Simulated irrigation scheduling assessment and the effect of soil hydraulic properties on crop yield and water balance

Fontanet, M. 1,2,3, Fernàndez-Garcia, D. 2,3, Ferrer, F. 1, Rodrigo, G. 1, Villar, J.M. 4

1LabFerrer, Cervera, 25200, Spain
2Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya (UPC), Barcelona, 08034, Spain
3Associated Unit: Hydrogeology Group (UPC-CSIC)
4Department of Environmental and Soil Sciences, Universitat de LLeida (UdL), Lleida, 25003, Spain
Summary

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Evidence suggests that two-thirds of the world population could be living in water-stressed countries by 2025 if current consumption patterns continue (FAO, 2016)
Introduction

- Weather conditions
- Low productivity

- Install irrigation systems
  - Drip irrigations
  - Subsurface drip irrigation

- Soil moisture monitoring
  - Remote Sensing
  - Drones
  - Sensors
Introduction

- **Irrigation scheduling:**
  is the process used by irrigation system managers to determine the correct frequency ($\Psi_{th}$), which can be optimized by defining the Plant Available Water (PAW) level of trigger the moment to irrigated to avoid soil water stress, and **irrigation duration** ($t_{irrig}$), which is related to how much water is applied to refill root zone moisture content, to guarantee maximum yield and profitability with the minimum volume of water applied.
SOIL WATER BALANCE OR WATER REQUIREMENTS

\[ ETo \cdot Kc = ETc \]  
(Allen et al., 1999)

How much water I need?  
How should I apply this water?
Introduction

CROP WATER STRESS MEASUREMENTS

- Stomatal conductance
- NDVI
- Transpiration

Direct crop water stress

Time reaction
SOIL WATER CONTENT AND SUCTION MEASUREMENTS

Direct soil moisture measurements

Where install soil sensors
Not $\Psi_{th}, t_{irrig}$
Introduction

• Simulate with Hydrus 1D different irrigation strategies combining different $\Psi_{th}$ and $t$ values and taking into account hydraulic properties, crop water stress function and water requirements.

• Define an objective function and define which strategy is better using water balance components.

• Application in a real case.
Objectives

• Define how water moves in our soil and understand which its behavior is.
• Define how different irrigation scheduling effects water balance components.
• Have information before start irrigate and install any kind of sensor.
• Determine optimal irrigation of our field.
• Give qualitative information to agricultures.
Methodology

- **Hydrus 1D (Šimůnek, et al., 2018)**
  - Unsaturated equation flow
    \[
    \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K(h) \frac{\partial h}{\partial z} - K(h) \right] - S
    \]
    Richards (1931)

- **Crop Net Water Requirements**
  \[
  NWR = ETo \cdot Kc = ETo + P
  \]
  Allen et al., (1998)

- **Soil hydraulic parameters**
  \[
  \theta(h) = \begin{cases} 
  \theta_r + \frac{\theta_s - \theta_r}{(1 + \alpha h^m)^n} & h < 0 \\
  \theta_s & h \geq 0 
  \end{cases}
  \]
  \[
  K(h) = K_s S_e^m \left[ 1 - (1 - S_e^{1/m})^m \right] 
  \]
  \[
  S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} 
  \]
  \[
  m = 1 - \frac{1}{n} 
  \]
  van Genuchten, (1980)

- **Crop water stress function**
  \[
  \alpha(h) = \begin{cases} 
  \frac{h - h_4}{h_3 - h_4} & h_3 > h > h_4 \\
  \frac{h - h_1}{h_2 - h_1} & h_1 > h > h_2 \\
  0 & h \leq h_1 \text{ or } h \geq h_4 
  \end{cases}
  \]
  Feddes et al., (1978)
Methodology

Atmospheric BC

Free Drainage BC

Ψ

E

I

Ψ_{th}

Ψ_1

Ψ_2

Ψ_3

Ψ_n

Q

t_1

Ψ_1

Ψ_2

Ψ_3

Ψ_n

t_2

Ψ_1

Ψ_2

Ψ_3

Ψ_n

t_3

Ψ_1

Ψ_2

Ψ_3

Ψ_n

t_n
Methodology

• Yield

\[ Y_a = Y_p \prod_{k=1}^{4} \left( 1 - k_y \left( 1 - \left( \frac{ET_a}{ET_p} \right)_k \right) \right) \]

