

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

B Grové, P van Heerden and M Venter

T: +27(0)51 401 9111 | info@ufs.ac.za | www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



OUTLINE

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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



“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 ?

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



ALTERNATIVE OPTIMISATION METHODS: MP-SEASONAL

	<u>Irrigation 1</u>	<u>Availability</u>	<u>Deficit / Surplus</u>
Total	595	595	0

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



ALTERNATIVE OPTIMISATION METHODS: MP-DISAGGREGATED

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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

ALTERNATIVE OPTIMISATION METHODS: MP-DISAGGREGATED (YIELD REDUCTION)

	<u>Irrigation 1</u>	<u>Availability</u>	<u>Deficit / Surplus</u>	
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		

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



ALTERNATIVE OPTIMISATION METHODS: MP-DISAGGREGATED (YIELD REDUCTION)

None of these methods
considers soil water supply
as a stock resource!

	17	10	35	25
Total	595	595	-5	

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



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	

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



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.

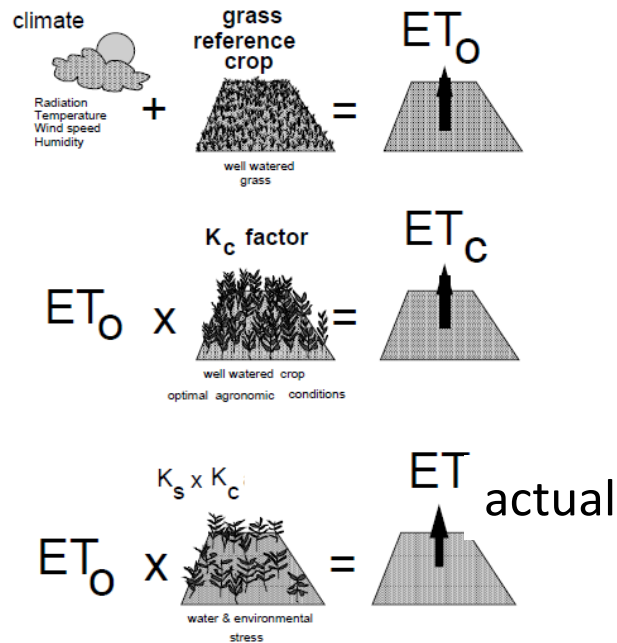
T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



PROCEDURES

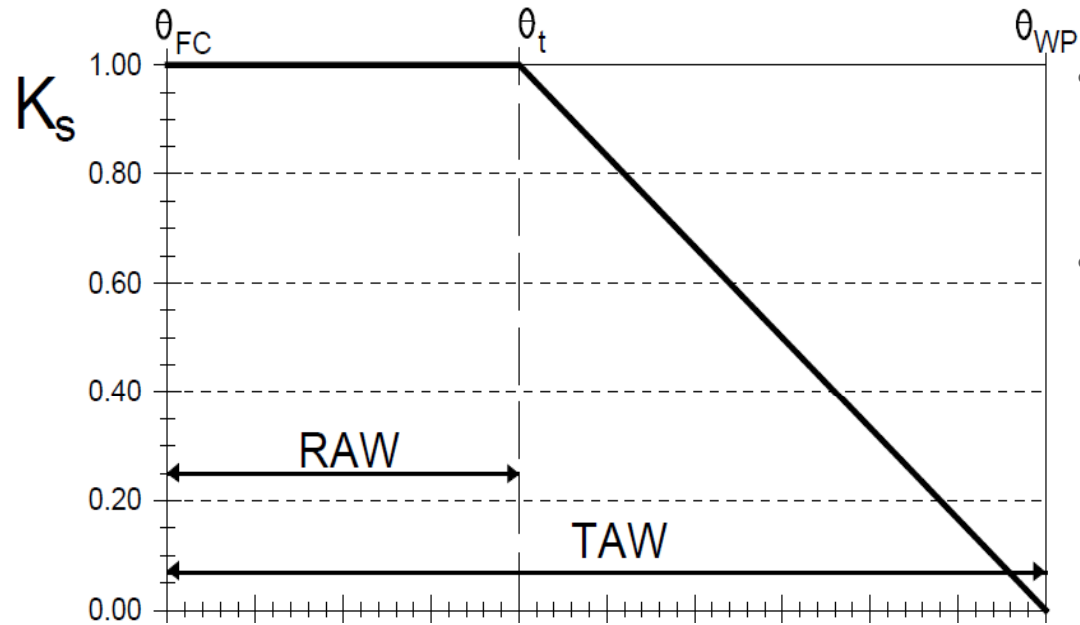


- Reference ET (ET_0)
 - Penman-Monteith
- Maximum crop ET_c
- Water stress conditions
 - ET_c is adjusted to determine ET_{actual}
 - Need water budget calculations to calculate K_s

