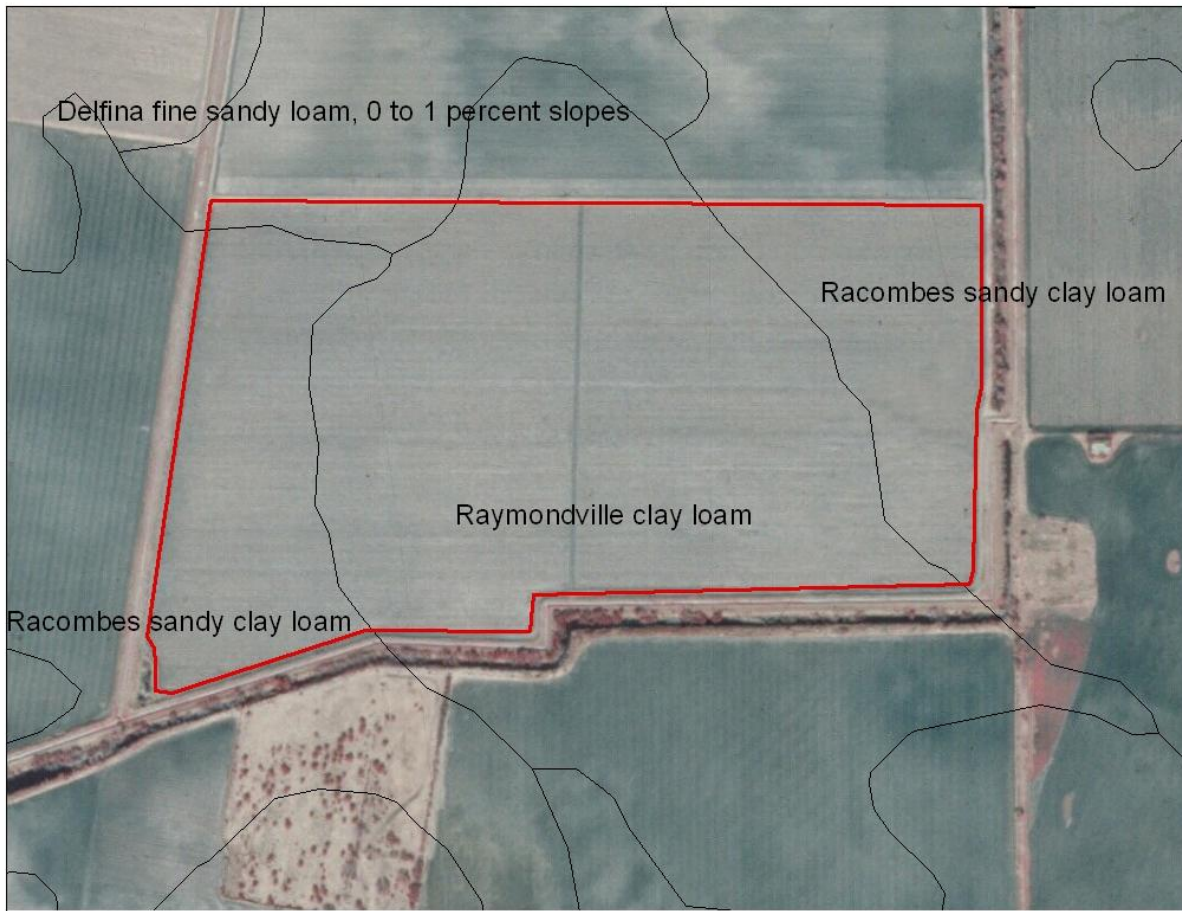Figure 4. Delta Lake ID: Double drainage system for salinity control

Figure 5. Delta Lake ID: soils map from the Cameron County Soil Survey (USDA, 1977)

Lower Rio Grande Valley, Brownsville Irrigation District (multiple crops)

The model was run for a season's worth of data (year 2010) for approximately 170 individual fields in the Brownsville Irrigation District (BID) (Fig. 6). Fields had an average size of 10 ha, and the crops grown were pasture, winter wheat, soybean, rice, and sunflower. The irrigation methods used were flood and furrow irrigation.

Daily rainfall data were obtained from the National Weather Service (NOAA's website, 2011) and consisted of two (2) locations North and South of the district. Temperature was obtained from the Texas ET Network website (2011) for the Weslaco Annex weather station. The soil texture assigned to individual fields was the prevalent one from the Cameron County Soil Survey (USDA, 1977). Specifically, the main soils identified for the study area were Laredo Silty Clay Loam, Harlingen Clay, Olmito Silty Clay, Benito Clay, Chargo Silty Clay, Rio Grande Silt loam, Matamoros Silty Clay, Harlingen Clay Saline, and Rio Grande Silty Clay Loam. Crop data for each fields and irrigation records were obtained from the BID database, or estimated on the basis of common practices observed in the Rio Grande Valley (planting and harvesting dates).

All other data were calculated by the model. We chose the analytic method to compute water fluxes, the van Genuchten equation to estimate the soil-water retention curve, and the Hargreaves equation to calculate the ETo. The model was run for a total soil profile of 150 cm, and data were input manually. The model was not calibrated, because no field data on soil moisture was available, but we did a comparison between predicted soil moisture and observed irrigation dates to evaluate if model predictions were reasonable.

In the analysis of this case study we expressed the soil moisture as percentage of Total Available Water (TAW). The TAW is the soil water content between FC and the Wilting Point (WP). TAW is commonly used when deciding the day of irrigation (FAO, 1998). Ideally, irrigation should be done when only a fraction of TAW, the Readily Available Water (RAW) is depleted in the root zone, otherwise reduction of ET occurs. RAW depends on various factors such as crop, growing period, and ET.
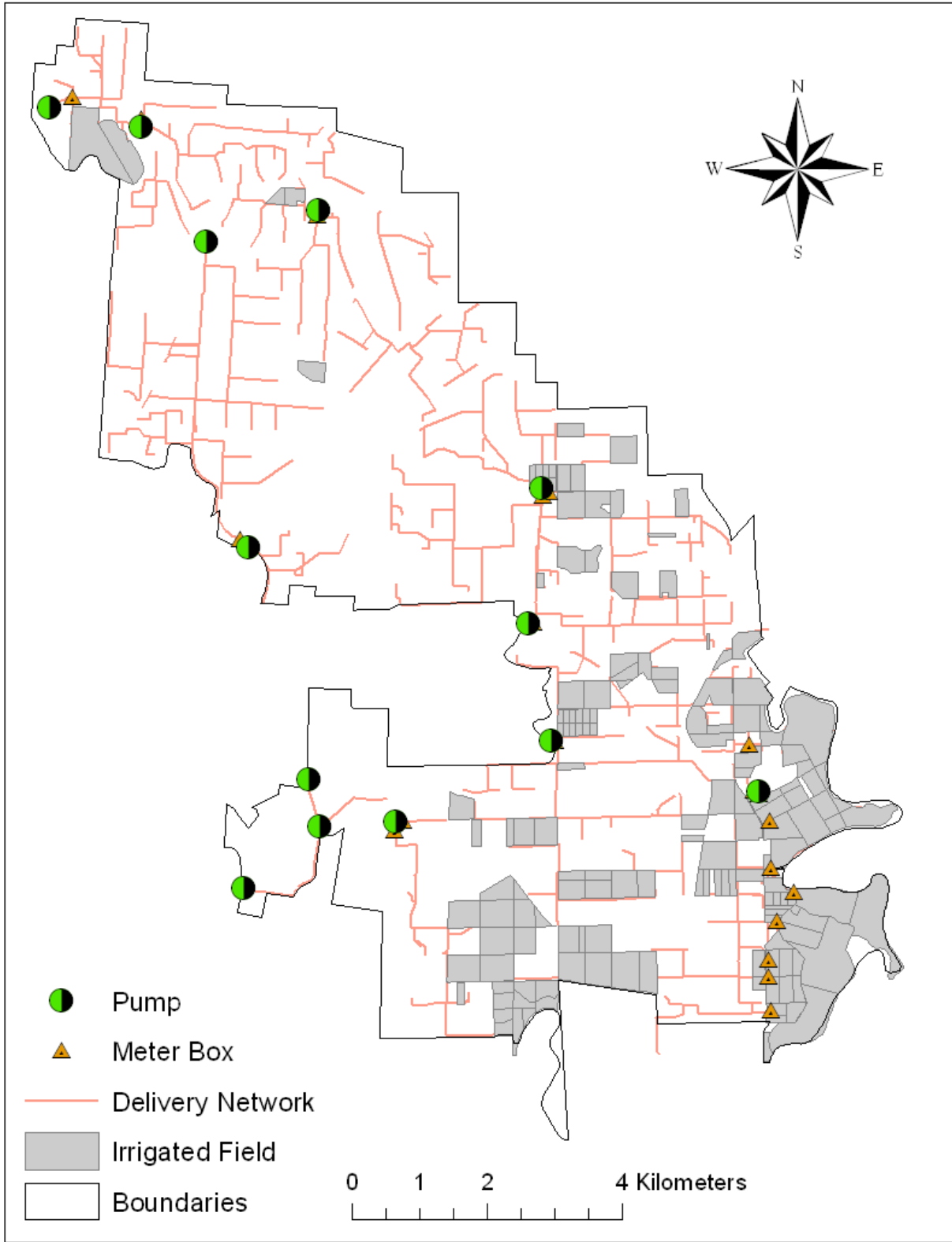
Figure 6. BID: Irrigated fields analyzed in our study, and water distribution network

Measured vs predicted soil water properties

We conducted laboratory measurements of soil water properties from undisturbed soil samples collected at the Delta Lake ID case study field. Figure 7 shows some of the phases of the work carried out in the field and the laboratory. The objective was to compare measured values to predict values generated by CRITERIA using only texture identification.

