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Aqua crop model : An efficient tool for agricultural water management

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Introduction : Freshwater is a critical natural resource that is essential for the development of any country. However, many regions worldwide are currently facing a scarcity of freshwater. This scarcity is being aggravated by competing demands for water from an ever-growing population, agriculture, industry, and ecology. Consequently, water allocation has become a challenging issue for policymakers, and it is caused not only by physical constraints but also by inefficient usage and poor management. In most developing countries, irrigation is the primary user of water, accounting for about 75% of all water usage, and this demand is expected to increase by 14% by 2030. However, irrigation has been criticized for its wasteful use of water, especially in water-scarce regions. To address this issue, sustainable methods to increase crop water productivity are gaining importance, particularly in arid and semiarid regions. Simulation models, such as AquaCrop, offer a low-cost approach to investigate a wide range of management strategies for enhancing water productivity in crop growth. Water-driven crop growth models, which assume a linear relationship between biomass growth rate and transpiration, offer several advantages over radiation-driven models, such as the ability to normalize the water productivity parameter for climate, making it more applicable in different locations under varying spatio-temporal settings.

What is Aqua Crop Model? The crop growth model known as AquaCrop was developed by the Land and Water Division of the Food and Agriculture Organization (FAO) to address the issue of food security and to evaluate the impact of environmental factors and management practices on crop production. AquaCrop focuses on simulating the yield response of herbaceous crops to water, and is especially useful in situations where water is the primary limiting factor for crop growth. During its development, the creators of the model sought to strike a balance between simplicity, accuracy, and robustness. In order to make it widely applicable, AquaCrop relies on a relatively small number of explicit parameters and mostly-intuitive input variables that can be determined using simple methods. However, the model's calculation procedures are grounded in basic and often complex biophysical processes to ensure an accurate simulation of crop response in the plant-soil system. There are several features that distinguish AquaCrop from other crop simulation models (such as SWAP, DSSAT, CropSyst, and InfoCrop) used in the field of agricultural water management. These include its primary focus on water, its use of canopy cover instead of leaf area index, its ability to be used in diverse locations, seasons, and climates (including future climate scenarios), its requirement for a relatively small amount of input data with explicit and mostly-intuitive parameters and variables, its well-developed user interface, its balance between accuracy, simplicity, and robustness, and its applicability to diverse agricultural systems around the world.

Practical Applications of AquaCrop Model: AquaCrop is a versatile tool that can be used for planning and management decisions in both irrigated and rainfed agriculture. The model is particularly valuable for understanding crop responses to environmental changes, serving as an educational tool, comparing attainable and actual yields in fields, farms and regions, and identifying constraints to crop production and water productivity. AquaCrop can also be used to develop irrigation schedules for maximum production, including seasonal strategies and operational decision-making, and for climate scenarios. In addition, AquaCrop can be used to develop strategies under water-deficit conditions to maximize water productivity through irrigation strategies (such as deficit irrigation) and crop and management practices (such as adjusting planting dates, cultivar selection, fertilization management, the use of mulches, and rainwater harvesting). The model is also useful for studying the effect of climate change on food production by running AquaCrop with both historical and future weather conditions. AquaCrop can be used to analyse scenarios that are relevant to water administrators and managers, economists, policy analysts, and scientists for planning purposes. Finally, AquaCrop can support decision-making on water allocations and other water policies.

Limitations of AquaCrop Model: Although AquaCrop is a valuable tool for simulating daily biomass production and final crop yields for herbaceous crops with single growth cycles, it does have some limitations. For instance, AquaCrop is designed to predict crop yields at the single field scale, meaning that it conducts point simulations. Additionally, the model assumes that the field is uniform, without any spatial differences in crop development, transpiration, soil characteristics, or management. Finally, AquaCrop only considers vertical incoming (rainfall, irrigation, and capillary rise) and outgoing (evaporation, transpiration, and deep percolation) water fluxes, and thus does not account for lateral flows of water.

Stakeholder of AquaCrop Model : The AquaCrop model is intended primarily for practitioners working in extension services, governmental agencies, non-governmental organizations, or farmer associations. However, it can also be useful for scientists and as a training and education tool to understand the role of water in determining crop productivity.

Input requirement for AquaCrop Model: AquaCrop requires a relatively small number of explicit parameters and mostly intuitive input variables that are widely available or can be determined using simple methods. The inputs required for the model include weather data, crop and soil characteristics, and management practices that define the environment in which the crop will develop. Soil characteristics are divided into soil profile and groundwater characteristics, while management practices are categorized as either field management or irrigation management practices.

Steps for operation of AquaCropmodel : AquaCrop simulates final crop yield in four steps (which run in series in each daily time increment), as described below. The four steps are easy to understand, thereby ensuring transparency in the modelling approach.