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

K_s -ADJUSTMENT FACTOR

θ : soil water content



- **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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

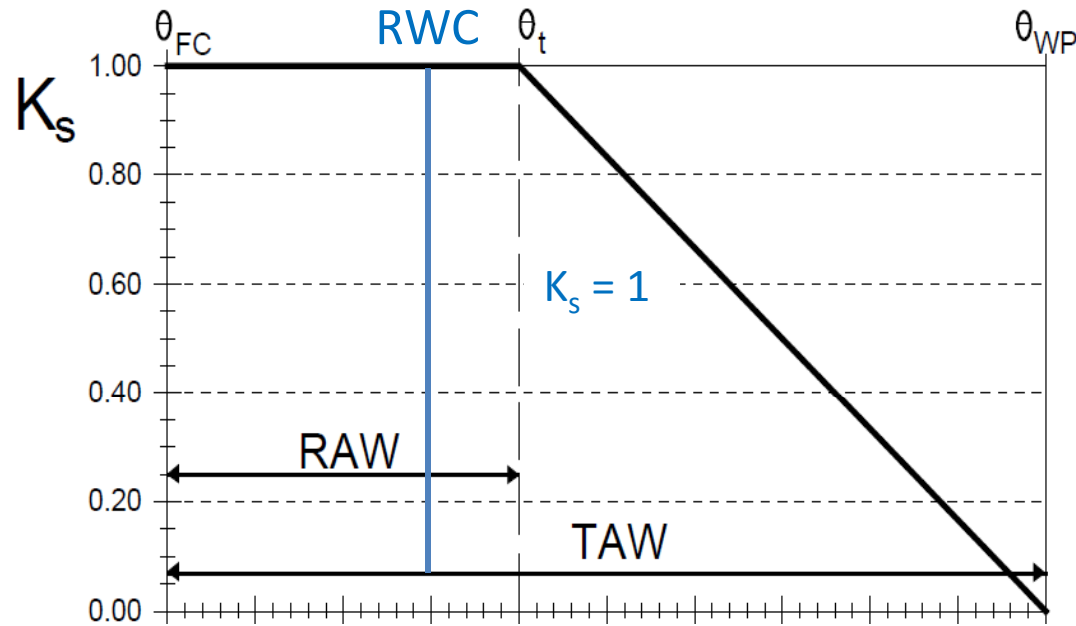
© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



K_s-ADJUSTMENT FACTOR

θ : soil water content



- **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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

