Introducing AQUACROP

Much progress has been made in quantifying and understanding crop growth in relation to water in the last 30 years. This led to the development of AquaCrop, the FAO's crop water productivity simulation model. For this development, FAO organized consultations with recognized authorities and experts from major scientific and academic institutions, national and international research centers and governmental organizations worldwide. The outcome is a revised framework that treats herbaceous crops and tree crops separately. The herbaceous crops are to be simulated by the model AquaCrop, parameterized for each crop species. The model is to strike a balance among accuracy, simplicity and robustness. It is to be used for irrigation management, project planning, and scenario simulations at different scales. The tree crops present additional complexities which are not easy to simulate. Hence, only guidelines regarding water management and yield estimation are being written for important tree crop species.

AquaCrop Conceptual Briefs

In the FAO Irrigation and Drainage Paper No. 33 "Yield Response to Water", the fundamental relation of the yield estimate in response to water is expressed through the following equation,

$$\left(\frac{Yx - Ya}{Yx} \right) = Ky \left(\frac{ETx - ET}{ETx} \right) \quad (1)$$

where Yx and Ya are the maximum and actual yield, ETx and ET are the maximum and actual evapotranspiration, and Ky is the proportionality factor between relative yield loss and relative evapotranspiration reduction.

AquaCrop evolves from Eq. (1) by (i) dividing the ET in soil evaporation (Es) and crop transpiration (Tr), (ii) obtaining biomass (B) from the product of water productivity (WP) and cumulated crop transpiration, as reported in Eq. (2), (iii) expressing the final yield (Y) as the product of B and Harvest Index (HI), (iv) normalizing Tr with reference evapotranspiration (ETo), and (v) calculating crop water use, growth and production in daily time steps instead of only as the final ET and Y.

$$B = WP \cdot \Sigma T_r \qquad (2)$$

The division of ET into Es and Tr avoids the confounding effect of the non-productive consumptive use of water (Es). This is important for growing periods when canopy cover is incomplete. The expression of Y in terms of B and HI allows a distinction of the basic functional relations between environmental conditions and B, and environmental conditions and HI. The normalization of Tr makes the B-Tr relationship general, applicable to different climatic regimes. The simulation of water use and production in daily time steps permits a more realistic accounting of the dynamic nature of water stress effects and crop responses.

A schematic representation of these evolutionary steps is reported in Figure 1.
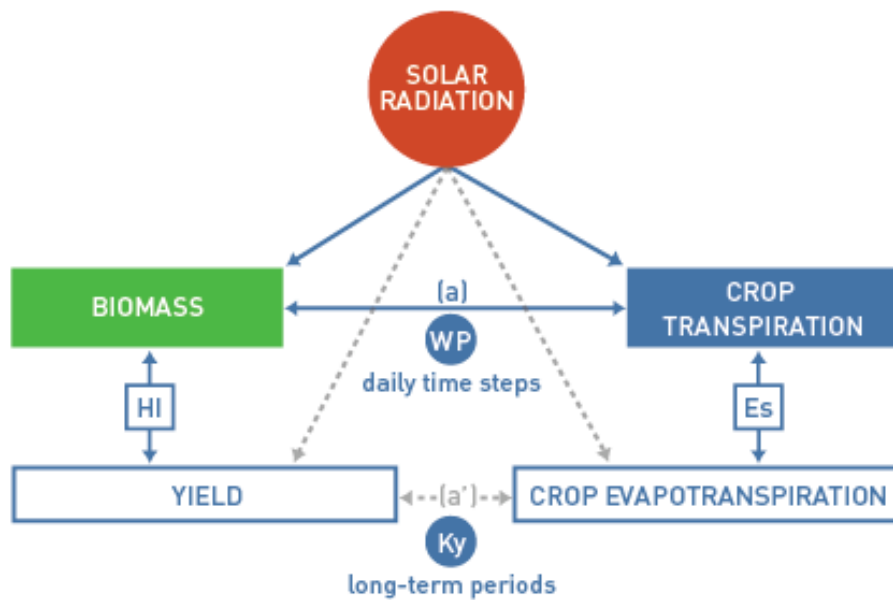

Figure 1. Evolution of AquaCrop from Eq (1), based on the introduction of two intermediary steps: the separation of soil evaporation (Es) from crop transpiration and the attainment of yield from biomass and Harvest Index (HI). The relationship a', linking yield to crop evapotranspiration is expressed through Eq. (1) via the Ky parameter and normally applies to long periods. The relationship a, linking biomass to crop transpiration, is expressed through Eq. (2) via the WP parameter and has a daily time step.

As Eq. (1) of Paper No. 33, AquaCrop is water-driven, meaning that the crop growth and production are driven by the amount of water consumptively used (Tr). AquaCrop focuses on the fundamental relation between B and Tr (Eq.2) rather than Y and ET (Eq.1), relying on the conservative behaviour of WP.

Similarly to many other crop-growth models, AquaCrop further develops 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.

