A general framework for optimal crop selection and water allocation using dynamic crop models

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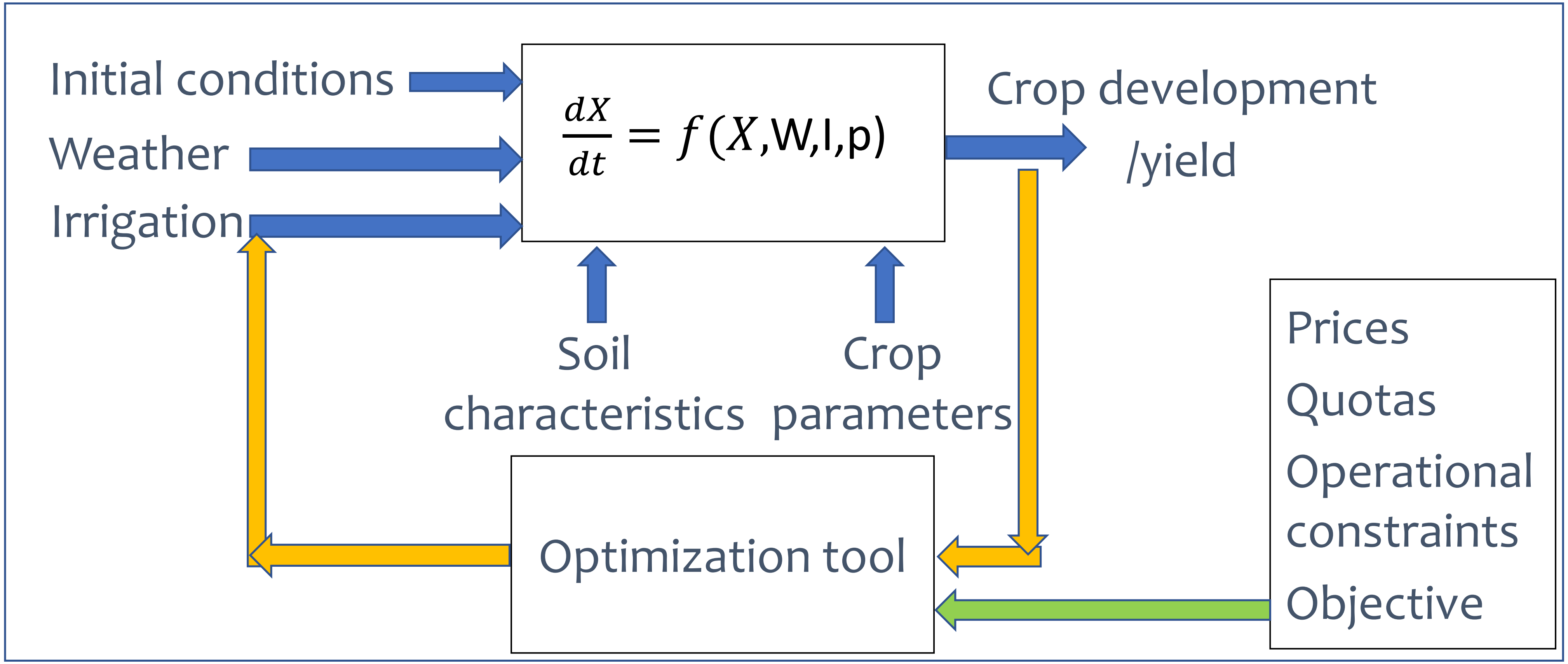
Better use of water involves decisions at two levels:

- Strategic level (Choice of crop, acreage, etc.)
- Tactical level
    - Crop and soil are given
    - Sowing/planting date is set
    - Fertilization etc. are given
    - “Only” unknown (decision variables) is irrigation schedule

Focus of talk: Unified methodology for dealing with both decision levels

Previous work: Model-based (sub-) optimal irrigation scheduling (single crop)



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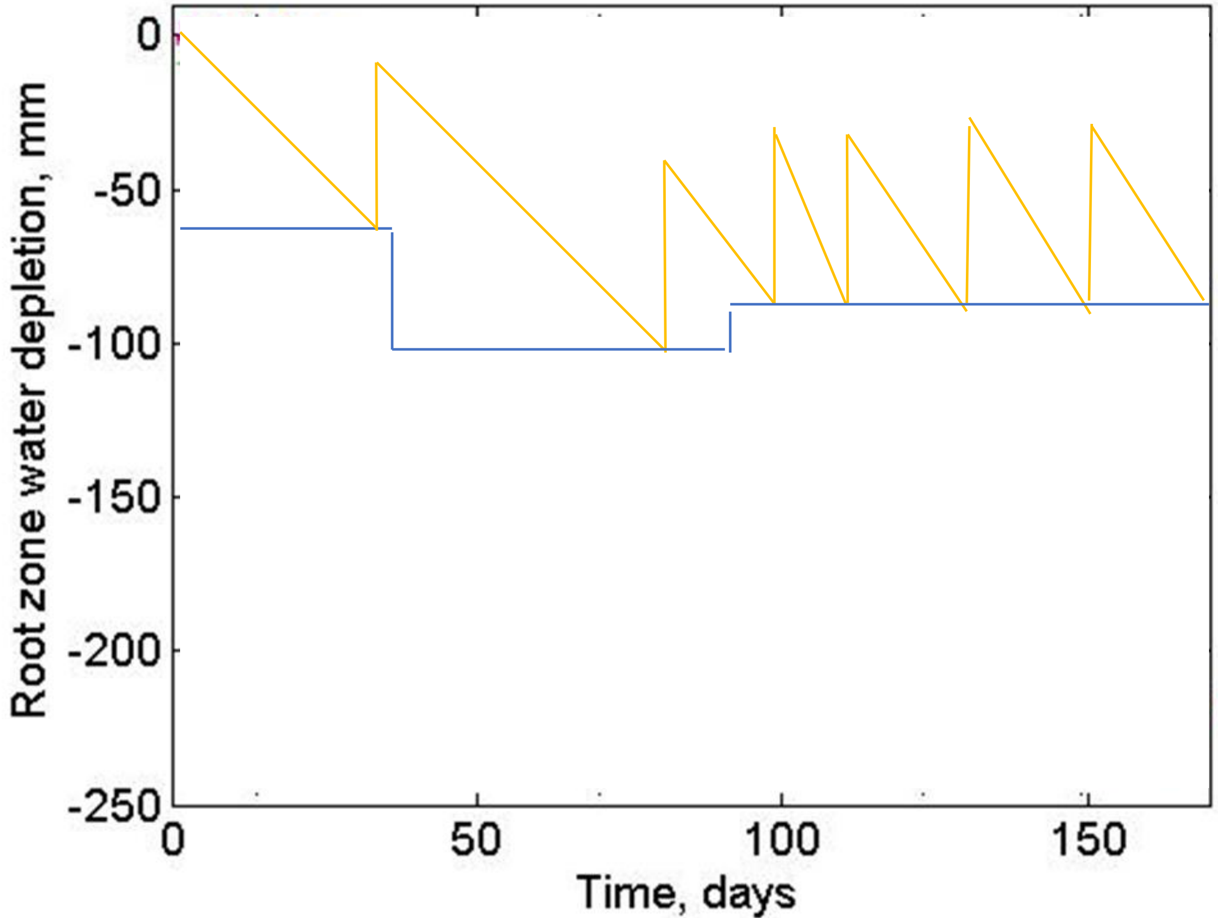
The optimization can be performed efficiently by defining as decision variables irrigation thresholds at which irrigation is triggered



