Modeling vadose zone and water table interactions at field scale in the Lower Mondego Valley, Portugal

Manuel Nunes [1,2]

José M. Gonçalves [1,2]

Tiago B. Ramos [1,3]

João L.M.P. de Lima [4]

Luis S. Pereira [1]

[1] *LEAF, Institute of Agronomy, University of Lisbon, Portugal*

[2] *Polytechnic Institute of Coimbra, College of Agriculture, Portugal*

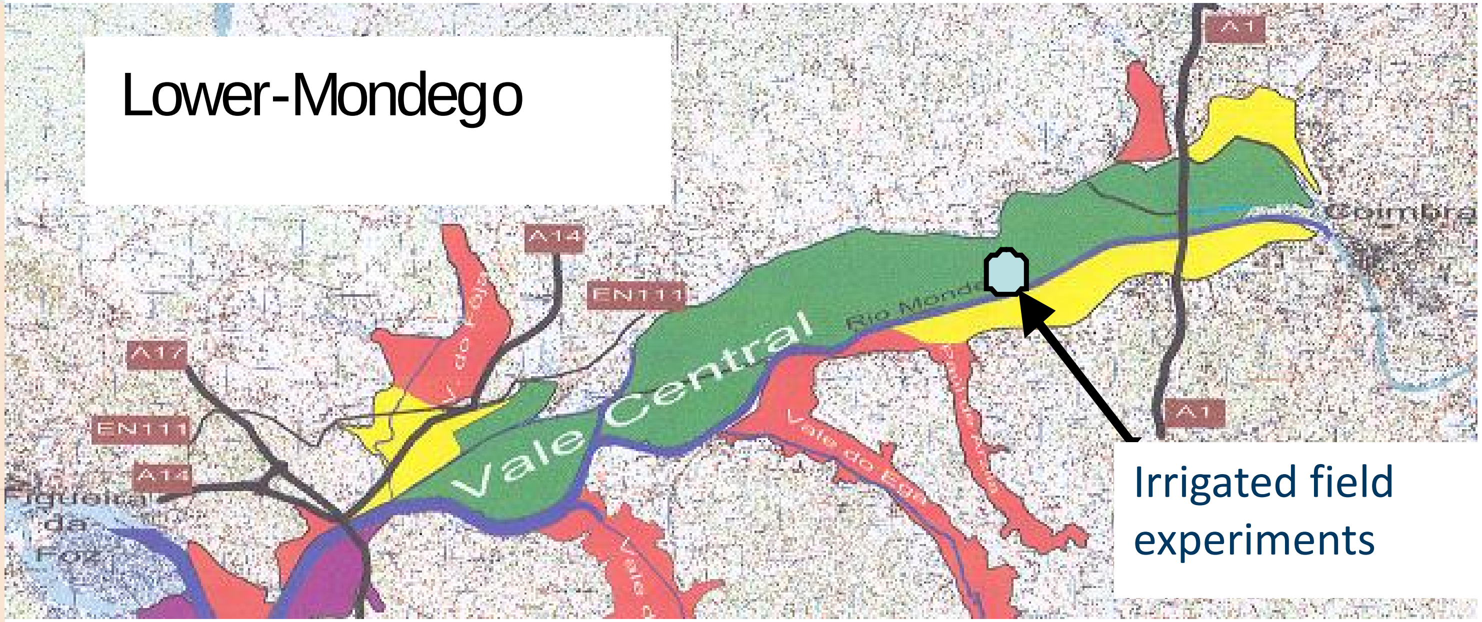
[3] *Technical High Institute, University of Lisbon, Portugal*

[4] *Department of Civil Engineering, Faculty of Science and Technology , University of Coimbra, Portugal*

Objectives

- Study hydrological flows of capillary rise and drainage in the vadose zone at field scale
- Model groundwater dynamics and its relationships with irrigation management
- Use calibrated model to test irrigation scheduling scenarios, in order to control excess irrigation

