

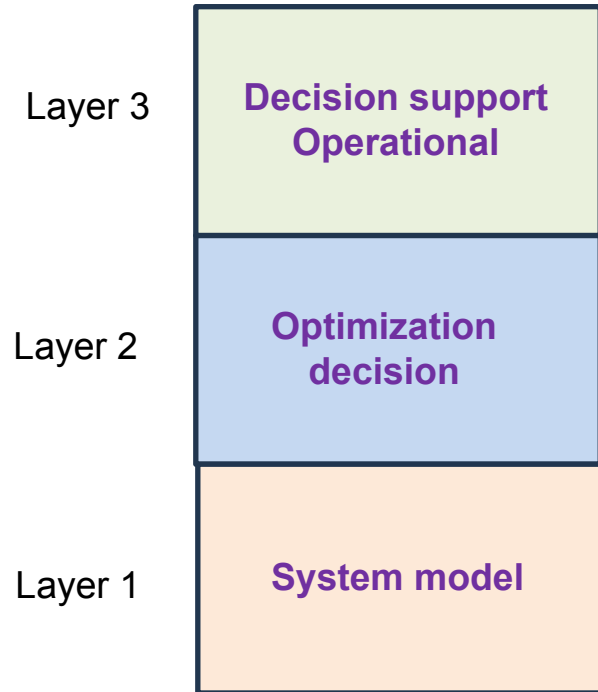
AI4Water

AquaCrop: the FAO's crop water productivity model and its adaptation for the AI4Water project.

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1. Introduction: a three-layer water optimization framework



Turn the solution returned by the optimization process into something usable by stakeholders

Solutions translated into calendar-like irrigation plan, including rules for specific and practical implementations. **GUI**.

Optimizer: Genetic Algorithm, Reinforcement Learning

Search for irrigation plans that the model layer can evaluate

Objective and constraints

crop-soil-water model

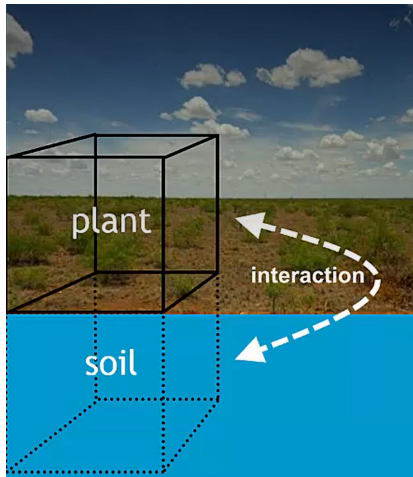
used as simulation model for optimization candidates

digital twin that mirrors the real-world behavior of the irrigation system

1. Introduction: What is AquaCrop?

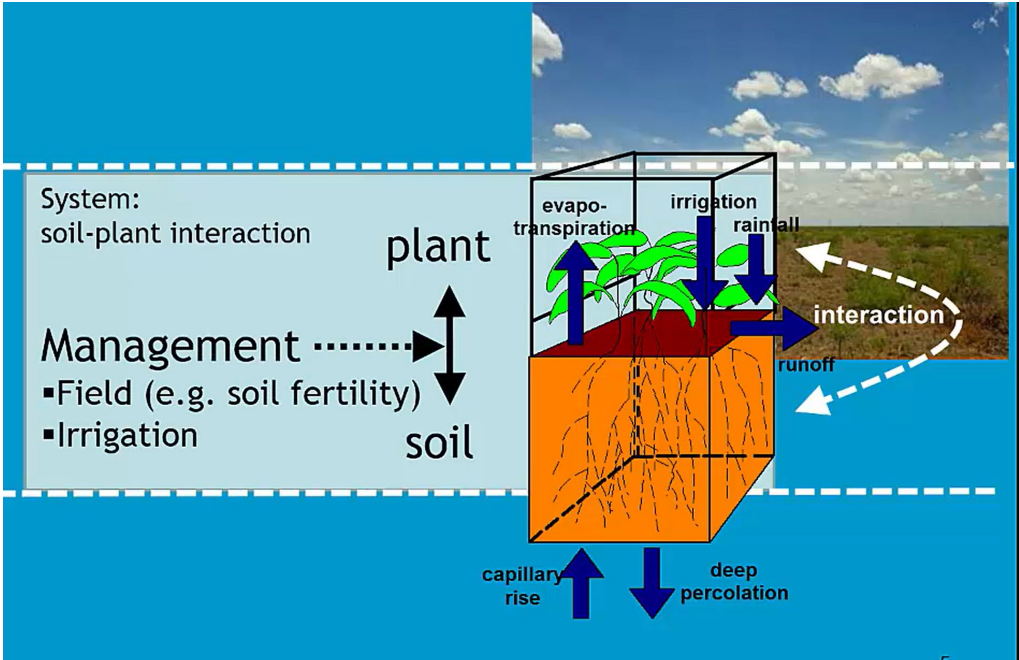
It is the FAO crop growth model to simulate **yield response of herbaceous crops to water**

