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SOIL WATER CONTENT SIMULATIONS UNDER WATER STRESS CONDITIONS

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1. INTRODUCTION

A very important aspect for determination of soil water content is its usefulness for an efficient and rational use of water in an appropriate management of crop for higher productivity.

Water stress affects crops depending on the phenological stage involved and many experimental researches were conducted with the aim of studying its impact on yield production. Ritchie and Hanway (1982), stated out that water stress occurring between about two weeks before to two weeks after silking (R1 stage, female flowering) will result in larger grain yield reduction than similar stress at any other period during the growing season. That is because water stress may cause a lag between pollen shed and ovule development, and a consequent reduction in the fertilized ovules to generate grains (Andrade et al., 1996). Although not as severe as at R1, stress during grain filling (R3 and later stages) can still have some effect on yield by shortening the period of dry matter accumulation into the grains. As ripening progress, the amount of potential yield reduction from water stress diminishes (Ritchie and Hanway, 1982). Experimental studies made in the Southeast of Buenos Aires Province (Argentina), revealed that maize plots exposed to water stress suffered a yield loss between 20 and 40 kg ha^{-1} per each millimeter of reduction in water extracted from soil. The highest yield losses occurred when a severe water stress was imposed around flowering (Andrade and Sadras, 2000).

The lack of observational data of soil water content demands the application of estimation methods such as the water balance.

There are two main methods to model the soil water content: the volumetric balance model (Rao, 1987; Rao et al., 1988, 1990; George, 1997; Hajilal *et al*, 1998) and the dynamic model. The former is better known as it is simpler, requires fewer data input and may be used on a local scale. Volumetric balance models are based on the principle of mass conservation within the thickness of the soil, whose lower limit is determined by the maximum depth of penetration of the crop roots. The soil thickness, which acts as a water reservoir, is divided into two layers. The first one, the active root zone, is the area where the roots have already developed. The second layer, the so-called passive root zone, lays between the bottom of the previous zone and the maximum depth the roots are expected to reach. The first layer is where the water balance is estimated taking into consideration the input (rainfall and irrigation) and output (runoff, evapotranspiration and percolation) in the system. In the second layer, percolation – deep percolation is considered as an input - output mechanism.

The aim of this study was to model the soil water content along a crop growing season using the conceptual soil water balance model suggested by Panigrahi and Panda (2003), adapted for the Balcarce (37º45'S, 50º18'W) area in Buenos Aires Province, Argentina. An experimental corn (*Zea mays* L.) field was used to make daily estimates of the soil water content from the time of sowing to physiological maturity. The results obtained were validated with the information obtained during the 1998-1999 field campaign, during which the crop was under different water stress conditions.

2. METHODOLOGY AND MATERIALS

The daily balance is:

$$CAS_i\, ra_i = CAS_{i-1} ra_{i-1} + P_i + R_i + \Delta ra_i\, CAS0_{i-1} - Pe_i - EVTr_i - Es_i \quad (1)$$

where *i* is the number of days after sowing, *CAS* is the soil water content in the active root layer (mm/cm), *CAS0* is the soil water content in the passive root layer (mm/cm), *ra* is the depth of the active roots (cm), *P* is the rainfall (mm), *R* is irrigation (mm), Δ*ra* the variation in the depth of the active roots (cm), *Pe* is percolation in the active root layer (mm), *EVTr* is the real evapotranspiration of the crop (mm) and *Es* is

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the runoff (mm). Fig.1 shows the components of the system and the estimated variables.
Parameterizations used for the depth of active roots, percolation, deep percolation, surface runoff and real crop evapotranspiration are widely described in Gassmann *et al*, 2006.

Potential water conditions for growing plots were found to be dependent on the phenological stages. Thus, it was considered a box-type function as it is shown in Fig. 2. The upper limit of the function represents 65% of available water and the lower limit 50%.

