Approches de contrôle optimal pour l'irrigation et la fertilisation par réutilisation des eaux uses

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Webinaire TREASURE - INRAE REUSE
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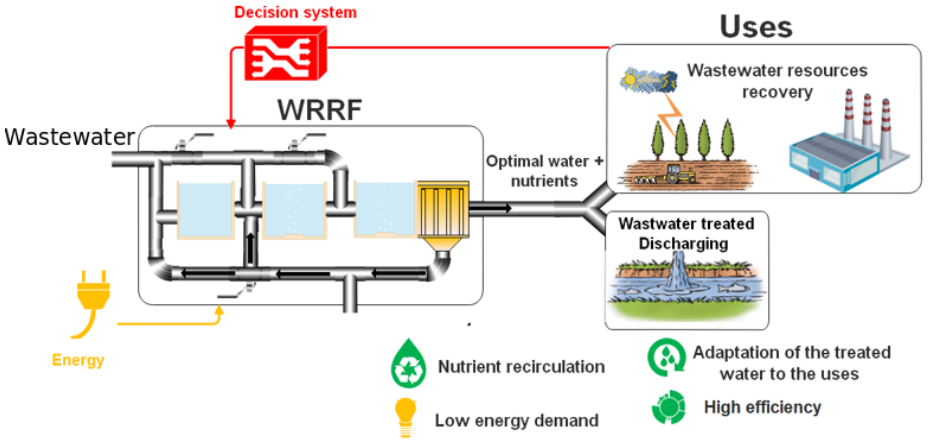
Introduction : Control4Reuse



Optimal crop requirements

Objective

Determine crop requirements for irrigation and fertilisation with treated wastewater

- Optimal control approach : find controls that maximize reward and/or minimize costs

Controls :
Irrigation Volume [mm]
Nutrients concentration
(Nitrogen [g/L], ...)
$\longrightarrow$ Crop Model $\longrightarrow$
Costs and Rewards :
Biomass [T/ha]
Irrigation and fertilisation costs
Enviromental costs
(N leached [kg/ha], ...)

- Dynamic problem : controls are time dependent functions

Crop growth models

Complex simulation computer models

- Many variables and parameters
- Unclear mathematical structure
- Extensively validated with field data

Simplified dynamical system models

- Few variables and parameters
- System of differential equations
- Limitied domain of validity

Double modelling approach

1. Calibration of simplifed model from data generated with complex model
2. Solve optimal control problem with simplifed model
3. Evaluation of optimal control and calibration with complex model

Case study

STICS model

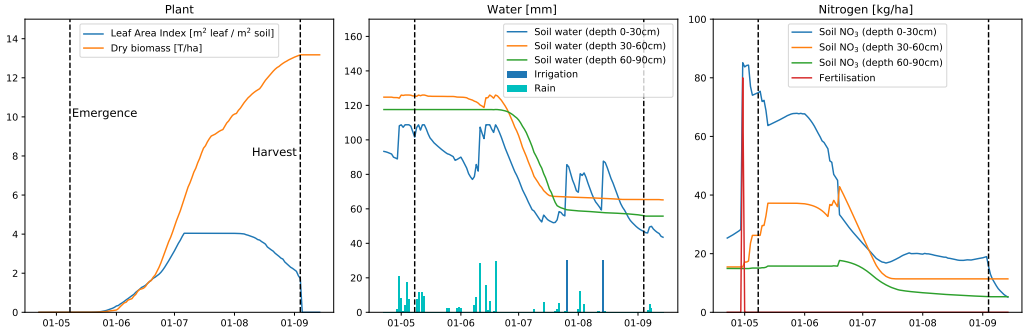
- Detailed representation of soil-plant system, 1 cm soil layers,
- Generic crop model, 600+ parameters and options
- Parameters calibrated for 34+ crops

Ecohydrological model

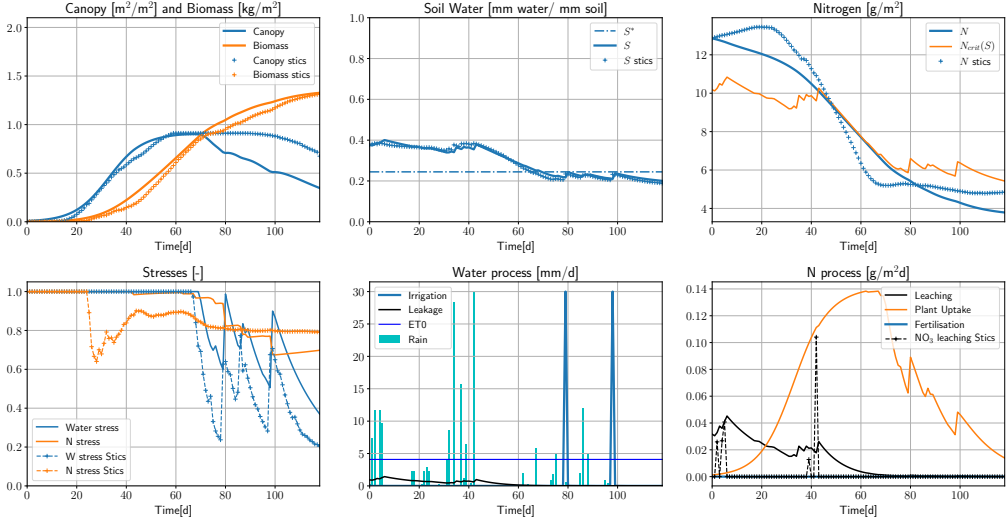
- Homogeneous representation of soil and plant, 4 variables
  - Soil : water and nitrogen content
  - Crop : canopy cover and biomass
- Only 2 developement stages, no pests