Helpful to formulate **recommendations** to improve **water use efficiency**



Focus specifically in the interaction between the plant and the soil

1. Introduction

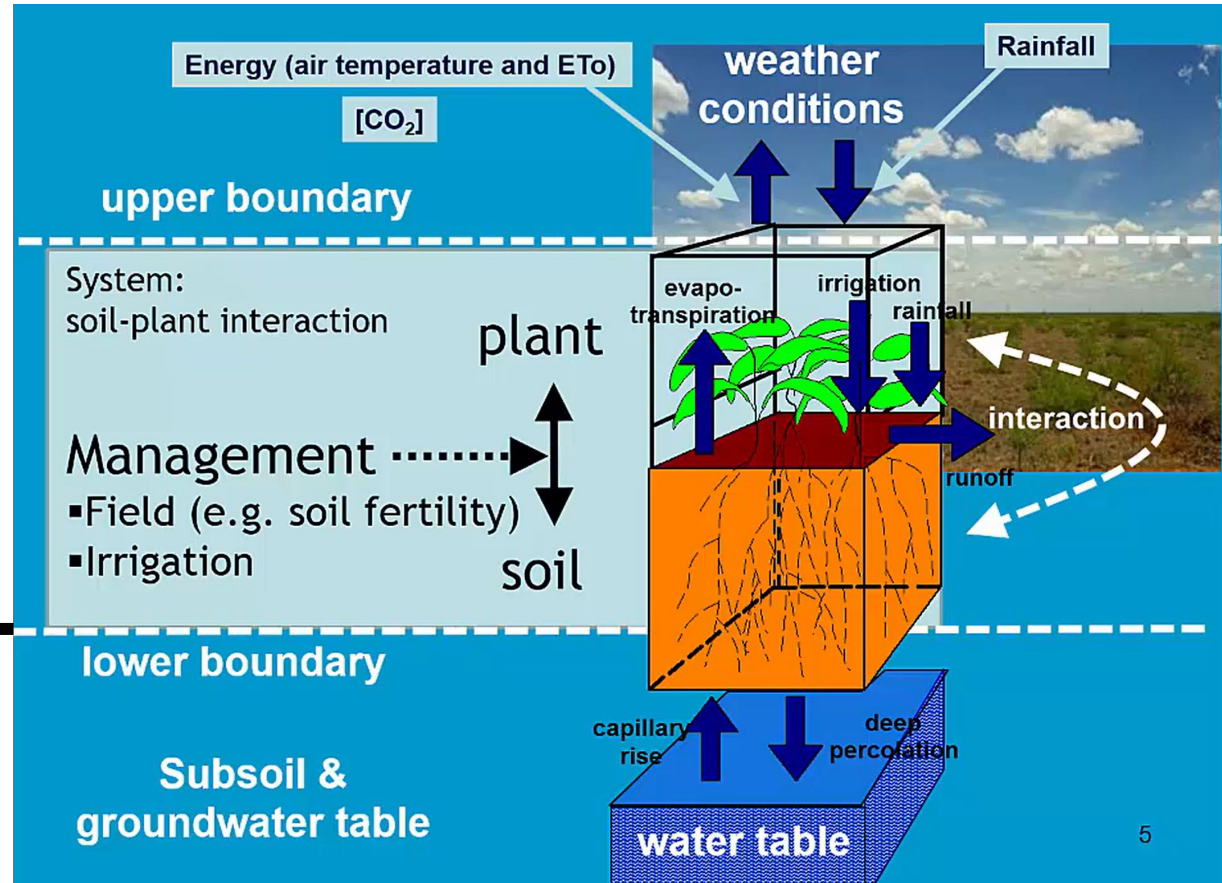


1. Introduction

AquaCrop model



No simulations of water table variations or depth, or water quality → user defined



1. Introduction



AquaCrop uses a relatively small number of parameters (explicit and mostly intuitive) and attempts to balance simplicity, accuracy and robustness.