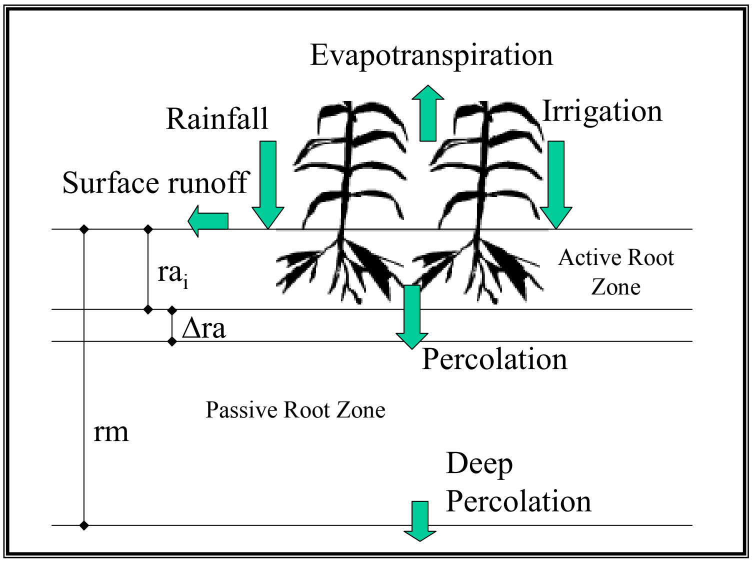


Fig. 1: Diagram of the soil – plant – atmosphere system and balance components.

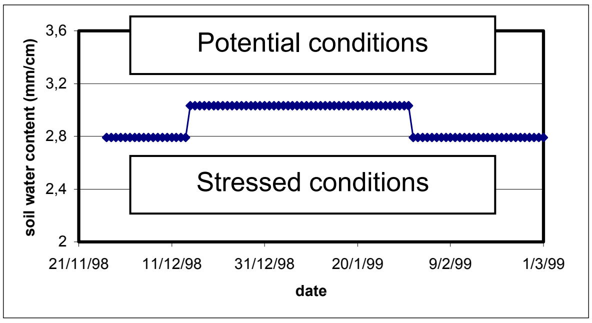


Fig. 2: Limit of potential conditions using a box-type function

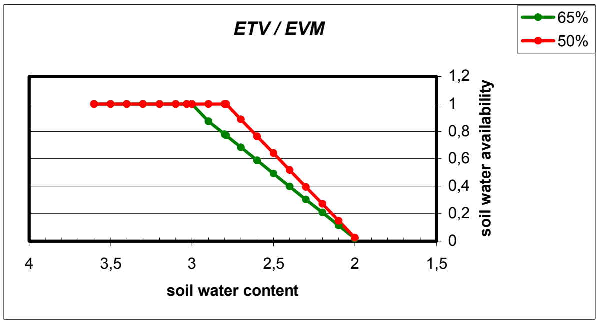


Fig. 3: Relation between real and maximum evapotranspiration as a function of soil water content.

The relation between real and maximum evapotranspiration according to the availability of soil water content is shown in Fig.3. Plant transpiration was estimated using the model proposed by Gardiol et al (2003).

3. DESCRIPTION OF THE EXPERIMENT

The simple balance model was applied to simulate soil water content during the development of maize cops (Zea mays L.) in the area of Balcarce, Buenos Aires province (Argentina). Annual average precipitation in Balcarce is 910 mm (130 m AGL.). Data were collected during a field experiment at the Unidad Integrada Facultad de Ciencias Agrarias UNMdP-EEA INTA. Maize (Dekalb 639) was planted on October 16 with a density of 85,714 pl/ha on a 0.7-m row spacing on a loam soil (illitic thermic loam petrocalcic Paleudoll). Crop was controlled to be pest and disease free. The simulation was performed from 11/27/1998 to 03/01/1999.
The maize plot was split into three different treatments according to their soil water content (Table 1). Each of them was replicated in four sub-plots whose soil was covered with a black polyethylene of 100-µm thickness in order to