Objectives



Lower-Mondego Irrigation District is located in the Centre-West of Portugal

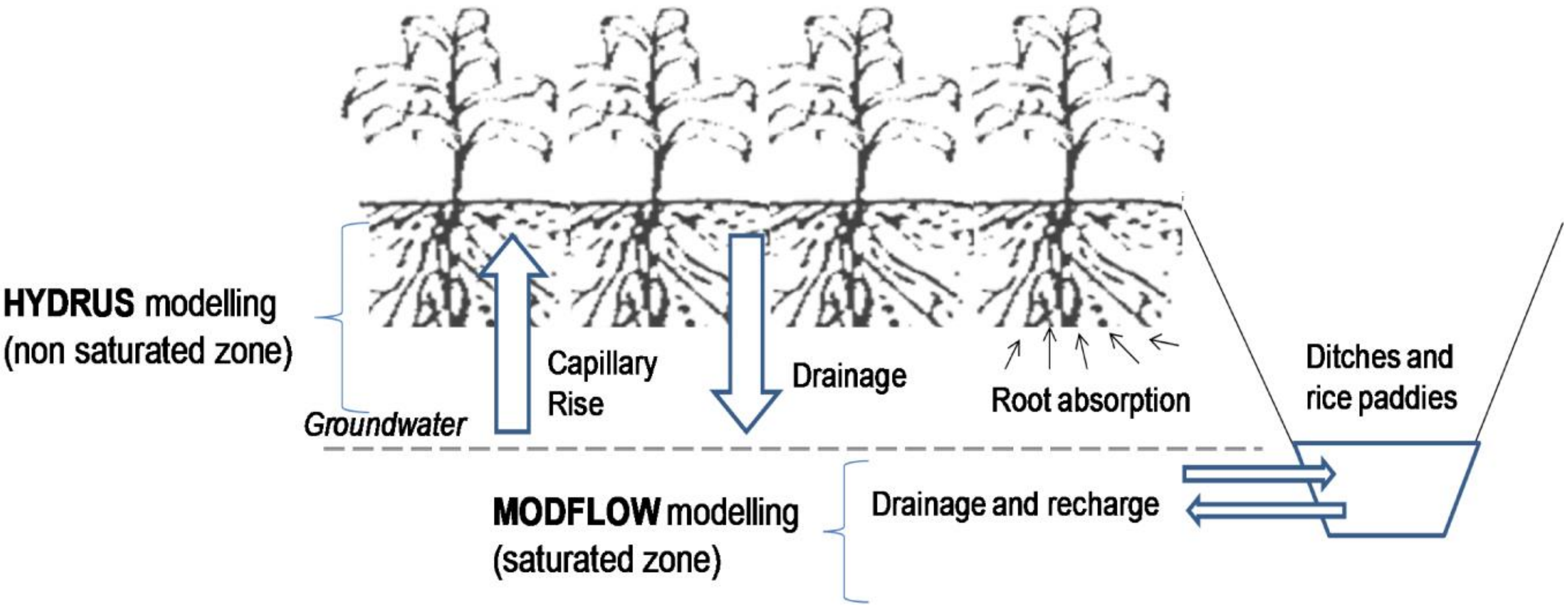
Total irrigated area around 12600 ha

Main crops: maize and paddy rice

Surface irrigation systems

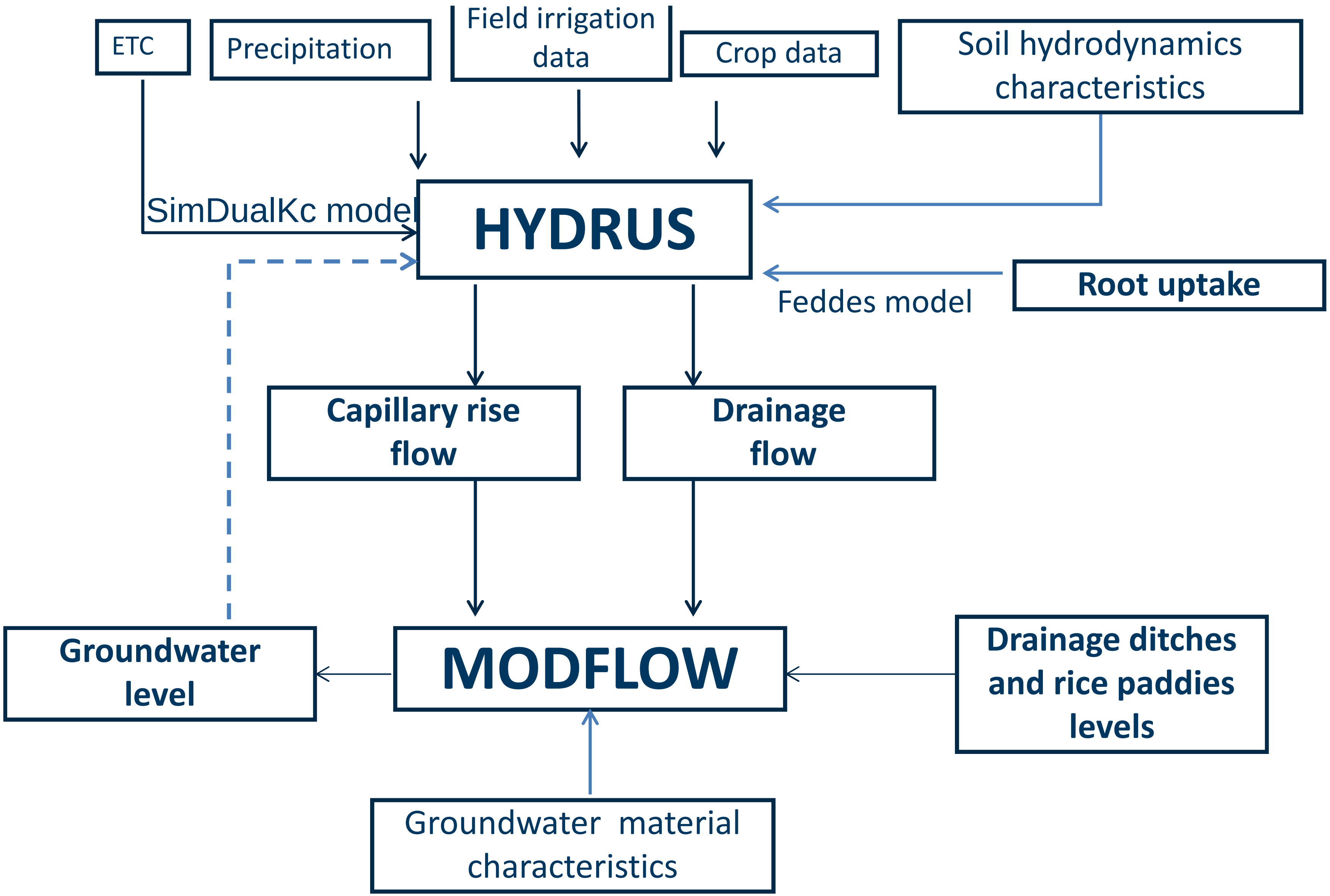
Groundwater table generally shallow rising throughout the crop season (due to paddies and irrigation excesses)

