MODELING WATER AND NITROGEN FATE FROM SWEET SORGHUM IRRIGATED WITH FRESH AND BLENDED SALINE WATERS USING HYDRUS-2D

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OBJECTIVES

The Alentejo region of southern Portugal normally exhibits high summer temperatures and very low rainfall that limit crop production.

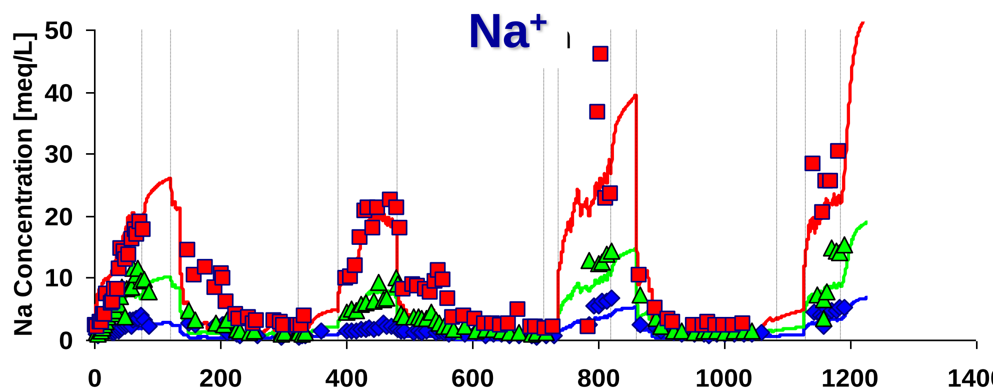
In this water scarce region, irrigation plays a fundamental economical and social role but has enhanced several environmental problems as a result of poor irrigation and water management practices.

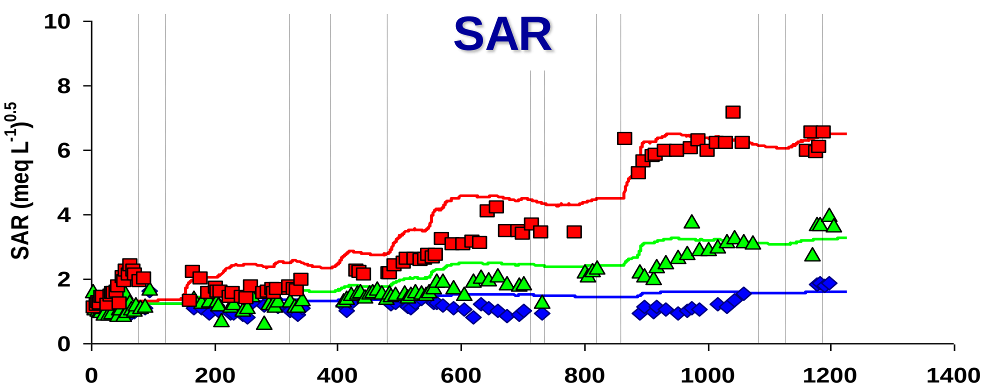
Human-induced salinization and sodification, and non-point source pollution from agricultural fertilization are among the recognized problems.

Modeling of subsurface water flow and the transport of major soluble ions in and below the root zone is essential for predicting groundwater quality, implementing better irrigation and fertilization practices