Reference Simulation

- Corn crop grown on loam soil, in south of France (near Toulouse), climate from 2013
- Sowing 22/4, but considered time interval from emergence 8/5 to harvest 4/9



Calibration



Multi-objective optimisation

- Different objectives, possibly conflicting : maximize final biomass but minimize irrigation, fertilisation and minimize N leaching
- Constrained Optimal control problem :

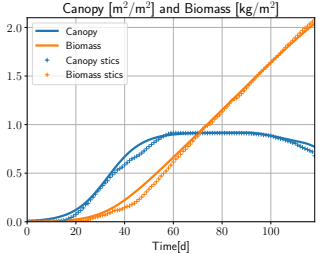
Maximize final biomass but with restrictions on total N fertilisation

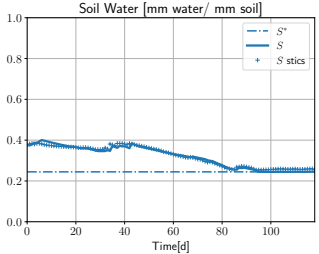
$$\begin{array}{c}\text{Controls}\\ \text{Irrigation : } I \text{ [mm]}\\ \text{Nitrogen concentration : } C_N \text{ [g/L]}\end{array} \longrightarrow \text{Crop Model} \longrightarrow \begin{array}{c}\text{Rewards}\\ \text{Biomass [T/ha]}\end{array}$$

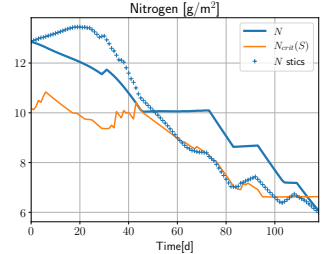
such that total mass of N added to field, F_N [kg/ha] is less that a given amount