Step 1 – Simulation of green canopy cover (CC): AquaCrop uses green canopy cover (CC) to express foliage development. Foliage development is expressed through green canopy cover (CC) rather than leaf area index. CC is the fraction of the soil surface covered by the canopy; it ranges from zero at sowing (*i.e.* 0 per cent of the soil surface covered by the canopy) to a maximum value at mid-season as high as 1 if full canopy cover is reached (*i.e.* 100 per cent of the soil surface is covered by the canopy). By adjusting the water content in the soil profile each day, AquaCrop keeps track of stresses that might develop in the root zone. Soil-water stress can affect the leaf and therefore canopy expansion; if severe it can trigger early canopy senescence.

$$CC = \frac{\text{Soil surface covered by the green canopy}}{\text{Unit ground surface area}}$$

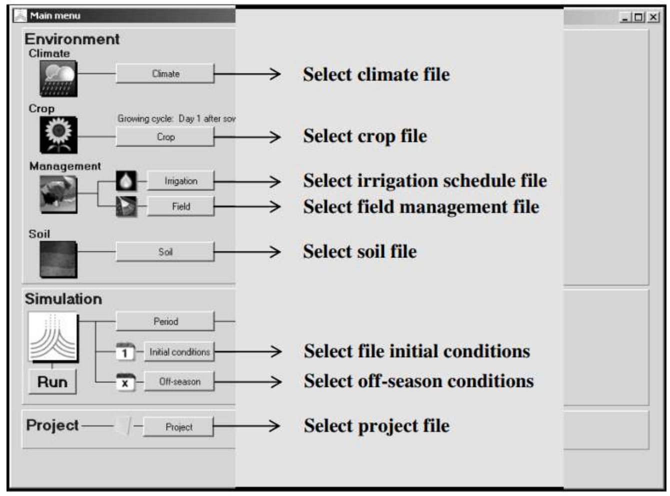

Fig. 1: Main menu of aqua crop model (Source: FAO)

Step 2 – Simulation of crop transpiration (Tr) : Crop transpiration (Tr) is calculated by multiplying the reference evapotranspiration (ETo) with a crop co-efficient (KcTr). The crop co-efficient is proportional to CC and hence varies throughout the life cycle of a crop in accordance with the simulated canopy cover. Not only can water stress affect canopy development, it can also induce stomata closure and thereby directly affect crop transpiration.

$$Tr = (KcTr)ETo$$

Step 3 – Simulation of the above-ground biomass (B) production : The quantity of above-ground biomass (B) produced is proportional to the cumulative amount of crop transpiration (ΣTr), the proportional factor is known as biomass water productivity (WP). In AquaCrop, WP is normalized for the effect of climatic conditions, making normalized biomass water productivity (WP*) valid for diverse locations, seasons and concentrations of carbon dioxide

Step 4 – Simulation of the crop yield (Y): The simulated above-ground biomass integrates all photosynthetic products assimilated by a crop during the season. Crop yield (Y) is obtained from biomass (B) by using a harvest index (HI) – which is the fraction of B (biomass) that is harvestable product.The actual HI is obtained during simulation by adjusting the reference harvest index (HI_o) with an adjustment factor for stress effects.

$$Y = HI\ B$$

Procedure and calculation scheme under AquaCrop model:

InputAquaCrop → **Output** → (Biomass and crop yield for given environmental conditions such as Weather, Crop, Management - Field management and Irrigation management, Soil Profile and Ground water

Performance indicator → $\mathbf{WP_{ET}} = \frac{kg(yield)}{m3(ET)}$

(ET water productivity)

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

$$B = WP \cdot \Sigma Tr \quad (2)$$

Evaluation of performance of AquaCrop model: Performance of AquaCrop Simulation model can be evaluated by calculating different test statistics which are described below with following sub-heads.

*Root Mean Square Error (RMSE):*Itis the standard deviation of the residuals (prediction errors). Residuals are a measure of how far from the regression line data points are; RMSE is a measure of how spread out these residuals are. In other words, it tells you how concentrated the data is around the line of best fit. Root mean square error is commonly used in climatology, forecasting, and regression analysis to verify experimental results. It ranges from 0 to ∞

Index of Agreement (d): It is a statistical measurement that examines how differences in one variable can be explained by the differences in a second variable. It ranges from 0 to 1. Value '1' shows perfect agreement between simulated and observed. Value '0' shows no agreement between simulated and observed.

Normalized RMSE (NRMSE): Normalized root mean square error gives an indication of the relative differences between simulated and observed values.

Co-efficient of determination (R^2): The co-efficient of determination is a statistical measurement that examines how differences in one variable can be explained by the difference in a second variable, when predicting the outcome of a given event.It ranges from 0 to 1.

Prediction error % (Pe) between simulated and observed data: Prediction error refers to the difference between the predicted values made by some model and the actual values.

These measurements are calculated as follows:

✓ $$\textbf{RMSE} = \left[\sum_{i=1}^{n}(p_i - o_i)^2/n\right]^{0.5}$$

✓ $$\textbf{MPD} = \left[\sum_{i=1}^{n}\left(\frac{o_i - p_i}{o_i}\right)100\right]/n$$

✓ $$\textbf{Error (\%)} = \left(\frac{(p - o)}{o}\right)100$$

✓ $$\mathbf{d = 1 -} \left[\frac{\sum_{i=1}^{n}(p_i - o_i)^2}{\sum_{i=1}^{n}\left(|p_i'| + |o_i'|\right)^2}\right]$$

Conclusion :

The AquaCrop model is targeted towards practical end users, including farmers and irrigation associations, extension services, governmental agencies, planners, and economists involved in water management and water-saving strategies. AquaCrop is particularly suitable for use in different climate change scenarios. Compared to other simulation models, AquaCrop requires a small number of parameters and input data to simulate crop yield response to water. Despite its simplicity, the model highlights the fundamental processes involved in crop productivity and the responses to water deficits from both physiological and agronomical perspectives.

Future perspective : Furthermore, as AquaCrop continues to evolve, it is anticipated that it will be integrated into GIS and decision support systems that take into account the spatial variability of soils and weather. It can also leverage existing FAO software products such as Terrastat, ClimWat, and ClimaAgri to extend crop productivity and water use from small sections of fields to entire fields, farms, landscapes, and watersheds.

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