PREVIOUS STUDIES

Salt transport in soil lysimeters with the UNSATCHEM model

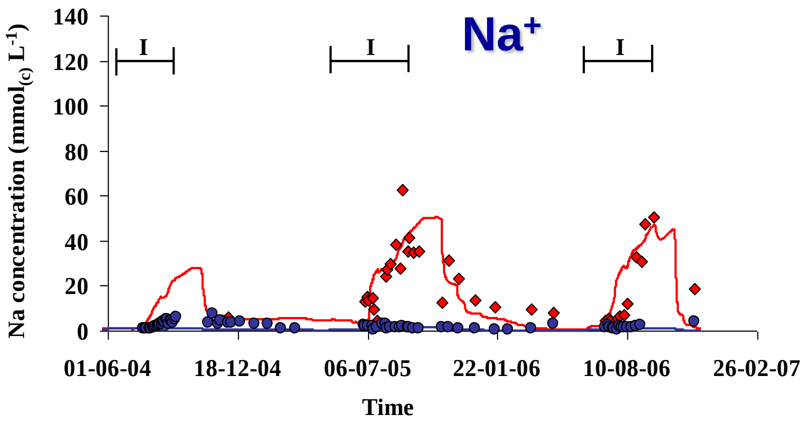


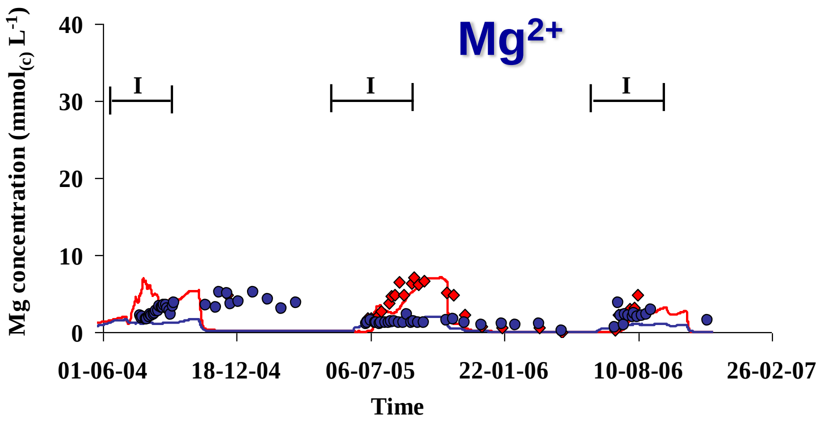


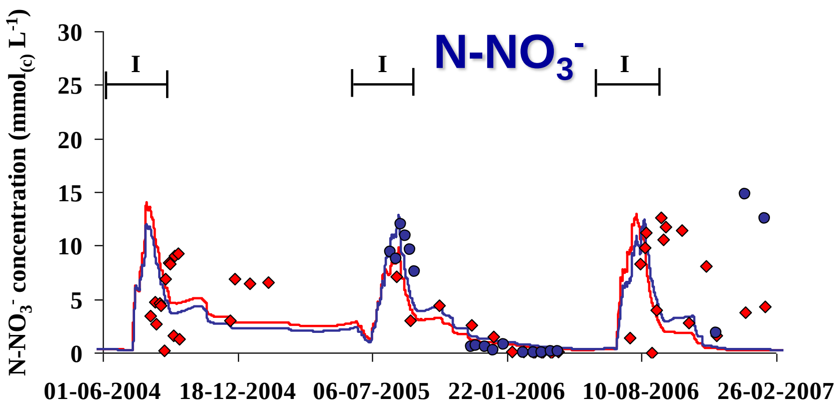
Gonçalves, M.C., Šimůnek, J., Ramos, T.B., Martins, J.C., Neves, M.J., Pires, F.P., 2006. Multicomponent solute transport in soil lysimeters irrigated with waters of different quality. *Water Resour. Res.* 42, 17, W08401, doi:10.1029/2005WR004802.

PREVIOUS STUDIES

Salt and nitrogen transport in the soil with HYDRUS-1D







Ramos, T.B., Šimůnek, J., Gonçalves, M.C., Martins, J.C., Prazeres, A., Castanheira, N.L., Pereira, L. S., 2011. Field Evaluation of a multicomponent solute transport model in soils irrigated with saline waters. *J. Hydrol*. 407: 129-144, doi:10.1016/j.jhydrol.2011.07.016.

OBJECTIVES

Two-dimensional modeling of water and nitrogen fate in a plot with sweet sorghum grown under Mediterranean conditions while considering different drip fertigation and water quality scenarios.

