Combined simulation and optimization framework for irrigation scheduling

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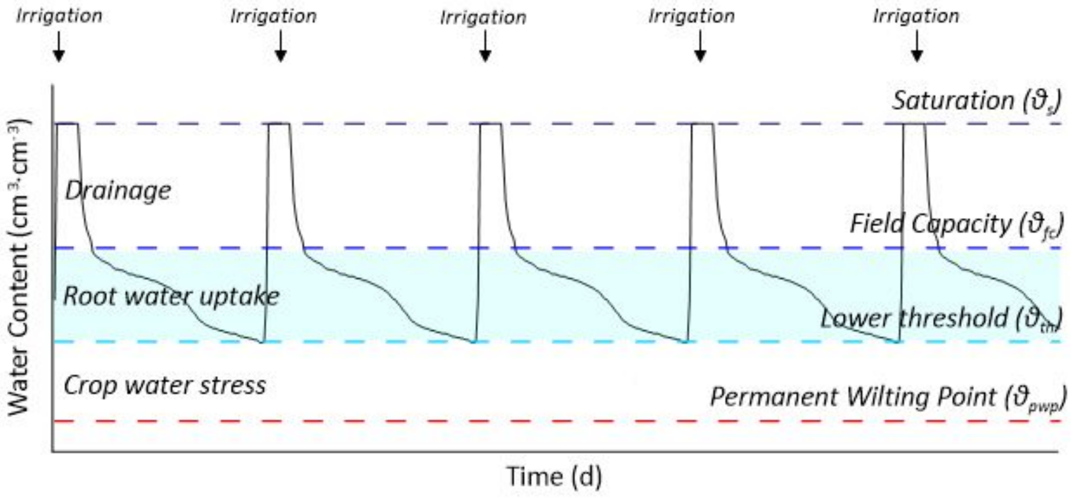
Introduction

Irrigation scheduling definition and main goals

- Irrigation scheduling is the processes used by agricultures and stakeholders to apply water in the soil with a correct frequency and irrigation time.
  - To maintain crop under optimal soil water content conditions.
  - To save water.
  - Maximum crop yield and economical profit

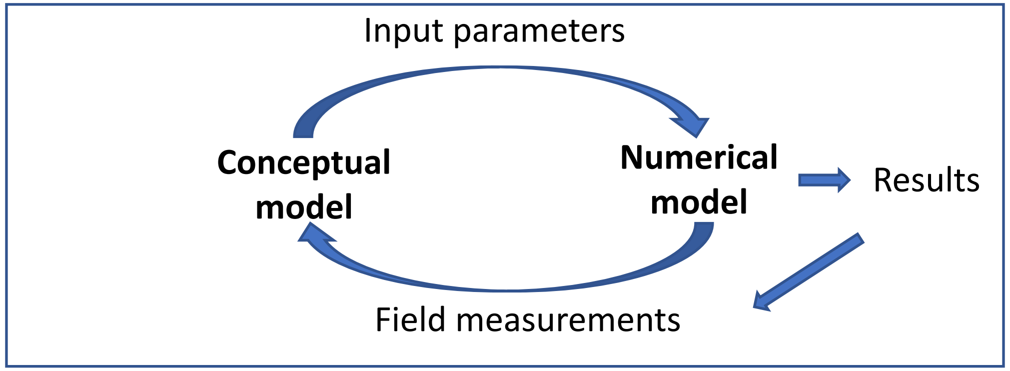


Soil hydraulic parameters are important!

Soil water content dynamics

- Depending on soil water status several processes can be identified.
- Those processes are delimited by several soil hydraulic parameters.

Introduction



Objetives

To present a combined simulation and optimization framework. It should provide us the irrigation schdeuling parameters to maximize crop yield, with minimum volume of water water, without soil salinization and guaranteeing maximum net profit.

- The methodology should account for the water movement in the unsaturated zone and it should be easily exported to any field.

- To apply the method to a specific and real field site.

- To analize the impact of soil hydraulic properties on irrigation scheduling strategy.

