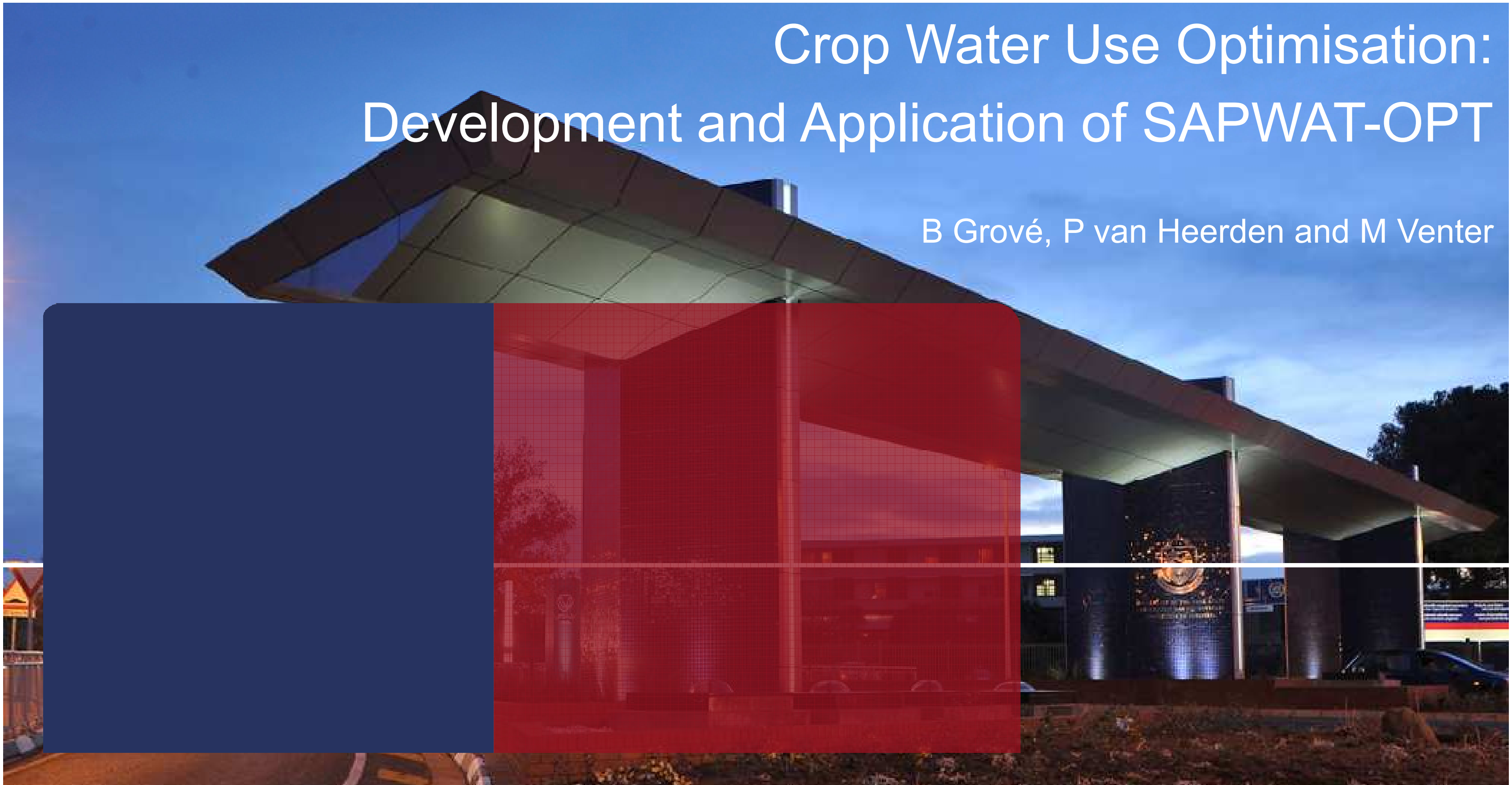
Crop Water Use Optimisation: Development and Application of SAPWAT-OPT

B Grové, P van Heerden and M Venter



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OUTLINE

- Background and motivation
- Description of the problem and objective
- Procedures
- Verification/Results
- Conclusions / Future developments

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"IRRIGATION IN A CHANGING ENVIRONMENT"

- Rising electricity costs
  - Increases the cost of applying irrigation water
    - What is the optimal level of water application?
    - Is it worth while to apply water to achieve maximum yield?
- Water resources under pressure
  - E.g. Environmental flows
    - Catchments are over-allocated
      - Water curtailments ?
      - Reduced security of supply ?

