Introducing AquaCrop

AquaCrop is FAO's crop water productivity model resulting from the revision of FAO Irrigation and Drainage Paper No. 33 *Yield response to water* (Doorenbos and Kassam, 1979). For over two decades, this paper was a key reference for estimating the yield response of field, vegetable and tree crops to water.

Scientific and experimental progress in crop-water relations since 1979 led FAO to organize a consultation with qualified professionals, recognized authorities and experts from major scientific and academic institutions, national and international research centers and governmental organizations worldwide in order to revise Paper No. 33. The consultation resulted in a revision framework where field and tree crops are treated separately. For field crops, it was recommended to develop a model with a suitable structure and conceptual framework that would be accurate, simple and robust, to use for planning, management and scenario simulations at different scales: AquaCrop.

This quick reference to AquaCrop provides basic information allowing the user to become familiar with AquaCrop's concepts.

AquaCrop Conceptual Briefs

In Paper No. 33, the fundamental relation of the yield estimate in response to water is expressed through the following equation,

$$\left(\frac{\mathrm{Y_x} - \mathrm{Y_a}}{\mathrm{Y_x}}\right) = k_{\mathrm{y}}\left(\frac{\mathrm{ET_x} - \mathrm{ET_a}}{\mathrm{ET_x}}\right) \qquad \text{eq.(1)}$$

where Y_x and Y_a are the maximum and actual yield, respectively, ET_x and ET_a are the maximum and actual evapotranspiration, respectively, and k_y is the proportionality factor between relative yield loss and relative evapotranspiration reduction.

AquaCrop evolves from Eq. (1) by separating:

(i) the field crop evapotranspiration (ET_a) into soil evaporation (E_s) and crop canopy transpiration (T_a), and;

(ii) the final yield (Y_a) into biomass (B) and harvest index (HI). The separation of ET_a into E_s and T_a avoids the confounding effect of the non-productive consumptive use of water (E_s). This is important especially during growing stages with incomplete ground cover. The separation of final yield into B and HI allows a distinction of the basic functional relations between environmental conditions and B, and environmental conditions and HI.

A schematic representation of this evolutionary step is shown in Figure 1:

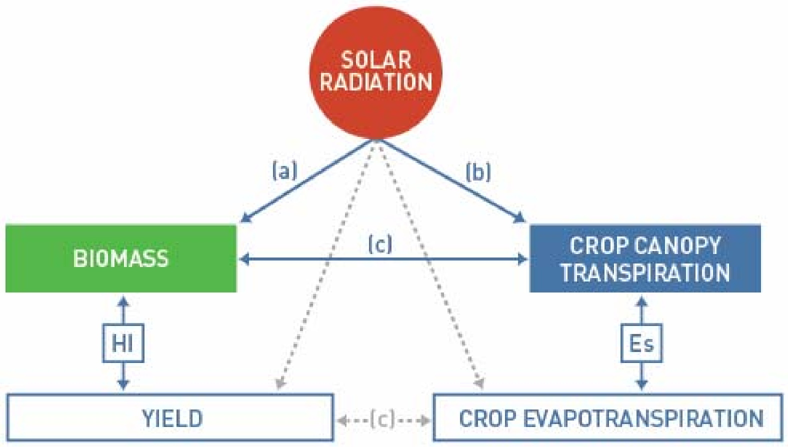

Figure 1. Evolutionary step of **AquaCrop** from Eq (1), leading to the introduction of two intermediary steps: the separation of soil evaporation (Es) from crop canopy transpiration (Ta) and the attainment of yield from Biomass and harvest index (HI)

Both Eq.(1) and AquaCrop are water-driven in their growth engine (the relationship indicated with [c] in Figure 1). By focussing on the fundamental relation between biomass and transpiration -- rather than yield and evapotranspiration -- AquaCrop relies on the conservative behaviour of the *biomass water productivity* (WP), also called *biomass water use efficiency* (WUE), indicated here as *water productivity coefficient.*

Maintaining biomass water productivity (WP) at the core of the model, AquaCrop further develops, similarly to many other crop-growth models, a structure (sub-model components) that includes: the soil, with its water balance; the crop, with its development, growth and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration (CO_2); and the management with its major agronomic practice such as irrigation and fertilization.

Several features distinguish AquaCrop from other crop-growth models achieving a new level of simplicity, robustness and accuracy. Some of it’s key features include:

- Canopy development is expressed through ground canopy cover (CC) and not through leaf area index (LAI). This offers a significant simplification in the simulation by reducing the overall aboveground canopy expansion to a sigmoid function. Beyond CC, where differences due to canopy architecture and height are important in influencing other processes (e.g. aerodynamic conductance in determining evapotranspiration), simple correction factors are introduced. The ground canopy cover (CC) simulation reflects three fundamental processes: leaf expansion; transpiration as regulated by stomatal conductance (gs); and senescence as loss of transpiration and assimilation capacities.

