Optimal and Sub-Optimal Irrigation Scheduling using AquaCrop

R. Linker, I. Ioslovich
Technion – Israel Institute of Technology, Israel
Decision Support System Engine

Crop model
Expected weather
Water quotas
Soil data
Prices

DSS Optimization procedure

Optimal irrigation schedule(s)
Whenever information becomes available:

New information  \[\leftrightarrow\]  Expectations

Update of scheduling required?

If yes, repeat optimization

Crop model
Expected weather
Water quotas
Soil data
Prices

Optimization procedure

Optimal irrigation schedule(s)
Decision Support System Engine

Whenever information becomes available:

New information  Update of model required?  Expectations

If yes, update model parameters and/or states (data assimilation)
Decision Support System Engine

Whenever information becomes available:

New information → Expectations

Update of scheduling required?

If yes, repeat optimization

Crop model
Expected weather
Water quotas
Soil data
Prices

Optimization procedure

Optimal irrigation schedule(s)
AquaCrop model

- Developed by FAO to simulate crop development and yield in response to various irrigation scenarios
- Includes modeling of soil water content
- Calibrated for many crops
- Not too complex
- Can be used to determine irrigation required in order to keep soil water content within user-specified boundaries
Remaining of talk

- What should be optimized?
- Approaches for computation of optimal and sub-optimal irrigation schedules
- Simulation results
Optimization criterion

- Minimize irrigation
- Maximize yield
- Maximize yield under water quota
- Maximize water use efficiency
- Maximize net return
Minimize irrigation
Maximize yield
Maximize yield under water quota
Maximize water use efficiency
Maximize net return
Multi-objective optimization:

Maximize yield and minimize irrigation
or equivalently
\((-Yield, Irrigation) \rightarrow \text{min}\)

Advantage of multi-objective approach: Provides a number of optimal solution for the farmer to choose from
Multi-objective optimization

Irrigation, mm

Yield, t/ha

Target yield
Multi-objective optimization

Irrigation, mm vs. Yield, t/ha

Target yield

Target “return”

Local derivative, t/ha per mm

Multi-objective optimization involves optimizing multiple objectives simultaneously. In this context, the graph illustrates the relationship between irrigation, yield, and the local derivative of yield with respect to irrigation. The target yield and target "return" are indicated, showing the optimization focus on achieving the highest yield while considering the local derivative.
Remaining of talk

- What should be optimized?
- Approaches for computation of optimal and sub-optimal irrigation schedules
- Simulation results
Optimization approaches

“Full” optimization

Find \((n,d_1,w_1,d_2,w_2,...,d_n,w_n)\) such that \(\text{Yield} \rightarrow \max\) subject to

\[
\sum_{i=1}^{n} u_i \leq w
\]

\[
0 \leq u_i \leq u_{\text{max}}
\]

Repeat with different values of quota \(w\) to obtain “Water Productivity Function” \(Y_{\text{max}} = f(w)\)
Optimization approaches

➢ “Full” optimization
Optimization approaches

➢ “Full” optimization

Find \((n,d_1,w_1,d_2,w_2,\ldots,d_n,w_n)\) such that \(Yield \to \max\)
subject to
\[
\sum_{i=1}^{n} u_i \leq w
\]
\[
0 \leq u_i \leq u_{\text{max}}
\]

Repeat with different values of quota \(w\) to obtain “Water Productivity Function” \(Y_{\text{max}} = f(w)\)

Not suitable for real-time applications but provides benchmark results to which other approaches can be compared
Optimization approaches

- “Full” optimization
- Optimization of soil moisture levels at which irrigation is triggered
Optimization approaches

- “Full” optimization
- Optimization of soil moisture levels at which irrigation is triggered
Optimization approaches

- “Full” optimization
- Optimization of soil moisture levels at which irrigation is triggered
Optimization approaches

- “Full” optimization
- Optimization of soil moisture levels at which irrigation is triggered
Optimization approaches

