A MODEL OF THE CONTINUOUS SOIL-PLANT-ATMOSPHERE FOR COTTON CROPS

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Abstract

A water balance model is coupled to a function which estimates midday leaf water potential of cotton plants. The water balance model predicts soil evaporation, plant transpiration, run-off, and drainage. Rainfall and irrigation are inputs. Maximum crop evapotranspiration is estimated with Penman's equation using climatic data. The water balance model simulates the water distribution within the soil profile, and generates plant available water weighted for root distribution. An empirical function relating the weighted plant available water to midday leaf water potential was then calibrated using field data collected in an experiment with several irrigation treatments.

Introduction

Water deficit affects cotton production by limiting vegetative growth and inducing square and boll shedding. Leaf expansion is linearly related to midday leaf water potential (LWP) (Grimes and Yamada, 1982) and to plant available water (PAW) below certain threshold (Rosenthal et al., 1987). Functional relationships between abscission and PAW are unknown; however, some quantitative relationships between LWP and abscission are available (Guinn and Mauney, 1984).

Crop simulation models often include a water balance to calculate PAW. PAW may be used to estimate vegetative growth reduction, but a more direct indicator of water stress, such as LWP, may be necessary to estimate abscission of fruiting forms.

This paper presents a simple soil water balance for cotton crops able to estimate PAW. PAW is then used in conjunction with the ambient evaporative demand to predict LWP by means of an empirical function.

Material and Methods

Soil water Balance

The water balance considers rain and irrigation, soil evaporation, transpiration, run-off and drainage. Surface run-off is predicted from daily precipitation using an adaptation of the SCS curve number method (Soil Conservation Service, 1972). In addition to considering precipitation, soil type, land use and management, the method is modified to include the effect of field slope (Williams, 1991) and the calculation of a weighted soil water content for layered soils.

Four soil water boundaries are distinguished in each soil layer: the saturated water content (SAT), the air dry water content (AD), the drained upper limit (DUL), and the lower limit of plant extractable water (LL). DUL and LL limit the plant extractable water (Ritchie, 1981). Infiltrated water (precipitation minus run-off) is redistributed following a cascade approach. The water deficit below SAT of the first layer of soil is calculated. If this water deficit is less than the amount of water added, the layer will be filled to SAT. Drainage will then occur to the second layer. This procedure will be repeated for the next layers until drainage from a layer is less than the water deficit of the layer below. Two situations can then exist: the soil water content is less or greater than DUL. Drainage from the last layer is calculated in the latter case using an unsaturated drainage rate (a soil parameter). The amount of drainage water is added to the next layer. Drainage below the profile will occur when the soil water content of the deeper layer is above DUL.

Maximum crop evapotranspiration (ET_{max}) is computed as 1.2 times the reference evapotranspiration (ET_o), obtained from Penman's equation. When the leaf area index (LAI) is less than 2.7, ET_{max} is linearly reduced from $1.2ET_o$ to ET_o as LAI decreases from 2.7 to zero. The computation of soil and plant evaporation is based on Ritchie's (1972) model adapted after some modifications to the water balance in layered soils (Jones et al., 1986). Soil evaporation, is subtracted from the water content of the upper soil layer. If the recalculated soil water is such that its value is less than AD, the water content is set to AD. Upward flow of water to replace evaporated moisture is not considered in the present version of the model. Potential plant evaporation is calculated as a function of LAI. The corresponding plant water extraction from each layer is calculated by multiplying a relative root distribution factor by the previously calculated potential plant evaporation. Actual plant water uptake from each layer is linearly reduced when less than certain threshold of the extractable water in the layer is present. Actual plant evaporation is then calculated as the sum of plant uptake from each layer.

Experimental

A field experiment was carried out in 1995 at the Experimental Farm of the Instituto de Agricultura Sostenible at Cordoba, Spain, in order to collect data for developing and testing the model. Cotton was planted on April 10 with a row spacing of 0.8 m on a deep loam soil. Plant density after thinning was 5 plants/m^2. Preplant N-P-K-fertilizer was applied. The experimental design was a split-plot with irrigation treatment as main factor and cultivar (Coker-310 and IRMA-1243) as second factor. There were three replications per treatment with elemental plots of 8 rows 12-m in length. The irrigation treatments were to produce early stress (T1), mid stress (T2), late stress

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(T3) and a well irrigated control (T4). The elemental plots were sprinkler irrigated.

Climatic data were collected at a weather station located on the experimental. A number of routine measurements were made on the crop. The measured variables of interest in this study were LWP, water content, LAI and root length. LWP was determined twice a week on 6 leaves per treatment using a pressure chamber. Water content was measured the same days that LWP at different depths down to 2 m using a neutron probe and also a TDR for the upper layer. LAI was measured weekly using a fish-eye sensor. Soil samples were collected on two dates (mid-August and harvesting) to determine root distribution.

Leaf Water Potential Function

LWP was related to different variables to obtain an empirical relationship for LWP. Some of the main variables which may affect LWP are plant available water, net radiation, vapor pressure deficit, and ETo. The plant available water was obtained from the soil water balance model, and it was weighted (PAW_w) with the relative root distribution factor. The other variables were obtained from the weather data. A number of functions were tested by multiple regression analysis and the agreement between estimated and measured LWP was used to evaluate the relationship.