PARADIGM SHIFT (ENGLISH ET AL.,2002)

- Old paradigm
  - Apply irrigation water to achieve biological objective of maximizing production
- Rising electricity costs and water scarcity/reduced water supply reliability
  - Emphasise the importance of:
    - Balancing the cost of applying irrigation water to a specific crop with the expected economic benefit from doing so.
    - Opportunity cost of water
      - Trade-off between alternatives
- New paradigm
  - Optimise water use to increase profitability

NEW GENERATION DECISION SUPPORT

- The fundamental procedures for irrigation scheduling/planning
  - relatively straight forward and simple
- Providing decision support to optimise water use to improve profitability
  - complex
- DSS under new paradigm should consider (Hillyer, 2011)
  - Economic consequences
  - Farm level constraints and the conjunctive scheduling of all irrigation fields
  - Deficit irrigation (yield reduction)
  - Full season forecasting in order to facilitate planning

ALTERNATIVE OPTIMISATION METHODS

- Simulation- Optimisation (SIMCOM- Botes, et al., 1996)
  - Complex
  - Difficult to solve water use between multiple crops
- Mathematical programming
  - Seasonal
  - Intra-seasonal
    - Disaggregated
      - Yield reduction
      - Multiple alternatives

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ALTERNATIVE OPTIMISATION METHODS: MP-SEASONAL

	Irrigation 1	Availability	Deficit / Surplus
Total	595	595	0

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ALTERNATIVE OPTIMISATION METHODS: MP-DISAGGREGATED

	Irrigation 1	Availability	Deficit / Surplus	
1	12	35	23	
2	40	35	-5	Reduce area (12.5%)
.		.	.	
.		.	.	
16	15	35	20	
17	10	35	25	
Total	595	595		

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ALTERNATIVE OPTIMISATION METHODS: MP-DISAGGREGATED (YIELD REDUCTION)

	Irrigation 1	Availability	Deficit / Surplus	
1	12	35	23	Same area
2	40	35	-5	Yield reduction with
.		.	.	relative ET deficit of 1%
.		.	.	
16	15	35	20	
17	10	35	25	
Total	595	595		

ALTERNATIVE OPTIMISATION METHODS: MP-DISAGGREGATED (YIELD REDUCTION)

Non of these methods considers soil water supply as a stock resource!

17	10	35	25
Total	595	595	-5

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ALTERNATIVE OPTIMISATION METHODS: MP-DISAGGREGATED (MULTIPLE ALTERNATIVES)

	Irrigation 1	. .	Irrigation n	Availability	Deficit / Surplus	
1	12		17	35	18	
2	40		35	35	0	No yield reduction
.				.	.	
.				.	.	
16	15		15	35	20	
17	10		10	35	25	
Total	595		595	595	0	

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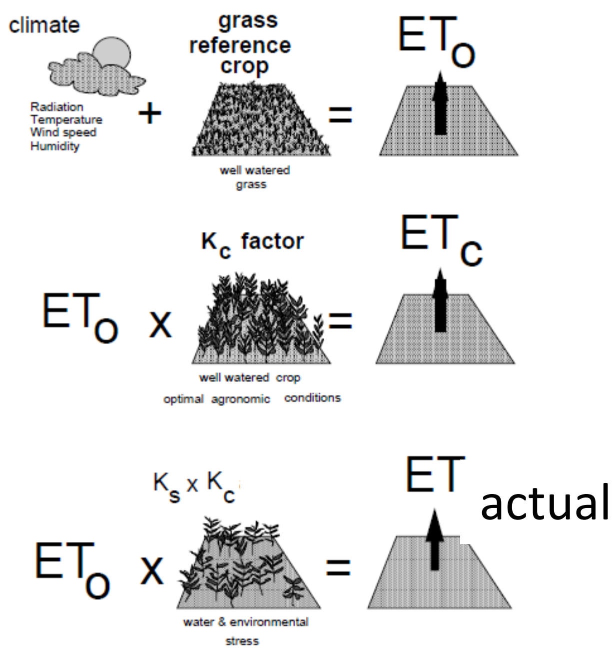
LET'S SUMMARISE

- Simulation-Optimisation
  - To complex for planning
- MP based approaches (currently)
  - Ignores the stock nature (dynamics) soil water supply
    - Multiple alternatives
      - Need many alternatives
      - Only approximation
      - Typically will identify more than one alternative for same area
- A soil water balance approach is a prerequisite for proper planning