Simple model based on general concepts
It requires only commonly available input

Accurate plant physiological processes
Accurate soil-water budgeting processes

2. AquaCrop model: overview of the input

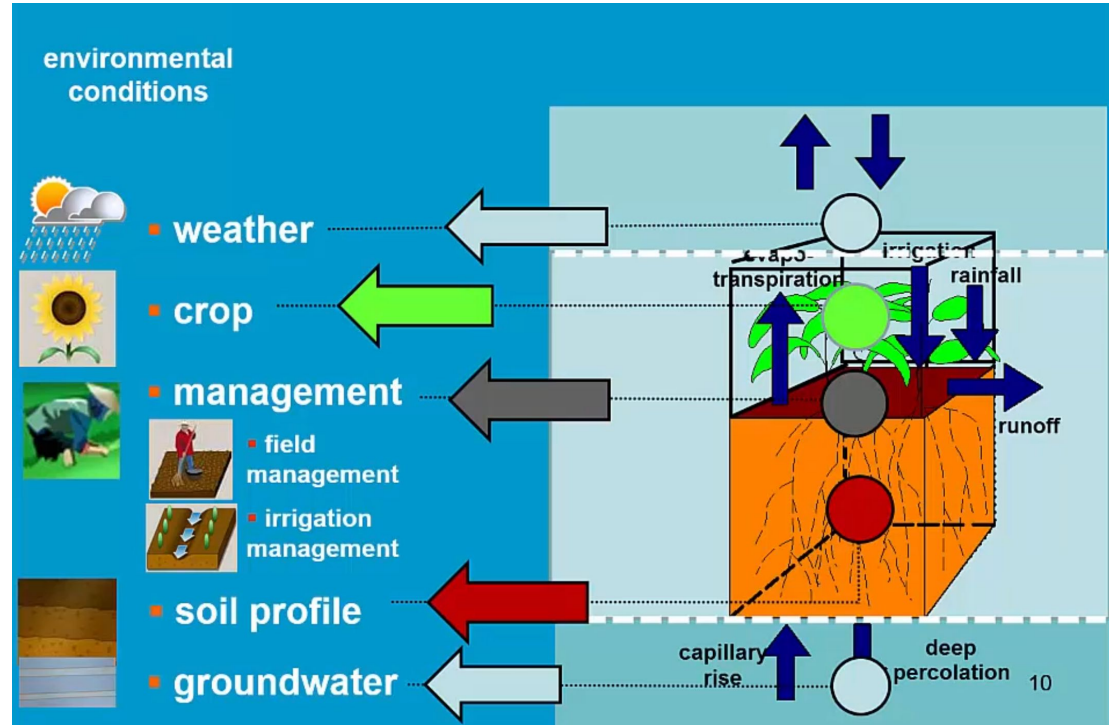
weather conditions

crop characteristics

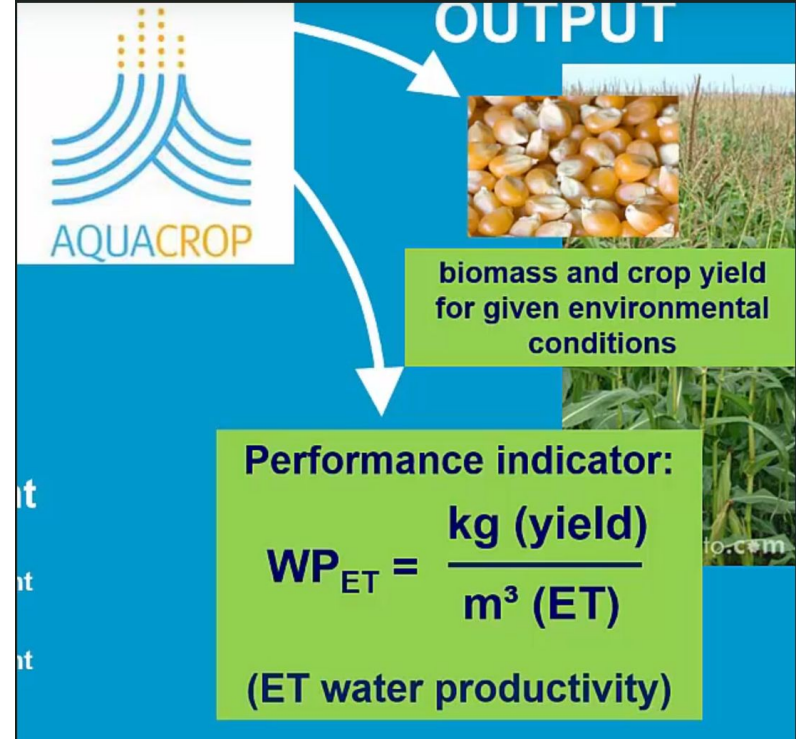
management

soil characteristics

depth of the groundwater table



2. AquaCrop model: the output