The procedure was as follow:
- Collection of soil cores
- Laboratory analysis for texture, soil-water retention curve, and saturated hydraulic conductivity
- Comparison of the soil-water retention curves measured from undisturbed soil samples vs calculated with pedotransfer functions

Field samples were collected on the North-West corner of the field, 1 m away from the closest sugar cane plant, and 20 m from the soil moisture monitoring site (Fig. 3). We used an AMS Soil Core Sampler and collected six (6) cylindrical samples 8.7 cm in diameter and 5.6 cm long. Samples were collected at depths of 15, 30, and 60 cm in two (2) adjacent holes.

Laboratory analysis was done in collaboration with the Vadose Zone Research Group, at the Texas A&M University. For texture analysis, we used the hydrometer method (Gee and Bauder, 1986) and for the saturated hydraulic conductivity the Constant-Head method. The soil-water retention values between 0 and 30 cbar pressure head were measured with a Tempe Cell, and between 50 to 300 cbar with a Pressure Plate. The pressure heads investigated were 0, 1, 3, 4, 5, 10, 20, 30, 50, 100, and 300 cbar.

The measured soil-water characteristics were compared to those calculated by CRITERIA and by the Soil Water Characteristics Calculator (SWCC) (Saxton and Rawls, 2009). The same comparison was performed for Bushland site where measured data was available for texture, conductivity, and bulk density.
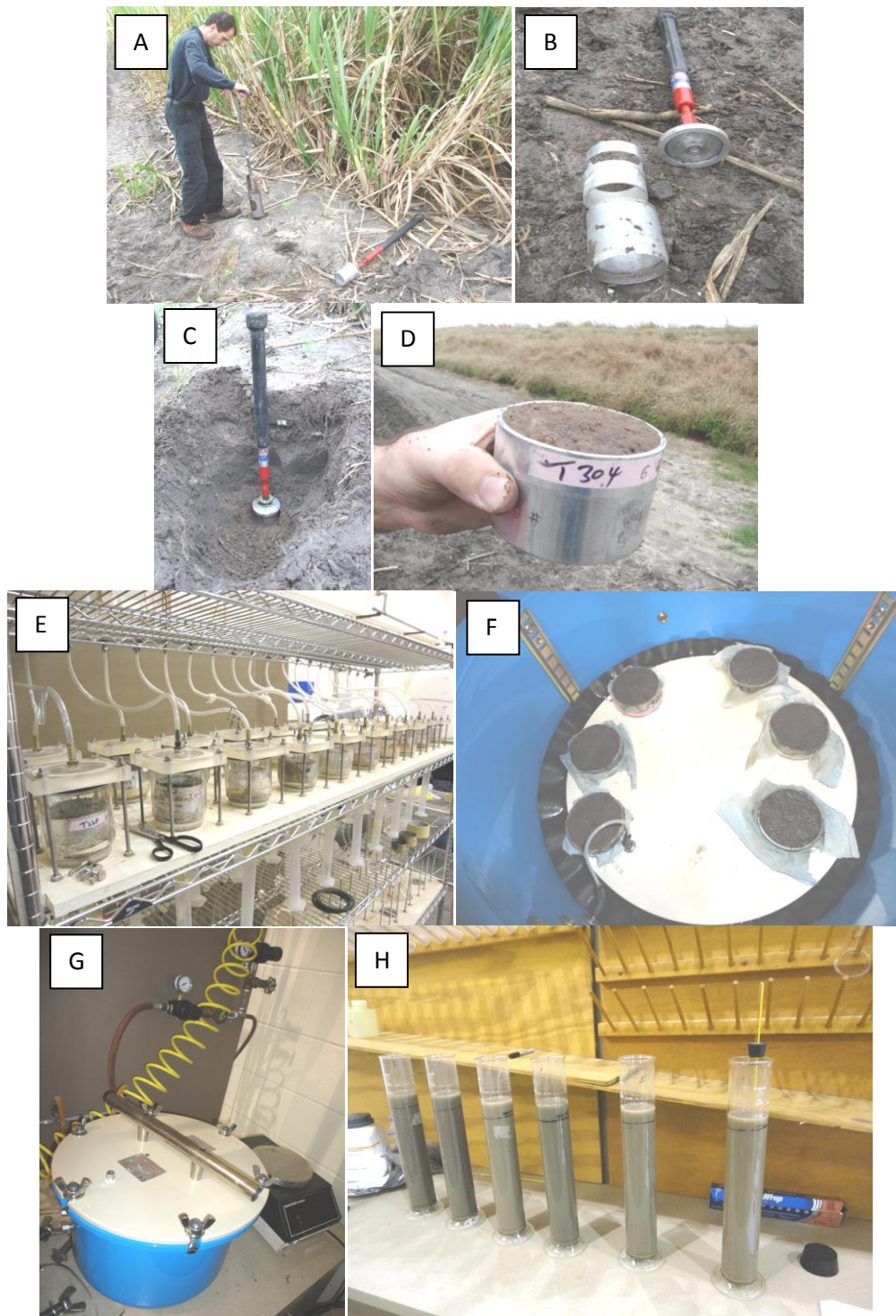
Figure 7. Sample collection and analysis. A-D: Soil cores collection, E: Tempe Cell (1-30 cbar pressure head), F-G: Pressure Plate (50-300 cbar pressure head), H: texture analysis

RESULTS AND DISCUSSION

Case studies

USDA-ARS Laboratory, Bushland

Figure 8 shows observed and predicted soil moisture in the top soil layer (10-50 cm) for the 2003 growing season. CRITERIA predictions were in good agreement with measured data. Below 50 cm, though, differences were larger (Fig. 9). One possible reason is the existence of a thick clay layer at 50 cm of depth which likely produced an unusually shaped root zone. Such a root shape was not well described by the ones currently available in the model. Measured drainage was close to 0, which was also predicted by the model.