OBJECTIVE

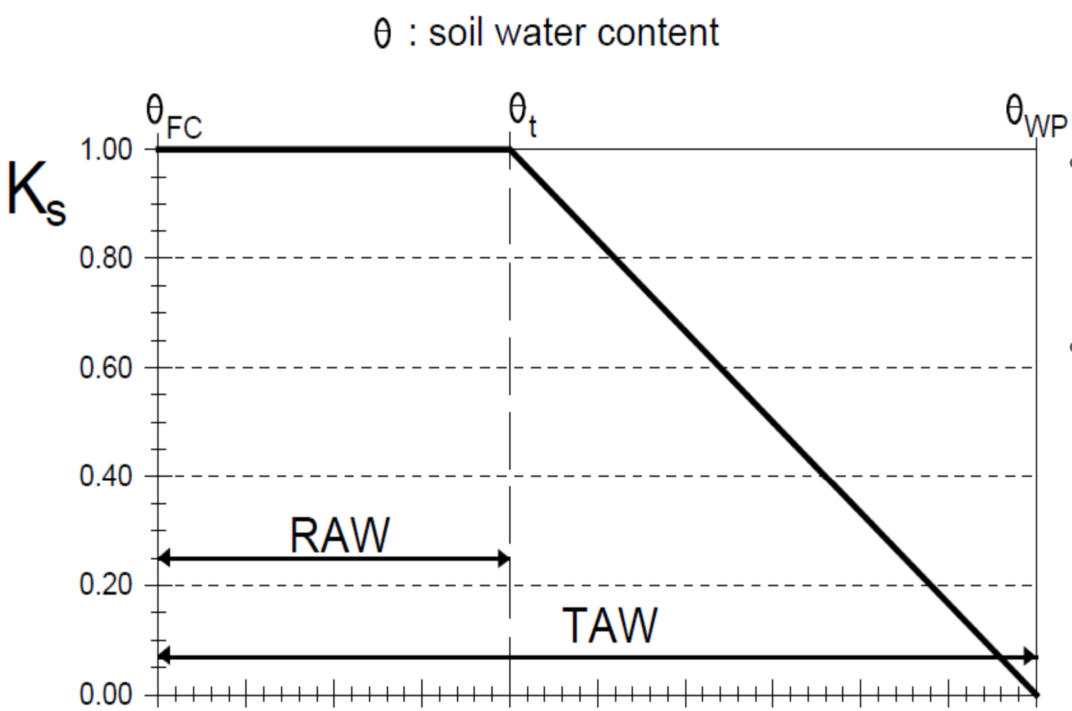
- The main objective of this research was:
  - To determine whether it is possible to include the SAPWAT soil water budgeting routine into a LP framework to facilitate crop water use optimisation.

PROCEDURES



- Reference ET (ET_0)
  - Penman-Monteith
- Maximum crop ET_c
- Water stress conditions
  - ET_C is adjusted to determine ET_{actual}
  - Need water budget calculations to calculate K_s

K_S-ADJUSTMENT FACTOR



- **TAW**: amount of water that a crop can extract from its root zone
- **RAW**: fraction of TAW that a crop can extract from the root zone without suffering water stress

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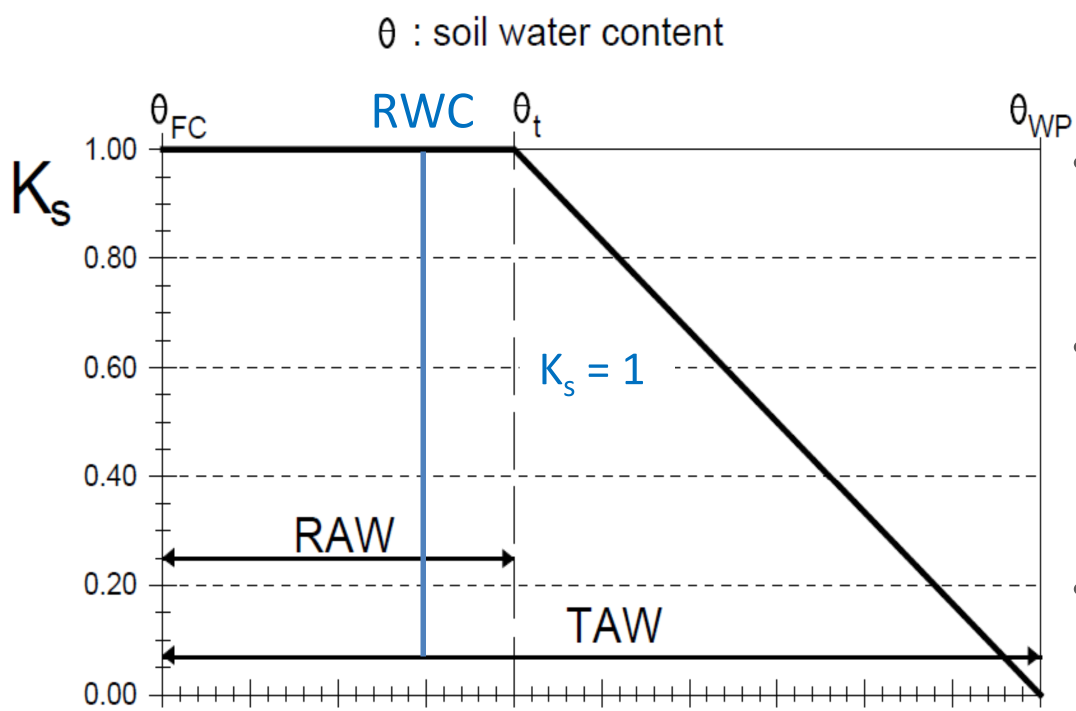
K_S-ADJUSTMENT FACTOR