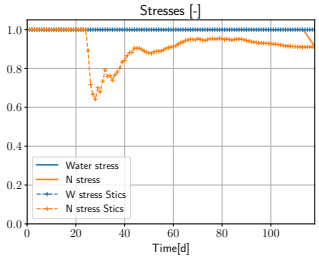
$$F_N = \int_0^T I(t) C_N(t)\, dt$$

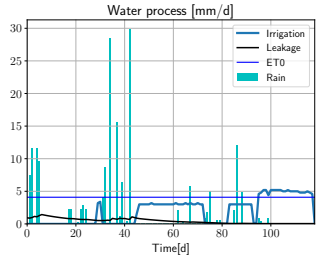
Optimal Reuse for 70 kg/ha

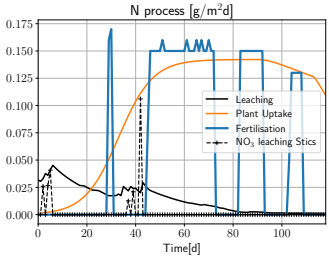




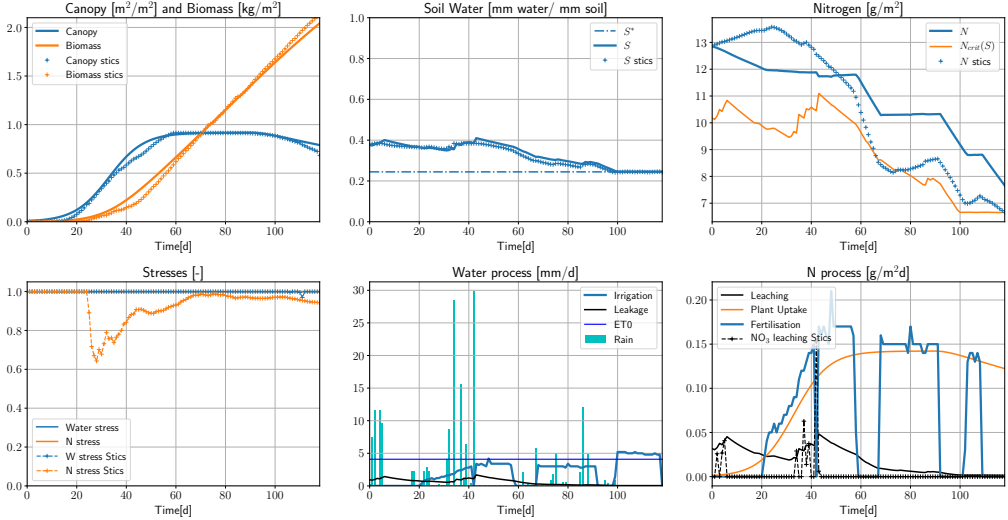




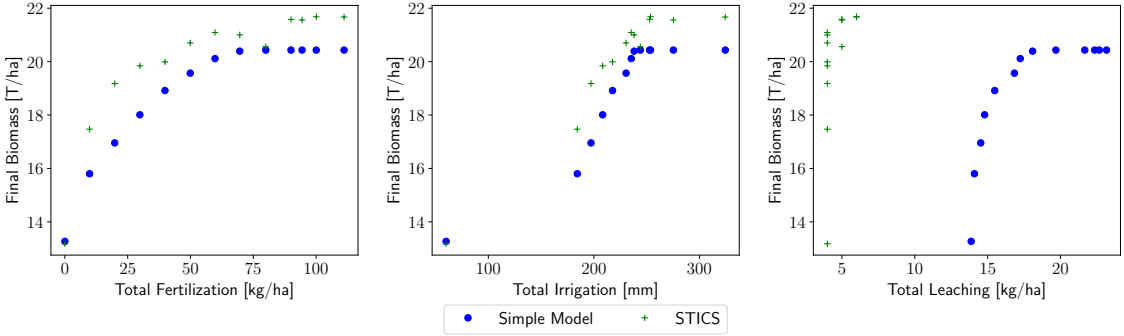




Optimal Reuse for 90 kg/ha



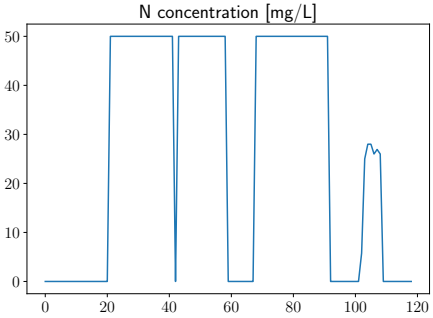
Optimal Reuse



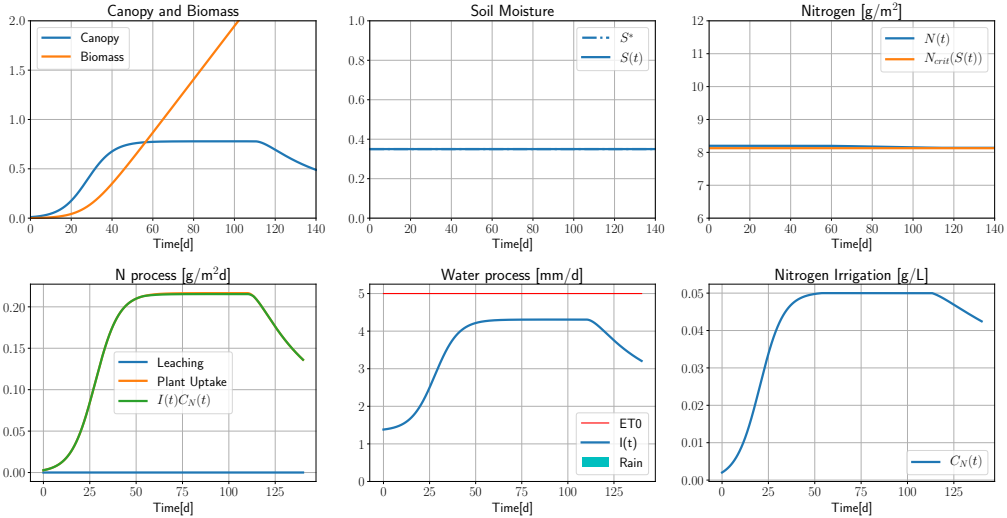
Optimal control

- Control aims at avoiding stress, follows plant uptake
  $\Longrightarrow$ Importance of calibrated stress level parameters : optimal controls maintain system at or above these levels
- Optimal N concentration nearly always maximum but low N in wasterwater :
  - Estimate if there is enough N in soil and irrigation water
  - If not, need to combine water reuse with other fertilizations methods
- Impact of rain : stop irrigation to avoid leaching

For 90 kg/ha



No rain


Canopy and Biomass
Canopy
Biomass
Time[d]
Soil Moisture
S^*
$S(t)$
Time[d]
Nitrogen [g/m^2]
$N(t)$
$N_{crit}(S(t))$
Time[d]
N process [g/m^{2}d]
Leaching
Plant Uptake
$I(t)C_N(t)$
Time[d]
Water process [mm/d]
ET0
I(t)
Rain
Time[d]
Nitrogen Irrigation [g/L]
$C_N(t)$
Time[d]

Merci pour votre attention !