We found a good correlation between observed and simulated soil moisture for the top soil layer (Fig. 10), with a coefficient of determination (R^2) for the regression function equal to 0.70. When all layers were considered we found a correlation $R^2 = 0.53$ (Fig. 11). These R^2 were an improvement (7 and 34%, respectively) of those obtained without measured soil lab data.
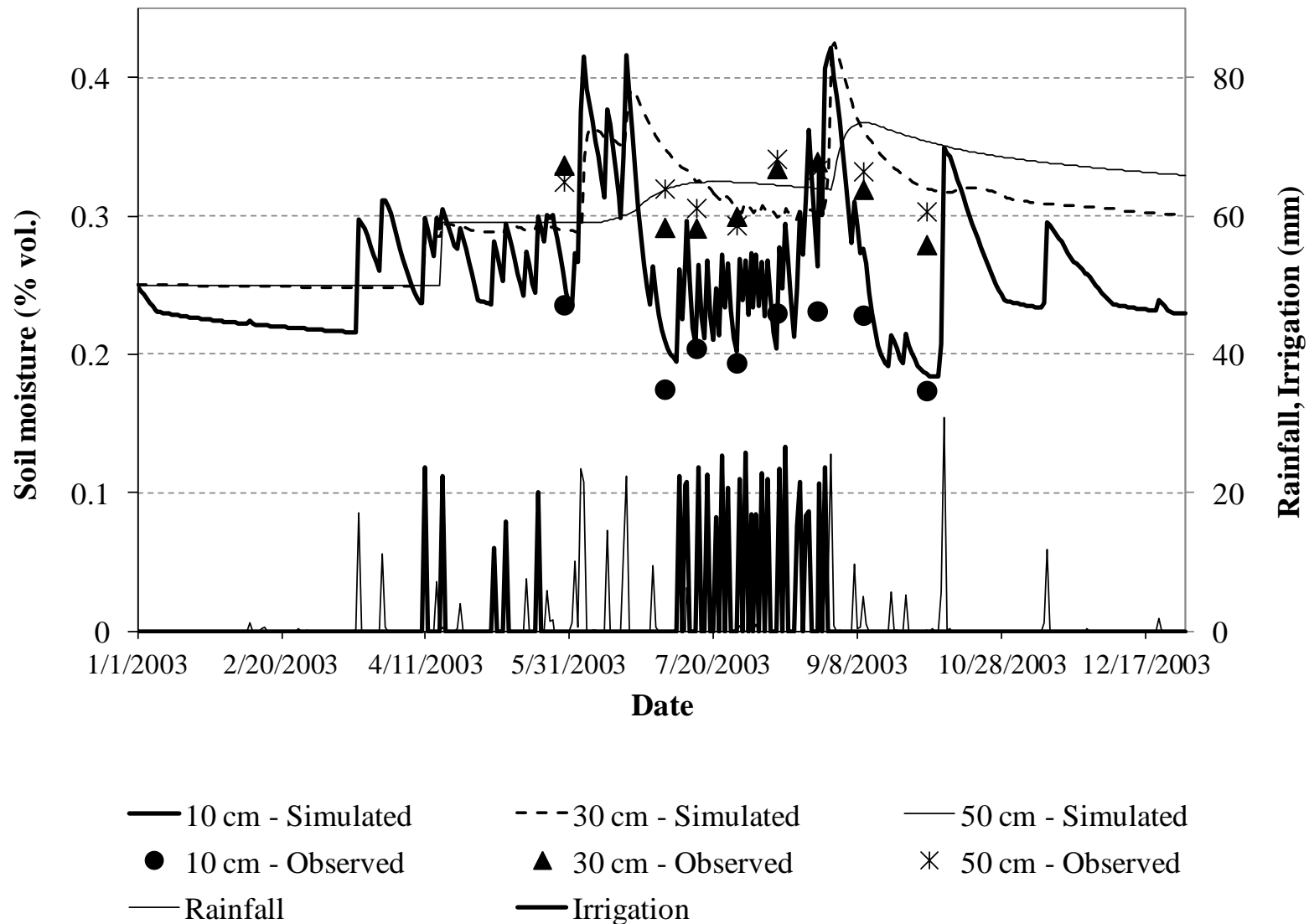
Figure 8. Bushland: Observed and predicted soil moisture in the layers 10-50 cm in 2003, together with rainfall and irrigation
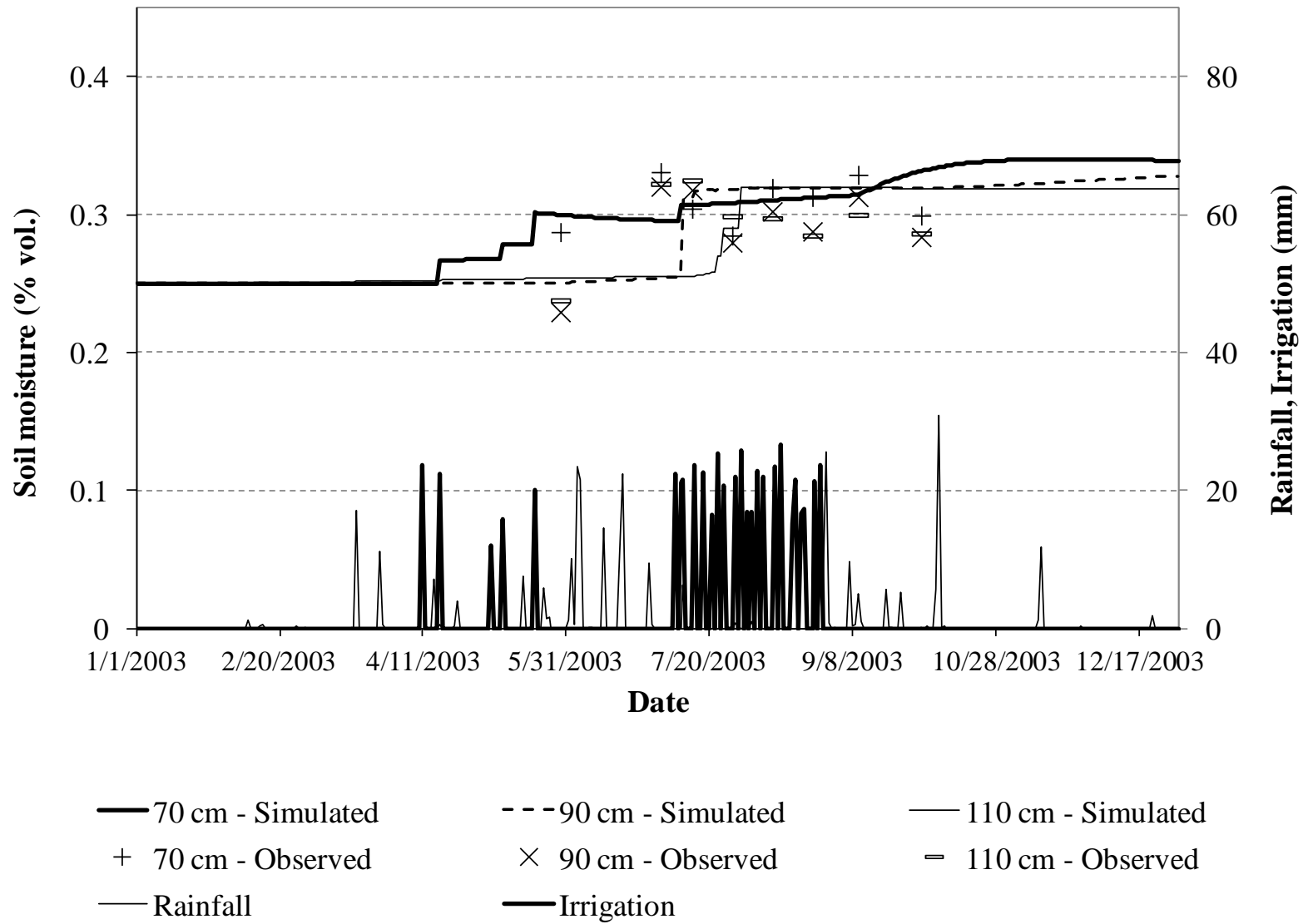
Figure 9. Bushland: Observed and predicted soil moisture in the layers 70-110 cm in 2003, together with rainfall and irrigation
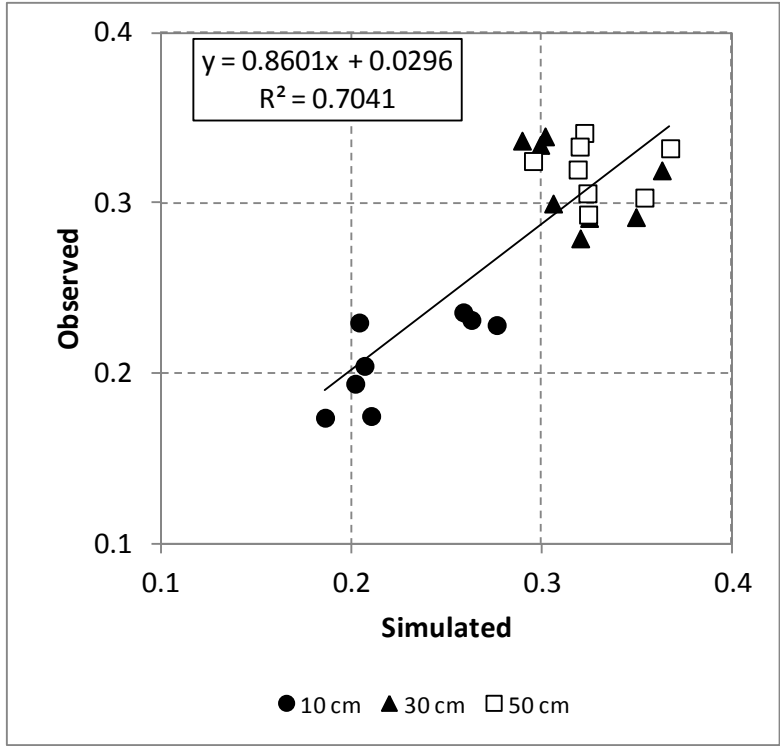
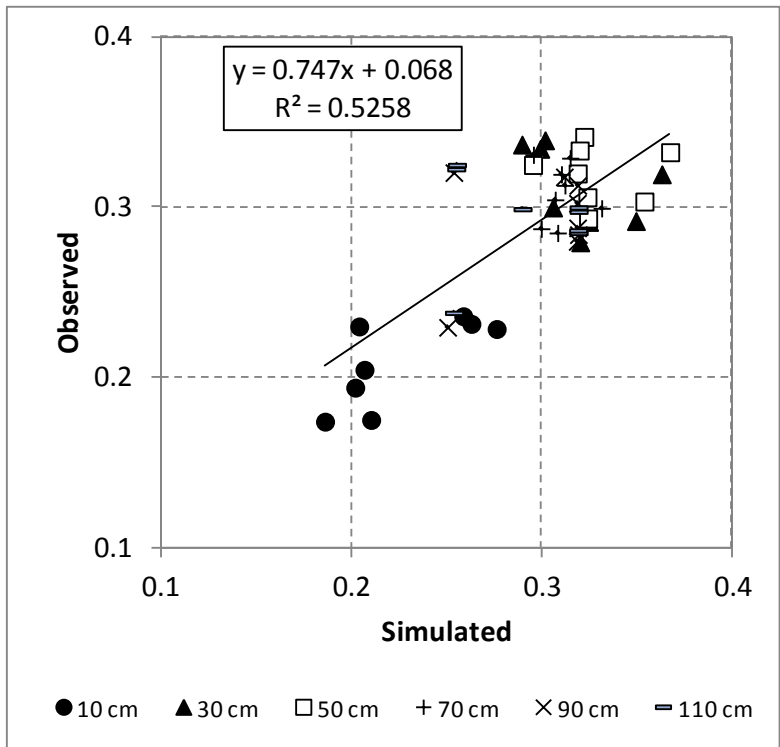Figure 10. Bushland: Observed and predicted soil moisture in the layers 10-50 cm in 2003

