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

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ABSTRACT

CRITERIA is a soil water balance model which is currently being evaluated in Italy for irrigation scheduling in irrigation schemes. The model predicts soil moisture status on a daily basis. Required input data includes weather conditions, soil hydrological properties, and crop management data. The model requires some calibration using a combination of measured soil water characteristics and actual ET, although the model has algorithms to estimate these in the absence of site specific information. This paper reports the results of an initial evaluation of CRITERIA for Texas conditions. The model is compared to actual data from two distinct climatic regions: the High Plans and the semi-tropical Lower Rio Grande Valley. Predictive and observed soil moisture data are compared for each case at several different depths, as well as model accuracy at different levels of calibration and input data. The model is also evaluated for use in an irrigation district where irrigation requirements are simultaneously simulated for many fields with different crops and water management strategies. Results show that the model is a very useful tool for irrigation scheduling. Good results were obtained, especially when the model was calibrated using soil moisture measured with a neutron probe and with other observed data.

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). It is interesting because it is a simple 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). Research has shown these types of models can give useful information even with a small amount of input data with proper calibration (Borin at al., 2000).

In this paper, the results of an initial evaluation of the model for use in Texas are reported. CRITERIA was calibrated and compared to experimental data collected in the Texas High Plains and the Lower Rio Grande Valley, which represent very different environmental conditions. We also examine model accuracy with calibration at various levels of input data, and for use in an irrigation district.

MATERIALS AND METHODS

The model

The primary inputs required are rainfall, temperature, drainage layout, crop data(such as planting date, tillage, irrigation and harvesting, irrigation volumes and methods), soil texture, and soil organic matter content. Based on these data, the model has algorithms to estimate soil infiltration, soil moisture flux, surface and subsurface drainage, and ETo. There are several options for the calculation of vertical water flux, ETo, and soil water characteristics; and the model allows also for input of measured data. A geographical component of the model allows for interpolation of input spatial data (rainfall and water table depth, for example), and the output data are in *.shp format, therefore readable by GIS software.

Case studies

The model was calibrated at two 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 (BID) (Fig. 1).

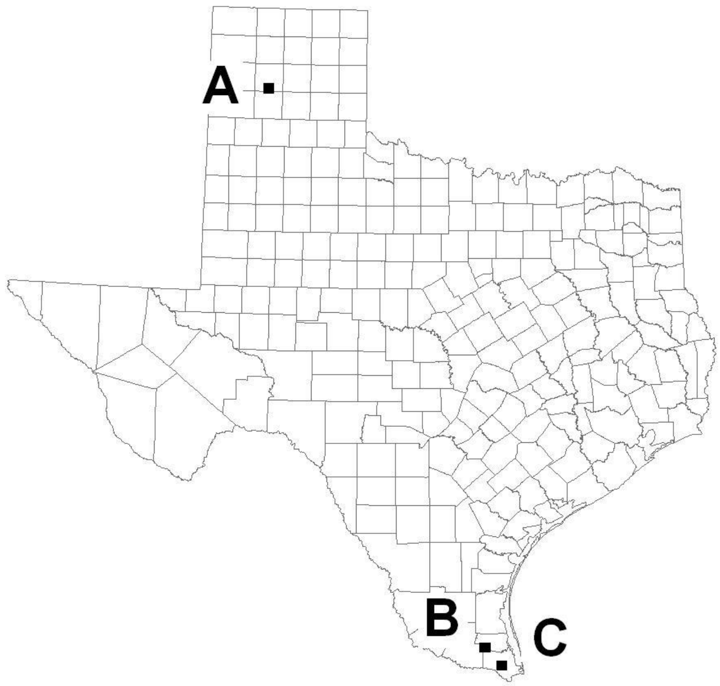

Figure 1 – Location of case studies: A = Texas High Plains, B = Sugarcane (Lower Rio Grande Valley), C = Brownsville Irrigation District

For the High Plains, CRITERIA was compared to data collected using a 6-m large lysimeter at the USDA-ARS Lab in Bushland, for soybean over a two year period. The lysimeter is located in the middle of a larger field and is irrigated with a center pivot equipped with LEPA (Low Energy Precision Application). The soil 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). Measured data included soil moisture to a depth of 190 cm, soil retention curve, and saturated conductivity. Soil moisture was measured with a neutron probe. ETo was calculated using data from an on-site agricultural weather station using the standardized Penman-Monteith equation.