Evaluate the effectiveness of HYDRUS-2D to:

(i) Predict water contents and fluxes,

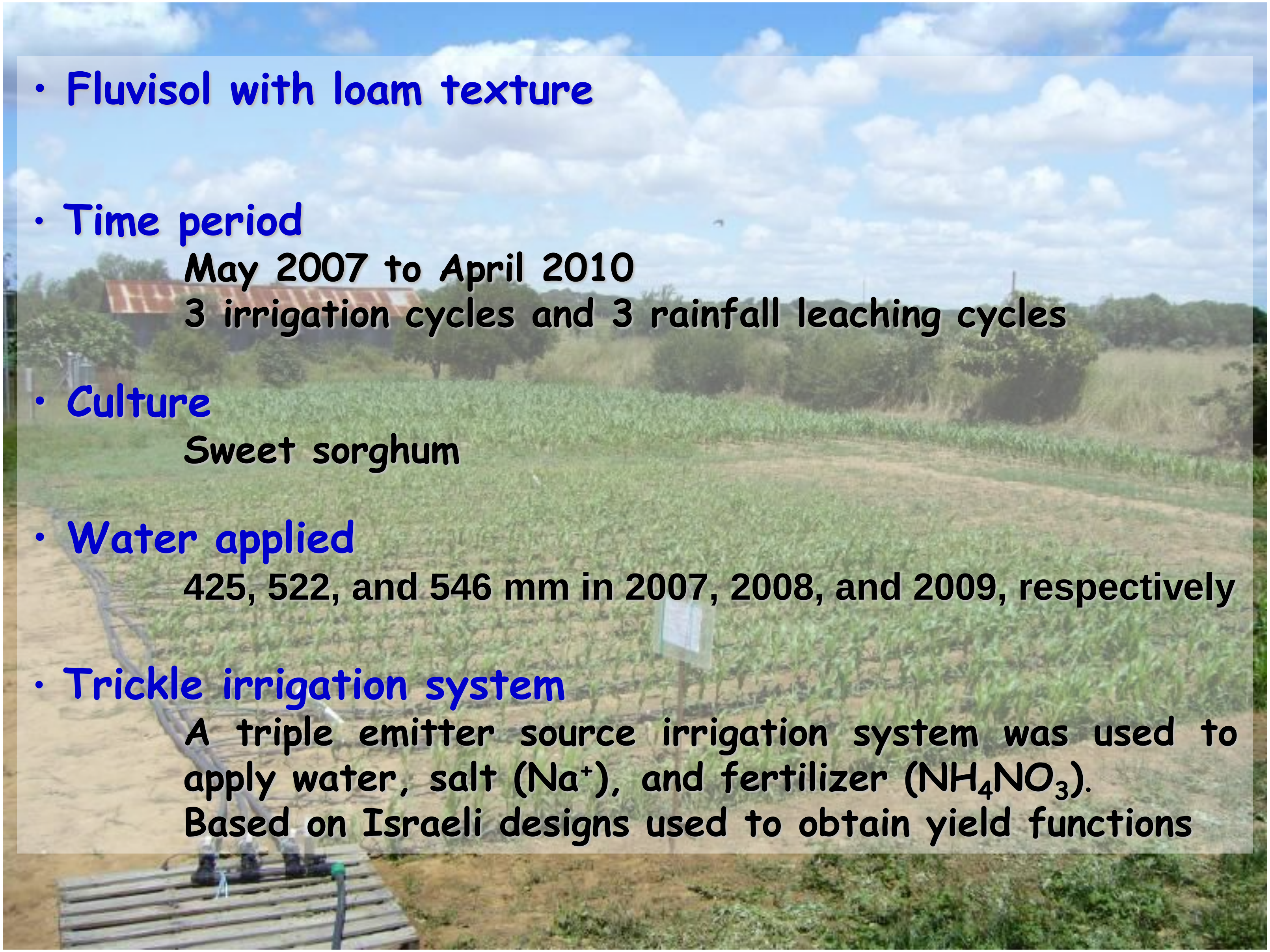
(ii) Predict overall salinity given by EC_{sw},

(iii) Quantify water uptake reductions due to the use of saline waters,

(iv) Predict $N\text{-}H_4^+$ and $N\text{-}NO_3^-$ concentrations in the soil and leaching.

Ramos, T.B., Šimůnek, J., Gonçalves, M.C., Martins, J.C., Prazeres, A., Pereira, L.S., 2012. Two-dimensional modeling of water and nitrogen fate from sweet sorghum irrigated with fresh and blended saline waters. *Agric. Water Manage.* 111: 87-104, doi:10.1016/j.agwat.2012.05.007.