MATERIALS AND METHODS



MATERIALS AND METHODS

Model links



MATERIALS AND METHODS

HYDRUS MODEL

Soil water dynamics relationship

Richards equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\frac{\partial h}{\partial z} - K(h)\right] - S(z,t)$$

θ - volumetric soil water content [$L^3\ L^{-3}$]

h - pressure head [L],

K - hydraulic conductivity [$L\ T^{-1}$]

S - sink term accounting for water uptake [$L^3\ L^{-3}\ T^{-1}$]

MATERIALS AND METHODS

HYDRUS MODEL

Unsaturated soil hydraulic properties

van Genuchten-Mualem equations

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1 + |\alpha h|^{\eta}]^{1-1/\eta}}$$

$$K(h) = K_s \frac{\left[(1+|\alpha h|^{\eta})^{\left(1-\frac{1}{\eta}\right)} - |\alpha h|^{\eta-1}\right]^2}{(1+|\alpha h|^{\eta})^{\left(1-\frac{1}{\eta}\right)(l+2)}}$$

θ_r - residual soil water content $[L^3 L^{-3}]$

θ_s - saturated soil water content $[L^3 L^{-3}]$

K_s - saturated hydraulic conductivity $[L\ T^{-1}]$,

α, ¦ - empirical shape parameters

MATERIALS AND METHODS

Groundwater system fluxes

Darcy Equation (three dimensional groundwater flow)

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t},$$

K - saturated hydraulic conductivity along x, y, z coordinates [$L\ T^{-1}$]

h - potential head [L]

W - volumetric flux [L^3T^{-1}]

S_s - specific storage of porous material [L^{-1}]