Methodology

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Optimization problem

$$\mathbf{p}_1 \le \mathbf{p} \le \mathbf{p}_2 \qquad g(\mathbf{c}) \le \boldsymbol{a}$$

$$\boldsymbol{p}_{opt} = \max_{\mathbf{p}} NM(\mathbf{p},T)$$

$$NM(\mathbf{p},T) = GM(\mathbf{p},T) - Opex(\mathbf{p},T) - Capex$$

- $NM(\mathbf{p},T)$: Net Margin (benefit)
- $GM(\mathbf{p},T)$: Gain Margin
- $Opex(\mathbf{p},T)$: Operational Expenses

$\mathbf{p}$: *irrig. scheduling param.*

$\boldsymbol{c}$: *solute concentration*

$\boldsymbol{a}$: *solute threshold*

T: *Time Duration*

$$Opex(\mathbf{p},T) = C_{Fix} + \int_0^T q_i(\mathbf{p},t')\,(C_{wVar} + C_e)\,dt'$$

Numerical model

Gain Margin → Crop Yield → Soil Water Availability → Flow & Transport models

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Gain margin– crop productivity relationship

Gain Margin

$$GM(\mathbf{p},T) = Y_a(\mathbf{p},T)\, C_y$$

$\boldsymbol{C_y}$: *Harvest price*

Crop yield
(Stewart et al., 1977)

$$Y_a = Y_p \prod_{k=1}^{N_y} \left(1 - K_{y_k}\left(1 - \left(\frac{ET_a}{ET_c}\right)_k\right)\right)$$

$\boldsymbol{Y_p}$: *Potential yield*

$\boldsymbol{K_y}$: *Crop yield response*

Potential evapotranspiration

$$ET_c = K_c\, ET_0$$

Actual evapotranpiration

$$(ET_a)_k = \int_{t_K} q_{evap}\, dt' + \int_{t_k} \int_{z_{top}-L_R}^{z_{top}} S(h, h_\Phi, z, t')\, dz\, dt'$$

Combined simulation – optimization framework

Flow and transport model

$$\frac{\partial \theta}{\partial t} = \nabla \cdot [K(h)\nabla h + K(h)\nabla z] - S$$

$$\frac{\partial (R\theta c_i)}{\partial t} = -\nabla \cdot (\boldsymbol{q} c_i) + \nabla \cdot (\theta \mathbf{D} \nabla c_i) + f_i, \qquad i = 1, \dots, N_s$$

$$|q(z_{top}, t)| \leq |X(t)| \qquad h_d \leq h \leq h_s$$

$$S(h, h_\Phi, z, t) = \alpha(h, h_{\Phi,})\, \beta(z,t)\, T_p(t)$$

$$\alpha(h) = \begin{cases} \dfrac{h - h_4}{h_3 - h_4} & h_3 > h > h_4 \\ 1 & h_2 \geq h \geq h_3 \\ \dfrac{h - h_1}{h_2 - h_1} & h_1 > h > h_2 \\ 0 & h \leq h_4 \text{ or } h \geq h_1 \end{cases}$$

Feddes et al., 1977

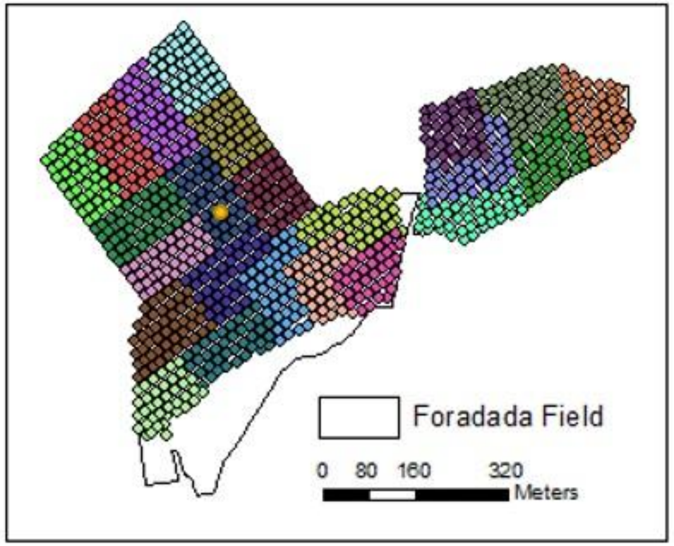
$$\alpha(h_\Phi) = \begin{cases} 1, & a \leq h_\Phi \leq 0 \\ 1 + b(h_\Phi - a) & a > h_\Phi > -\dfrac{1}{b} \\ 0, & h_\Phi \leq a - \dfrac{1}{b} \end{cases}$$