Figure 11. Bushland: Observed and predicted soil moisture in the layers 10-110 cm in 2003

Lower Rio Grande Valley, Delta Lake Irrigation District

Good agreement was obtained between measured and simulated soil moisture for most of the growing season. Figure 12 and Figure 13 show the results for each layer and for the average top soil layer (0-30 cm) in the 2008 growing season. These results are encouraging especially considering that irrigation volumes are estimated and the limited amount of soil data. On Jul 23, there was a tropical storm that produced 197 mm of rainfall, and the field was waterlogged for over a week. As no data was available on drainage conditions for that period, the model could not simulate soil moisture properly. This data and some other shown in Figure 10 were excluded for further analysis. Good agreement between measured and observed soil moisture was also obtained for the deeper layers (data not shown). The predicted drainage was in the order of magnitude of that estimated by the farmer.

As mentioned before, the measured soil moisture data for this case study were available for a 2-hours time step, and not daily as the simulated output. After averaging measured data to a daily step, observed and simulated peak values matched, as shown in Figure 14, for Mar 6, Apr 28, May 16. This figure also shows that some of the daily measured peaks are shifted by one (1) day when compared to simulated data (e.g. Apr 23 and Jun 20). This is likely due to the exact timing of an event compared to use of daily average.

We found good correlation between observed and simulated soil moisture for the 0-30 cm top soil layer (Fig. 15, chart A), with an $R^2 = 0.82$. In this comparison we used averaged daily data and excluded the periods indicated in Figure 13. In few cases, the simulated data was significantly higher than the observed ones, as in Apr 23 (35 vs 27% vol.) and Jun 28 (32 vs 17% vol.). In both cases this is due to the shift of observed daily averages as explained before. The R^2 would improve from 0.82 to 0.87 when removing these two points.

Figure 15 (chart B) shows also the correlation between observed and simulated soil moisture for year 2007. As discussed above, this simulation was done for model validation, using the model set up identified for the year 2008. In this case we found a correlation $R^2 = 0.50$. Also in this comparison we excluded some periods because observed data were either missing or not reliable. The missing periods were from Jan 1 to Feb 18, from Jun 14 to Jul 10, and from Oct 10 to Nov 19. The non reliable periods were from Feb 19 to Mar 29 (model initial adjustment), and from Nov 20 to Dec 31 (right after a period with missing data).

The R^2 for this case study was better than the one obtained for Bushland, where we had more observed parameters. Nevertheless, for Bushland, we had only eight (8) moisture observations in the entire season which likely restrained the R^2 from higher values.
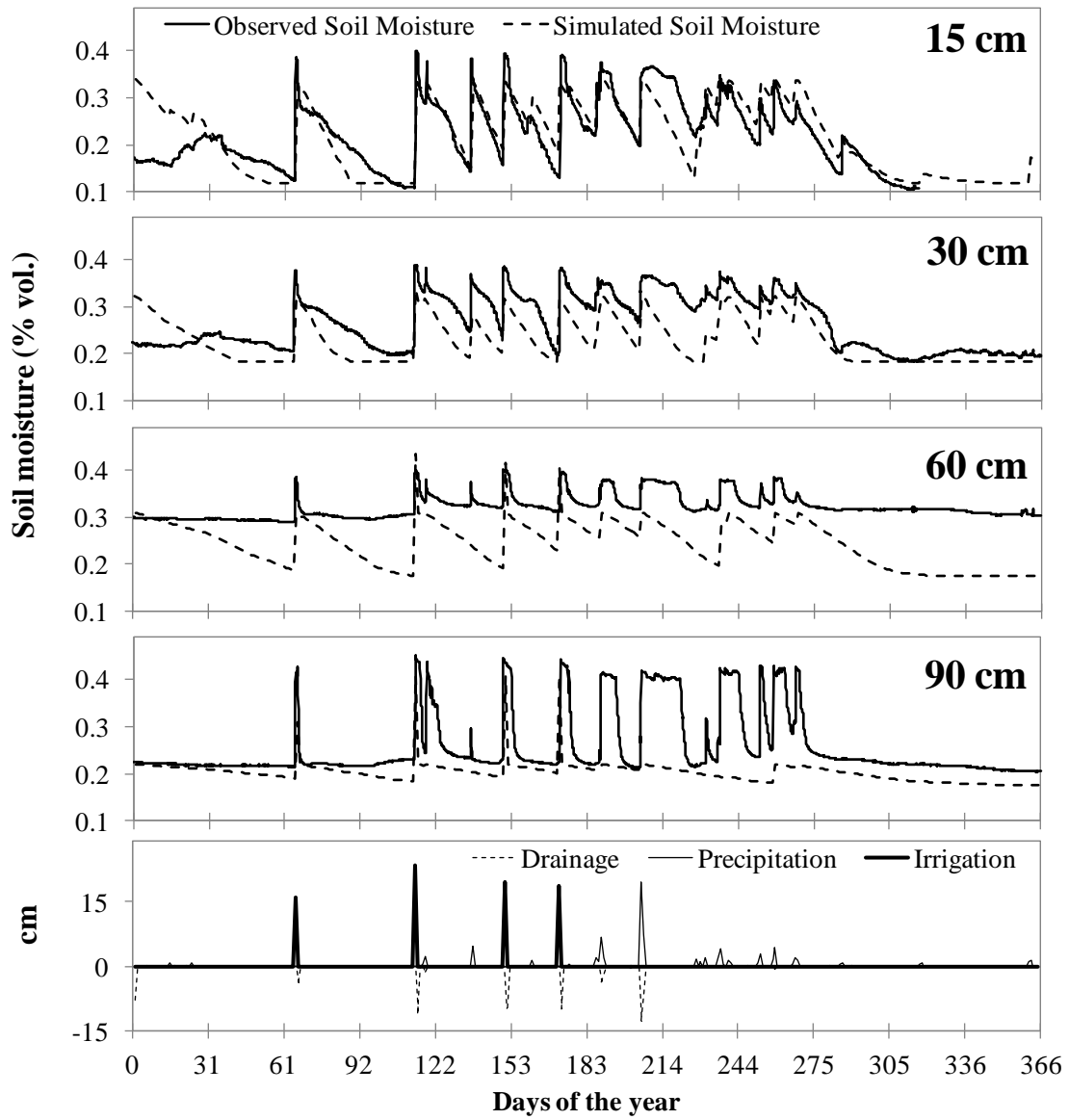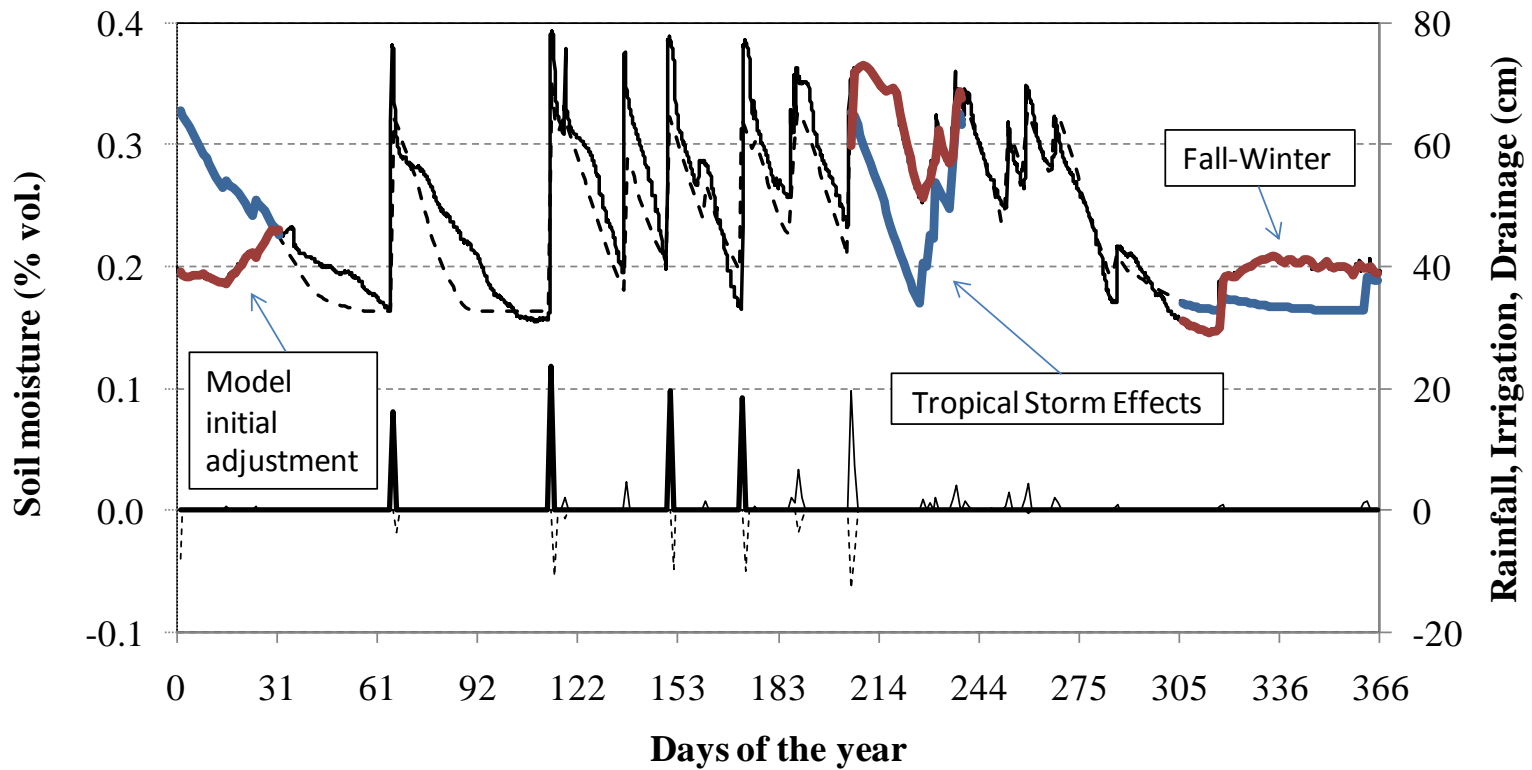
Figure 12. Delta Lake ID: Observed and simulated soil moisture in 2008 (observed hourly, predicted daily), together with rainfall, irrigation, and drainage