- **TAW**: amount of water that a crop can extract from its root zone
- **RAW**: fraction of TAW that a crop can extract from the root zone without suffering water stress
- **RWC**: water content of the root zone

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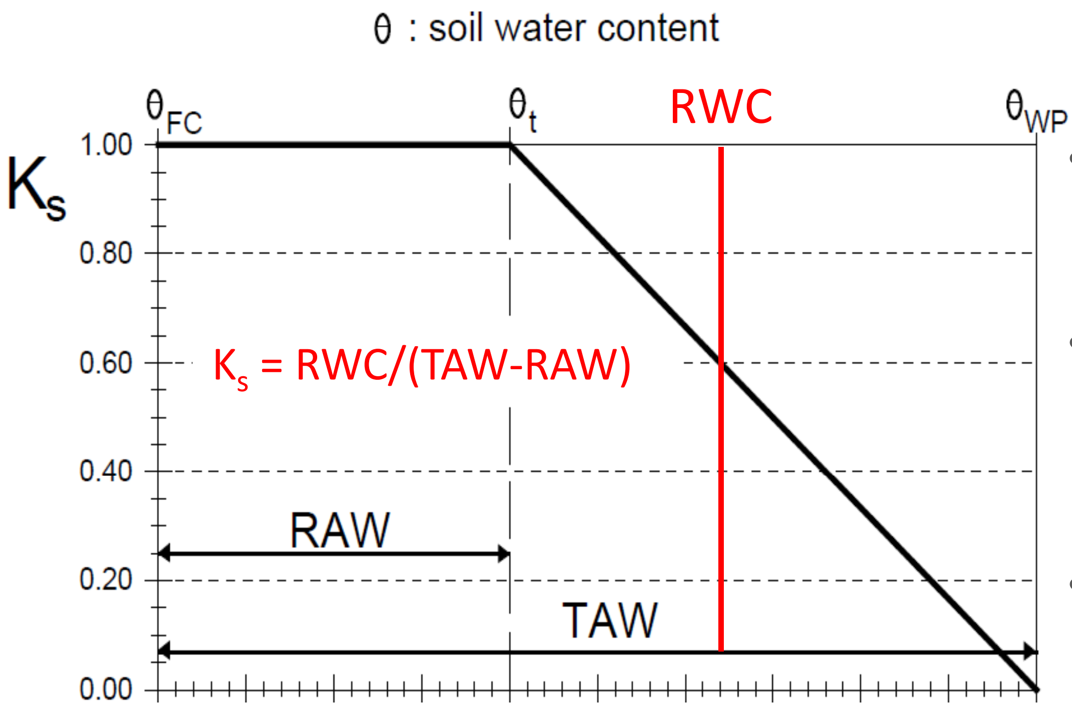
K_S-ADJUSTMENT FACTOR



- **TAW**: amount of water that a crop can extract from its root zone
- **RAW**: fraction of TAW that a crop can extract from the root zone without suffering water stress
- **RWC**: water content of the root zone

RWC CALCULATIONS

- Different from FAO 56
  - 2 cascading water layers
    - Root zone
    - Potential root zone
  - Allows water to be stored below root zone
  - Daily instantanuous calculations

$$RWC_t = \min \left| \begin{array}{l} RWC_{t-1} - ETa_{t-1} - R_{t-1} + IR_{t-1} + TR_t - BPR_{t-1} \\ RWCAP_t \end{array} \right.$$

$$PRWC_t = \min \left| \begin{array}{l} PRWC_{t-1} + BPR_t - TR_t - PERC_t \\ PRWCAP_t \end{array} \right.$$

CROP YIELD ESTIMATION

- Water budget calculations
  - K_s
  - ET_{actual}
  - Relative evapotranspiration deficits
  - Linear constraints
- Relative evapotranspiration crop yield estimates
  - Doornbos and Kassam
    - Linear
  - Stewart multiplicative
    - Non-linear