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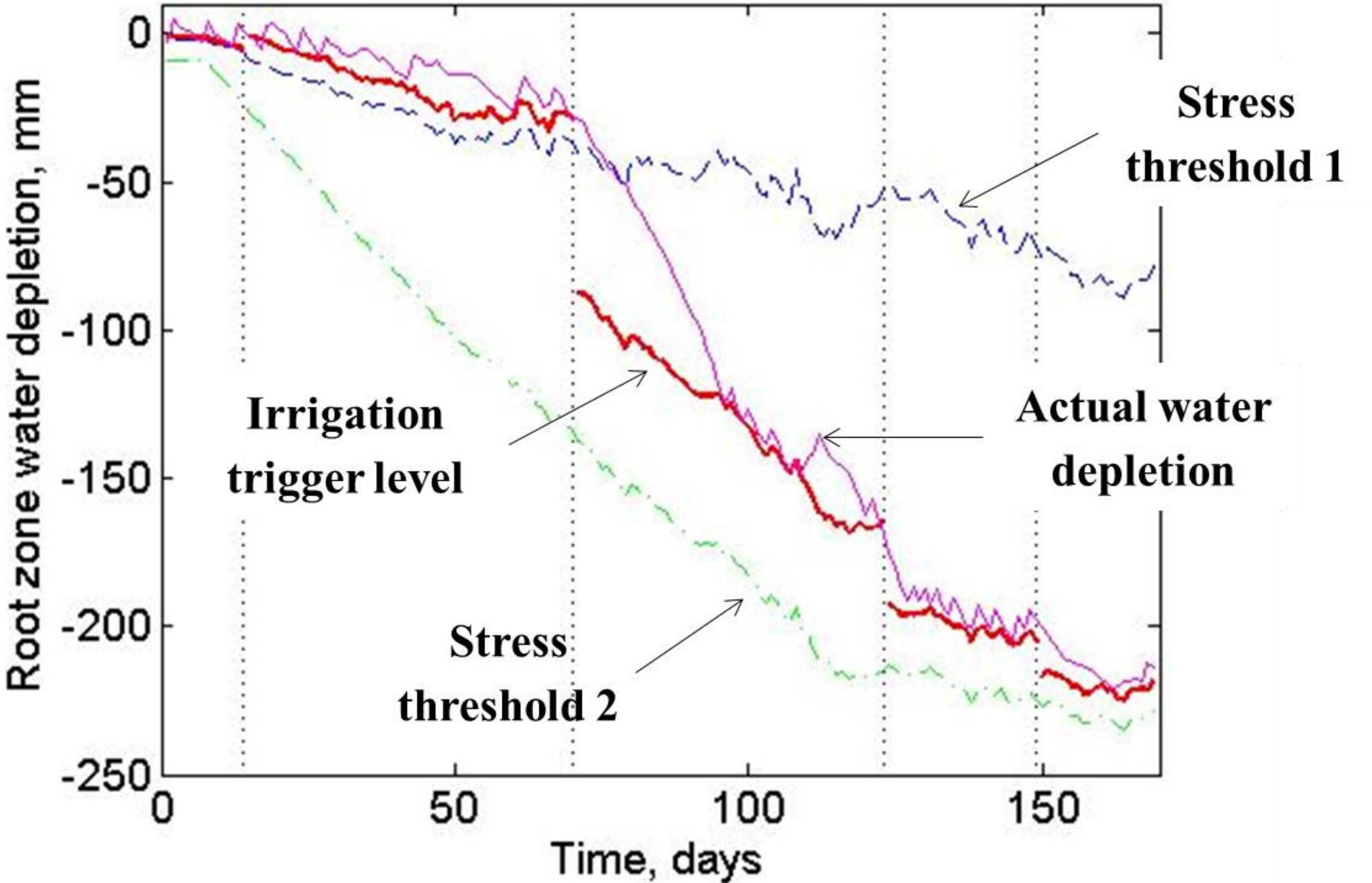