insulate from rainfall. Treatments were irrigated by sprinkling method

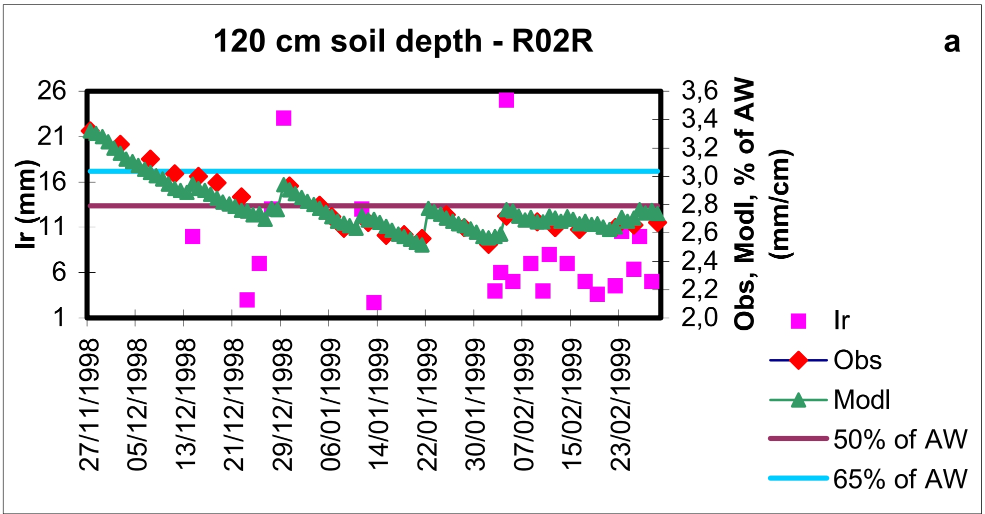
Table 1. Treatments applied to the maize plots and lower limits of available water (%) in the 0 to 0.6 m soil depth during different sub-periods of the growing season.

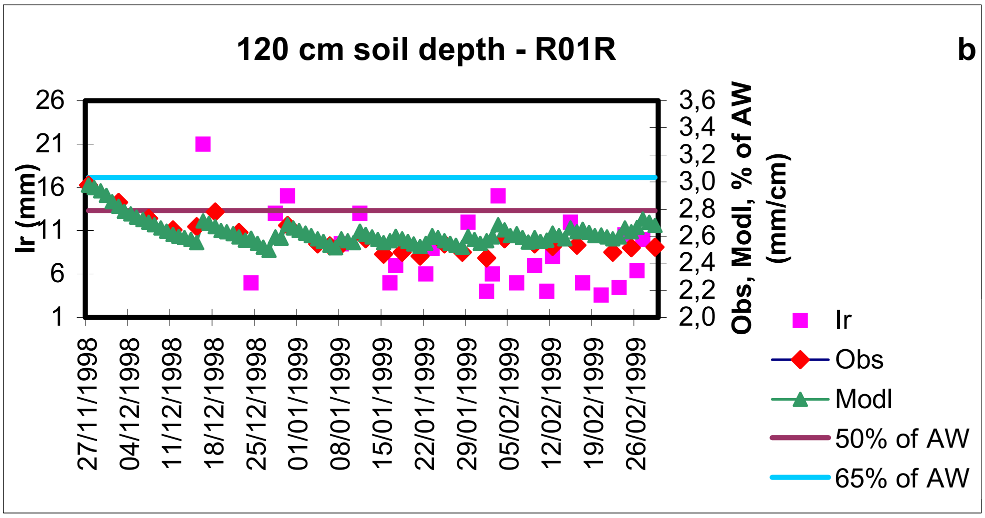
	SUB-PERIOD		
Treatmt.	Vegetative (before V12)	Flowering (V12-R2)	Grain filling (after R2)
R01R	50	50	50
R02R	50	30	50
RR0	50	70	30

The maize plot was fertilized with 150 kg/ha nitrogen when plants were in the V6 phenological stage (Ritchie and Hanway classification, 1982). The plots were irrigated with 217.5 mm (R02R), 216.5 mm (R01R) and 129.1 mm (RR0) of water. Soil water content was measured at 2-5 day intervals by the gravimetric method in the 0-0.1 m layer and by the neutron scattering method (Troxler 4300 Neutron Probe, Troxler E.L. Inc., Res. Triangle Park, NC) in the layers of 0.1-1.2 m for all plots. Meteorological data were collected at the INTA Balcarce agro-meteorological station, located 300-m away from the plots. Also, aerial biomass of plants was sampled six times during the growing season on particular phenological stages. The total green leaf area of the sample was estimated from the green leaf area of a subsample measured with an area meter (model LI-3000, Li-Cor Inc., Lincoln, NE), multiplying the measured leaf area by the ratio between the dry weight of leaves of the sub- and total-samples. The green leaf area index *(L)* was obtained by multiplying the mean green leaf area per plant by the number of plants per square meter.