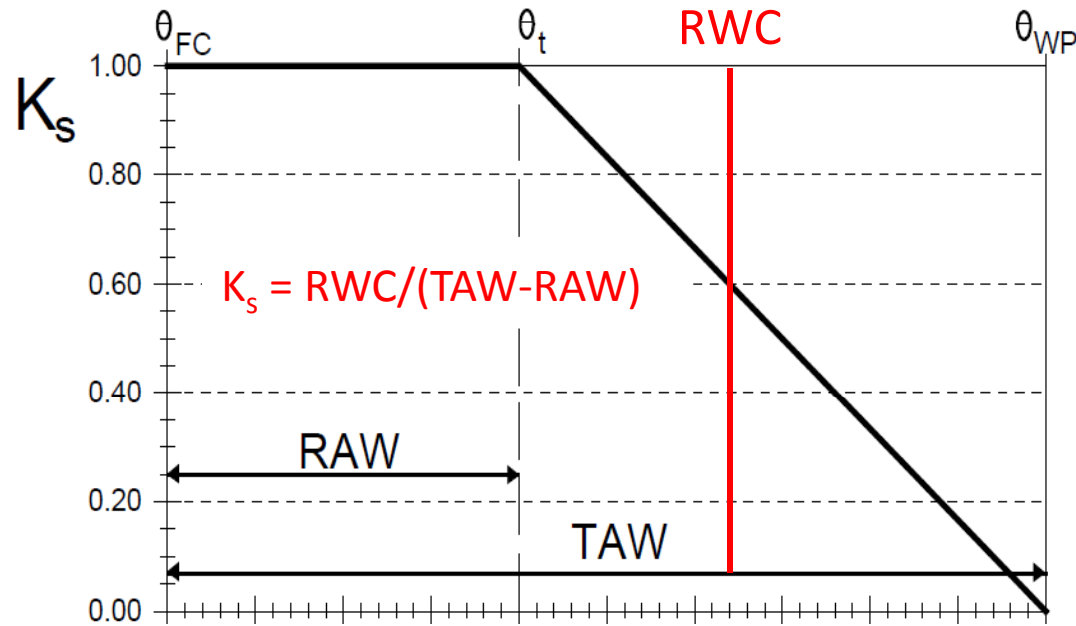


UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



K_s-ADJUSTMENT FACTOR

θ : soil water content



- **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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou



UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



RWC CALCULATIONS

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

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

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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

RESULTS

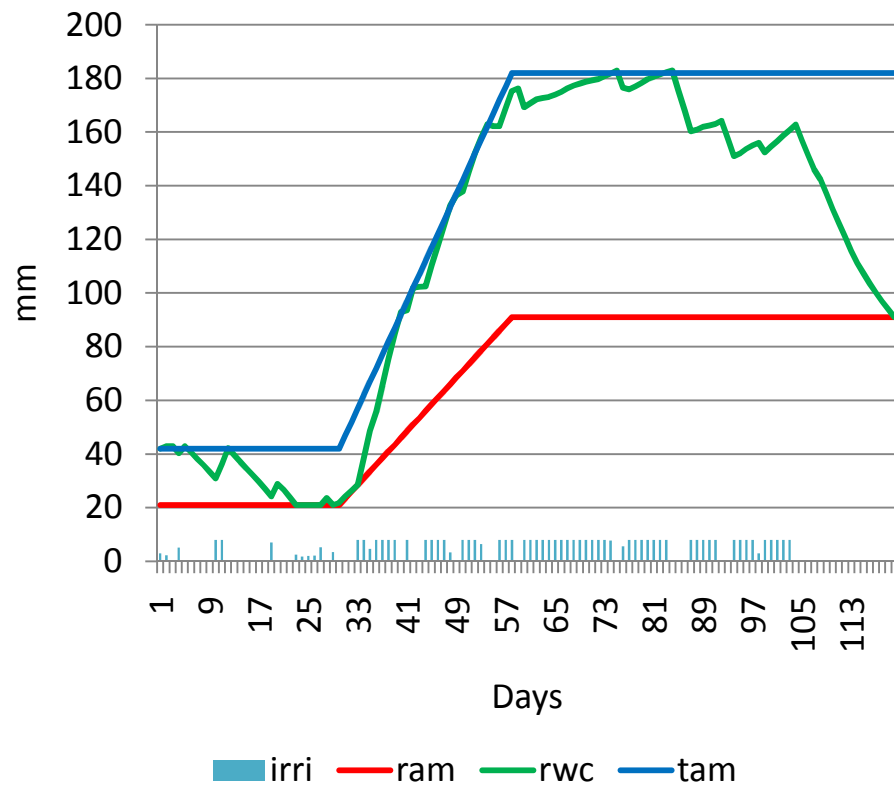
- Maize
- Soil water holding capacities
 - 140mm/m
 - 70mm/m
- 49 years of weather data
- Worked with the net amount of water entering water budget
 - No conversion to gross water applications