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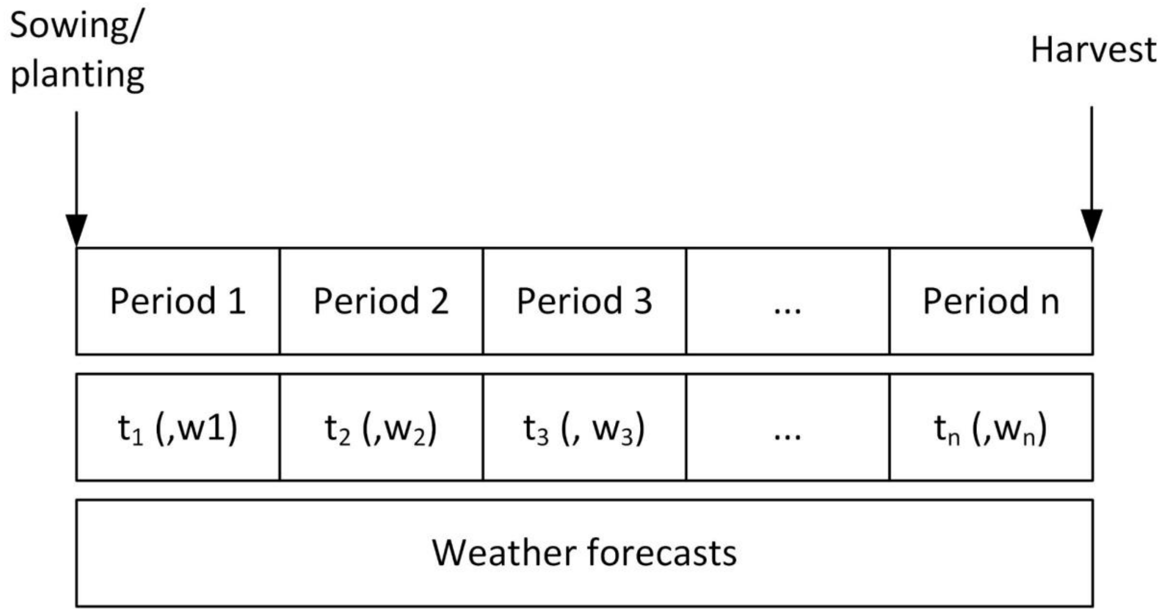

What to optimize? Maximize yield; marginal yield; water use efficiency; profit; …?

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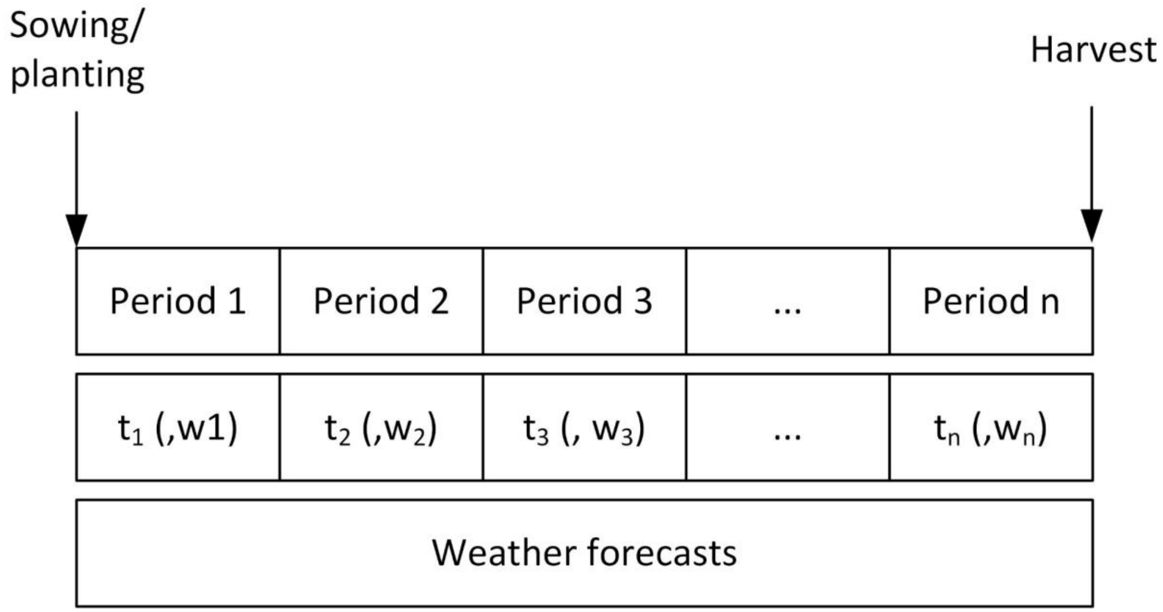

Find $(t_1, t_2, \ldots t_n\ (,w_1, w_2, \ldots w_n))$
such that
(-yield, total irrigation) $\longrightarrow$ minimum

What to optimize? Multi-objective optimization: Maximize yield and minimize irrigation

Previous work: Model-based (sub-) optimal irrigation scheduling (single crop)