- “Full” optimization
- Optimization of soil moisture levels at which irrigation is triggered
- Hybrid optimization
Optimization approaches

- “Full” optimization
- Optimization of soil moisture levels at which irrigation is triggered
- Hybrid optimization

<table>
<thead>
<tr>
<th>Start of season</th>
<th>Current day D</th>
<th>D+Δ</th>
<th>End of season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Run #1</td>
<td>Run #2</td>
<td>Run #3</td>
</tr>
<tr>
<td>Irrigation</td>
<td>Up to one</td>
<td>Generation of irrigation schedule by</td>
<td></td>
</tr>
<tr>
<td>previously</td>
<td>irrigation</td>
<td>AquaCrop</td>
<td></td>
</tr>
<tr>
<td>implemented</td>
<td>event</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Past weather</td>
<td>Short term</td>
<td>Long term weather predictions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>weather</td>
<td></td>
<td>predictions</td>
</tr>
</tbody>
</table>

2 decision variables

5 decision variables at the most
Remaining of talk

- What should be optimized?
- Approaches for computation of optimal and sub-optimal irrigation schedules
- Simulation results
Results: Schedule update during season (cotton, GR)
Results: Schedule update during season (cotton, GR)
Results: Denmark - Potato

- Target: 8 t/ha
- Target: 9 t/ha
- Target: 0.02 t/ha per mm

Empty: historical avg
Gray: GFS 4 days
Solid: GFS 6 days
Results: Greece - Cotton

![Graph showing yield versus irrigation]

- **Target:** 4.8 t/ha
- **Target:** 5.0 t/ha
- **Target:** 0.0075 t/ha per mm

Empty: historical avg
Shaded: GFS 4 days
Solid: GFS 6 days
Results: Italy - Tomato

Target: 6.5 t/ha
Target: 8.0 t/ha
Target: 0.01 t/ha per mm
Empty: historical avg
Shaded: GFS 4 days
Solid: GFS 6 days
Results: Italy - Maize

Target: 12.0 t/ha
Target: 12.5 t/ha
Target: 0.02 t/ha per mm
Empty: historical avg
Shaded: GFS 4 days
Solid: GFS 6 days

Yield, t/ha vs. Irrigation, mm graph
Results: Portugal - Maize

Target: 16 t/ha
Target: 17 t/ha
Target: 0.01 t/ha per mm
Empty: historical avg
Shaded: GFS 4 days
Solid: GFS 6 days
Results: Normalized deviation from optimum

\[\text{deviation} = \min \left\{ 100\% \sqrt{\frac{(Y_{\text{sub}} - Y^*)^2}{Y^*}} + \frac{(I_{\text{sub}} - I^*)^2}{I^*} \right\} \]

<table>
<thead>
<tr>
<th>Location and crop</th>
<th>Target (t/ha or t/ha per mm)</th>
<th>Type of weather forecasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Historical averages</td>
<td>GFS 4 days</td>
</tr>
<tr>
<td>DK</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>0.02</td>
<td>6</td>
</tr>
<tr>
<td>GR</td>
<td>4.8</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>0.0075</td>
<td>3</td>
</tr>
<tr>
<td>IT-tomato</td>
<td>6.5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>4</td>
</tr>
<tr>
<td>IT-maize</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>0.02</td>
<td>4</td>
</tr>
<tr>
<td>PT</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>1</td>
</tr>
</tbody>
</table>
Conclusions

- The hybrid formulation of the optimization problem allows to minimize the number of decision variables.
- The results obtained by repeating the sub-optimal computations daily are close to the optimal results unless the target yield is “too high”.
- The approach performs well using realistic weather forecasts (but the crop model was assumed to be perfect).
- The current accuracy of the short-term weather forecasts is such that using such forecasts do not improve the results drastically compared to using only historical averages.
- The sub-optimal procedure requires about one minute to complete.
- The procedure is suitable for real-time implementation (web-based service).