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

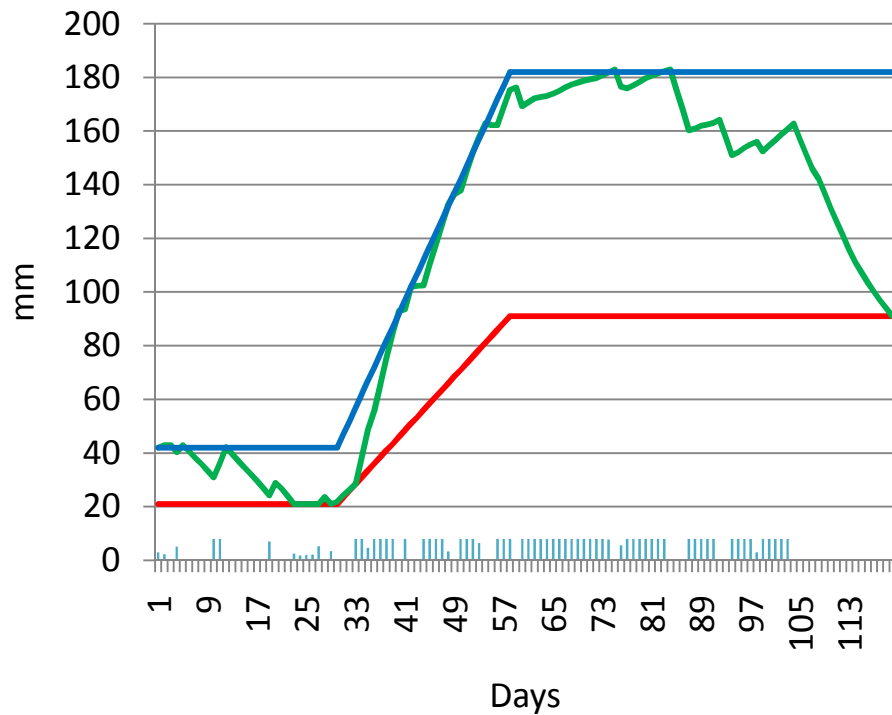
© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



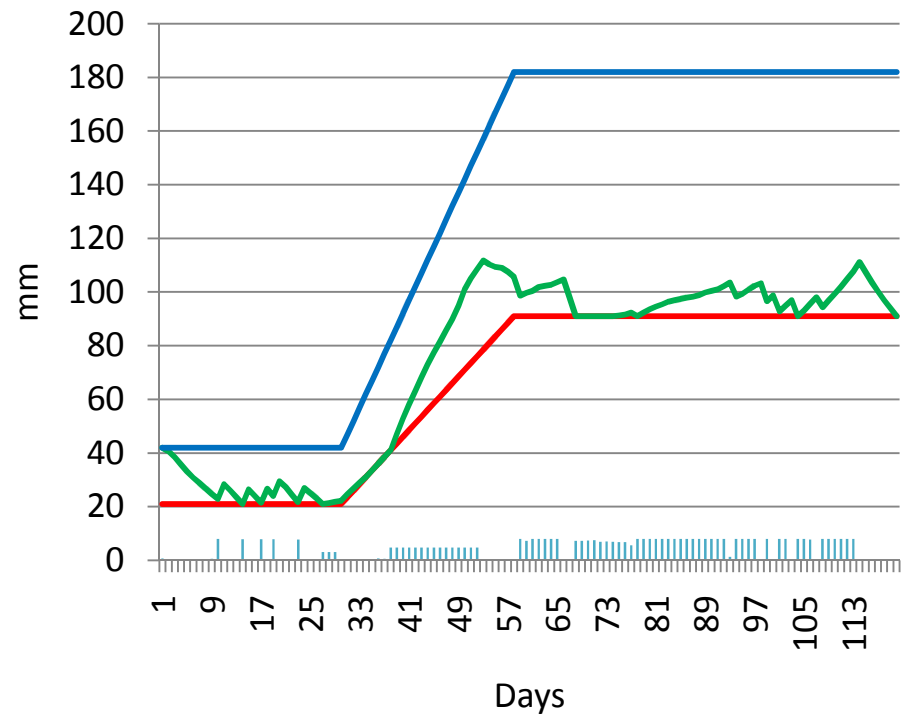


- Water holding capacity: **140mm/m**
- Yield: 16.92 ton/ha
- ET_m : 590.77 mm
- Irri: 497.27 mm
- Soil water: 93.50 mm
- Solver: **Minos**