For this study, we used the one-dimensional version, of CRITERIA3D (Bittelli et al., 2010). The model allows vertical flux to be computed using an analytic method or through a numerical solution method. For this case, we used the numerical solution and the van Genuchten method for the interpolation of soil retention curve from observed data.

For the Lower Rio Grande Valley, three years of data from a sugarcane field is used. The furrow-irrigated, 27-ha field is located near Monte Alto TX. The 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. Rainfall was measured at the South-West corner of the field. Drainage volume was not measured. Bulk density, soil texture and continuous soil moisture measurement were measured at the North-West corner of the field. Soil moisture was measured with an Echo Reading sensor.

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 within the model and the Hargreaves method for ETo. The calculation method for vertical flux involves successive steady-state calculations with has the advantage of a higher speed of computation compared to the numerical method. As sugar cane was not present in CRITERIA, necessary parameters for defining the crop were incorporated into the model. These include such factors as Kc, leaf area index, root growth, drought index, etc.

The model was also run for a season's worth of data for approximately 40 individual fields in the Brownsville Irrigation District. The purpose was to evaluate it use for such an application and results when using a minimal data. Daily rainfall data were obtained from the National Weather Service (NOAA's website) for two local stations located just north and south of the district. Soil texture data was obtained from the from the Cameron County Soil Survey (USDA, 1977). Crop data for each fields and irrigation records were obtained from the Brownsville Irrigation District database

All other data were estimated by the model, and we chose analytic method to compute water fluxes, the van Genuchten method for estimating the soil retention curve, and the Hargreaves method for ETo. At this site the model was not calibrated, because no field data on soil moisture was available.

RESULTS AND DISCUSSION

For the Texas High Plans case study, CRITERIA produced good agreement with the measured soil moisture for the top portion of the root zone, down to about 0.5 m. (Fig. 2). In the deeper layers, the simulated data did not match precisely the observed soil moisture (data not shown). One possible reason is the existence of a thick clay layer close to the surface which contributed to an usually shaped root zone. The type of root zone shape is a required input to the model. Only two types of shapes are currently included which do not correspond to the shape observed here.

For the sugarcane field in the Lower Rio Grande Valley, good agreement was obtained between measured and simulated soil moisture for most of the growing seasons. Figure 3 shows the results for the 2008 growing season. These results are encouraging especially considering that irrigation volumes are estimated and the limited amount of soil data. Good agreement between measured and observed soil moisture was also obtained for the deeper layers (data not shown). On July 23, there was a tropical storm which produced 197 mm of rainfall at the site. The field was waterlogged for over a week, and the model did not do a good job of simulating conditions during this period.

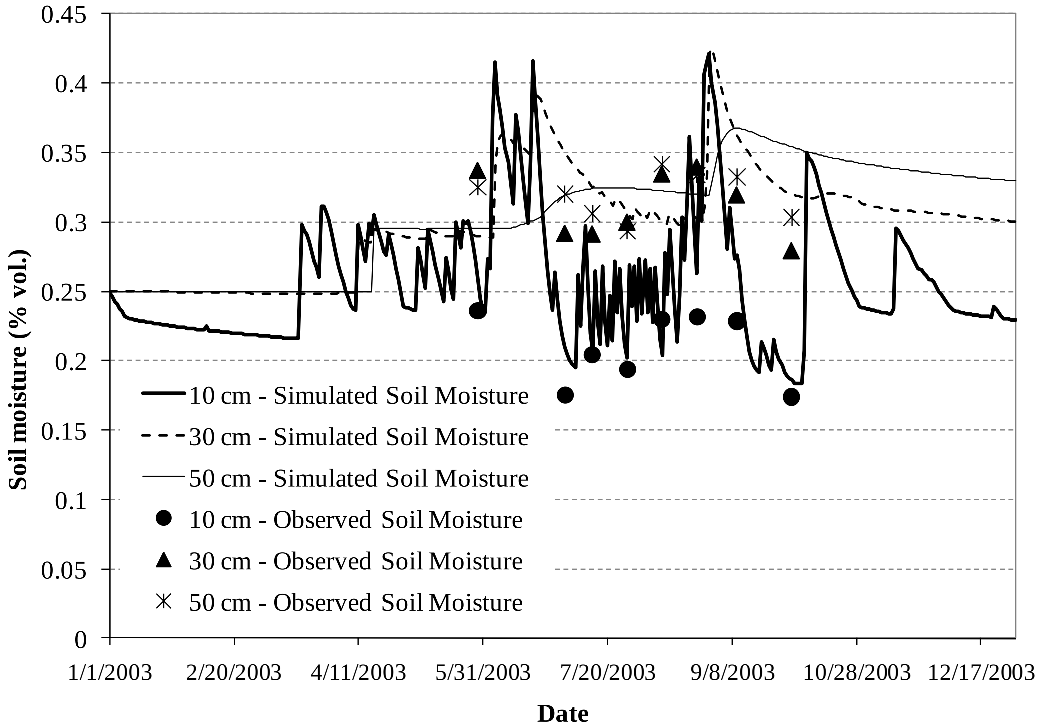

Figure 2 – Texas High Plains case study: Observed and predicted soil moisture with soybeans for the 2003 growing season.