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CROP YIELD ESTIMATION

- Water budget calculations
  - K_s
  - ET_{actual}
  - Relative evapotranspiration deficits
  - Linear constraints
- Relative evapotranspiration crop yield estimates
  - Doornbos and Kassam
    - Linear
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RESULTS

- Maize
- Soil water holding capacities
  - 140mm/m
  - 70mm/m
- 49 years of weather data
- Worked with the net amount of water entering water budget
  - No conversion to gross water applications

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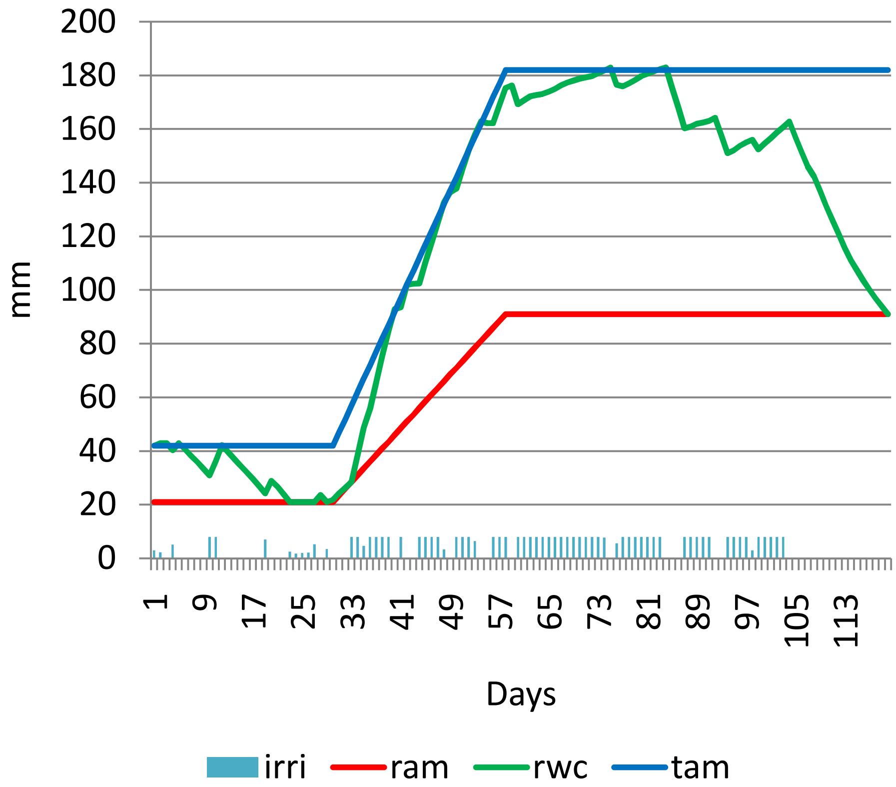

- Water holding capacity: **140mm/m**
- Yield: 16.92 ton/ha
- ET_m: 590.77 mm
- Irri: 497.27 mm
- Soil water: 93.50 mm
- Solver: **Minos**

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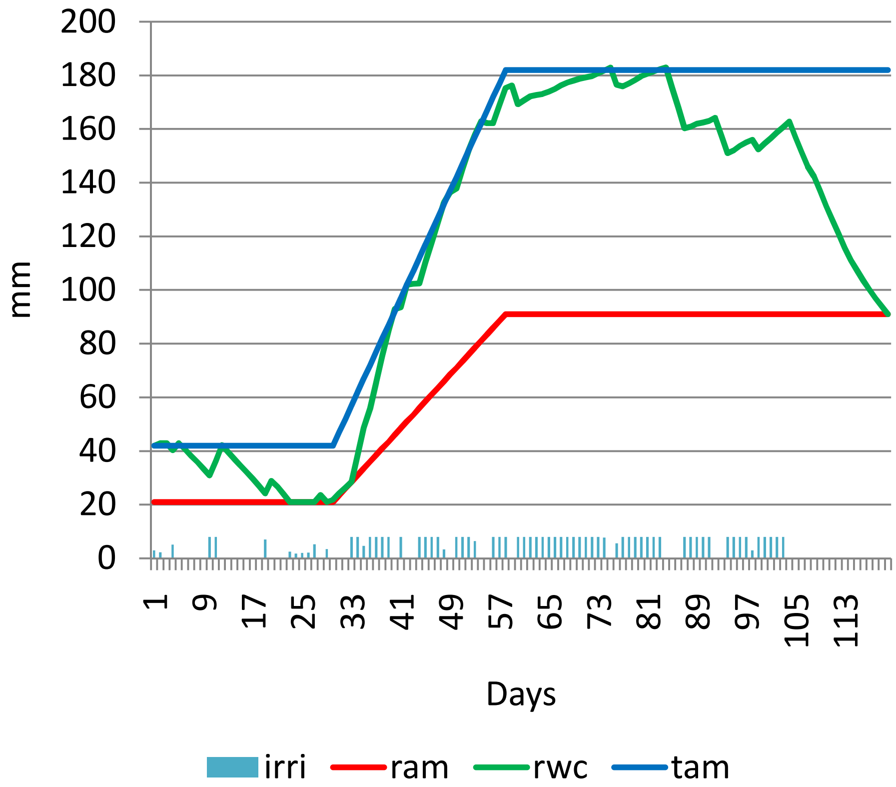