FIELD EXPERIMENT



- **Fluvisol with loam texture**

- **Time period**

  May 2007 to April 2010

  3 irrigation cycles and 3 rainfall leaching cycles

- **Culture**

  Sweet sorghum

- **Water applied**

  425, 522, and 546 mm in 2007, 2008, and 2009, respectively

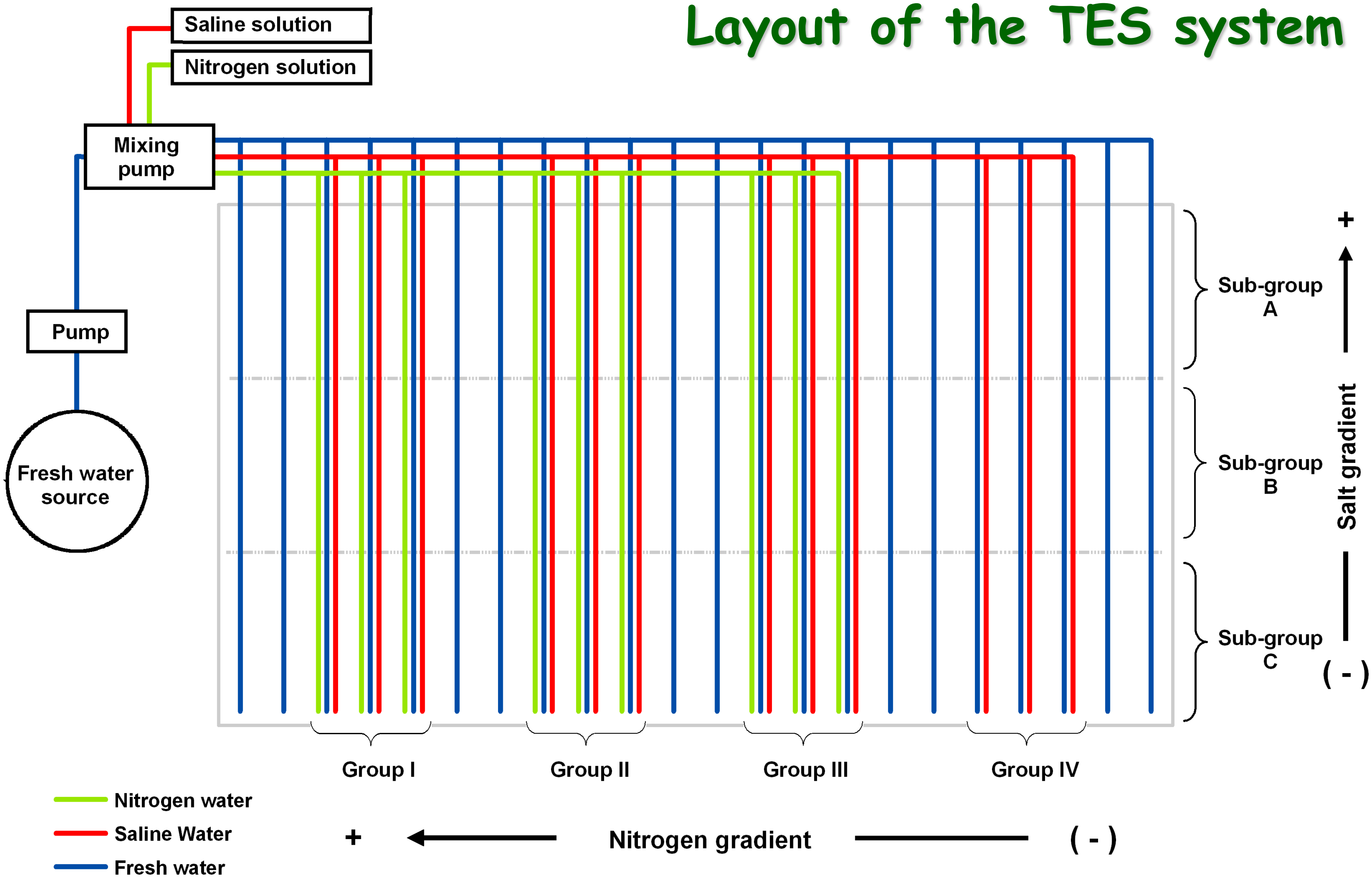
- **Trickle irrigation system**

  A triple emitter source irrigation system was used to apply water, salt (Na^+), and fertilizer (NH_4NO_3).