Maas and Hopmans 1978

Field application

Field site

- Foradada field site
- Soil type: Silty Clay Loam
- Sprinkle irrigation
- Crop: maize



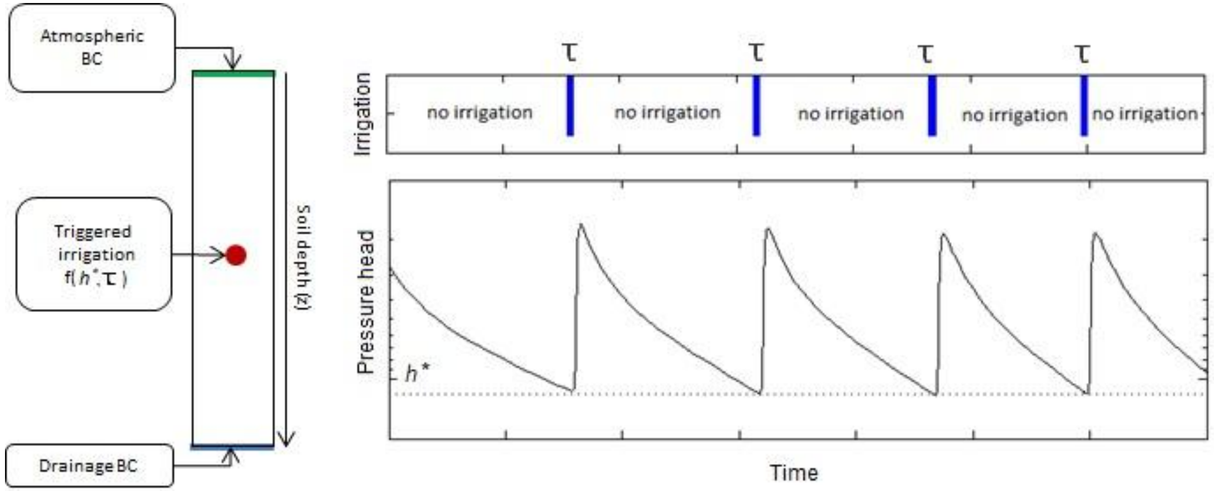
Irrigation strategies simulations

- Optimal irrigation

$$-10 \leq \boldsymbol{h}^{*} \leq -100 \text{ kPa}$$

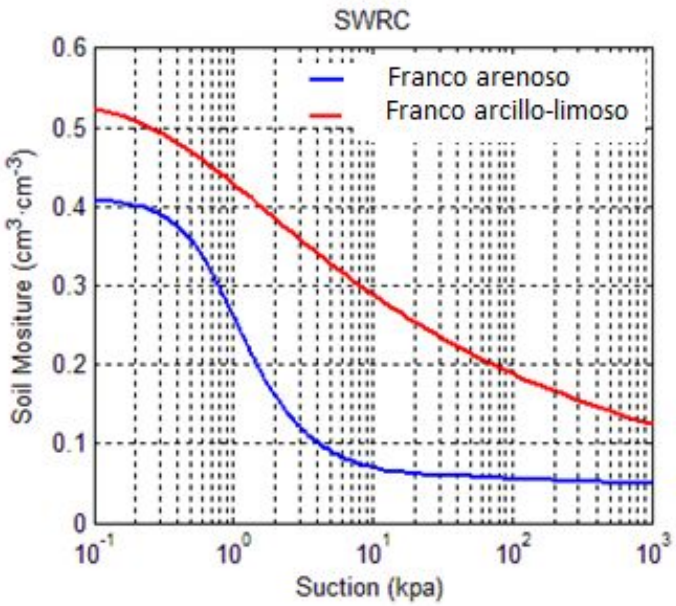
$$1 \leq \boldsymbol{\tau} \leq 4 \text{ h/d}$$