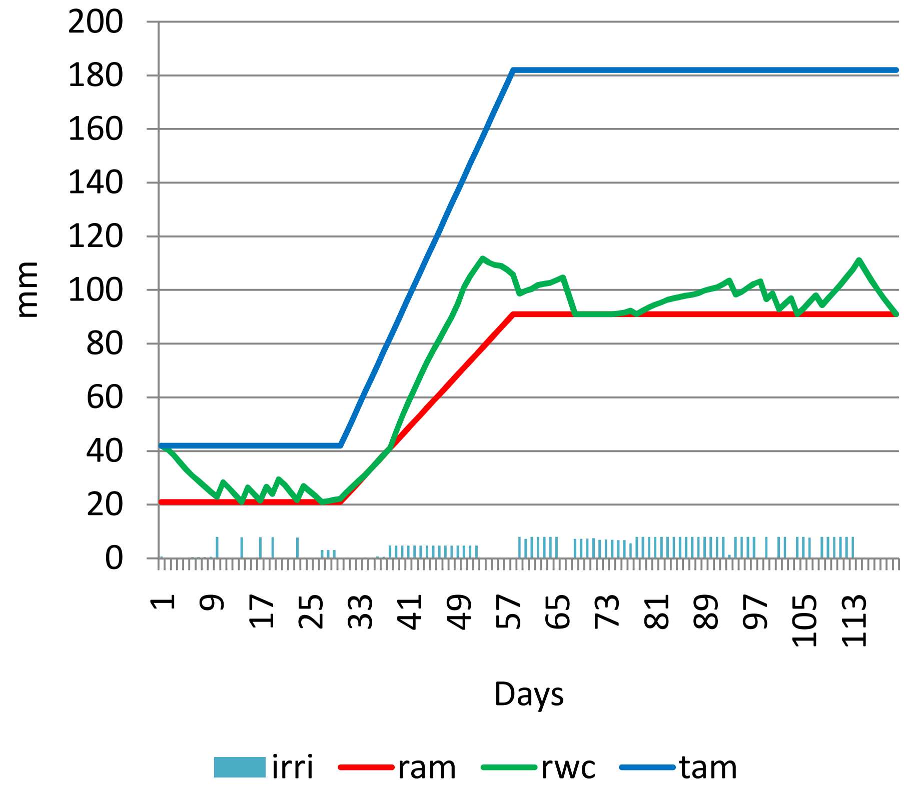

- Water holding capacity: **140mm/m**
- Yield: 16.92 ton/ha
- ET_m: 590.77 mm
- Irri: 497.27 mm
- Soil water: 93.50 mm
- Solver: **Minos**

- Water holding capacity: **140mm/m**
- Yield: 16.92 ton/ha
- ETm: 590.77 mm
- Irri: 497.27 mm
- Soil water: 93.50 mm
- Solver: **Conopt**