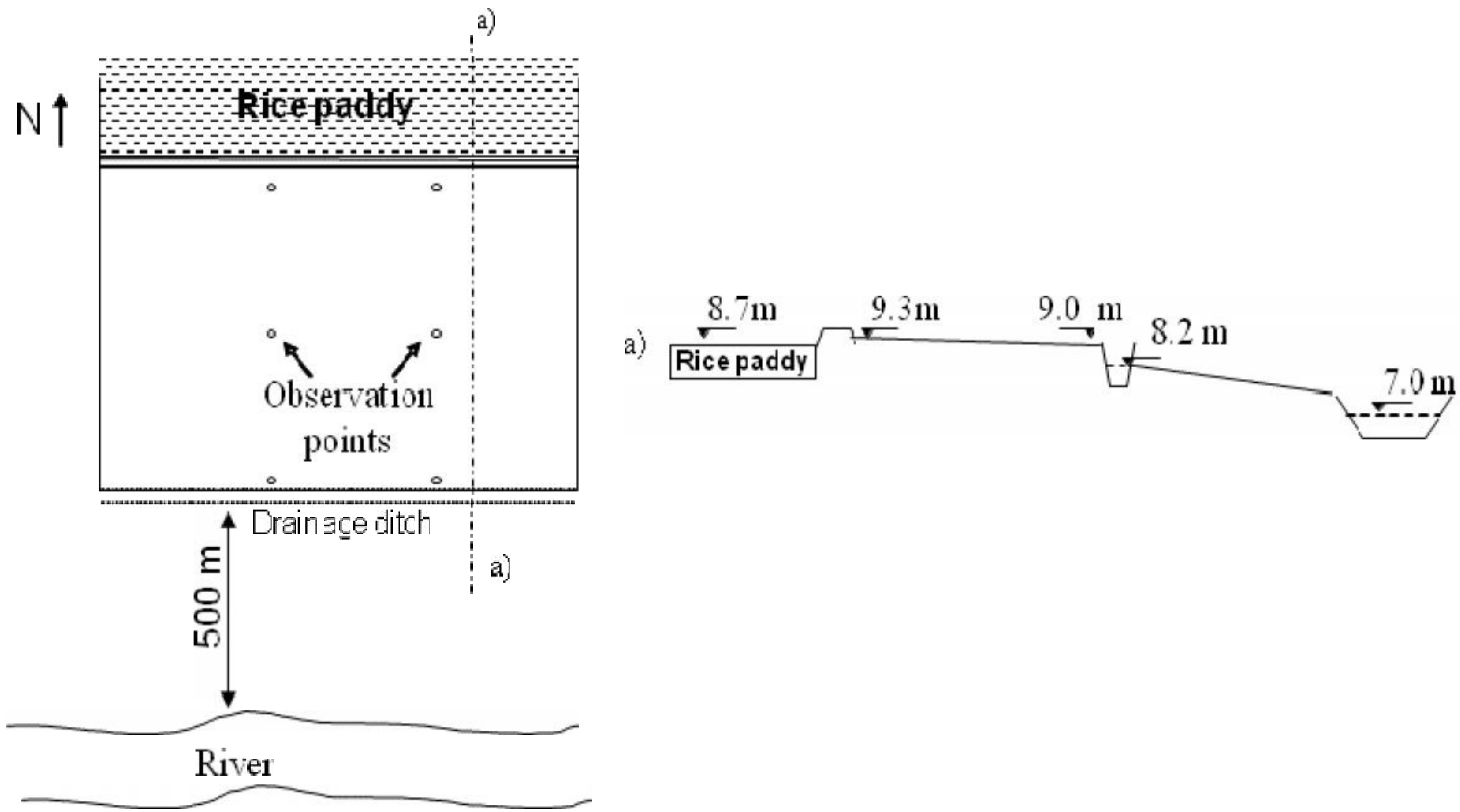
MATERIALS AND METHODS

MODFLOW packages used:

- Recharge - rain the irrigation deep percolating to the groundwater system
- Drain - removing water from the aquifer to drainage ditches
- Evapotranspiration – demand from groundwater to evapotranspiration (through capillary rise flux)
- General-head conditions - flows into field area from drainage ditches and rice paddies with high level

MATERIALS AND METHODS

Experimental field schema



Soil texture: sandy-loam

Total area: 4.0 ha (200 x 200 m)

MATERIALS AND METHODS

Field observations

MATERIALS AND METHODS

Models calibration:

HYDRUS

Soil Hydrodynamic Parameters of van Genuchten-Mualem eqs.