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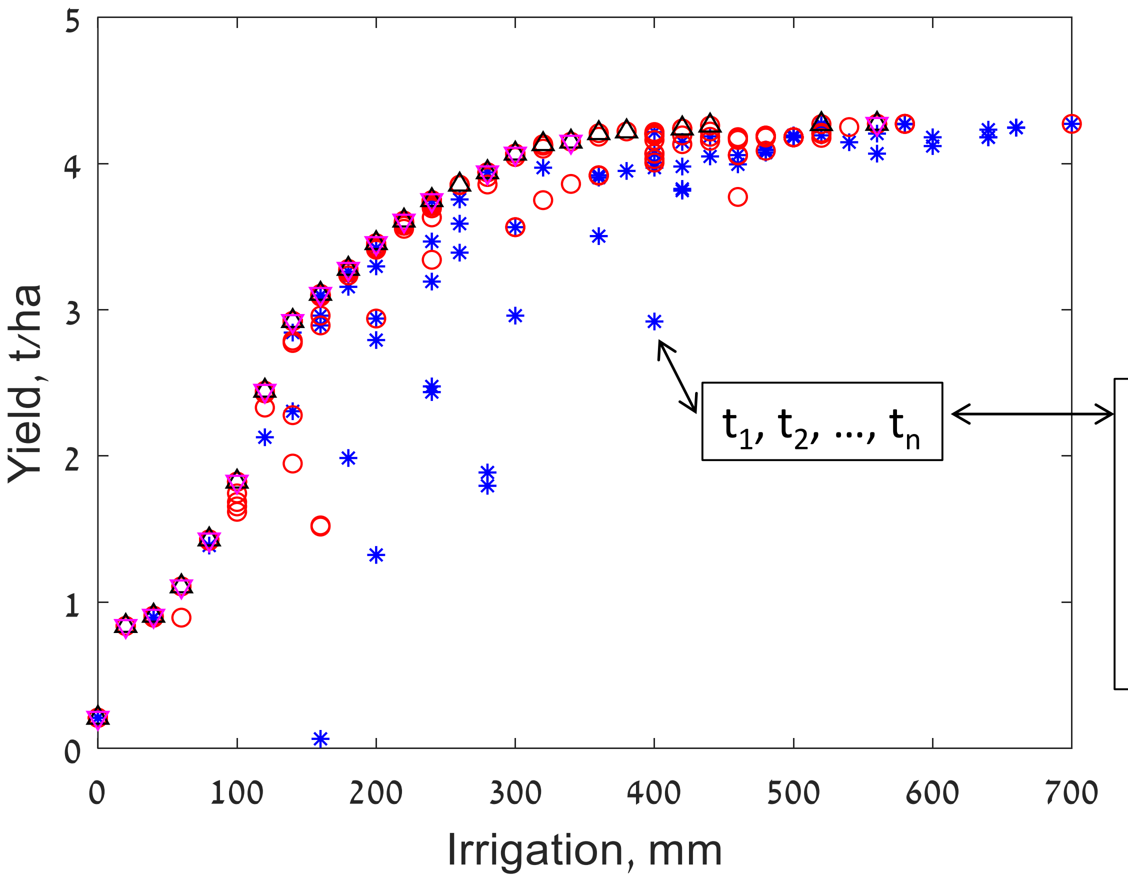
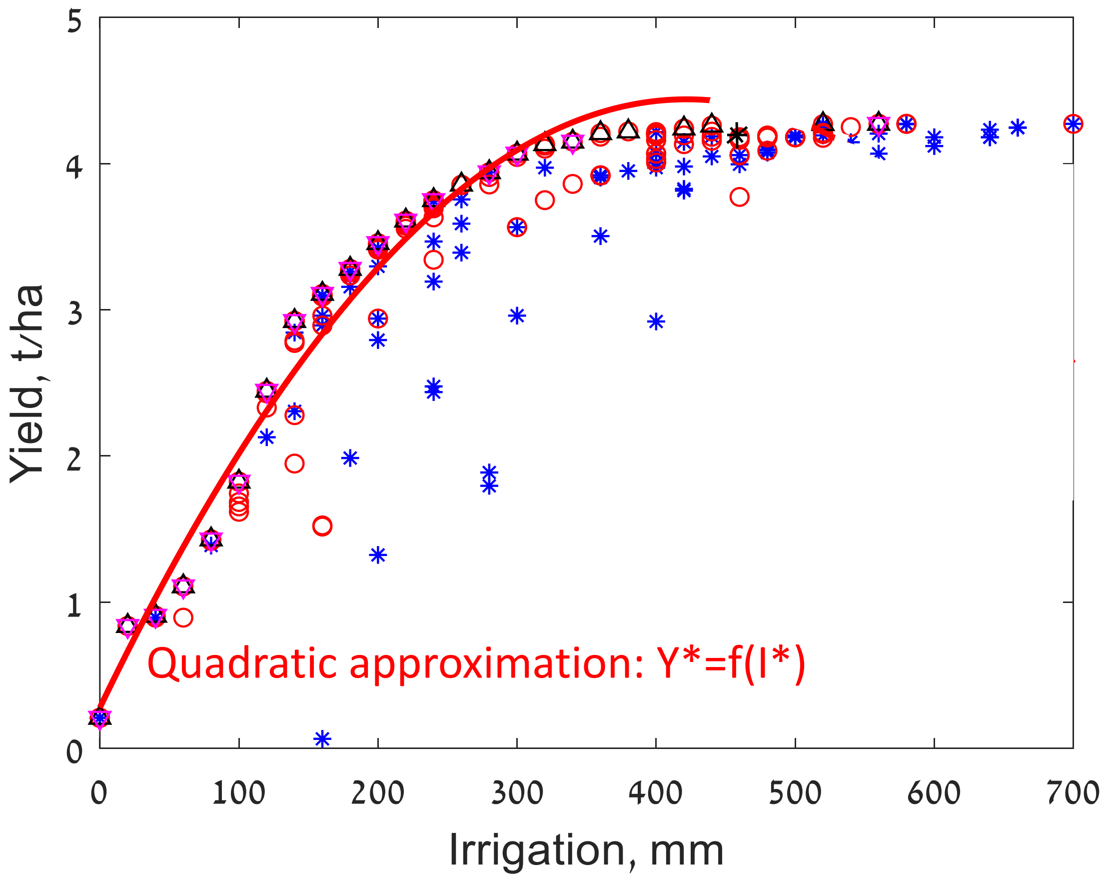