  Based on Israeli designs used to obtain yield functions

FIELD EXPERIMENT

Layout of the TES system



FIELD EXPERIMENT

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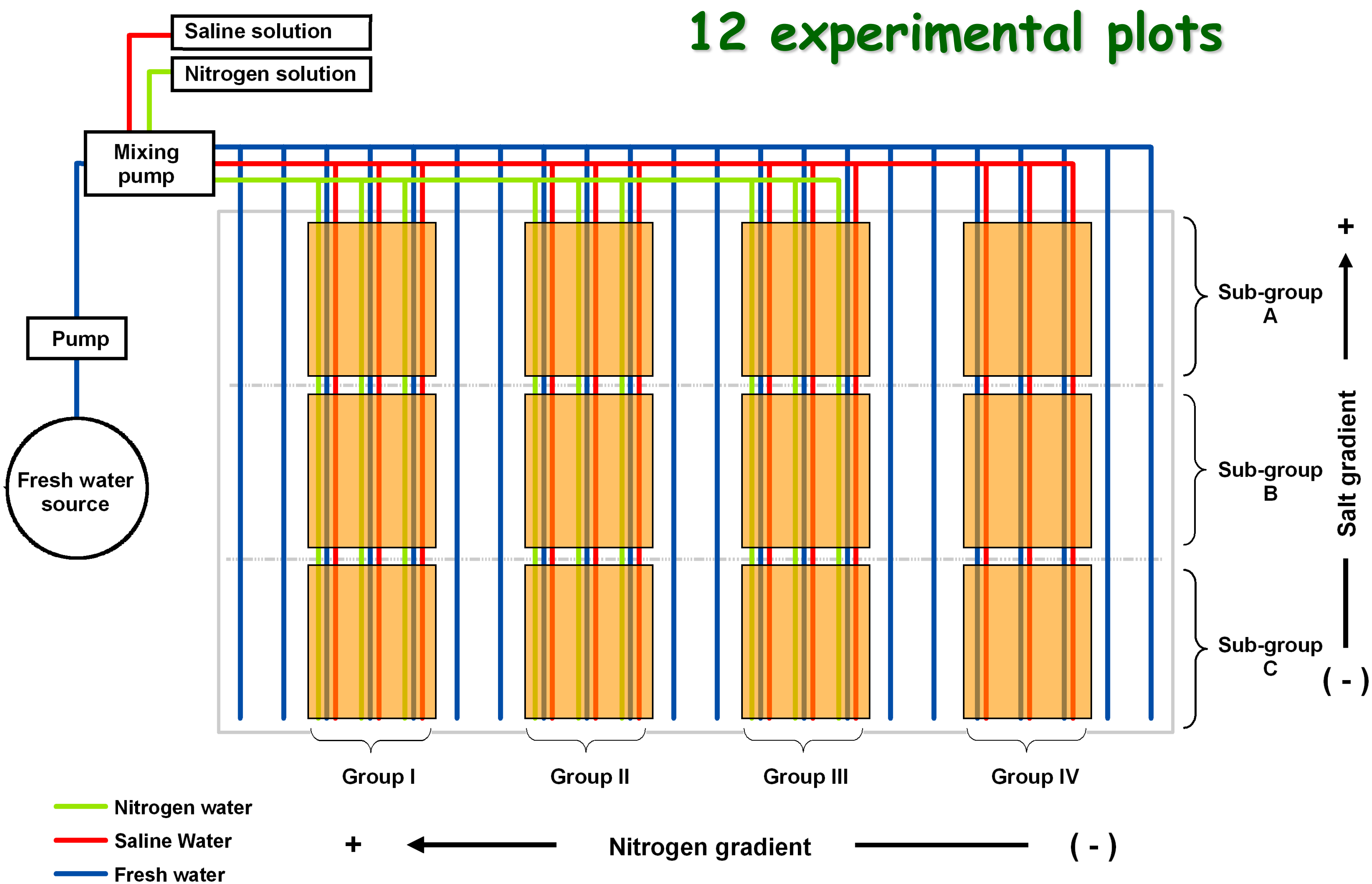
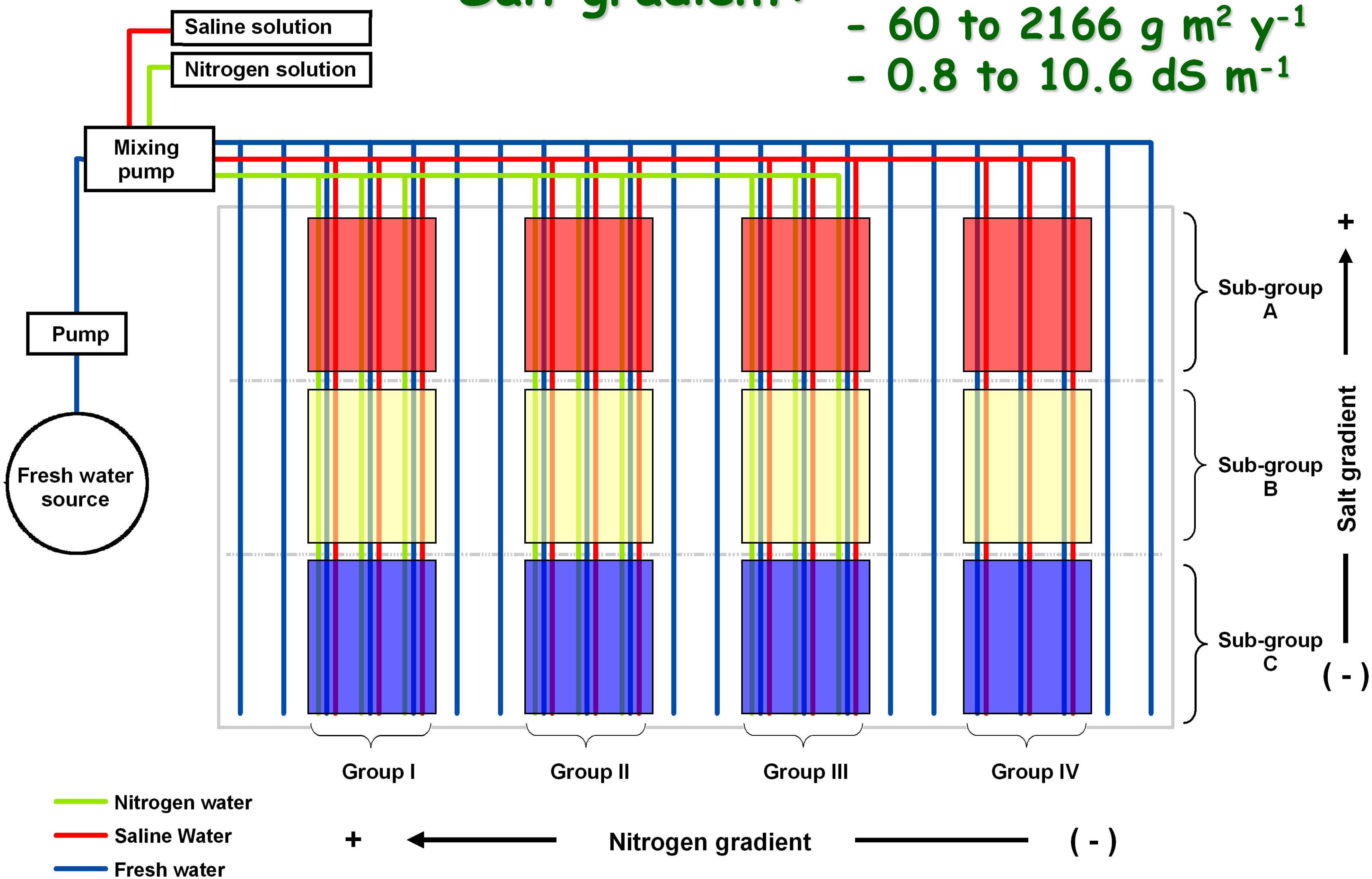