Figure 13. Delta Lake ID: Soil moisture in the top soil layer (0-30 cm) in 2008 (observed hourly, predicted daily, excluded data), together with rainfall, irrigation, and drainage
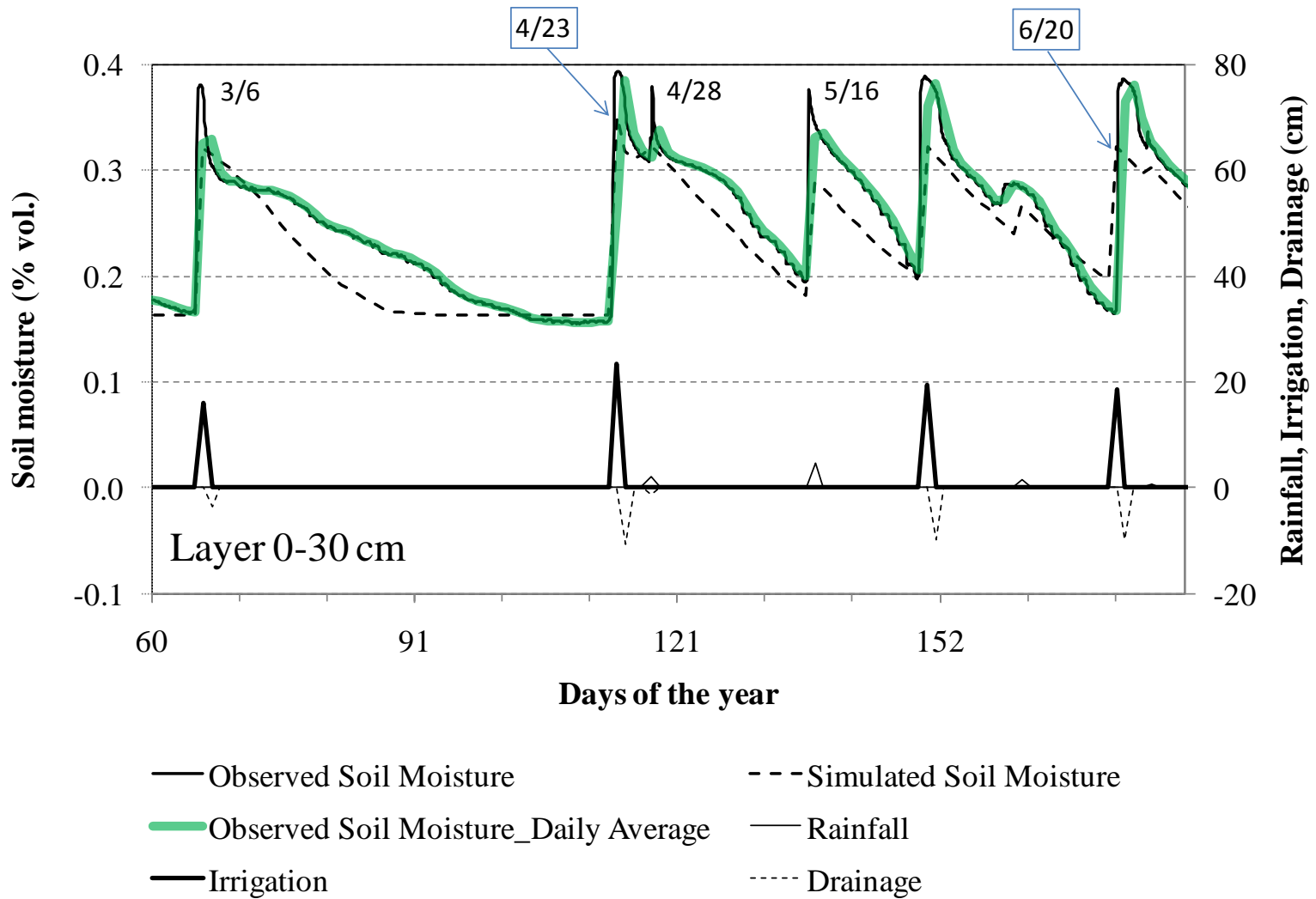
Figure 14. Delta Lake ID: soil moisture in the top soil layer (0-30 cm) for the 2008 irrigations period (observed hourly, observed daily average, predicted daily), together with rainfall, irrigation, and drainage
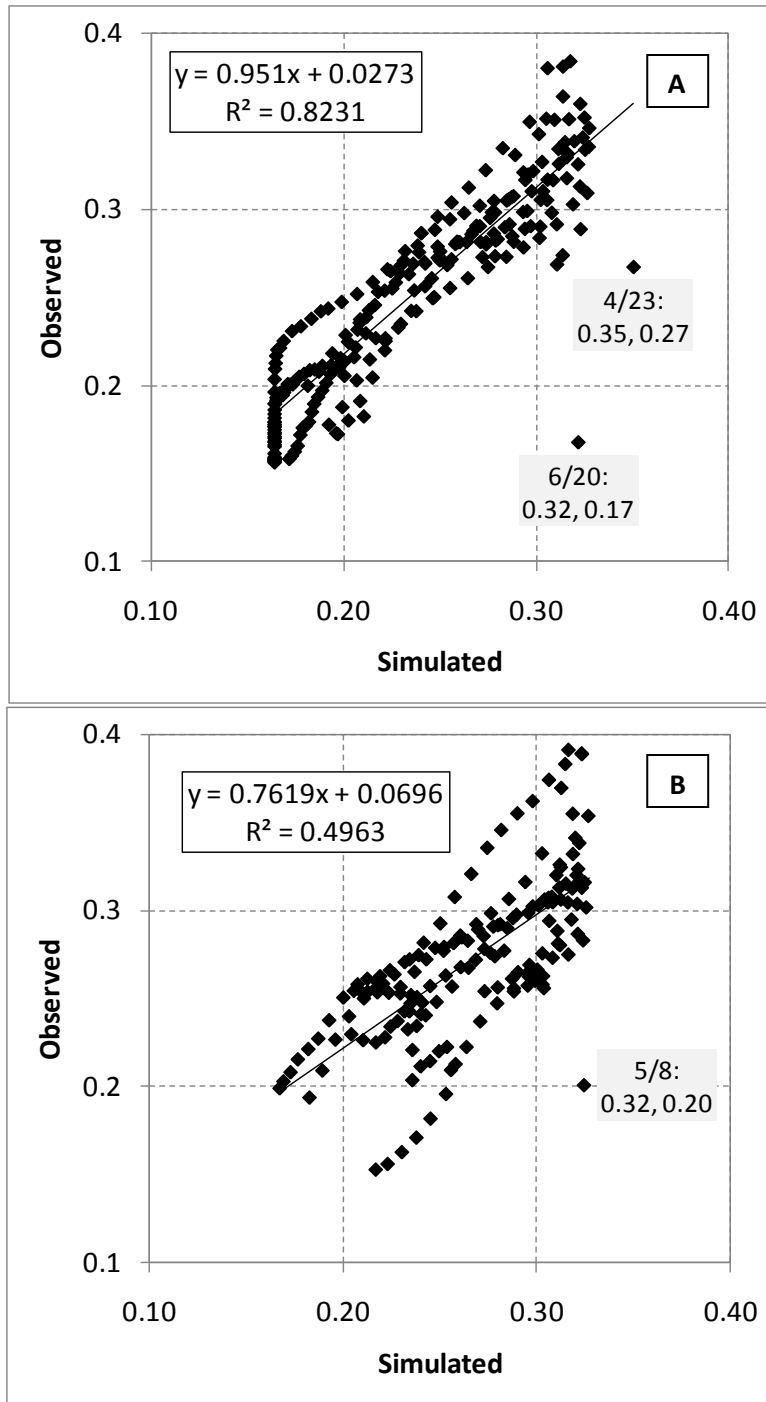
Figure 15. Delta Lake ID: Soil moisture in the top soil layer (0-30 cm) in 2008 (A) and 2007 (B) (observed daily average, predicted daily)