Irrigation on days
10
25
30
…

Previous work: Model-based (sub-) optimal irrigation scheduling (single crop)

What to optimize? Multi-objective optimization: Maximize yield and minimize irrigation



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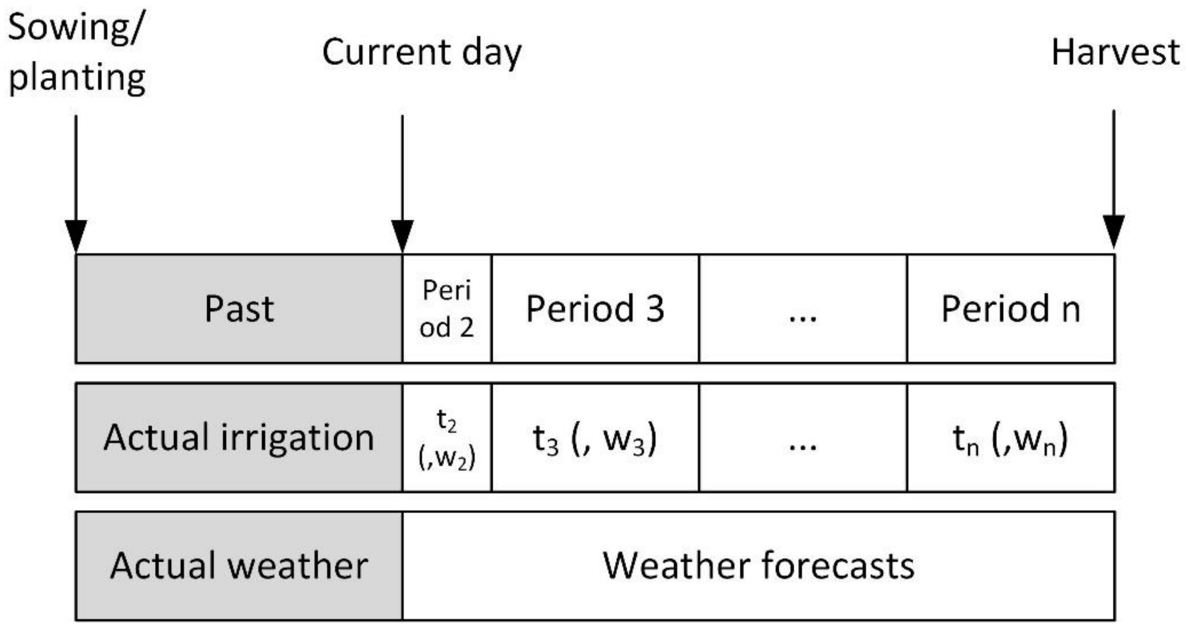
The optimization can be repeated during the season to account for the imperfectness of the weather forecasts



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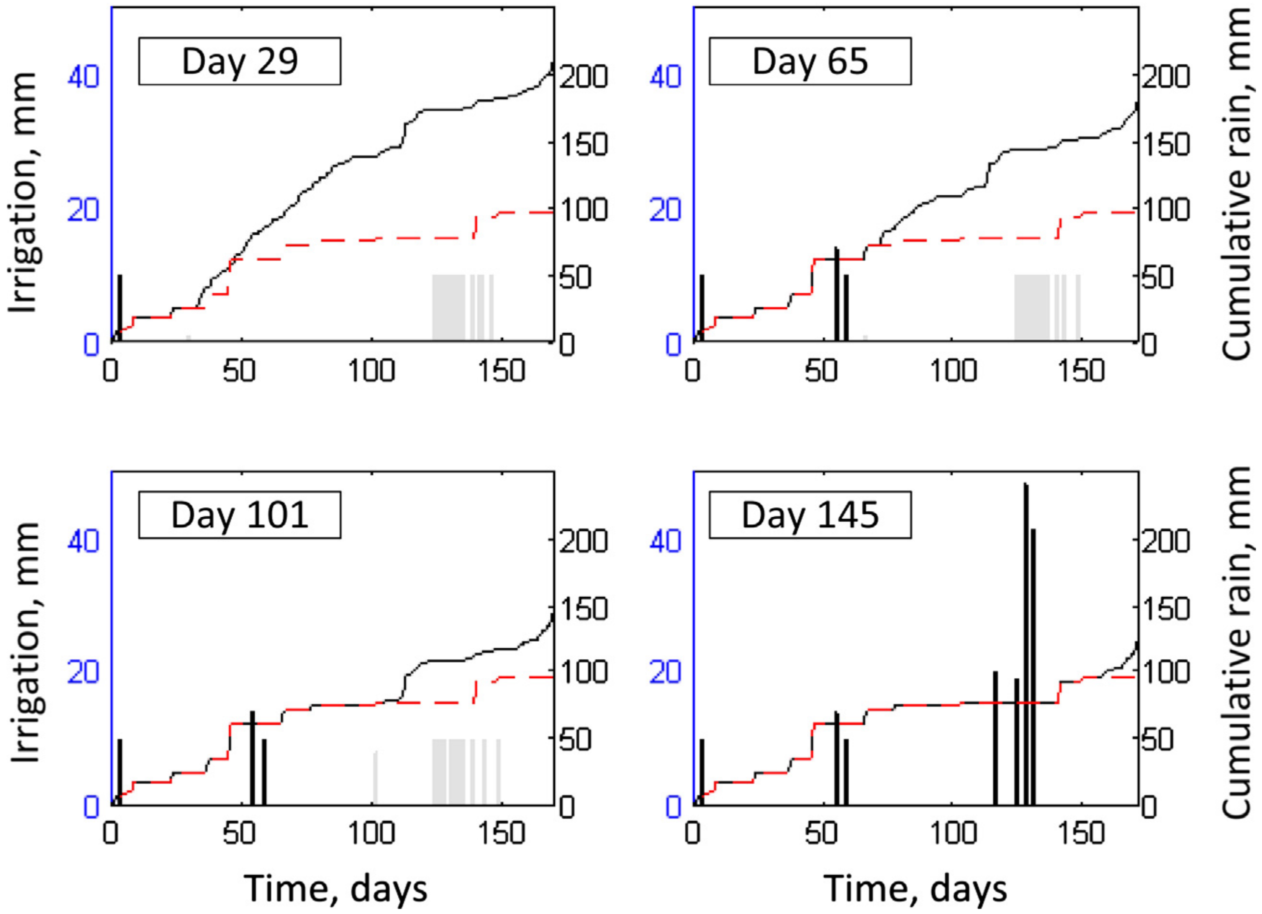