Root absorption model (Feddes) parameters

MODFLOW

Groundwater hydraulic parameters

Groundwater boundary conditions

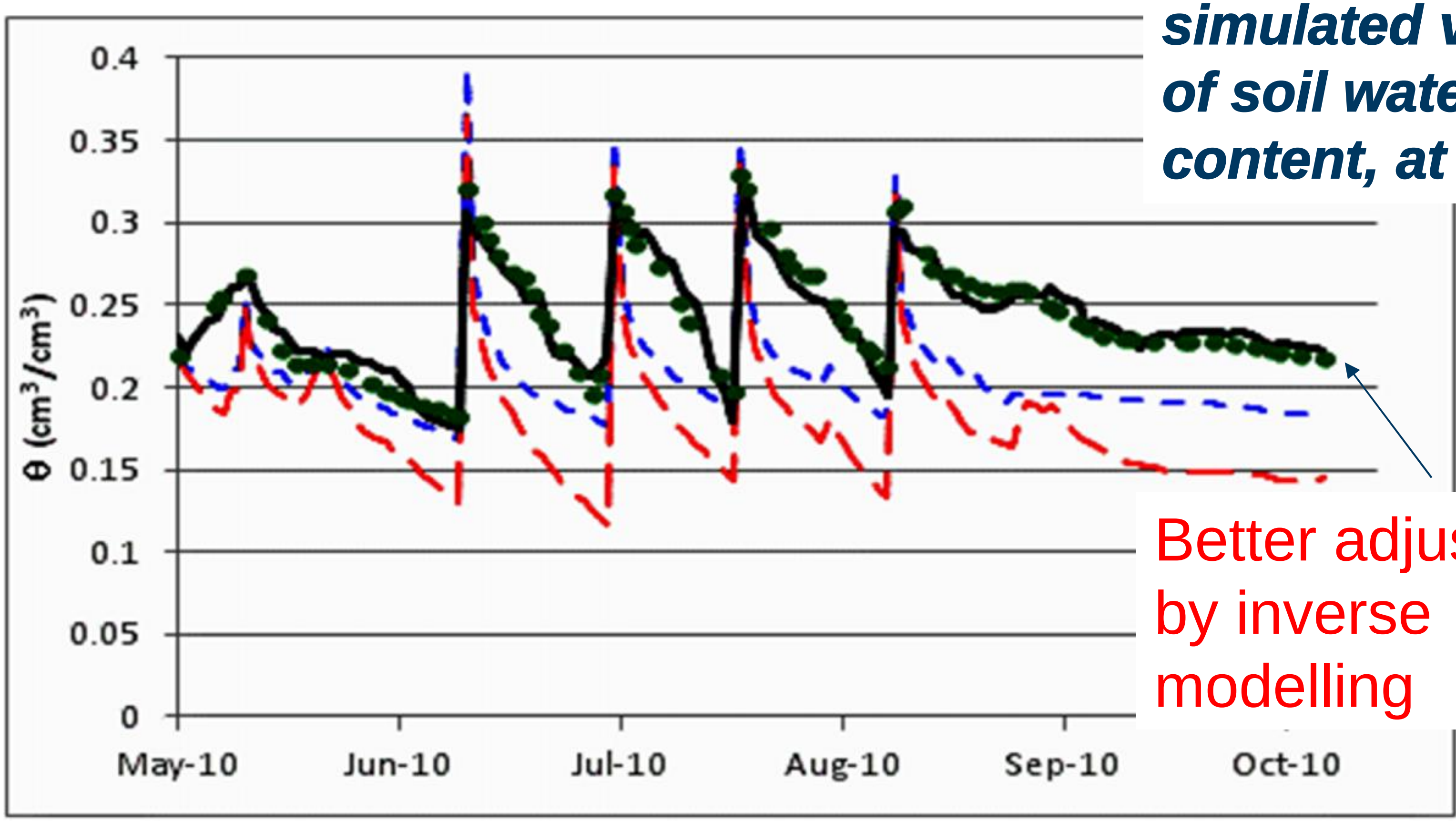
MATERIALS AND METHODS

Calibration methodology:

- Hydrodynamic parameters from laboratory
- Hydrodynamic parameters pedotransfer functions (Rosetta)
- Parameters from inverse modeling