FIELD EXPERIMENT

Salt gradient:

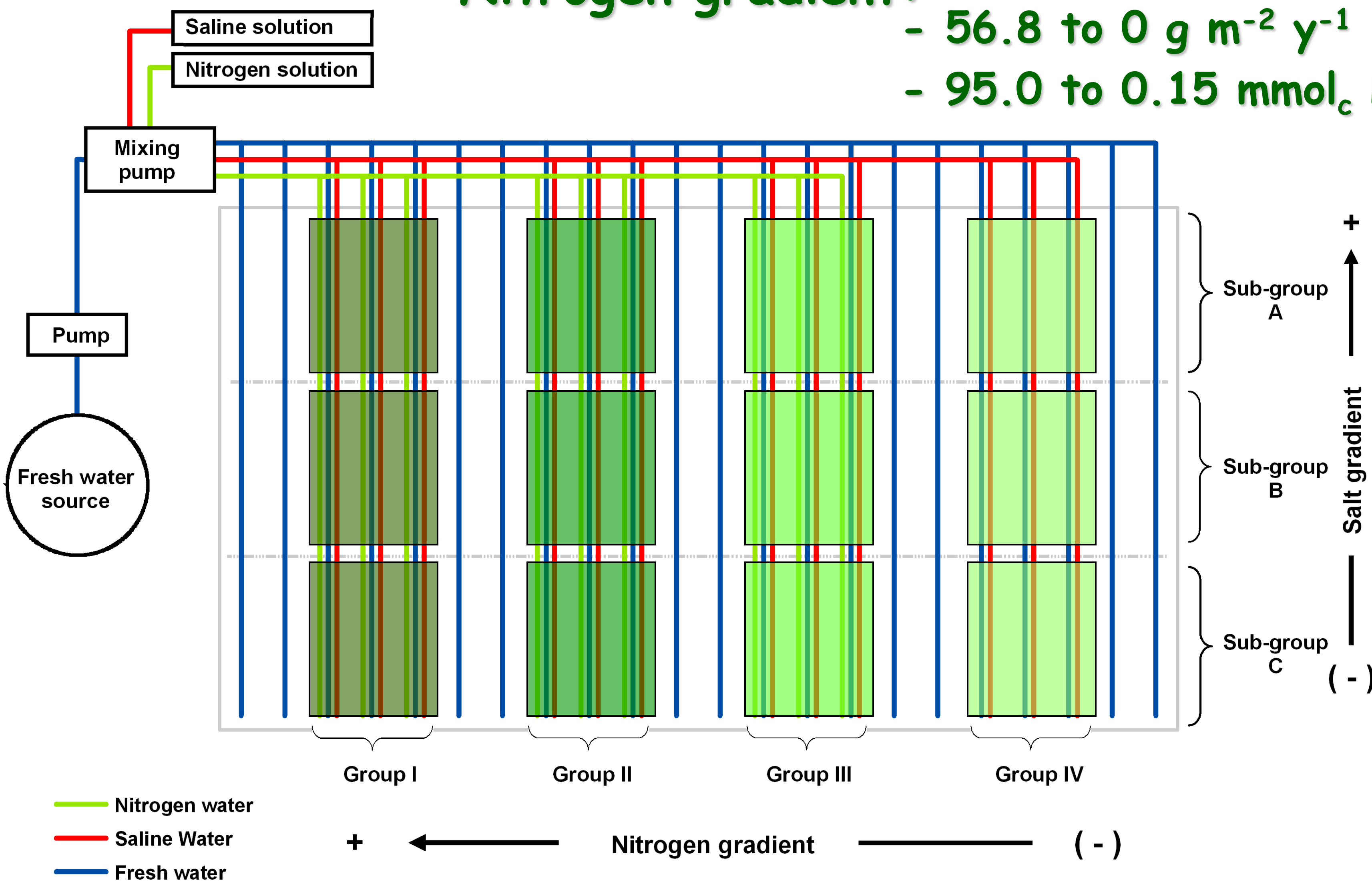
- 60 to 2166 g m^2 y^{-1}
- 0.8 to 10.6 dS m^{-1}