Investigation with different crops at different locations showed that in most cases the final (yield, irrigation) is very close to optimal

Formalism for optimal crop selection and water allocation

Assumptions:

- n crops
- m fields (soil areas)
- Weather forecasts/historical weather
- Prices for crops (p_i) and water (p_w)
- Operational constrains (water quotas, minimal yield, …)

n*m water productivity functions ($f_{i,j}$) determined by single-crop multi-objective optimization

$$\sum_{j=1}^{m}\sum_{i\in K_j} p_i x_{i,j} f_{ij}(w_{ij}) - p_w k \sum_{j=1}^{m}\sum_{i\in K_j} x_{i,j} w_{ij} \to \max$$

$$\sum_{i=1}^{n}\sum_{j\in L_i} k x_{ij} w_{i,j} \le W,\ 0 \le x_{ij},\ 0 \le w_{i,j}$$

$$\sum_{i\in K_j} x_{i,j} \le X_j,$$

$$\underline{C}_i \le \sum_{j\in L_i} x_j f_{i,j}(w_{i,j}),$$

Decision variables

$x_{i,j}$: Area of soil *j* allocated to crop *i*

$w_{i,j}$: Amount of water allocated to crop *i* cultivated on soil *j*

Formalism for optimal water allocation (during season or if cropping areas are fixed a priori)

Assumptions:

- n crops
- m fields (soil areas)
- Weather forecasts/historical weather
- Prices for crops (p_i) and water (p_w)
- Operational constrains (water quotas, minimal yield, …)

n*m water productivity functions ($f_{i,j}$) determined by single-crop multi-objective optimization

Recomputed using actual past weather and irrigation

$$\sum_{j=1}^{m} \sum_{i \in K_j} p_i x_{i,j} f_{ij}(w_{ij}) - p_w k \sum_{j=1}^{m} \sum_{i \in K_j} x_{i,j} w_{ij} \to \max$$

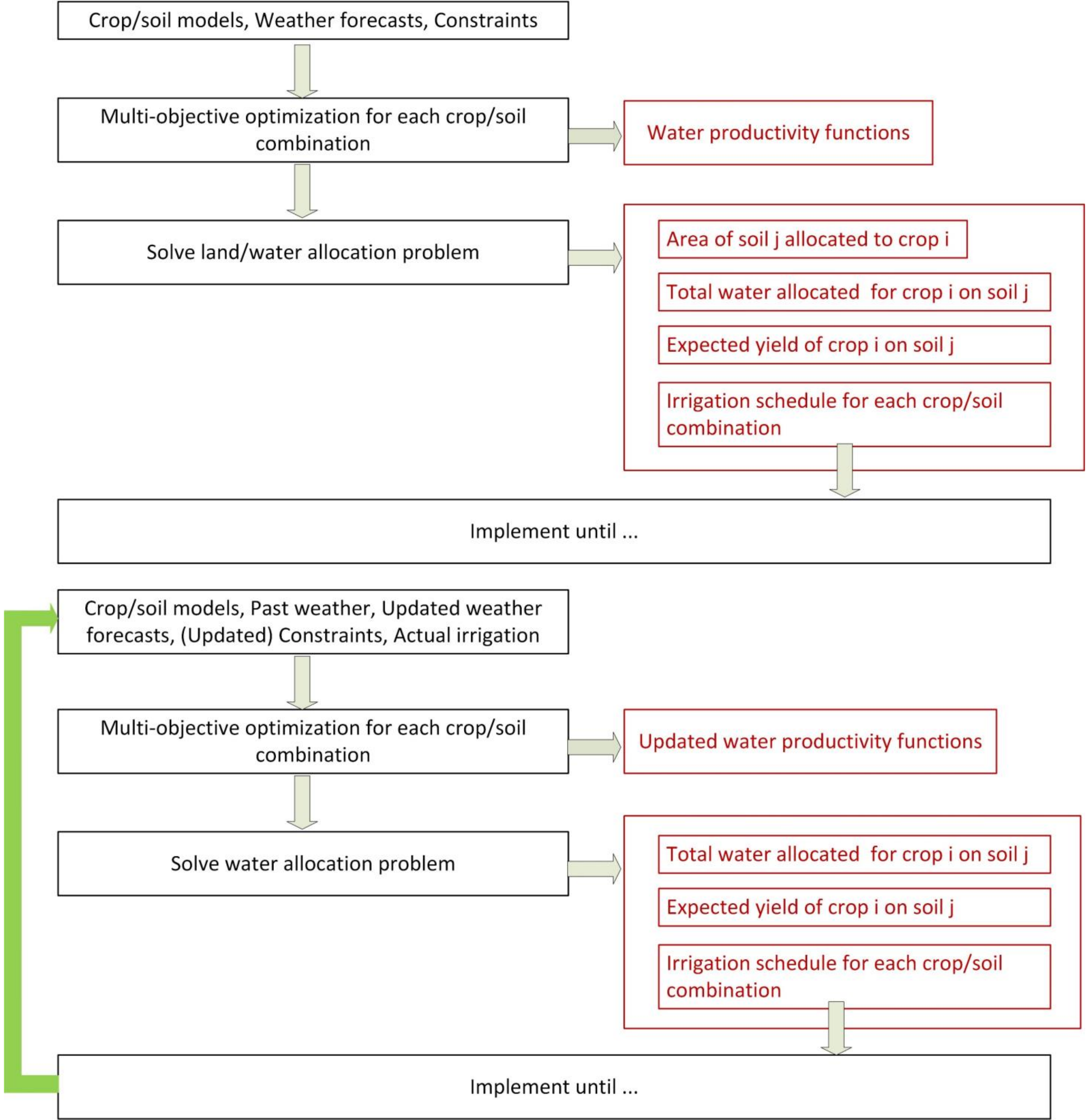
$$\sum_{i=1}^{n} \sum_{j \in L_i} k x_{ij} w_{i,j} \leq W, \; 0 \leq x_{ij}, \; 0 \leq w_{i,j}$$