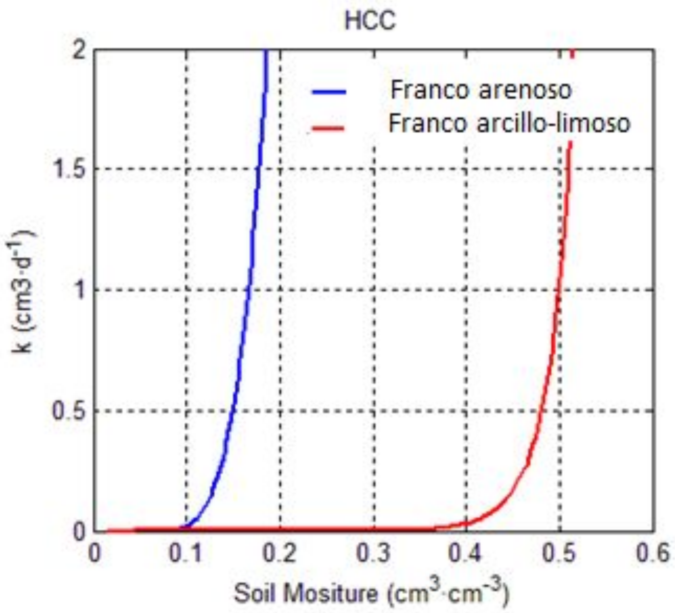
$$g(\boldsymbol{EC_e}) \leq 3.6 \text{ dS/m}$$