Lower Rio Grande Valley, Brownsville Irrigation District

Soil moisture predictions for the case of Field No. 3790 (soybean) on clay soil are shown in Figure 16. In this figure, soil moisture is averaged at various depths, and is expressed as percentage of Total Available Water (TAW). In general, and for soybeans, FAO suggests using a Readily Available Water (RAW) equal to the 50% of TAW. Based on common practices observed in the Rio Grande Valley (Fromme et al., 2010), we used Apr 1 as planting day, the first irrigation as done for germination, and a 120-days growth cycle.

In Figure 16, if we look at the line for the layer between 0 and 90 cm (which we assumed to represent the root zone), we see that the second irrigation was done when the model predicted a depletion of 70% TAW, while 50% TAW (RAW) was depleted about 10 days before. This can be explained assuming that either irrigation was done too late, or that the models prediction was not accurate due to lack of calibration. After May 14 there were no more irrigations, resulting in very dry soil conditions. Even without calibration, the model predicted soil moisture dynamics in a reasonable way.

Figure 17 shows the detailed soil moisture profile predictions for Field No. 3790 on selected dates for the first 100 mm of the profile. The dynamics of water infiltration and depletion can be seen for the second irrigation (98 mm on May 14, day 133) and the tropical storm (219 mm on Jun 30 and Jul 1, days 181 and 182).

Figure 18 illustrates how spatial data is handled for input into the model to obtain daily soil moisture output maps (example for Jul 1, 2010). The slight difference between the North and the South ends of the District in the rainfall map was consistent throughout the growing season.

Our evaluation is that CRITERIA is a very promising model for use in irrigation districts. However, in order to convert this preliminary test into a reliable and useful tool, calibration and validation at selected irrigation fields is required. The real value of CRITERIA is ease of integration with GIS.
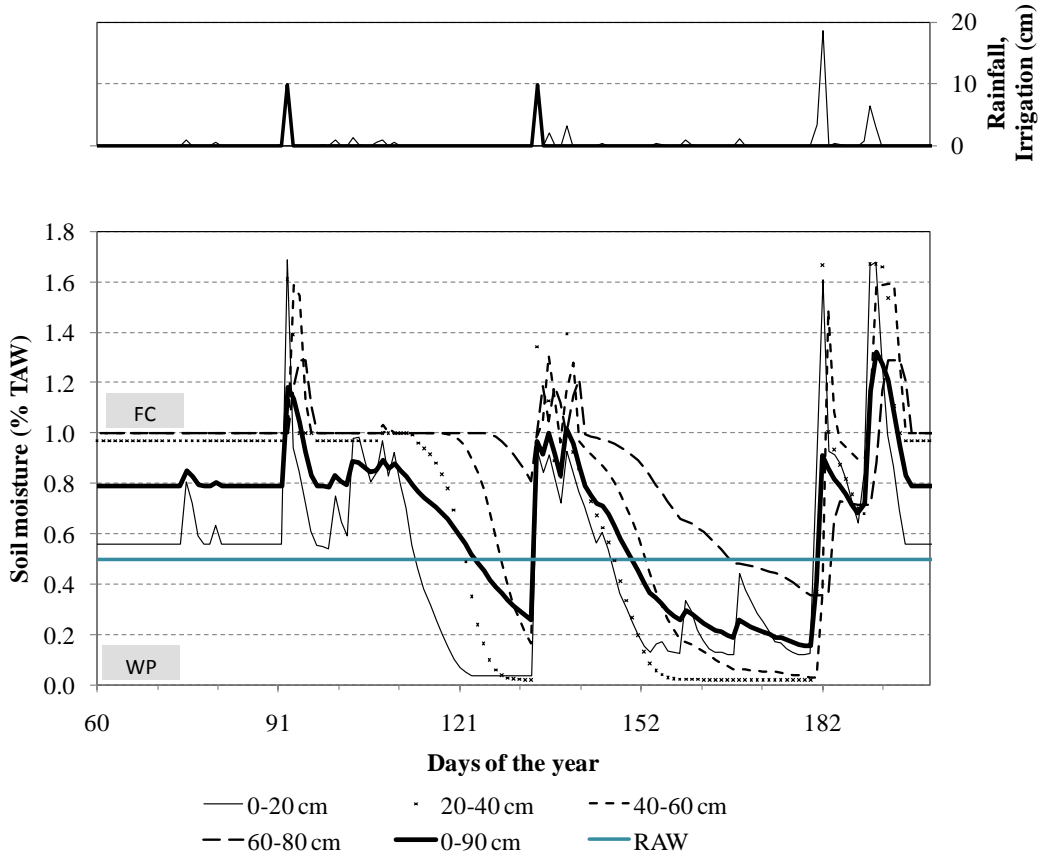
Figure 16. BID: Predicted soil moisture (percentage of Total Available Water) at various depths
for the 2010 growing season in Field No. 3790 (soybean), together with rainfall and irrigation
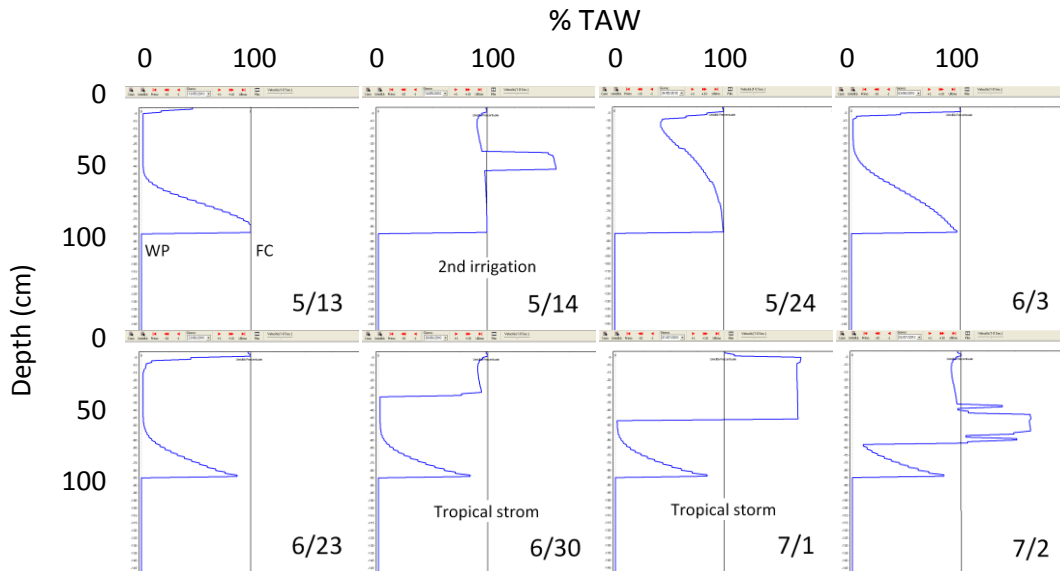