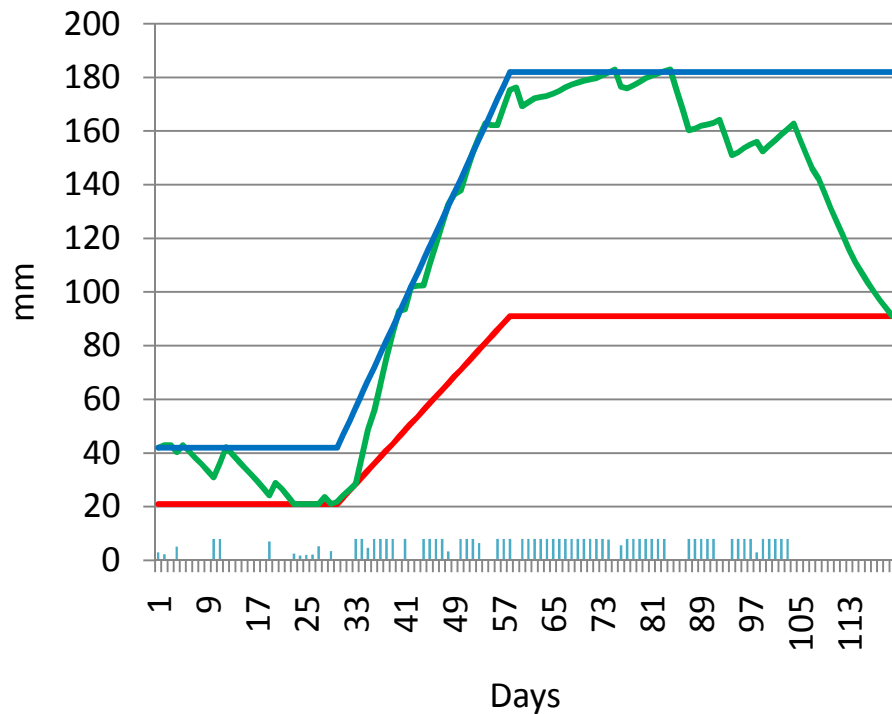
■ irri ■ ram ■ rwc ■ tam

- 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**



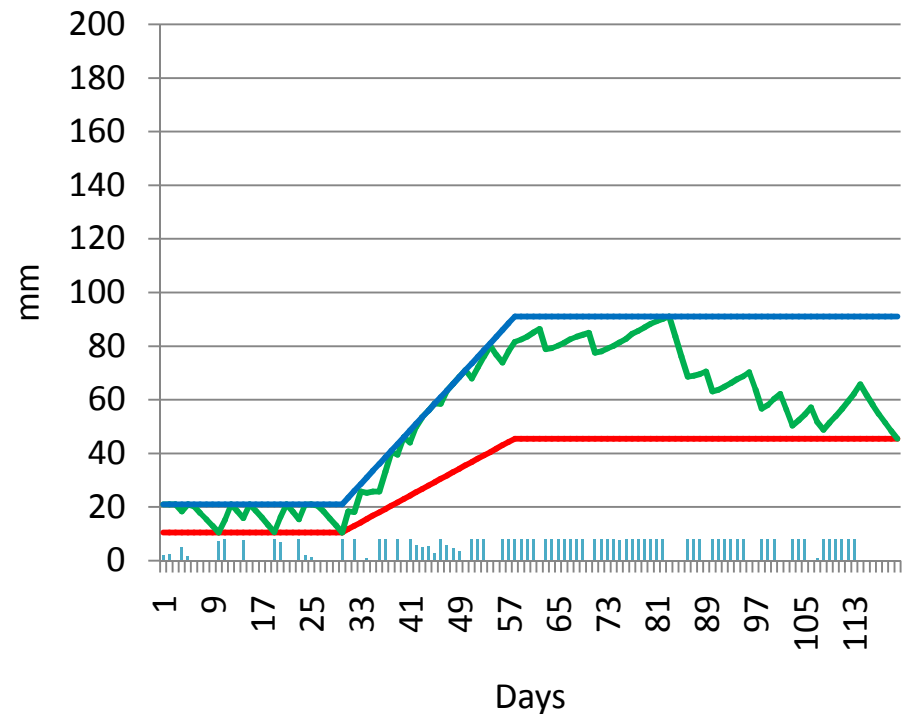
■ irri ■ ram ■ rwc ■ tam

- 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: **Conopt**



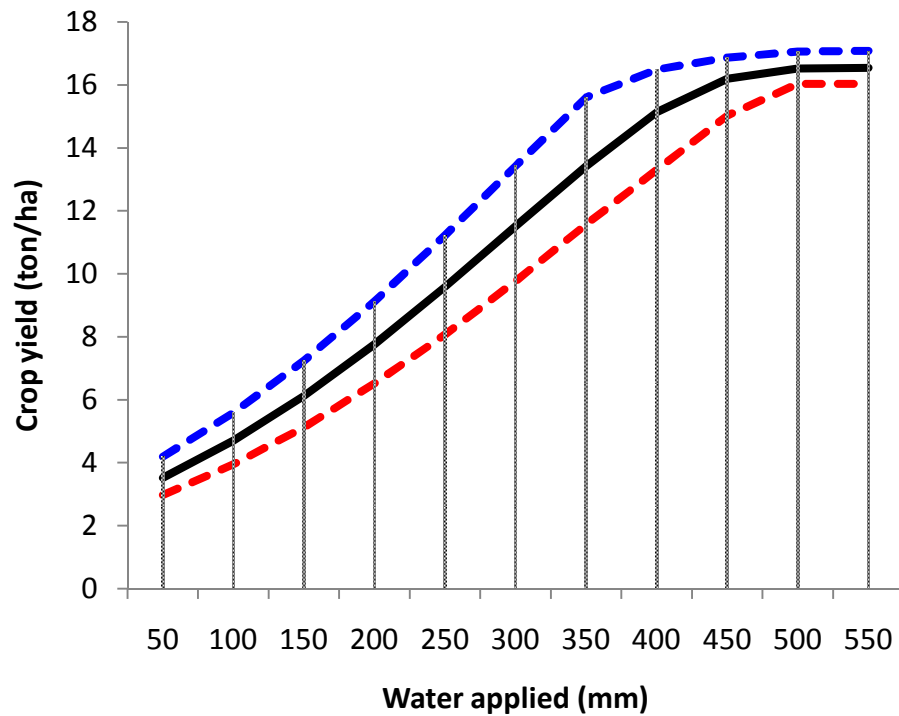
■ irri ■ ram ■ rwc ■ tam

- 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**



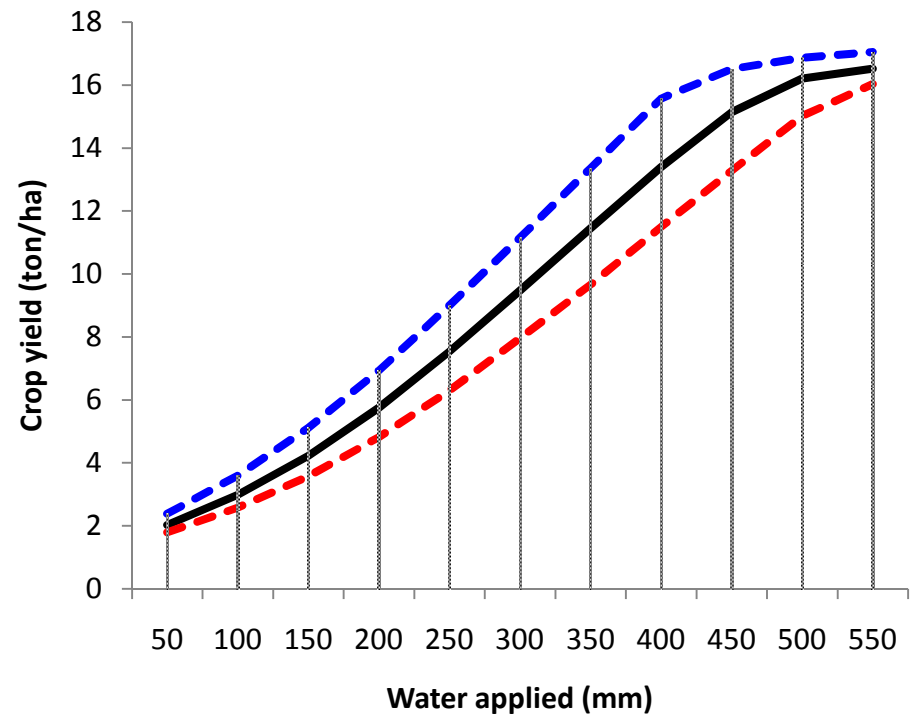
■ irri ■ ram ■ rwc ■ tam

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



— Average - - - 5th Percentile - - - 95th Percentile

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



— Average - - - 5th Percentile - - - 95th Percentile

- 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
 - K_c
 - Root growth

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



FUTURE DEVELOPMENTS

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

T: 051 401 9111 info@ufs.ac.za www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA



Thank You



WATER
RESEARCH
COMMISSION

T: +27(0)51 401 9111 | info@ufs.ac.za | www.ufs.ac.za

© Copyright reserved
Kopiereg voorbehou

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA

