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Water for agriculture, irrigation management

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ABSTRACT

This chapter aims to illustrate some of the recent methodologies that can be employed for improving water use efficiency in agriculture by optimizing irrigation management based on crop water requirements.

1. Introduction

Water for irrigation and food production constitutes one of the greatest pressures on freshwater resources. World agriculture consumes approximately 70% of the fresh water withdrawn per year (UNESCO, 2001). New threats include the challenges of climate change, which is likely to alter both water availability and agricultural water demands.

Optimal use of water resources for agricultural production is still one of the main challenges worldwide. Only about 17% of the world's cropland is irrigated, but this irrigated land produces 40% of the world's food (FAO, 2002). More efficient irrigation practices can reduce the volume of water applied to agricultural fields by 30–70% and can increase crop yields by 20–90%. Effective planning and management of water for crop production requires deep knowledge and efficient solutions. The water requirement of a crop must be satisfied to achieve potential yield. Therefore, to increase water use efficiency in agriculture the irrigation management must be optimized to avoid unnecessary waste of important and sometimes limited water resources. Thus, to achieve this goal the amount of water provided for irrigation during the growing season must not exceed the effective crop water requirements. Therefore, to improve the water use efficiency in agriculture the net irrigation and water requirements of the crops can be estimated using crop water productivity models (e.g. FAO model: AquaCrop).

2. Materials and methods

AquaCrop is a crop water productivity model developed by the Land and Water Division of FAO. It simulates yield response to water and is particularly suited to address conditions where water is a key limiting factor in the crop production.

AquaCrop performs a daily water balance that includes all the incoming and outgoing water fluxes (infiltration, runoff, deep percolation, evaporation and transpiration) and changes in soil water content. The effects of water deficit on the crop is expressed through four stress response coefficients, which are functions of the fractional depletion of the total available water (the volume the soil holds between field capacity and permanent wilting point) in the root zone.

The four coefficients are for leaf growth, stomatal conductance, canopy senescence, and pollination failure, each with its own sensitivity to water stress. Harvestable yield is calculated from the cumulative biomass with harvest index (HI), which increases with time after the onset of anthesis (Heng et al., 2009).

Yield response to water describes the relationship between crop yield and water stress as a result from insufficient supply of water by rainfall or irrigation during the growing period. In the FAO Irrigation & Drainage Paper n. 33 (Doorenbos and Kassam, 1979) an empirical production function is used to assess the yield response to water:

$$\left(1-\frac{Y}{Y_x}\right)=K_y\left(1-\frac{ET}{ET_x}\right) \tag{1a}$$

where Y_x and Y are the maximum and actual yield, $(1\text{-}Y/Y_x)$ the relative yield decline, ET_x and ET the maximum and actual evapotranspiration, $(1\text{-}ET/ET_x)$ the relative water stress, and K_y the proportionality factor between relative yield decline and relative reduction in evapotranspiration.

AquaCrop (Steduto et al., 2007) evolves from the K_y approach by separating:

(i) the actual evapotranspiration (ET) into soil evaporation (E) and crop transpiration (Tr):

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$$ET = E + Tr \tag{1b}$$

The separation of ET into soil evaporation and crop transpiration avoids the confounding effect of the non-productive consumptive use of water (soil evaporation). This is important especially when ground cover is incomplete early in the season or as the result of sparse planting, and

(ii) the final yield (Y) into biomass (B) and harvest index (HI):

$$Y = HI\ (B) \tag{1c}$$

The separation of yield into biomass and harvest index allows the partitioning of the corresponding functional relations as response to environmental conditions. These responses are in fact fundamentally different and their separation avoids the confounding effects of water stress on B and on HI.

The changes described leads to the following equation at the core of the AquaCrop growth engine:

$$B = WP\ \Sigma Tr \tag{1d}$$

where Tr is the crop transpiration (in mm) and WP is the water productivity parameter (kg of biomass per m^2 and per mm of cumulated water transpired over the time period in which the biomass is produced). This step-up from Eq. (1a) to Eq. (1d) has a fundamental implication for the robustness of the model due to the conservative behaviour of WP (Steduto et al., 2007). It is worth noticing, though, that both equations have water as driving force for growth.

To be functional, Eq. (1d) was inserted in a complete set of additional model components, including: the soil, with its water balance; the crop, with its development, growth and yield processes; and the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration. Additionally, some management aspects are explicitly considered (e.g., irrigation, fertilization, etc.), as they will affect the soil water balance, crop development and therefore final yield. AquaCrop can also simulate crop growth under climate change scenarios (global warming and elevated carbon dioxide concentration) while pests, diseases, and weeds are not yet considered.

To run AquaCrop the input data of four main model domains, i.e. Climate, Soil, Crop and Management must be collected. In Fig. 1 an overview of the model structure, input parameters and main processing steps is reported.

Particular features that distinguishes AquaCrop from other crop models are:

- its focus on water;
- the use of canopy cover instead of leaf area index;
- the use of water productivity (WP) values normalized for atmospheric evaporative demand and CO_2 concentration that confer the model an extended extrapolation capacity to diverse locations, seasons, and climate, including future climate scenarios;
- the relatively low number of parameters;
- input data which requires only explicit and mostly intuitive parameters and variables;
- a well developed user interface;
- its considerable balance between accuracy, simplicity, and robustness;
- its applicability to be used in diverse agricultural systems that exists worldwide.

Although the model is relatively simple, it emphasizes the fundamental processes involved in crop productivity and in the responses to water deficits, both from a physiological and an agronomic perspective.

A detailed model description is presented in Steduto et al. (2009) and Raes et al. (2009a).

3. Results and discussion

A water productivity model like for instance the FAO – AquaCrop can be applied worldwide and therefore it is very suitable for all climatic regions of the world. The main model results obtained for each simulation are the following:

- net irrigation based on crop water requirements;
- cumulative water balance (incoming and outgoing water fluxes);
- scenario simulation.

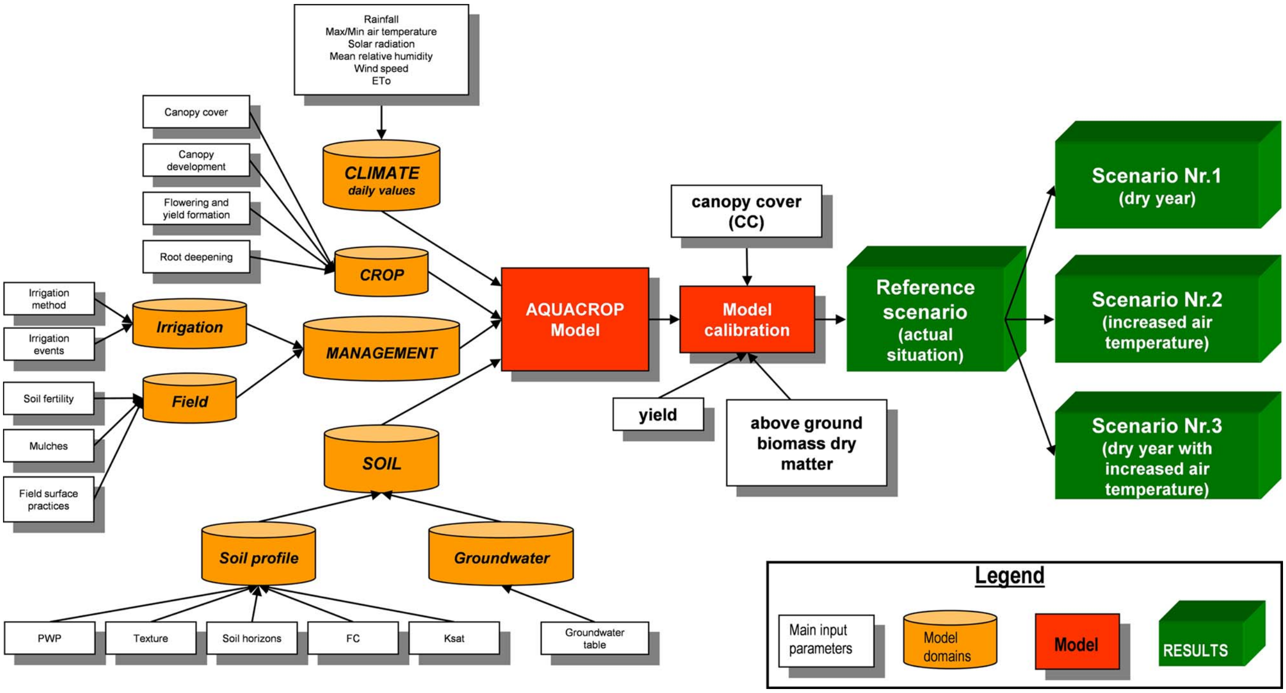

Fig. 1. Overview of the model structure, input parameters and main processing steps.