RESULTS

HYDRUS calibration



Measured and simulated values of soil water content, at 20 cm

Better adjustment by inverse modelling

- ***Observation with TDR***

— — ***Simulation with parameters from laboratory***

- - ***Simulation with parameters from pedotranfer function***

____ ***Simulation with inverse modelling***

RESULTS

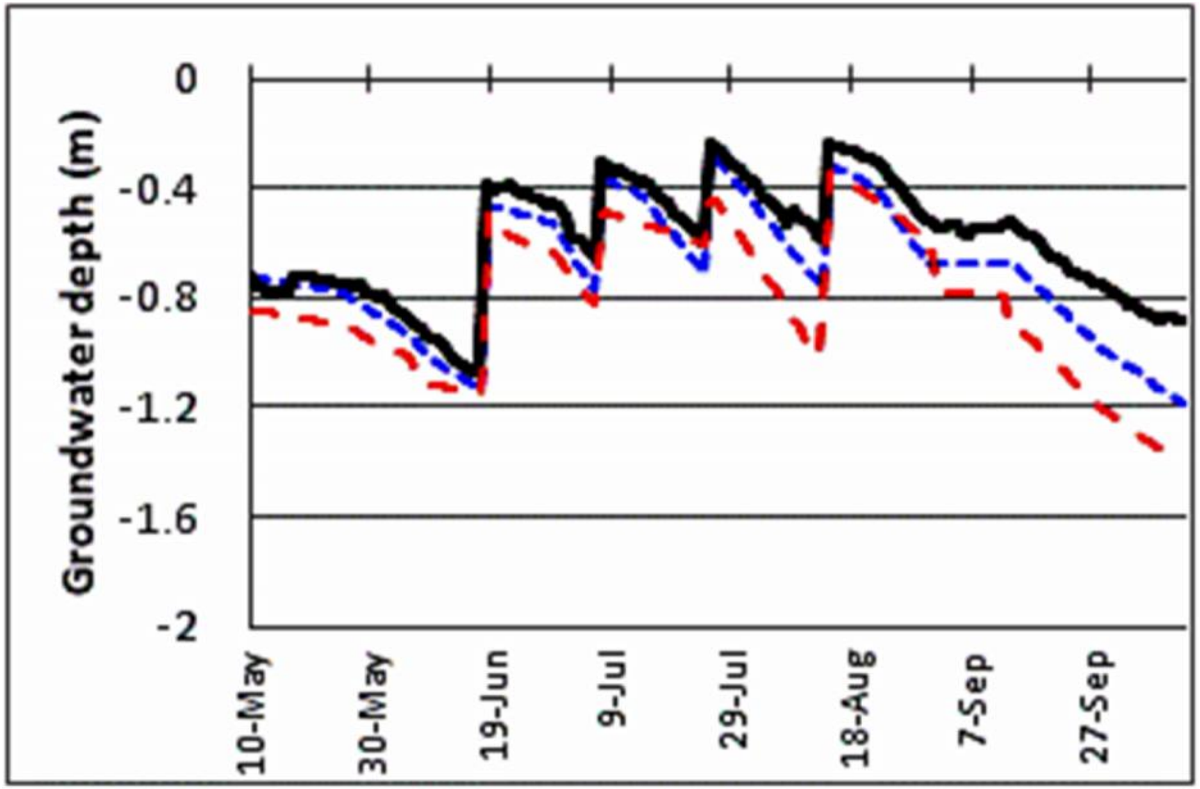
HYDRUS calibrated parameters

Parameter	Depth (cm)			
	20	40	70	100
θ_r ($m^3 m^{-3}$)	0.022	0.006	0.002	0.007
θ_s ($m^3 m^{-3}$)	0.438	0.426	0.376	0.408
Bulk density (g cm^{-3})	1,347	1.417	1.591	1.617
K_s (cm d^{-1})	623.4	287.8	748.9	15.68
α (cm^{-1})	0.196	0.135	0.125	0.010
η (-)	1,095	1.186	1,257	1.026
l (-)	-1.0	-1.0	-1.0	-1.0

RESULTS

MODFLOW calibration results

Measured and simulated values of groundwater depth



Parameter	*Labor.*	*Inv. Mod.*
Ks (m d^{-1})	0.148	0.125
Cd (m^2 d^{-1})	5.2	4.6
Specific storage (m^{-1})	1.1×10^{-4}	1.1×10^{-4}
Impermeable layer depth (m)	2	2

- ***Observation in piezometric tubes***

-- ***Simulation with parameters*** from laboratory observations

- - ***Simulation with using inverse modeling and ajusting hydraulic condutance***

RESULTS

Modeling water saving scenarios

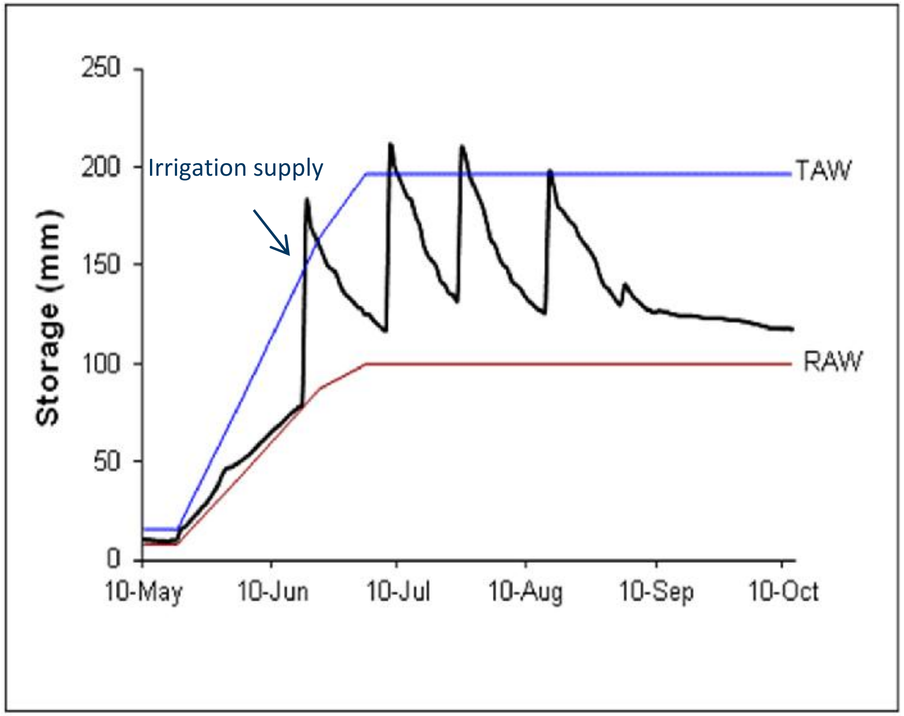
Scenarios:

- Farmer management (field observed, with 4 irrigation events)
- Water saving with 3 irrigation events, using the field observed irrigation depth, aiming:
  - Minimizing water excess in the cropping season
  - Keeping water storage at ideal levels to get maximum yield