Figure 17. BID: Predicted soil moisture profile (percentage of Total Available Water) between
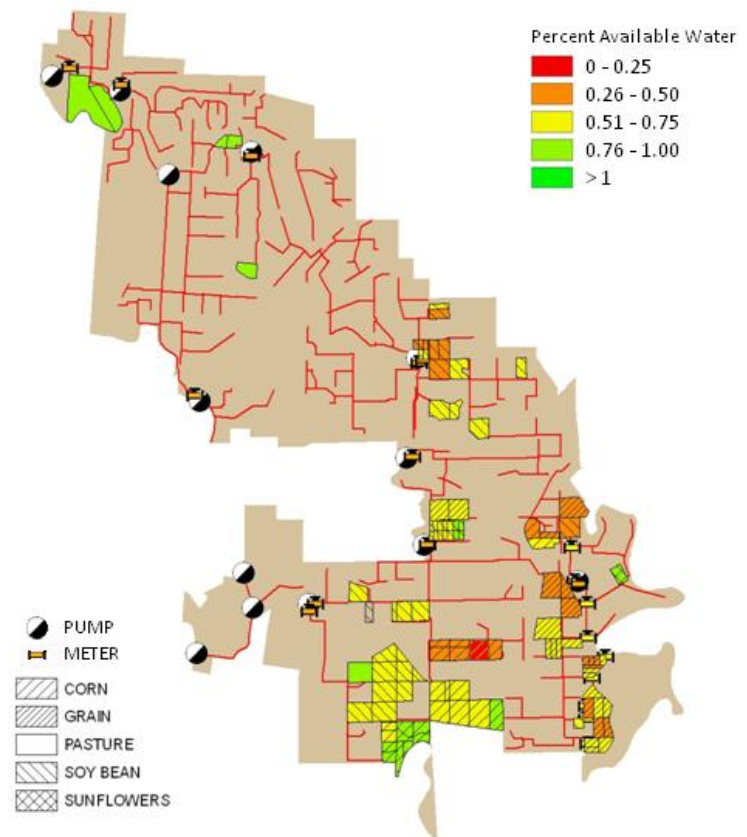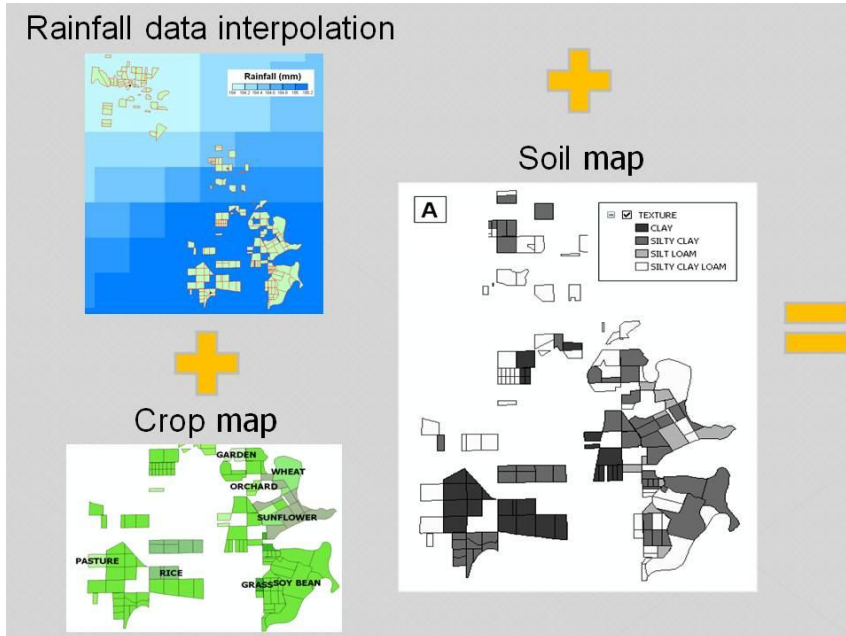the second irrigation and the tropical storm in Field No. 3790 (soybean)

Figure 18. BID: Process of creating a soil moisture output map (July 1st, 2010)

Measured vs predicted soil water properties

The measured values for soil saturated hydraulic conductivity were 3.33, 1.47, and 1.89 cm/d at depths 15, 30 and 60 cm, respectively. These values are all lower than those predicted by CRITERIA when using the soil texture option (6.5 cm/d).

The measured soil-water characteristics at three (3) depths are shown in Figure 19, which are consistent for adjacent cores. We observed a difference in measured vs predicted soil water characteristics for the Delta Lake site, particularly at the 15 cm depth as shown in Figure 20. Figure 21 shows the same comparison for the Bushland site, which matched more closely.

There was no improvement in predicted soil water characteristics when using the SWCC model, as illustrated in Figure 22.
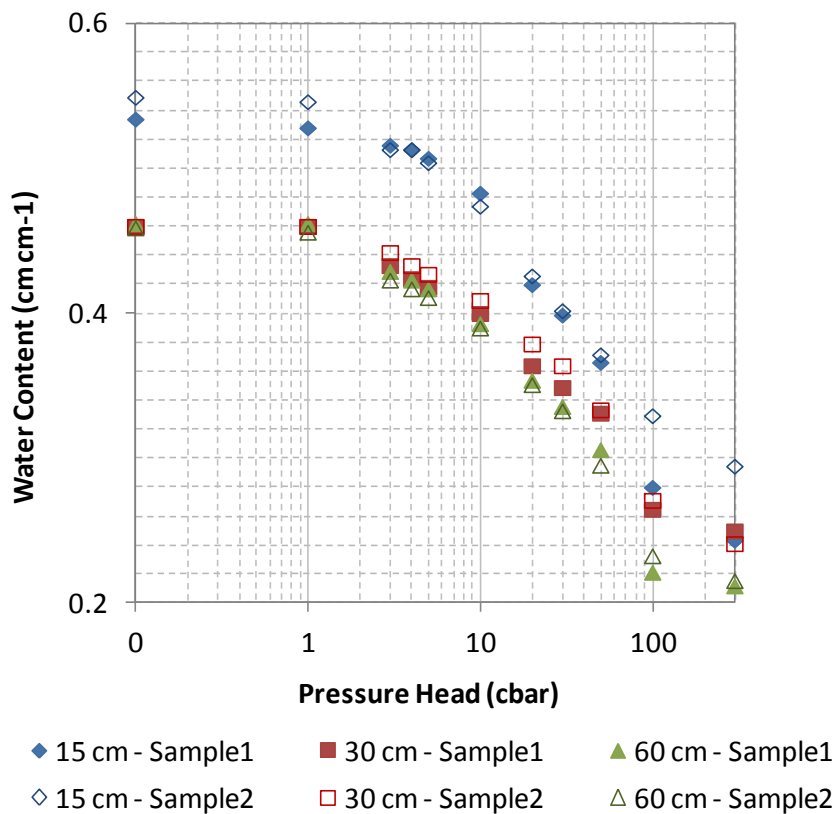

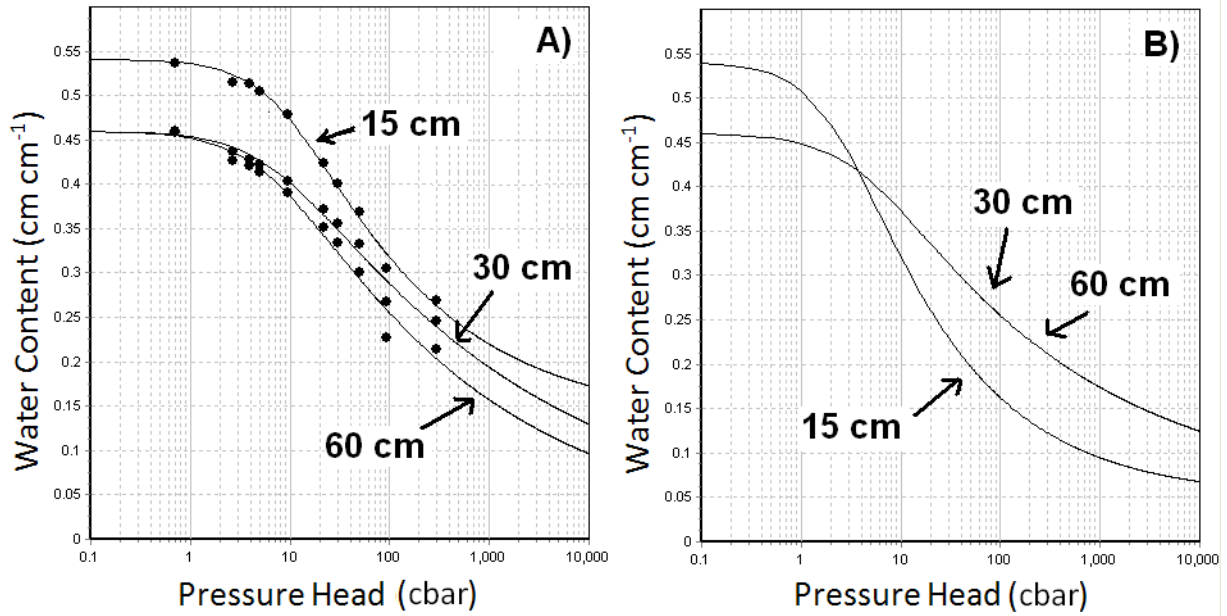Figure 19. Measured soil-water characteristics for the two series of data