2. AquaCrop model: what can the model be used for?

Water productivity (**WP**) or Water Use Efficiency (**WUE**)

$$WP_{ET} = \frac{\text{kg (yield)}}{\text{m}^3 \text{ (ET)}}$$

understand crop responses to environmental changes

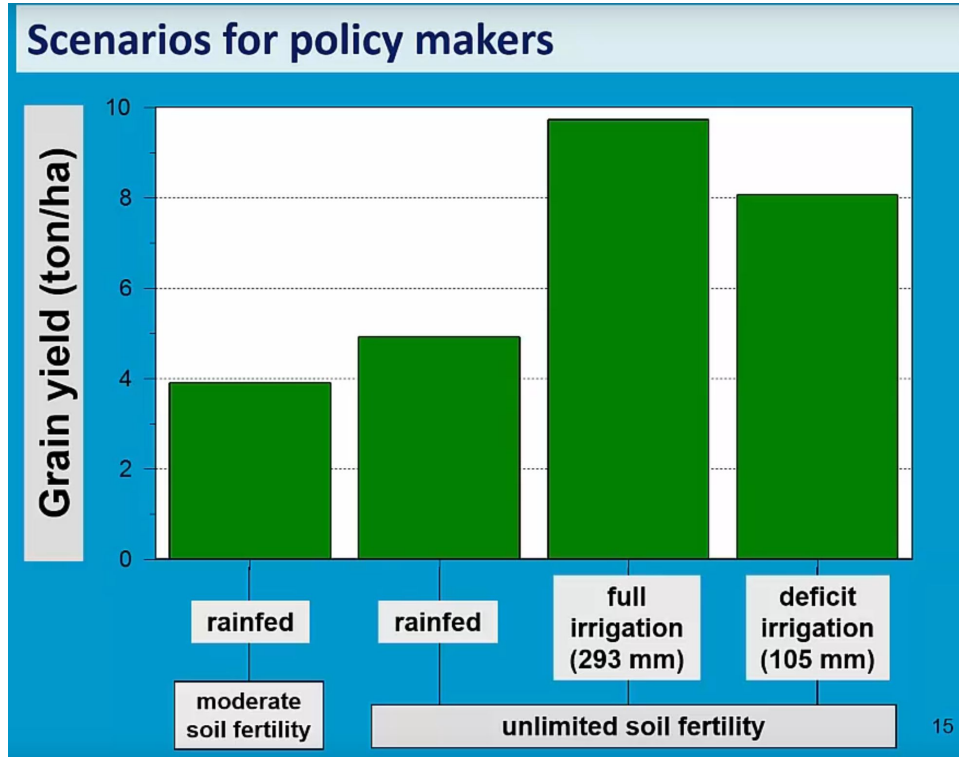
analysis of yield gap

calculate WP

- by changing the planting date
- by selecting another cultivation
- by changing the field management
- by introducing deficit irrigation