$$\sum_{i \in K_j} x_{i,j} \leq X_j,$$

$$\underline{C}_i \leq \sum_{j \in L_i} x_j f_{i,j}(w_{i,j}),$$

Decision variables

$w_{i,j}$: Amount of water allocated to crop *i* cultivated on soil *j*



Crop/soil models, Weather forecasts, Constraints
Multi-objective optimization for each crop/soil combination
Water productivity functions
Solve land/water allocation problem
Area of soil j allocated to crop i
Total water allocated for crop i on soil j
Expected yield of crop i on soil j
Irrigation schedule for each crop/soil combination
Implement until ...
Crop/soil models, Past weather, Updated weather forecasts, (Updated) Constraints, Actual irrigation
Multi-objective optimization for each crop/soil combination
Updated water productivity functions
Solve water allocation problem
Total water allocated for crop i on soil j
Expected yield of crop i on soil j
Irrigation schedule for each crop/soil combination
Implement until ...

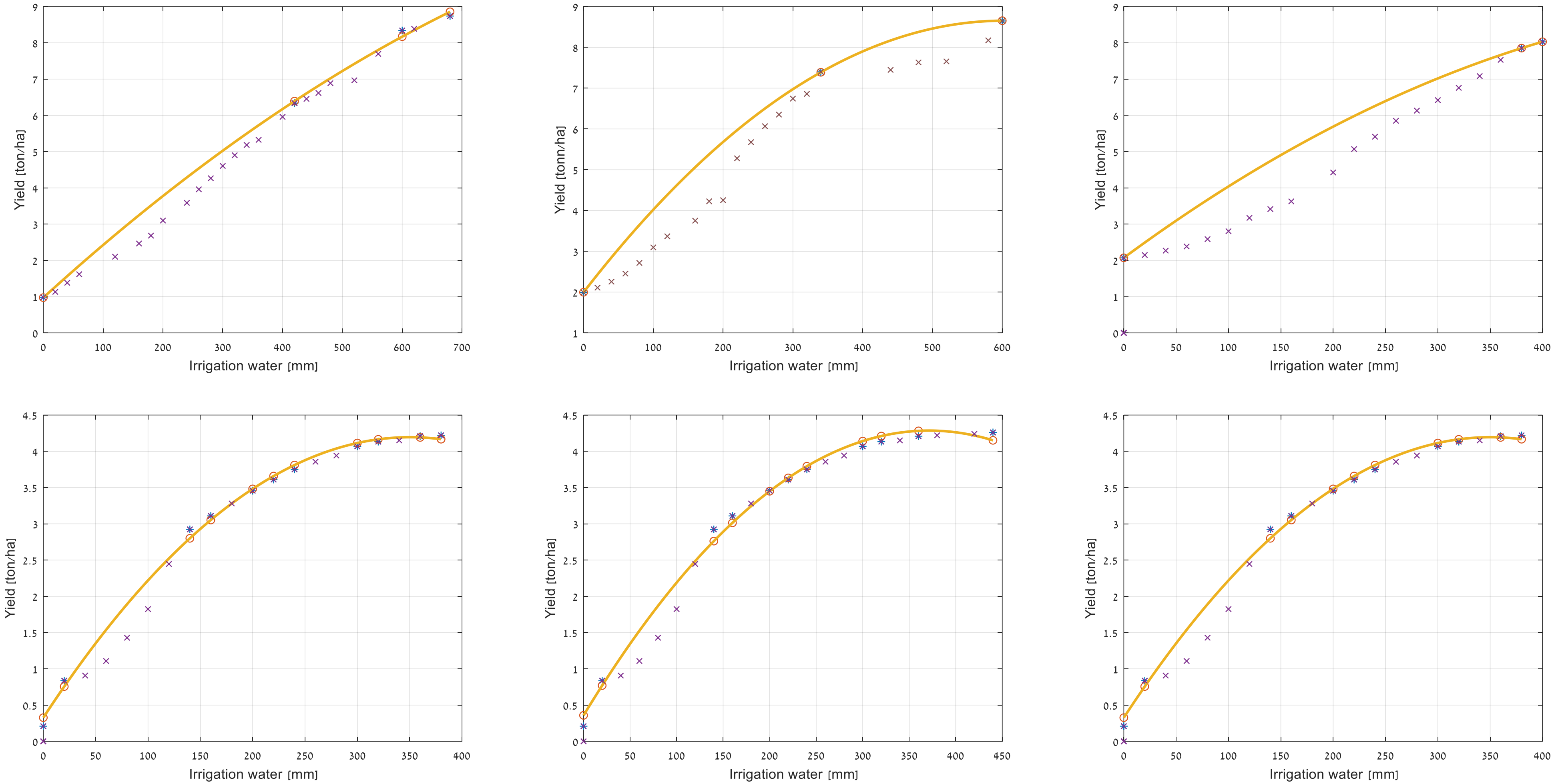
Example with 2 crops and 3 soils

- ➢Initial optimization with historical weather

Soil 1 | Soil 2 | Soil 3

Crop 1

Crop 2



Example with 2 crops and 3 soils

- Initial optimization with historical weather

Optimal allocations

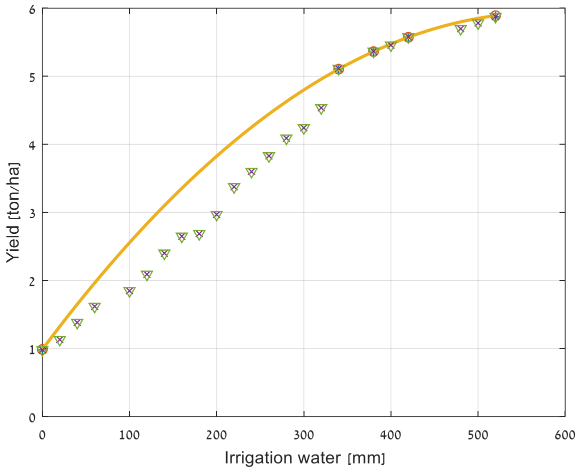
Crop	Soil	Allocated area, ha	Irrigation, mm	Total water, m^3	Expected yield, t
1	1	2.2	25	55	3.3
1	2	5.0	99	495	20.8
1	3	0	-	-	-
2	1	9.8	127	1250	25.2
2	2	0	-	-	-
2	3	7.0	0	0	20.4