4. DISCUSSION AND RESULTS

The daily soil water content in a column 120-cm. deep was calculated using the irrigation data.





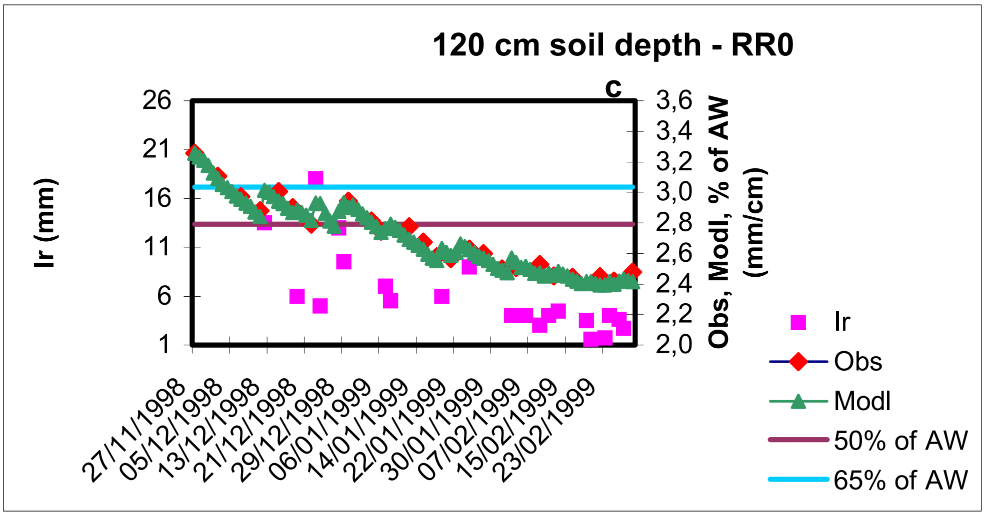


Fig. 4: Simulation of daily soil water content in a 120 cm deep column, covered plots a. R02R, b. R01R, c. RR0. (Ir: irrigation, Obs: Observed data, Modl: model estimation, AW: available water).

Although the crop was sown in the middle of October, the simulations began at the end of November. Observed data of soil water content was used as initial information for the first day of simulation.
The crop at the three plots became below potential conditions after the first week of December. The most stressed plot at the beginning of simulations was R01R, while the most stressed at the end of simulations was RR0. Simulations represented adequately the observed data (Fig.4a, b, c) with a good response to irrigation in the three treatments considering the average soil water content for the whole column. The representation of plant transpiration was adequate, according to the observed behavior in the three simulations.
A statistical evaluation was made to quantify the differences between observed and modeled values. Statistics used were the mean square error (MSE), the normalized mean square error (NMSE) and the mean fractional bias (FB).

Table 2: Summary of the statistical model evaluation

Plot	MSE	NMSE	FB
R02R	0.00311	0.00040	0.0158
R01R	0.00607	0.00089	0.0251
RR0	0.00134	0.00018	0.0110

The model worked well as shown by the low MSE and NMSE values and the mean fractional bias (Table 2). There was a slight tendency to overestimation, indicated by the sign of the fractional bias. Simulation of plot R01R soil water content showed the major errors.

5. CONCLUSIONS

Estimation of the soil water content is one of the more complicated parameters but it is necessary for evaluation of heat transference through the soil in estimation of energy balances in crop covered surfaces. In this case, a simple soil water content evaluation model was used in a 120-cm deep column for maize. The model was compared to data from three different irrigation conditions. Covered soil was used, therefore soil evaporation was neglected from simulation. The volume of water entering the system allowed the crop to develop under practically non-potential conditions. The model adequately predicted the evolution of the daily water content in the column studied with low errors in the estimation. The parameterizations used for each of the different terms considered proved to be adequate for the configuration of the system studied in the experiment. The behavior of the model with different crops will be studied under the same soil conditions and an attempt will be made to forecast the water content in different layers and for different crops.

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