calculate irrigation water requirement
irrigation schedule

2. AquaCrop model: what can the model be used for?



2. AquaCrop model: irrigation schedule

- It does not prescribe a unique optimal schedule
- It allows to design, evaluate or generate different irrigation schedules that match the management rules and water-supply constraints

Automatic Irrigation Schedule

define your irrigation method (drip, sprinkler, surface)

define rules such

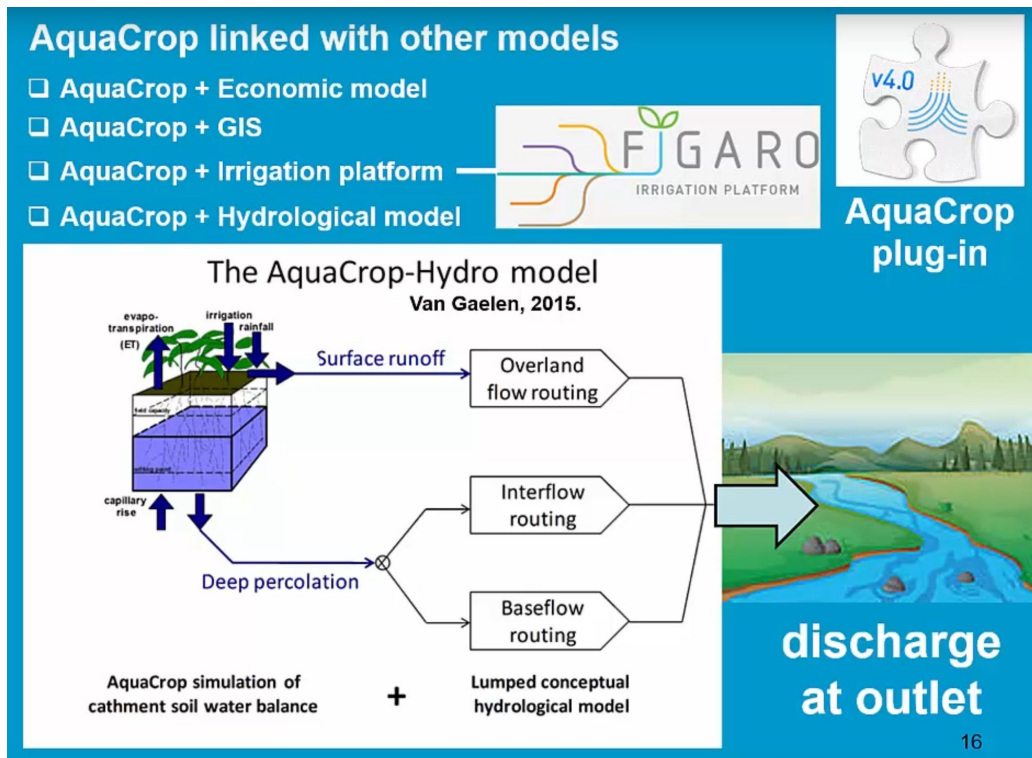
Time criterion (e.g., irrigate every 3–7 days), or

Soil-moisture criterion (e.g., irrigate when root-zone depletion reaches a certain % of available water, RAW)

AquaCrop computes a sequence of irrigation events (dates and net depths)

Run the simulation with that schedule and look at the water balance and irrigation-depth outputs to read back the actual schedule (day-by-day).