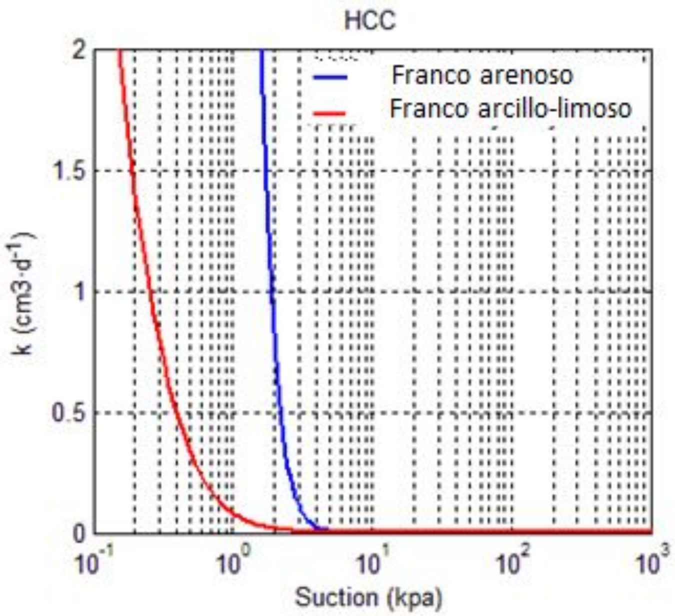


Field application

Two different soil types

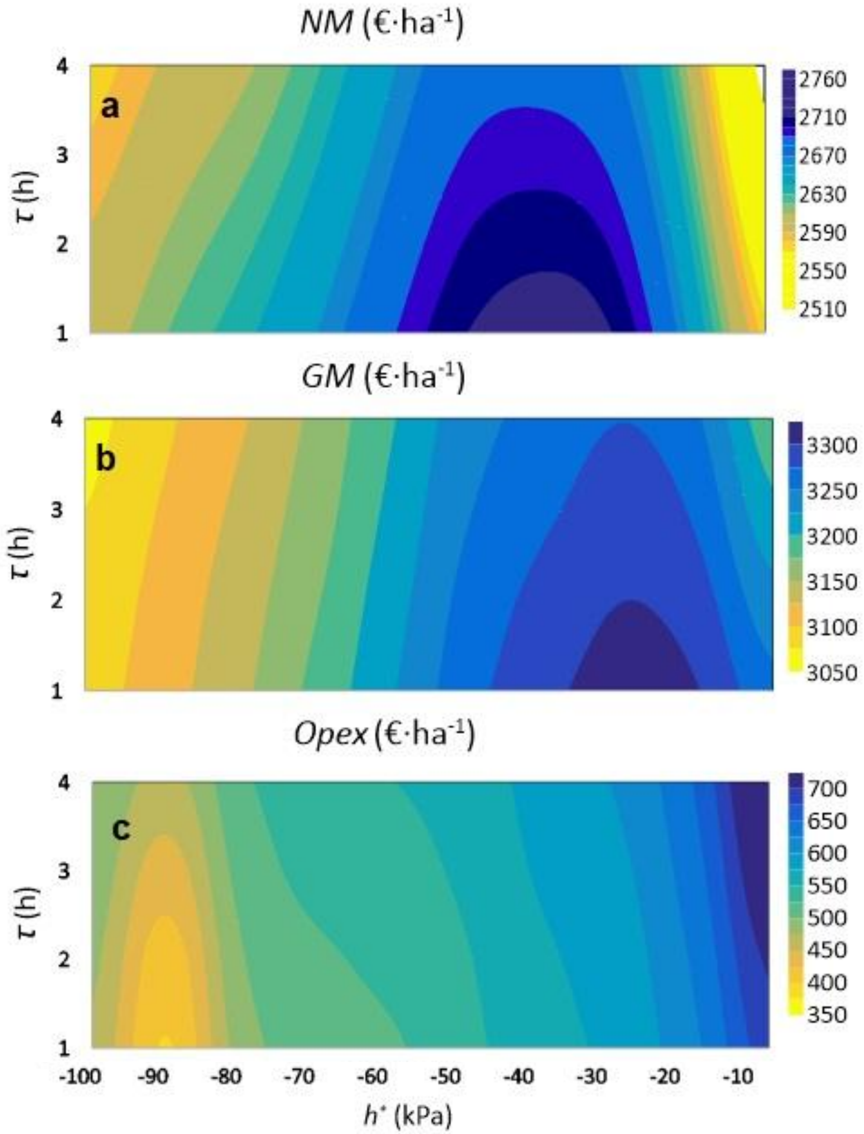


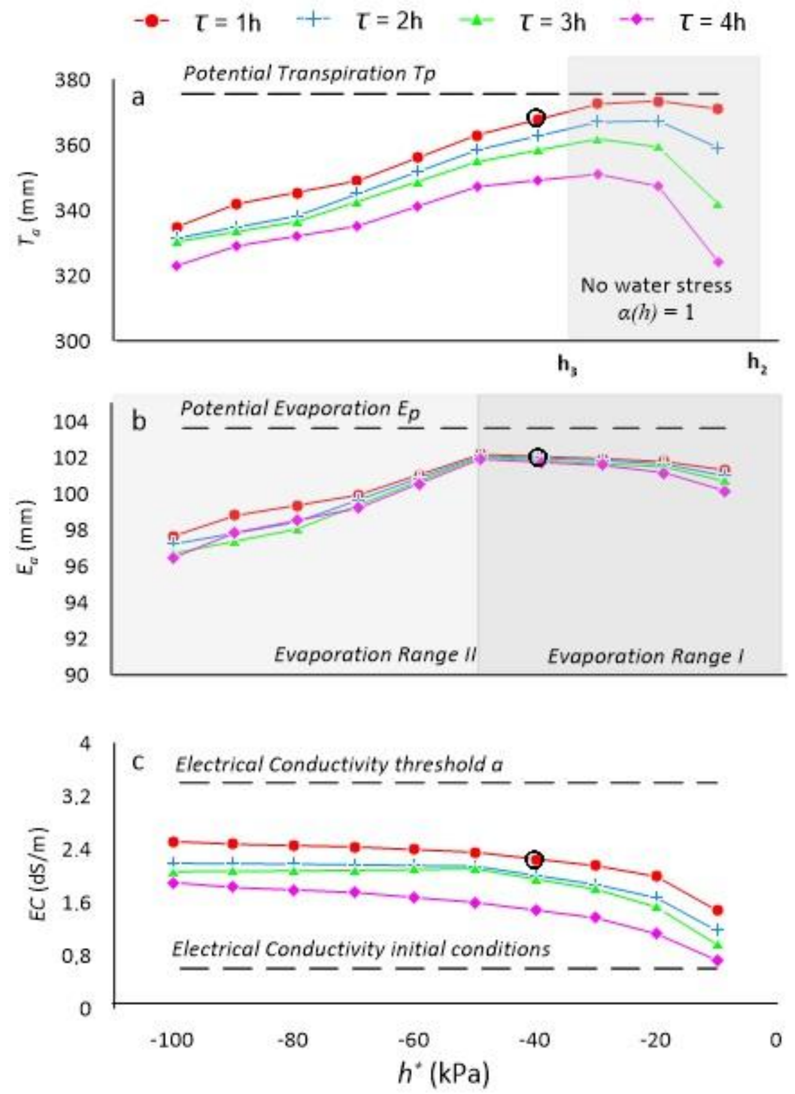




	Soil type						
Foradada	Silty Clay Loam	0.012	0.473	0.0678	1.186	12	0.5
Theoretical soil	Loamy sand soil	0.05	0.41	0.124	2.28	350	0.5

Results; Foradada soil (silty clay loam)