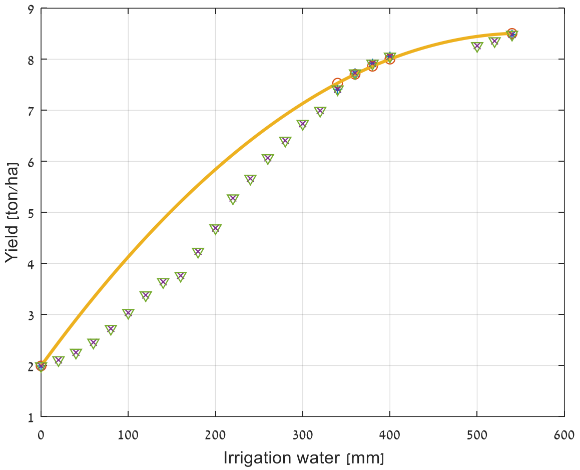
Example with 2 crops and 3 soils

- Update after 30 days

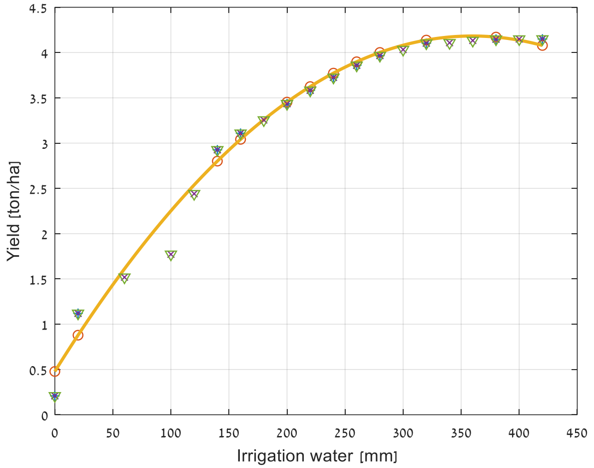
Soil 1 | Soil 2 | Soil 3

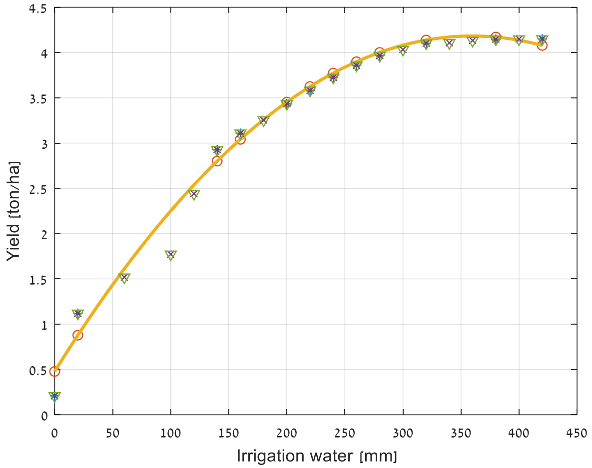
Crop 1





Crop 2





Example with 2 crops and 3 soils

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Optimal allocations | Updated allocations

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1	2	5.0	99	495	20.8	113	565	21.9
1	3	0	-	-	-	-	-	-
2	1	9.8	127	1250	25.2	125	1235	25.5
2	2	0	-	-	-	-	-	-
2	3	7.0	0	0	20.4	0	0	20.5

Summary

- A unified framework for land and water allocation has been presented
- The procedure relies on Water Productivity Functions which are estimated “in real-time” by solving (independently) a multi-objective optimization problem for each crop/soil combination
- The procedure can be applied for any crop/soil combination for which a model is available

On-going work/Open issues

- Stochastic optimization to deal with weather forecasts uncertainty
- Data assimilation (use of in-season measurements to improve model predictions) – Poster of A. Jamal

Thank you!

Collaborators: G. Sylaios (DUTH), I. Tsakmakis, F. Plauborg (Aarhus U.), Battiliani (CER), T. Ramos (U. Lisbon), L. Simionesei (U. Lison), I. Ioslovich (Technion) FP7-FIGARO (Flexible and precIse irriGation platform to improve faRm scale water prOductivity), I. Kisekka (UCDavis), M. Housh (U. Haifa), A. Jamal (Technion)