Figure 20. Curves obtained with interpolation of measured soil-water characteristics (A) and CRITERIA algorithms from texture observed data (B) with the van Genuchten equation
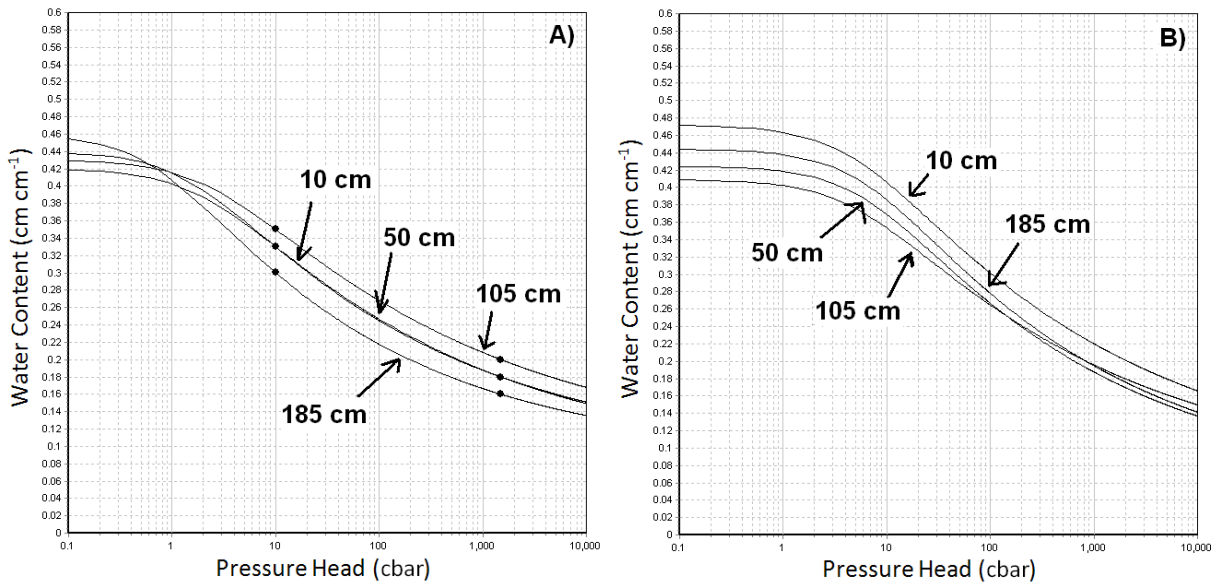

Figure 21. Curves obtained with interpolation of measured soil-water characteristics (A) and CRITERIA algorithms from texture, saturated conductivity and bulk density observed data (B) with the van Genuchten equation, at the Bushland case study field
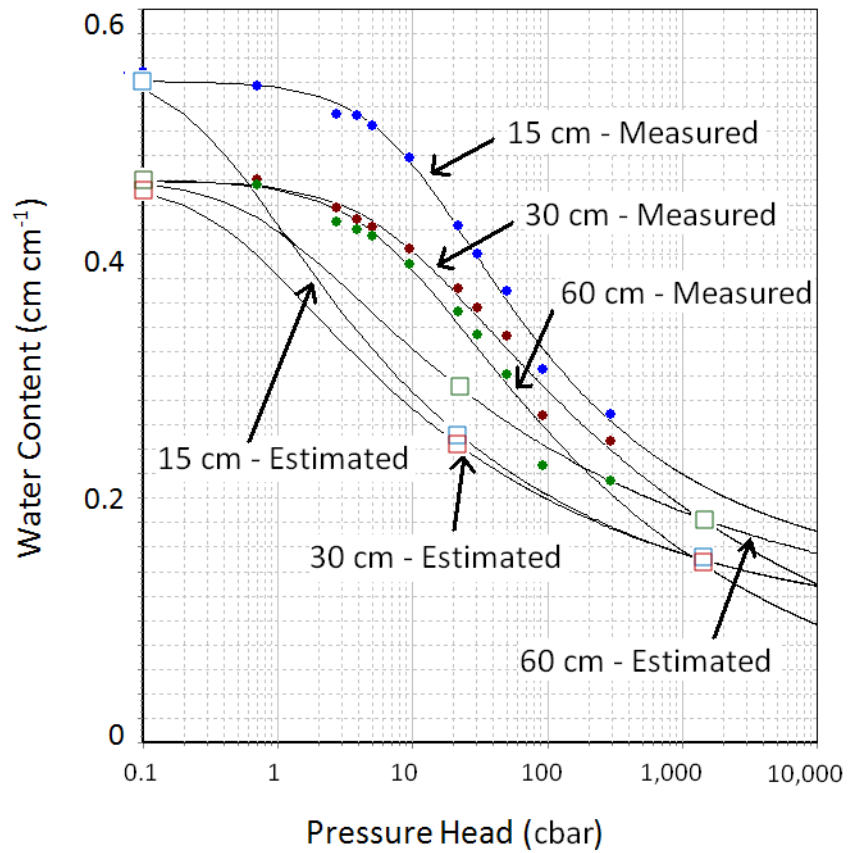
Figure 22. Interpolation of measured and estimated (SWCC) soil-water characteristics with the van Genuchten equation

CONCLUSIONS

The CRITERIA model, calibrated for individual fields, yielded good results, even for cases with limited data. Accuracy was improved with detailed soil sampling and analysis. The model is relatively easy to integrate with GIS when used in irrigation schemes, and these initial results suggest that a reasonable prediction at district-scale can be obtained with a relatively simple calibration. Nevertheless, measuring or scaling detailed meteorological and soil water properties data needs to be carried out. Some crop management information (planting and harvesting date, exact irrigation timing) is not being currently collected by many irrigation districts. Furthermore, soil moisture data are needed for model calibration with representative soils and crops.

More work is needed to verify default values and algorithms used in the model, and to validate the model with other soil types and crops. The model needs new crops and new root shapes options in its database to improve the accuracy of predictions. Finally, for use in irrigation schemes as an operational daily tool, scripts are needed to reduce the manual input of data, running of the model, and to present output results in an easy-to-use format.

ACKNOWLEGDEMENTS

REFERENCES

Bittelli, M., Tomei, F., Pistocchi, A., Flury, M., Boll, J., Brooks, E.S., Antolini, G. (2010). Development and testing of a physically based, three-dimensional model of surface and subsurface hydrology. Advances in Water Resources, 33(1), 106-122

Driessen P.M., 1986. The water balance of the soil. In Modelling of agricultural production: weather, soil and crops, H. Van Keulen e J. Wolfs, Eds. PUDOC, Wageningen, pag. 76

Evett, Steve. 2009. Personal communication, October 15

FAO, 1998. Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and Drainage paper No. 56

FAO, 2005. Materials for subsurface land drainage systems. FAO Irrgation and Drainage Paper No. 60 Rev.

Fromme D.D., Isakeit T., Falconer L., 2010. Soybean Production in the Rio Grande Valley. TWRI Technical Paper EM-108

Gee, G.W. and Bauder J.M. 1986. Partical-size analysis. In Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods. Agronomy Monogroph No. 9 (2nd edition), American Society of Agronomy, Madison, WI. Pp 383-411

Hargreaves, G.M., Samani, Z.A., 1985. Reference Crop Evapotranspiration from Temperature. Applied Engineering in Agriculture. 1(2): 96-99

Marletto, V., Zinoni, F. (1996). The CRITERIA project: integration of satellite, radar, and traditional agroclimatic data in a GIS-supported water balance modelling environment. International Symposium on Applied Agrometeorology and Agroclimatology (1996). Dalezios, N.R.), Volos, Greece, 173-178

NOAA's website, http://water.weather.gov/precip/download.php (Jan. 10, 2011)

Saxton Keith E., Rawls Walter, 2009. Soil Water Characteristics. Version 6.02.74. USDA, Agricultural Research Service, and Department of Biological Systems Engineering, Washington State University. http://hrsl.arsusda.gov/soilwater/Index.htm (Oct 29, 2009)

Texas ET Network, IDEA website, http://texaset.tamu.edu/ (Jan. 10, 2011)

Tomei F., Antolini G., Bittelli M., Marletto V., Pasquali A., Van Soetendael M. (2007). Validazione del modello di bilancio idrico CRITERIA. Italian Journal of Agrometeorology (1), Appendix

USDA (1977). Soil Survey of Cameron County, Texas

van Genuchten, M.Th. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of America Journal 44 (5): 892–898