Results

Soil Water Balance

Crop ET was reasonably well estimated by the water balance model. Estimations were compared with the soil water content difference after an irrigation and before the next irrigation. The regression of simulated *vs* observed values (expressed as mm per day) was ET_{sim}=0.83ET_{obs}+1.6 (r^2=0.80, n=255), showing not significant deviation from the 1:1 relationship.

The total soil water content (SW) was also well simulated by the model. Fig. 1 shows the evolution of SW along the season in treatment T2, cultivar IRMA-1243. The regression between simulated and observed SW (in mm) was SW_{sim}=0.90SW_{obs}+26 (r^2=0.89, n=517), with no deviation from the 1:1 relationship.

Leaf Water Potential Function

The best balance between accuracy and simplicity in the estimation of LWP was obtained with the equation $LWP(MPa)=-0.73(PAW_w/ET_o)^{-0.33}+0.21$ (r^2=0.77, n=143). This function shows how LWP decreases as PAW_w decreases, maintaining higher values for low evaporative demand (Fig. 2). Note that the maximum LWP for a given ET_o varies as ET_o changes, for instance, PAW_w equal to 1 gives LWP equal to -0.71 when daily ET_o is 2 mm and -1.37 MPa for 10 mm of ET_o. Therefore, both the effect of soil water availability and the effect of the climatic conditions are taken into account by the function.

A similar approach was presented by Hearn and Constable (1984). However, their function showed a sharper reduction in LWP with decreasing PAW. This is due to the PAW weighing as a function of the root distribution that we included in our model aiming to reflect the ability of the plant to readily uptake the available water rather than the available water computed for the total root depth.

The seasonal evolution of observed and simulated LWP showed quite close trends (Fig. 3). The regression of simulated *vs* observed LWP (LWP_{sim}=0.54LWP_{obs}+0.79, r^2=0.65, n=147) indicated some overestimation at high LWP and underestimation at low LWP. The discrepancy is probably due to errors in the simulation of PAW_w: a good estimation of PAW_w requires a good simulation of water distribution in the soil profile. In fact, when PAW_w was computed using soil water measurements instead of the water balance model, it improved the agreement between simulated and observed LWP.

We are aware of some discrepancies between measured and simulated water content in some soil layers (data not shown), which might be due to an incomplete soil profile characterization, or to limitations of the water balance model at its current stage.

Conclusions

Leaf water potential may be used in crop simulation models as an indicator for plant water stress. The function for LWP should account for the soil plant available water and the ambient evaporative demand. A good simulation of water distribution and active root density in the soil profile is necessary for the accurate estimation of LWP. Both aspects will be revised and further developed in a next version of the soil-plant-atmosphere model presented in this paper. A more mechanistic LWP model based on the Ohm's Law analogy will be also analyzed.

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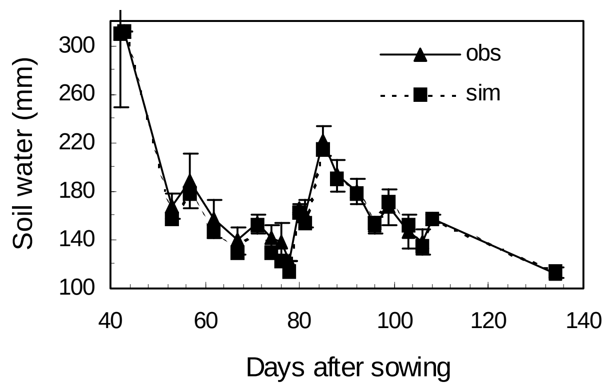

Fig. 1. Evolution of the measured and simulated soil water content in treatment T2 (mid stress, cultivar IRMA-1243)

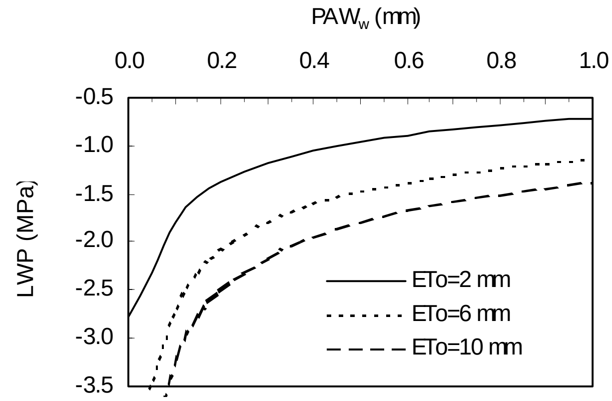

Fig. 2. Midday leaf water potential (LWP) as a function of the plant available water weighted for root distribution (PAW_w).

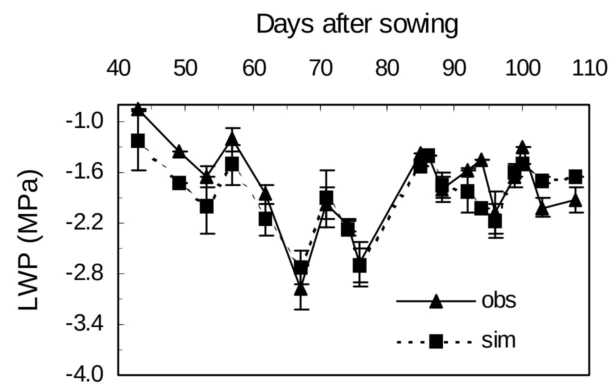

Fig. 3. Evolution of the measured and simulated midday leaf water potential (LWP) in treatment T2 (mid stress, cultivar IRMA-1243)