Stewart et al. (1977)

• Objective Function

\[ O.F. = Y_a C_y - \sum (I \Delta t((C_{wFix} + C_{wVar}) + C_e) + C_m + C_{cc}) \]
Applications and discussion

**SOIL TYPE:**
- Silty Clay Loam
  - 28% Clay
  - 58.4% Silt
  - 13.6% Sand

**CROP TYPE**
- Canola (winter – spring)
  - Not irrigated
- Corn (spring – autumn)
  - Irrigated (scheduling)

**IRRIGATION SYSTEM:**
- Sprinkles
  - Irrigation rate \( Q = 6.5 \text{ lm}^{-2} \text{h}^{-1} \)
  - Maximum irrigation time \( t_{\text{max}} = 24 \text{ h} \)
  - Number sectors = 23
  - 2 sectors same time
Applications and discussion

• Time
  – 150 days (corn cycle)

• Climate data
  – RuralCat (www.ruralcat.cat)
  – Oliola weather station from June – November 2008 to June - November 2016

• Hydraulic parameters
  – Experimental:
    • Hydraulic PROPERTIES Analyzer (HYPROP)
    • WP4c
    • Ksat
  – Fitted
    • van Genuchten (1980)

• Crop stress function
  – Hydrus 1D database (Wesseling et al. 1991)

• Scheduling combinations
  – $T_{irig} = 1, 2, 3, 4$ h/d
  – $\Psi_{th} = -10, -20, -30, -50, -100$ kpa
Applications and discussion

<table>
<thead>
<tr>
<th>$\Theta_s$ (cm$^3$/cm$^3$)</th>
<th>$\Theta_r$ (cm$^3$/cm$^3$)</th>
<th>$\alpha$ (1/h)</th>
<th>n (-)</th>
<th>Ks (cm/d)</th>
<th>I (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.54</td>
<td>0.012</td>
<td>0.266</td>
<td>1.1955</td>
<td>500</td>
<td>-3.811</td>
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</tbody>
</table>
Applications and discussion
Applications and discussion

ETc = 487.56 mm
Yp = 19.7 Tn/ha
Corn price = 167 €/ha
ASG Water cost: Fix cost = 115.35 €/ha
Var. cost = 0.1003 €/m³

Optimal Irrigation

<table>
<thead>
<tr>
<th>t_{irrig} (h)</th>
<th>\psi_{th} (kpa)</th>
<th>ETc (%)</th>
<th>€/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>-50</td>
<td>-17%</td>
<td>2538</td>
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Applications and discussion

<table>
<thead>
<tr>
<th>$t_{irrig}$ (h)</th>
<th>$\Psi_{th}$ (kpa)</th>
<th>ETc (%)</th>
<th>€/ha</th>
<th>TOTAL (€)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>-50</td>
<td>-20%</td>
<td>2528</td>
<td>58144</td>
</tr>
<tr>
<td>1</td>
<td>-10</td>
<td>-2</td>
<td>2327</td>
<td>53521</td>
</tr>
<tr>
<td>2</td>
<td>-10</td>
<td>14</td>
<td>2329</td>
<td>53567</td>
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</table>
Applications and discussion
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Applications and discussion

<table>
<thead>
<tr>
<th>Soil type</th>
<th>T irr (h)</th>
<th>$\Psi$th (kpa)</th>
<th>ETc (%)</th>
<th>€/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foradada (silty clay loam)</td>
<td>1</td>
<td>-50</td>
<td>-20</td>
<td>2528</td>
</tr>
<tr>
<td>Silt</td>
<td>2</td>
<td>-20</td>
<td>-15</td>
<td>2394</td>
</tr>
<tr>
<td>Sandy Clay Loam</td>
<td>2</td>
<td>-10</td>
<td>-19</td>
<td>1282</td>
</tr>
</tbody>
</table>
Conclusions

- Simulate irrigation scheduling combining $t_{irrig}$ and $\Psi_{th}$ can provide information about which is the best irrigation strategy
  - How water moves in the soil.
  - Assess irrigation system.
  - Information before irrigation campaign.

- Soil hydraulic properties have an effect on:
  - soil water balance components.
  - crop yield.
  - water applied.
Thanks!