Simulation runs of AquaCrop are executed with daily time steps, using either calendar days or growing degree days. Several features distinguish AquaCrop from other crop-growth models achieving a new level of simplicity, robustness and accuracy.

These key features include:

- canopy development expressed as canopy cover (CC) of the ground and not through leaf area index (LAI). This offers a significant simplification in the simulation by reducing canopy development with time to a sigmoid function using a canopy growth coefficient. Senescence of the canopy is simulated with a decline function

- root development is expressed in terms of effective rooting depth as a function of time (either calendar or thermal). A functional relationship is also established between root and shoot development

- B is calculated using WP and Tr. WP 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

- Y is calculated as the product of B and HI. HI increases mostly linearly with time (either calendar or thermal) starting after pollination and until near physiological maturity. Other than for the yield, there is no biomass partitioning into the various organs. This choice avoids the majority of uncertainties linked to this fundamental process that remains among the most difficult to model

- water stress is expressed through stress coefficients (Ks) specific of each basic growth expression. These are canopy expansion, stomatal control of transpiration (gs), canopy senescence and harvest index. Different Ks accomodate for different crop species sensitivities to water stress

- ET division in Es and Tr approximates the Ritchie approach (1972), but using CC rather than LAI as the crop parameter

- AquaCrop uses a relatively small number of explicit and mostly-intuitive parameters and input variables requiring simple methods for their determination.

The overall structure of AquaCrop's main components is shown in the flowchart of Figure 2.
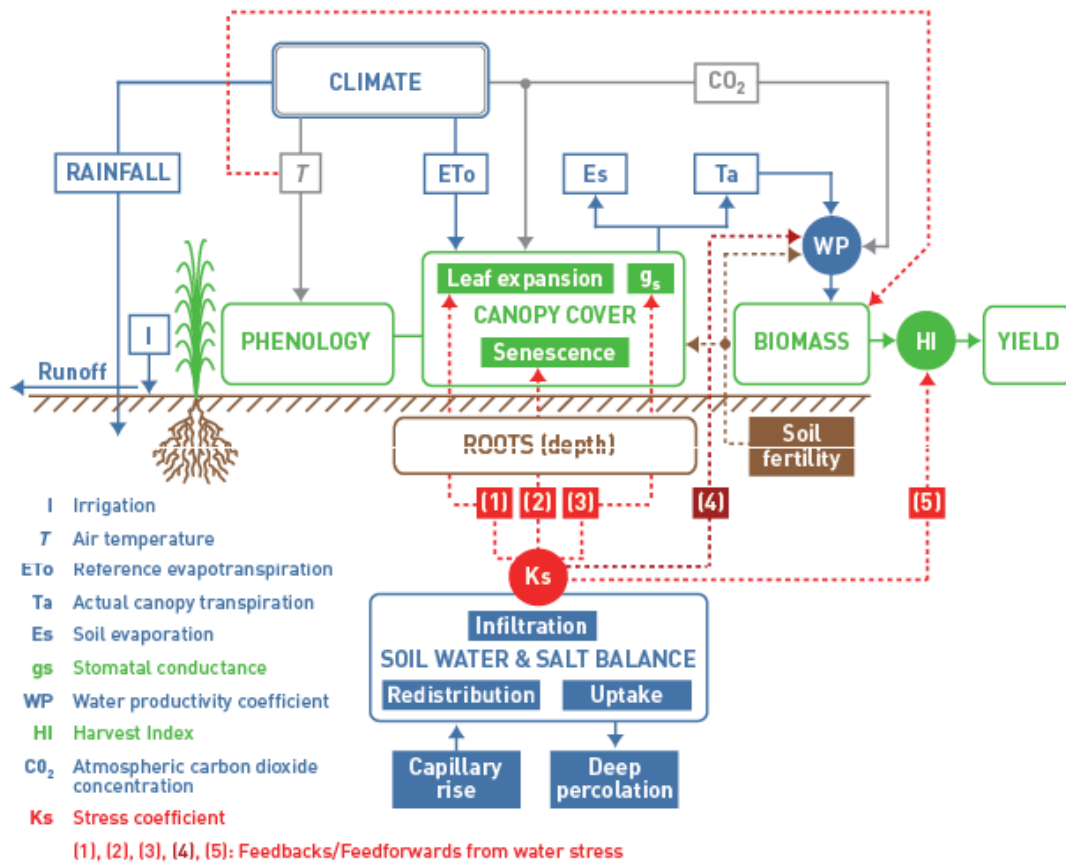
Figure 2. AquaCrop flowchart indicating the main components of the soil-plant-atmosphere continuum.

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, finding the most suitable crop calendar under rainfed agriculture and obtaining yield estimates for field crops under a variety of environmental conditions (including salinity and climate change). AquaCrop should also be of interest to scientists and for teaching purposes.

References:

Doorenbos J. and Kassam A.H. (1979). Yield Response to Water. Irrigation & Drainage Paper No 33, FAO, Rome

Ritchie J.T. (1972). Model for predicting evaporation from a row crop with incomplete cover. Water Resour. Res. 8 (5) 1204-1213