2. AquaCrop model



eco-system services:

- groundwater recharge
- improved water availability in the watershed

2. AquaCrop model: versions

<https://www.fao.org/aquacrop/>

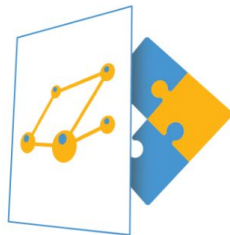
1. AquaCrop software



version 7.1

standard crop water productivity software model with GUI and database, developed by the Land and Water Division of FAO

2. AquaCrop plugin



to run several predefined "projects" and to store results in output files for individual locations without using GUI

3. AquaCrop-OSPy



<https://pypi.org/project/aquacrop/>

3. AquaCrop-OSPy

What is AquaCrop-OSPy?

- Open-source Python implementation of the FAO AquaCrop model
- Accurately reproduces the behavior of the official AquaCrop model

Why is it useful?

- Enables automated simulations through Python scripts
- Can be integrated with different Optimization Algorithms (Genetic Algorithms)

Key idea for our work

- AquaCrop-OSPy is used as a **system/physical model**
- Inputs: irrigation strategy (provided by optimization) + environmental conditions
- Outputs: crop yield and water use

3. AquaCrop-OSPy: Input example (I)

- **Crops:** type of crops and growth parameters (e.g., rooting depth, maturity)
- **Soil Type:** type of soil (Clay, Sandy Loam,...) and other parameters (FC, PWP, Curve Number, ...)
- **Initial soil water content:** typically set to Field Capacity.
- **Irrigation Management:** defines when and how much water is applied to the crop. **This input is given by the optimization algorithm.**



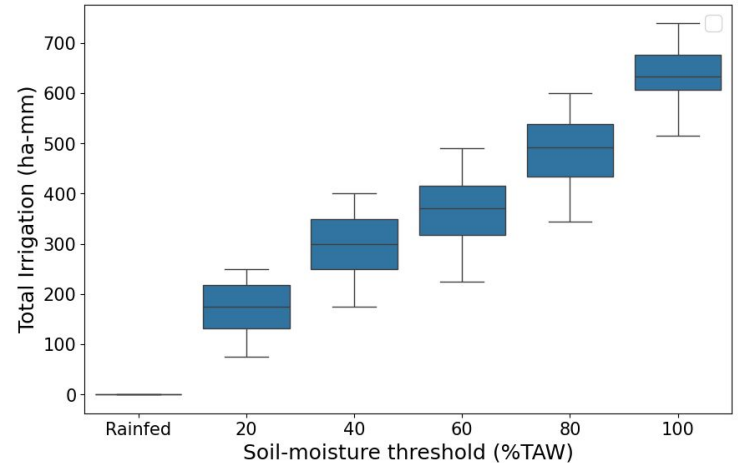
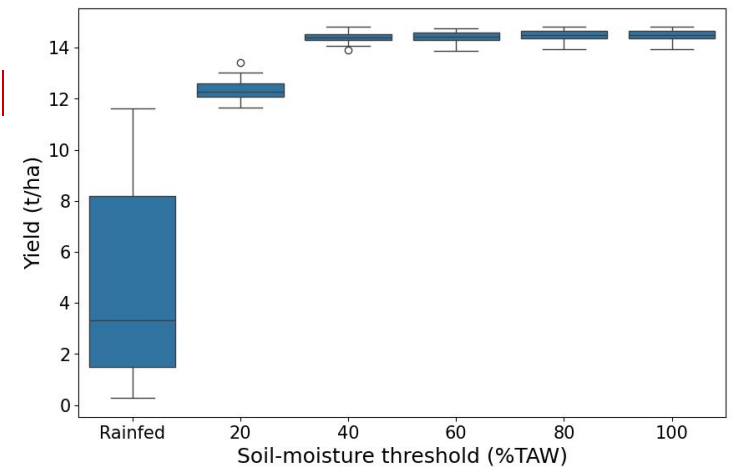
AquaCrop provides default values for the parameters, but they can be modified by the user!