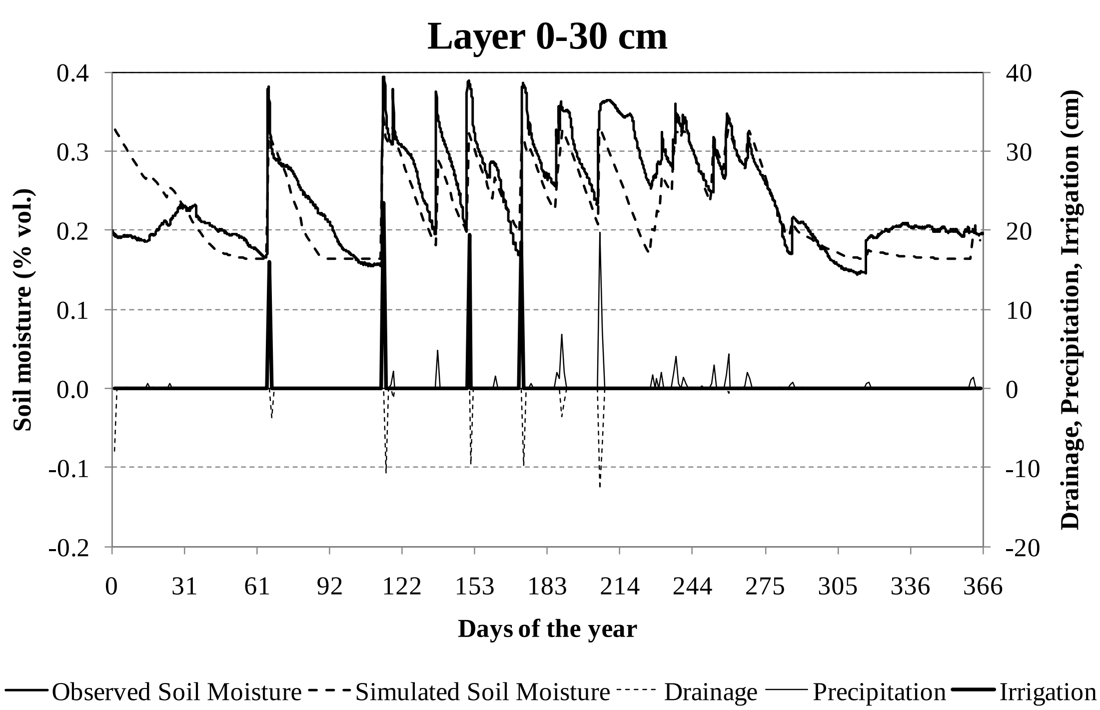

Figure 3 – Sugarcane case study: Average observed and predicted soil moisture in the top soil layer (0-30 cm) for the 2008 growing season.

For the Brownsville Irrigation District case study, the model was applied to approximately 40 fields for the 2010 growing season. The main purpose was to evaluate the practicality of using the model in an irrigation district and to determine if model results are reasonable. Our evaluation is that CRITERIA is a very promising model for use in irrigation districts.   The manager of BID expressed interest in beginning to manage water orders based also on such information. 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. Figures 4 and 5 illustrate how certain spatial data is handled for input into the model. Figure 4 shows the results from the interpolation of rainfall data. The slight difference in precipitation between the North and the South ends of the District was consistent during the growing season. Figure 5 shows the soil map created from the soil survey, and an example of the soil moisture output generated daily.