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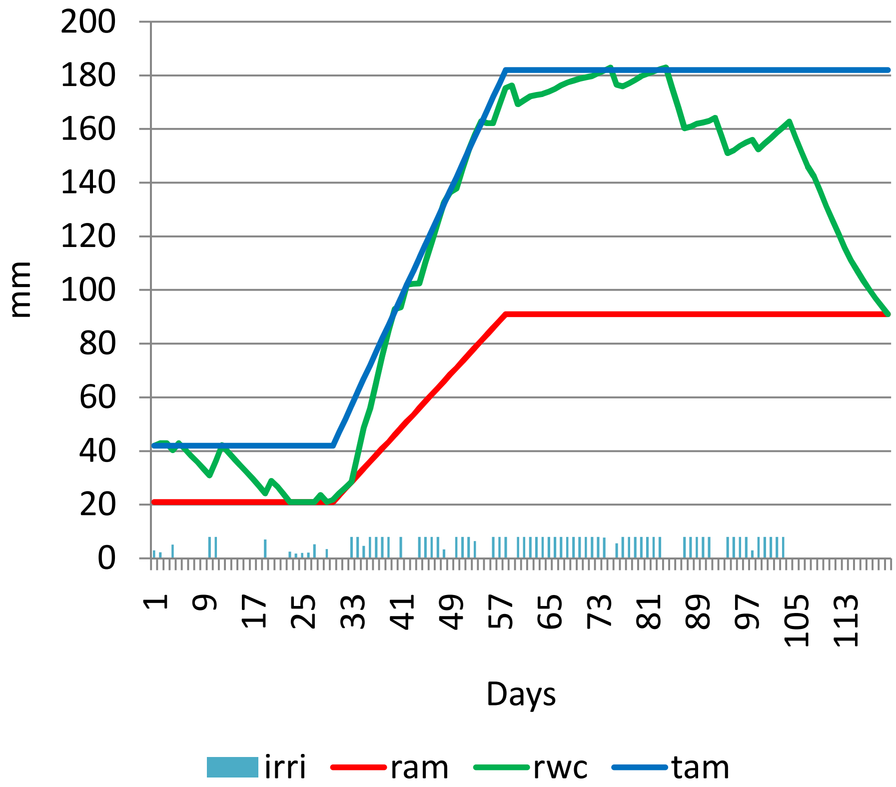