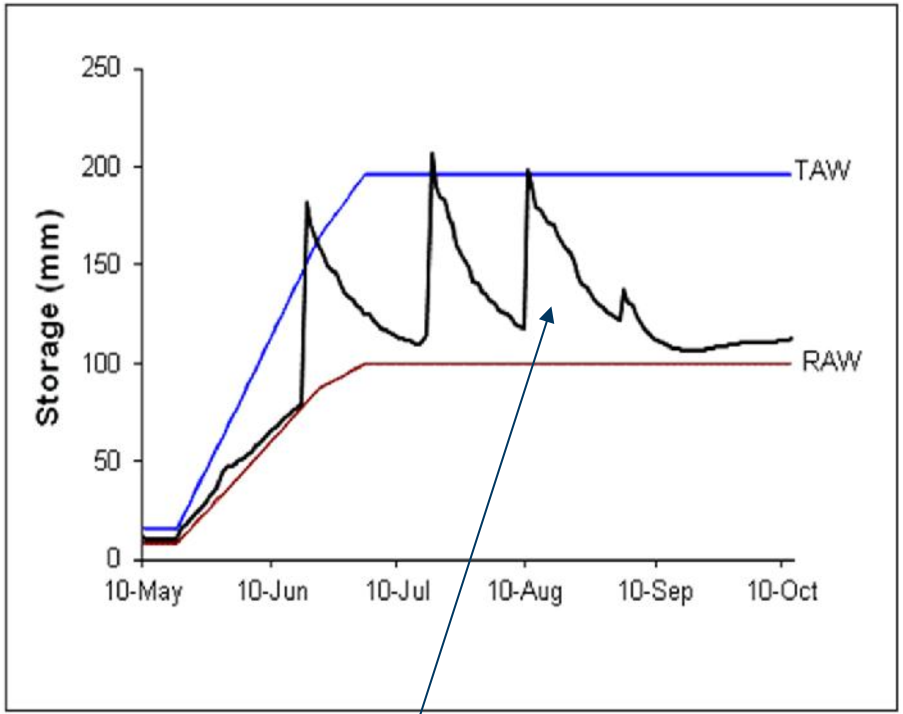
RESULTS

Soil water storage modeling

4 irrigation events
(farmer management)



3 irrigation events
(water saving)



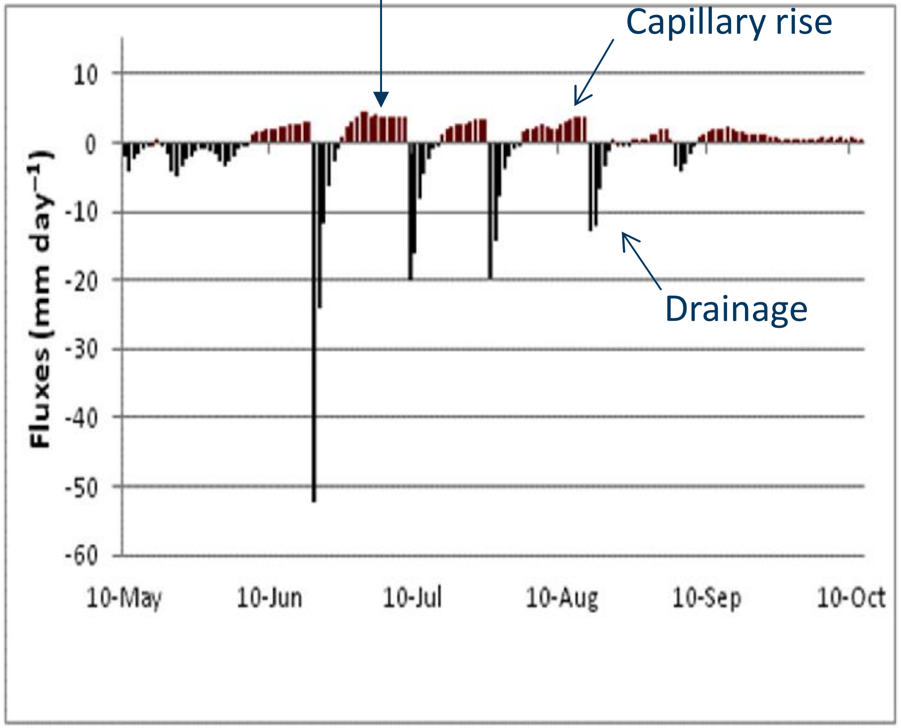
Water storage at ideal
during all season

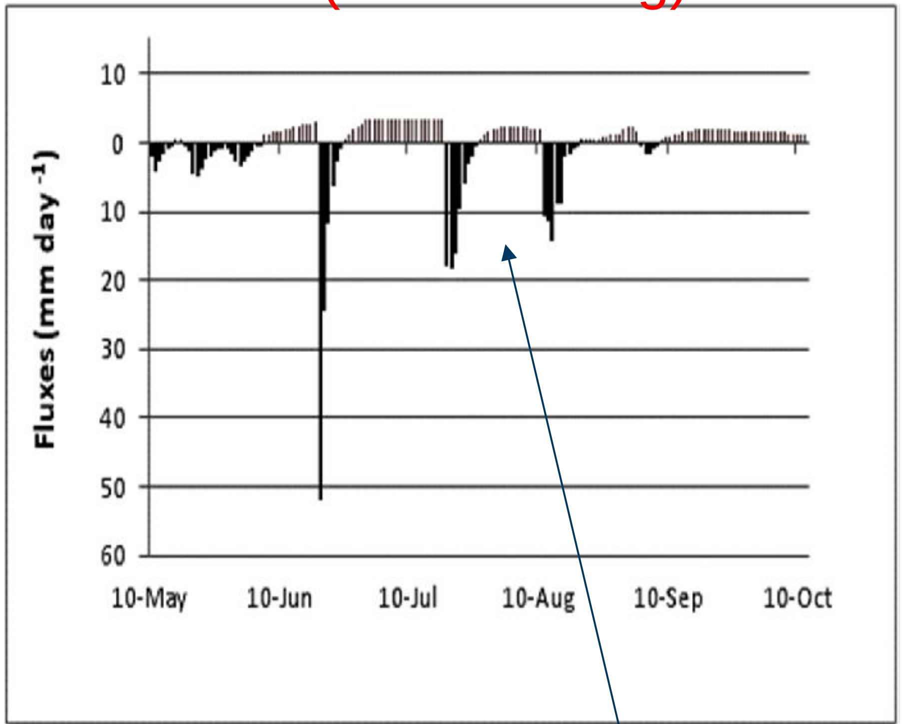
RESULTS

Fluxes in vadose zone

Importance of capillary rise fluxes

3 irrigation events (water saving)