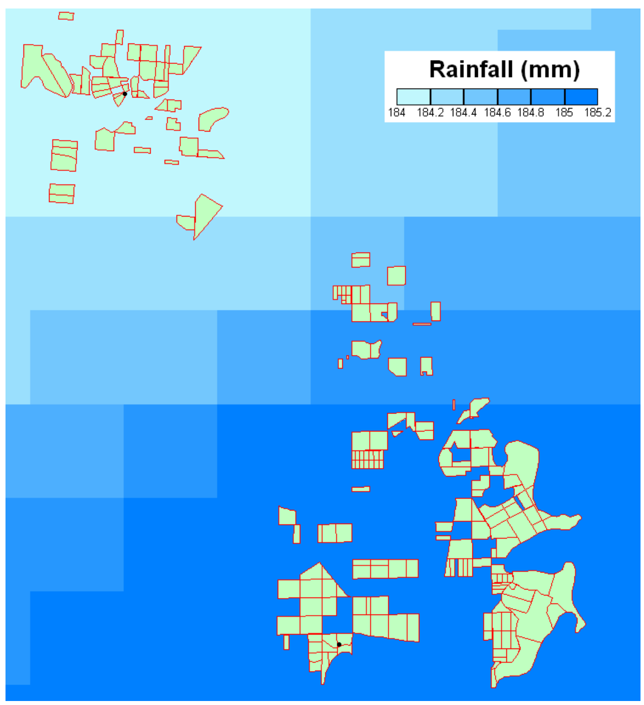

Figure 4 – Brownsville Irrigation District case study: Example of rainfall data interpolation (July 1, 2010)

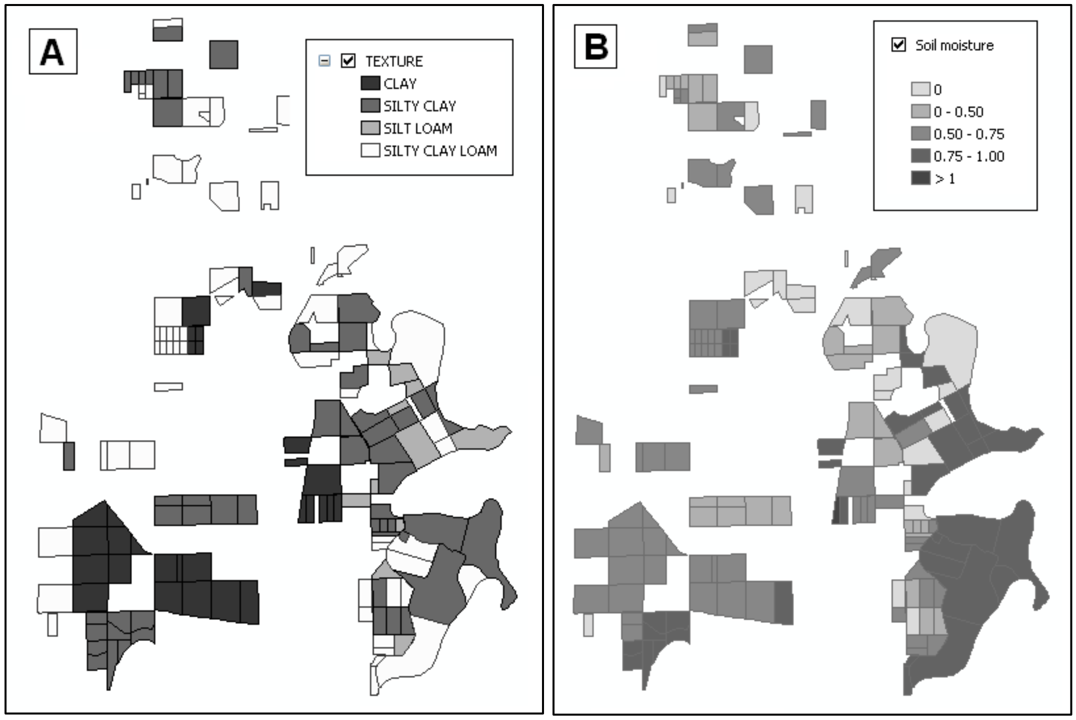

Figure 5 – Brownsville Irrigation District case study: A: texture classification of irrigated land. B: Example of soil moisture output expressed as percentage of available water in the layer from to 0 to 90 cm (July 14, 2010).

CONCLUSIONS

The CRITERIA model calibration yielded encouraging results, even for situations with limited amounts of input data. Calibration of the model with observed data greatly improves its accuracy. The model is relatively easy to integrate with GIS when used in irrigation schemes. More work is needed to define additional root zone shapes to improve model accuracy and to define the input parameters for different irrigation methods. For use in irrigation schemes, scripts are needed to reduce the manual input of data, running of the model and to present output results in an easy to use method. Additional evaluation is needed of the routines and interpolation methods used for soil water characteristics and vertical flux.

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