3. AquaCrop-OSPy: Input example (II)

- **Field Management:** refers to the set of soil and surface practices (such as mulching, bunds, inhibition of surface runoff, land preparation...) that influence how water is retained, lost, or distributed across the field. A Field Management **can also be specified for the fallow period.**
1. **Mulches:** presence of mulches (boolean var), percentage of soil that they cover and soil evaporation adjustment factor due to effect of mulches.
 2. **Bunds:** presence of surface bunds (boolean var), bund height and initial water height in surface bunds.
 3. **Curve Number:** percentage change over default curve number CN.
- Optionally **Ground Water:** is configured by specifying whether a water table is present, and if so, defining its depth as either constant or varying over time using dates and corresponding values.

3. AquaCrop-OSPy: Input & Output (II)

- **These inputs, together with climate data** (daily maximum and minimum temperatures, total precipitation, and reference evapotranspiration), are fed into the model to run simulations.
- The figure shows the results of a simulation in which the **irrigation management strategy applies water whenever the soil water content falls below a specified percentage of TAW** (Total Available Water).

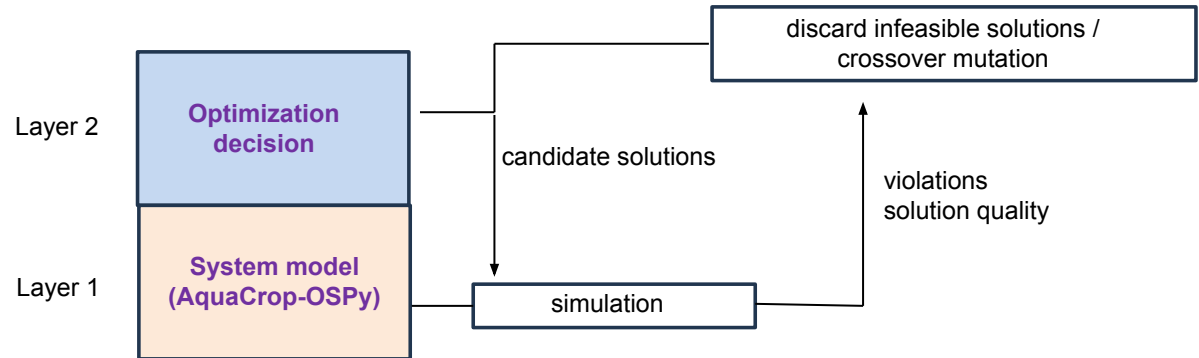


3. AquaCrop-OSPy: Output example (IV)

- **Simulation Stats** : harvest Date, Dry Yield, Fresh Yield, Seasonal Irrigation.
- **Crop Growth**: root Depth, Canopy Cover, Canopy Cover w/ no stress, Biomass, Biomass w/no stress, Harvest Index, Harvest Index w/ no stress.
- **Water Flux**: capillary Raise, Deep Percolation, Runoff, Infiltration Soil Evaporation, Potential Soil Evaporation, Transpiration, Potential Transpiration, Root Zone Water, ...
- **Water Storage**: water content at different depth levels (12 levels by default)

4. Integration of AquaCrop-OSPy with Optimization Tools (I)

- Our approach: the optimization algorithm generates a candidate irrigation schedule for each crop under consideration (i.e., the irrigation depth in mm to be applied at each time step).
- This schedule is then converted into an `IrrigationManagement` object and provided as input to the model. After running the simulation, the model outputs are used to evaluate crop yield and total water consumption, allowing us to assess the quality (fitness) of the proposed solution.



4. Integration of AquaCrop-OSPy with Optimization Tools (II)

Key challenge

- Optimization requires running a large number of simulations
- Each candidate solution corresponds to one AquaCrop simulation

Observed problem

- More than 15 minutes to evaluate 100 generations with 50 individuals
- Limits the scalability of the optimization process

4. Integration of AquaCrop-OSPy with Optimization Tools (III)

Proposed solutions

- **Parallel simulations**
 - Run independent simulations simultaneously
 - Achieves approximately **5–10× speedup**
- **JIT compilation (Numba)**
 - Accelerates frequently executed functions
 - Achieves approximately **4–8× speedup**

```
200 | 10000 | 15 | 0.1481049281 | ideal
Execution time: 138.20006989999999 seconds
```

4. AquaCrop-OSPy Optimization Pipeline

