Optimization of the Irrigation Management

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R. Linker
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)
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
Optimization criterion

- 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

  \[-Yield,\text{ Irrigation} \rightarrow \min\]

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

![Graph showing yield vs. irrigation]

Yield, t/ha

Irrigation, mm

Target yield
Multi-objective optimization

Yield, t/ha vs. Irrigation, mm

- Target yield
- Local derivative, t/ha per mm

Target “return”
Remaining of talk

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

“Full” optimization

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

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” \(Y_{max} = f(w)\)
Optimization approaches

- “Full” optimization
Optimization approaches

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

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- Optimization of soil moisture levels at which irrigation is triggered

![Graph showing root zone water depletion over time with stress thresholds and irrigation trigger levels.](image-url)
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

![Diagram showing optimization approach](image)
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 the relationship between yield and irrigation in Greece for Cotton. The target yield is 4.8 t/ha, and the target water use efficiency is 0.0075 t/ha per mm of irrigation. The graph includes historical average data (Empty), GFS predictions for 4 and 6 days (Shaded and Solid), and data points for different irrigation levels.]
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

![Graph showing yield vs. irrigation for maize in Italy. Targets are labeled as follows:
- Circle: Target: 12.0 t/ha
- Triangle: Target: 12.5 t/ha
- Square: Target: 0.02 t/ha per mm
Historical data is represented by an empty circle, shaded data by a triangle, and solid data by a square.

- Empty: historical avg
- Shaded: GFS 4 days
- Solid: GFS 6 days]
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

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

<table>
<thead>
<tr>
<th>Location and crop</th>
<th>Target (t/ha or t/ha per mm)</th>
<th>Type of weather forecasts</th>
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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)