- Water holding capacity: **140mm/m**
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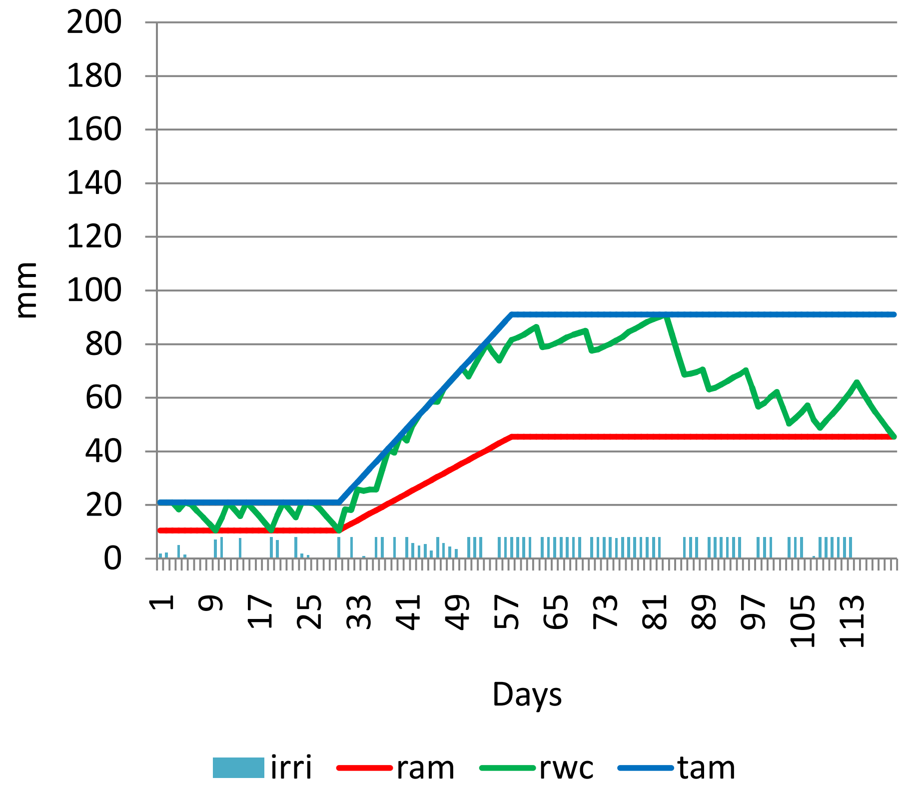
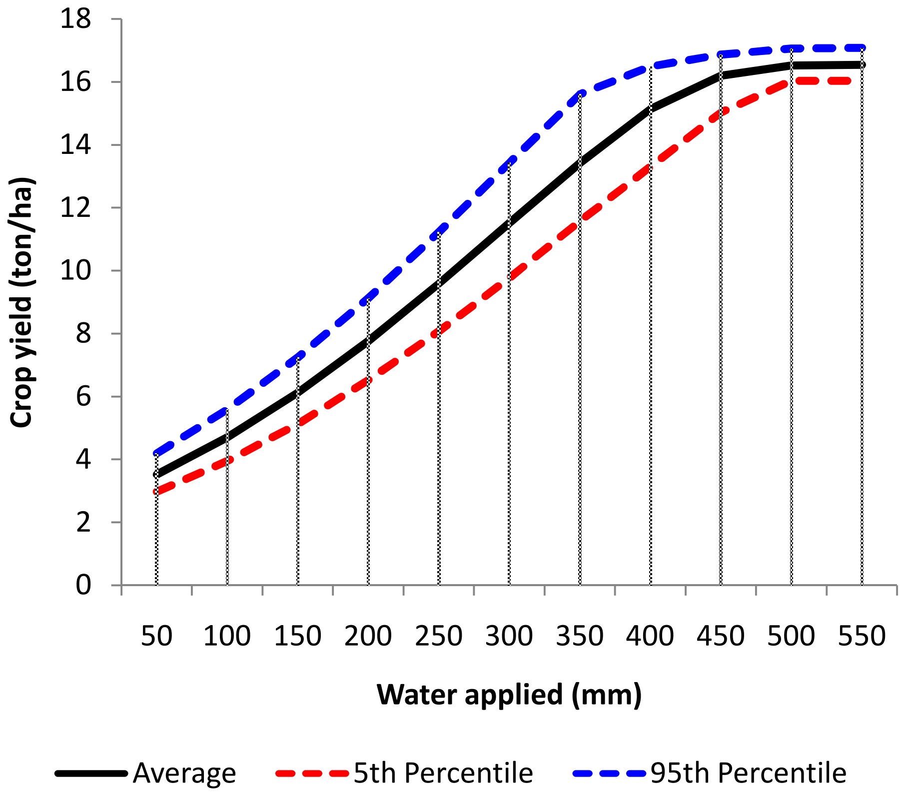
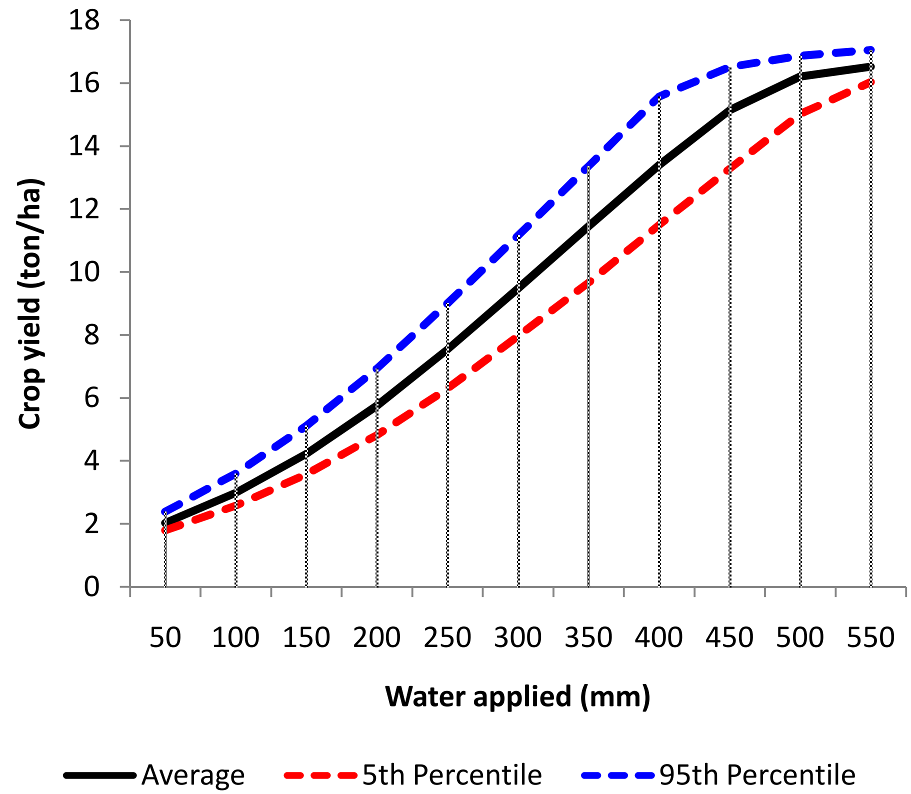
- Soil water: 93.50 mm
- Solver: **Minos**



- Water holding capacity: **70mm/m**
- Yield: 16.92 ton/ha
- ETm: 590.77 mm
- Irri: 542.77 mm
- Soil water: 48.00 mm
- Solver: **Minos**





- Water holding capacity: **140mm/m**
- Solver: **Minos**

- Water holding capacity: **70mm/m**
- Solver: **Minos**

CONCLUSIONS

- Verified that we are able to replicate SAPWAT within a MP framework
- Uses readily available data from SAPWAT
  - ET_0
  - Kc
  - Root growth

FUTURE DEVELOPMENTS

- Dual Kc approach
  - Add evaporation layer
- Net to gross module
  - 3 water budgets
    - Distribution uniformity
- Multiple crops/fields
- Energy accounting module

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Thank You

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