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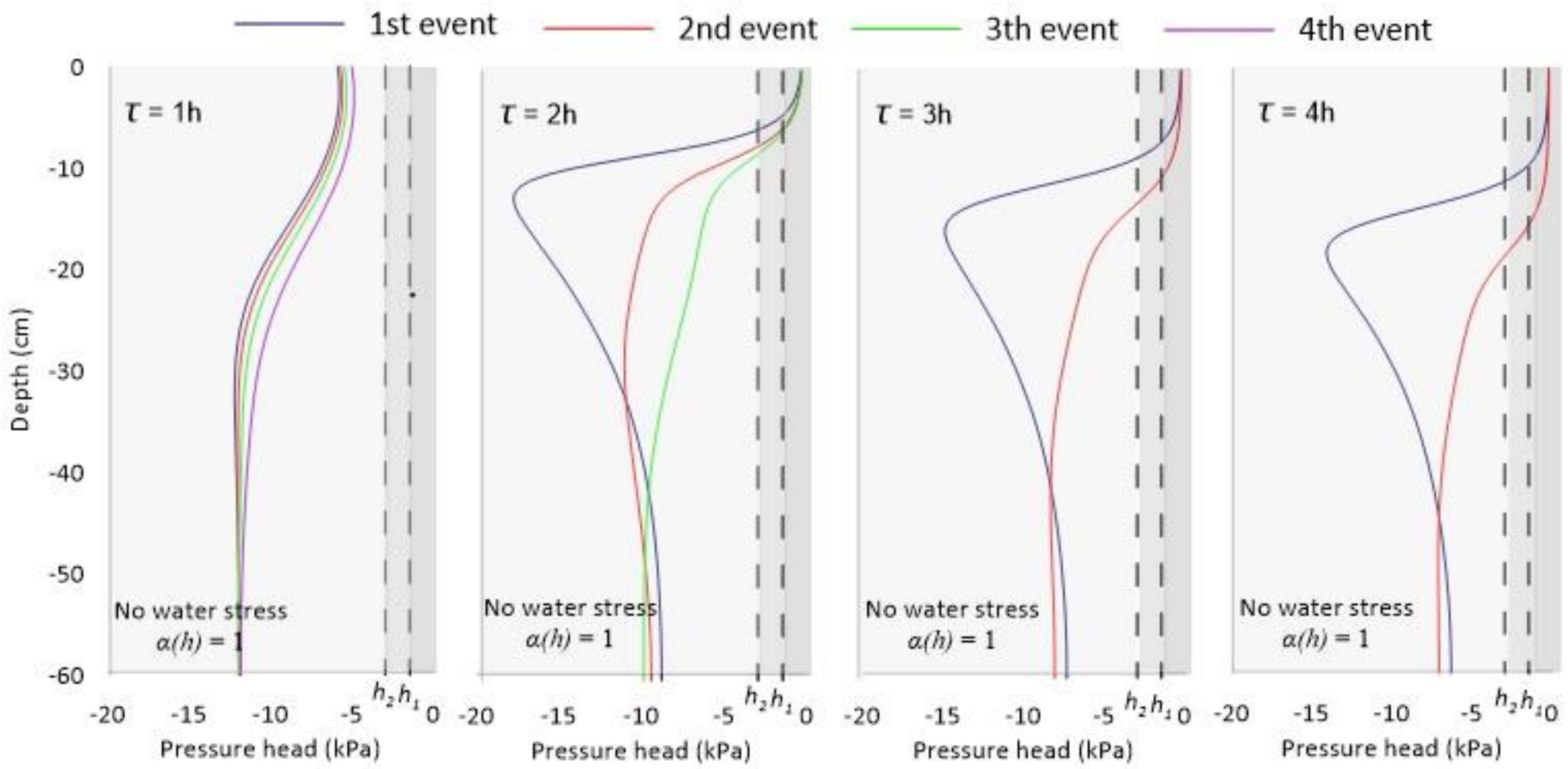
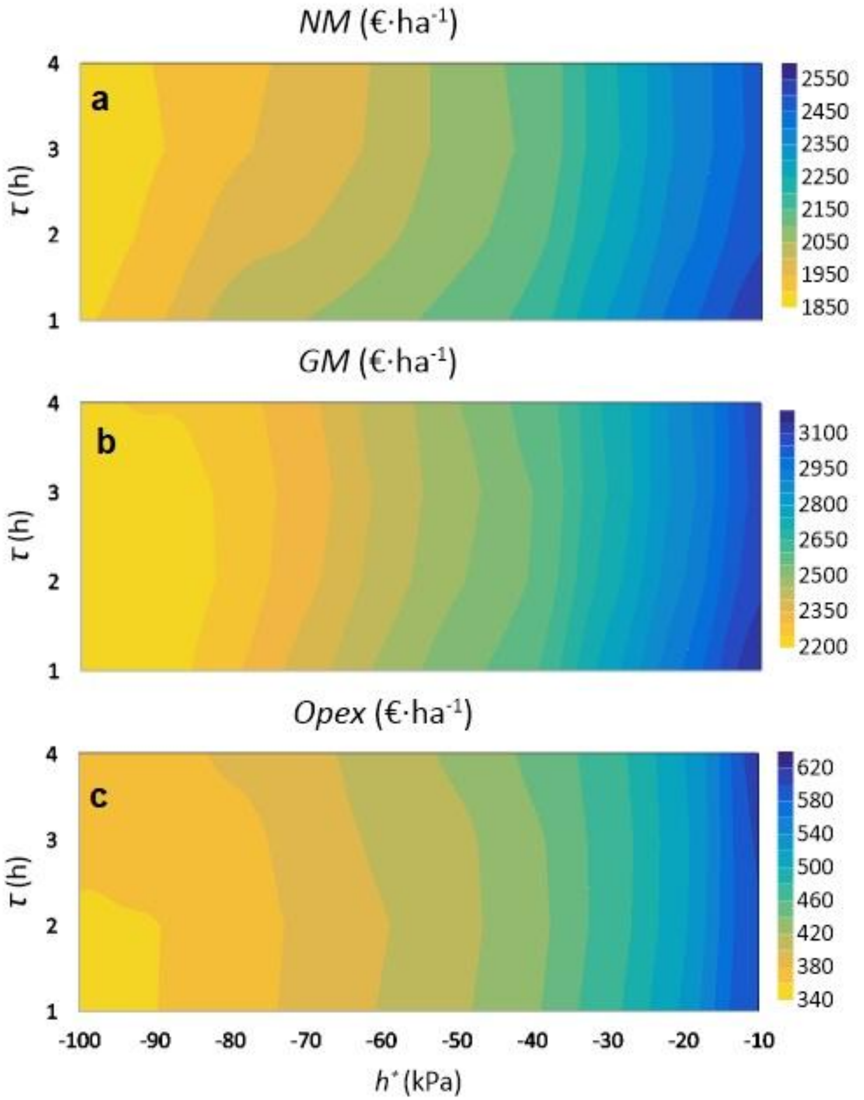
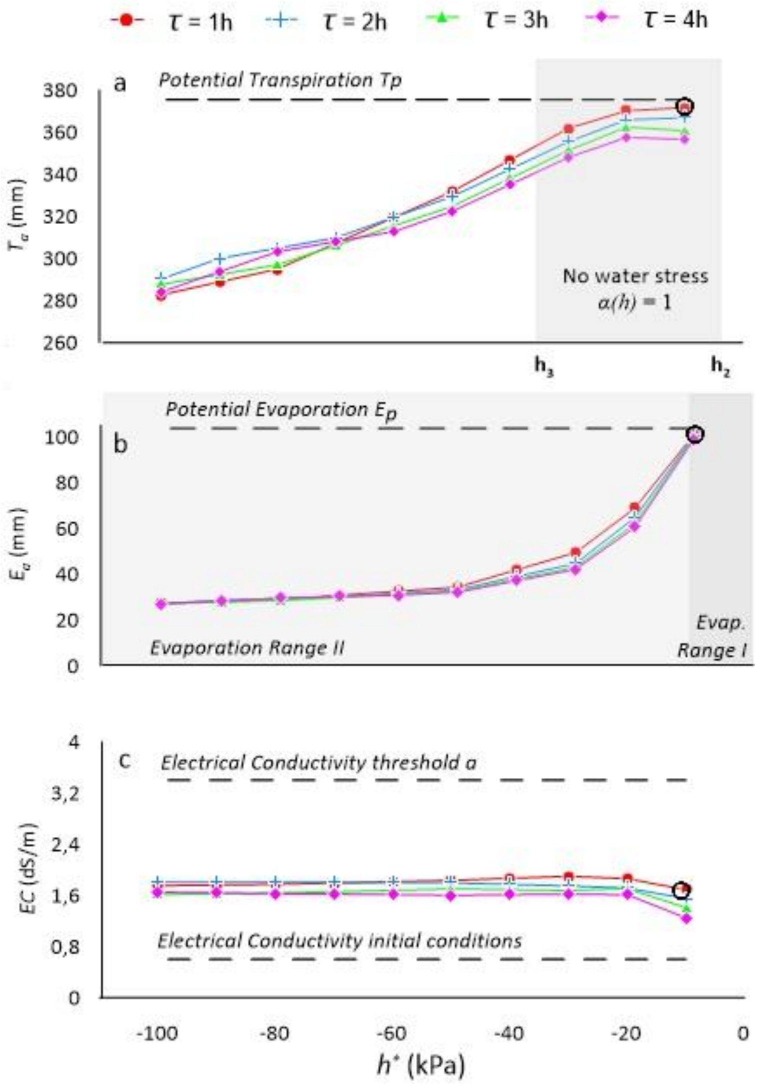


Results: Thoretical soil (Loamy sand)





Conclusions

We have presented a combined simulation and optimization framework. It estimates irrigation parameters that maximize the crop net margin.

- The optimal irrigation irrigation strategy for Foradada field represents medium frequent and short irrigations (τ = 1 h·d^{-1}, h^* = -40 kPa).

- The optimal irrigation strategy is also demostrated to properly balance crop gain margin and operational expenses. Thus, even though some stratgies can be more productive, irrigation expenses counter balance the economic benefit ultimately leading to a compromise between them.

- The Loamy sand soil has less water retention capacity than Foradada soil ans easier water front percolation. The irrigation irrigation strategy represents very frequent and short irrigations (τ = 1 h·d^{-1} , h^* = -10 kPa). Thus, irrigation strategy depends strongly on soil type.

¡Thanks!

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