- Roots have their own development (in depth, shape and uptake capacity) based on the constraints experienced in the soil and the degree of canopy development.
- Aboveground biomass (B) calculated using the biomass water productivity parameter (WP). This parameter, provided experimentally, is normalized for climate (atmospheric evaporative demand and carbon dioxide) so that it can be used in different climatic zones in space and time. WP is also partially affected by fertility levels.
- Biomass production decoupled from partitioning into the various organs, except into the fruits, grain or tubers whose partitioning occurs via the Harvest Index (HI). This choice avoids the majority of uncertainties linked to this fundamental process that remains among the most difficult to model. The drawback is that canopy development, the leading growing factor, relies on empirical algorithms for simulations. Nevertheless, the extensive set of experimental data on canopy development has led to a preference for this solution rather than adopting the more complex and uncertain processes of biomass partitioning. This solution has also facilitated the relationship between shoot and root which is maintained.
- Harvest index (HI) increases linearly with time (either calendar or thermal) starting after pollination and for a given period (depending on the variety) after which it remains constant. The simulation takes into account HI response to water stresses.
- Environmental stresses are expressed through stress indexes (Ks), specific for each of the most basic growth expressions of the crop, i.e. leaf expansion, stomatal conductance (gs) and senescence. In addition to these stress indexes, two are activated in special (or extreme) environmental conditions: one preventing pollination and one affecting the biomass water productivity parameter WP. Selecting and differentiating the sensitivity of the diverse crop expressions to environmental stresses offers AquaCrop a more crop-centered simulation dimension.
- Separation between soil evaporation (E_s) and crop transpiration (T_a) makes use of the Ritchie approach (1972) adapted to the CC rather than LAI.

AquaCrop uses a relatively small number of explicit parameters and mostly-intuitive input variables requiring simple methods for their determination. The overall structure of AquaCrop's main components is shown in the flowchart in Figure 2.

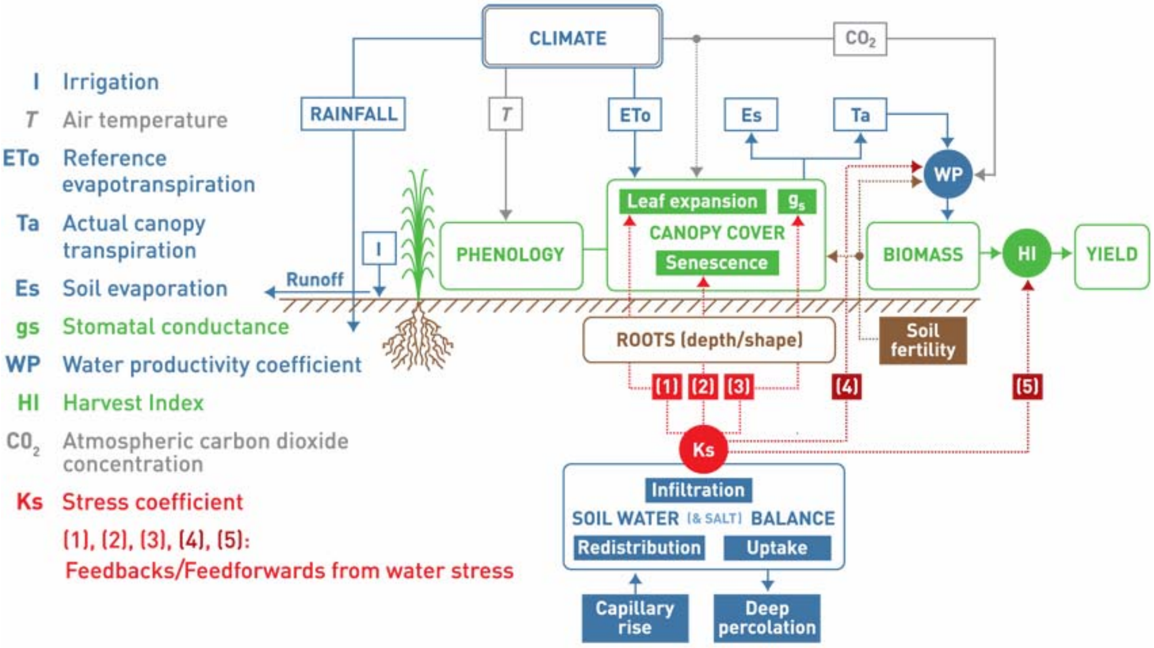

Figure 2: Flowchart of AquaCrop's main component.

AquaCrop is mainly intended for practitioners such as those working for extension services, governmental agencies, NGOs and various kinds of farmers associations. It is useful for developing irrigation strategies under water deficit conditions, finding the most suitable crop calendar under rainfed conditions and obtaining reliable yield estimates for field crops under a variety of environmental conditions (including salinity and climate change). AquaCrop may also be of interest to scientists for teaching purposes.