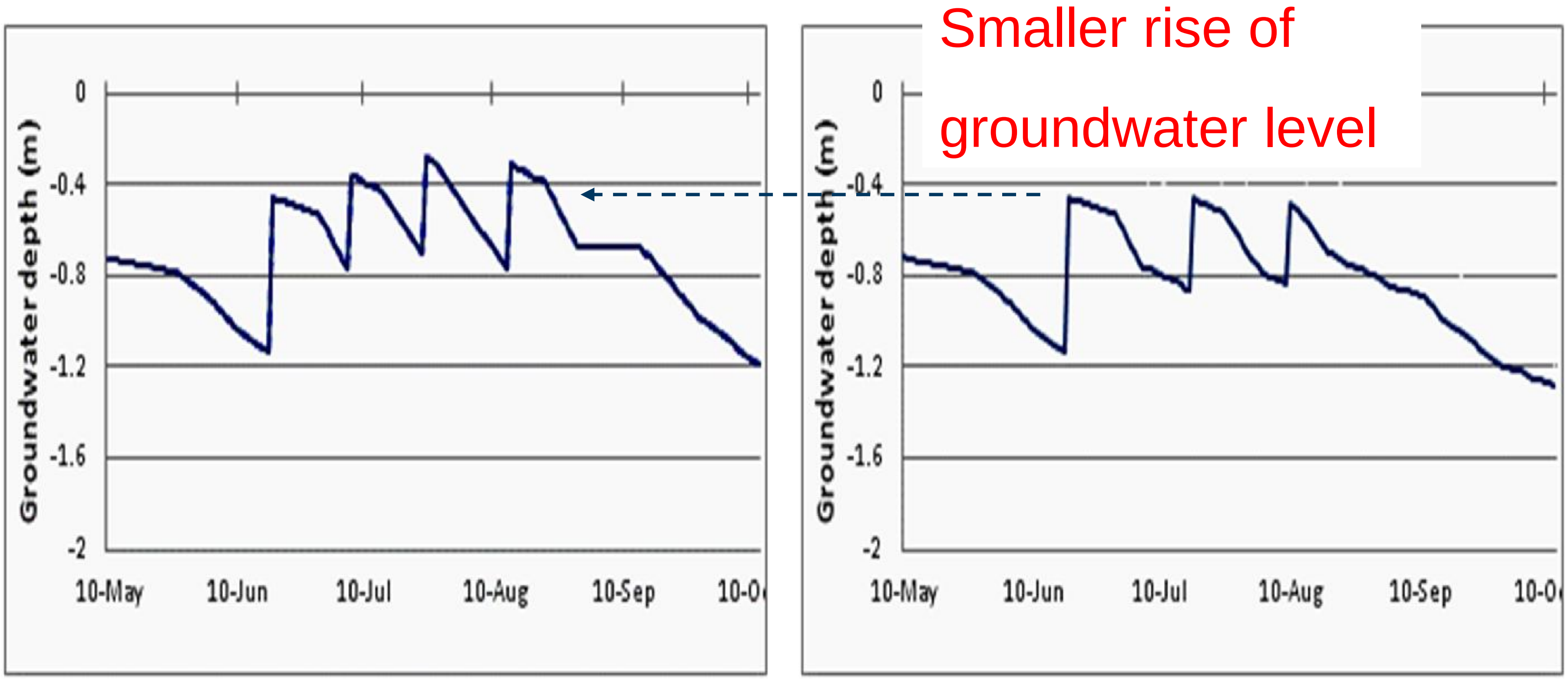


4 irrigation events (farmer management)

Reducing of drainage fluxes

RESULTS

Groundwater level modeling



DISCUSSION AND CONCLUSION

Combination of HYDRUS and MODFLOW models may be an important tool for simulate different scenarios of irrigation management

The calibration of these models is determinant

DISCUSSION AND CONCLUSION

The adequacy of Rosetta pedotransfer functions for HYDRUS calibration is questionable in the field conditions observed

The use of soil hydraulic parameter measured in the laboratory is a first step to HYDRUS calibration, followed by the inverse modeling

MODLOW calibration has an added difficulty due to the adjustment of the boundary conditions

Modeling results led to predict that water use could be improved by adjusting the irrigation schedule

Gracias

Thank you