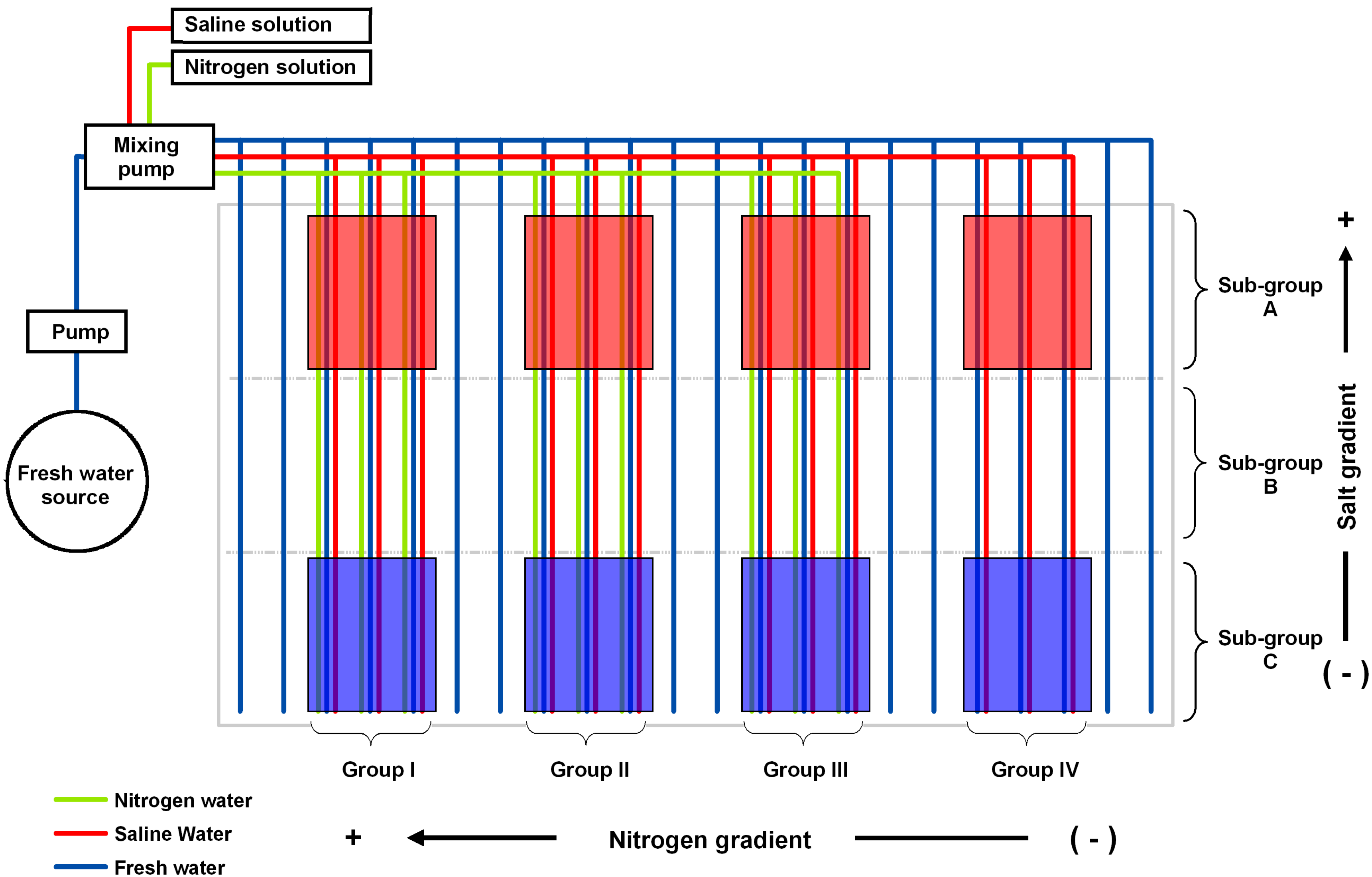
FIELD EXPERIMENT

Nitrogen gradient:

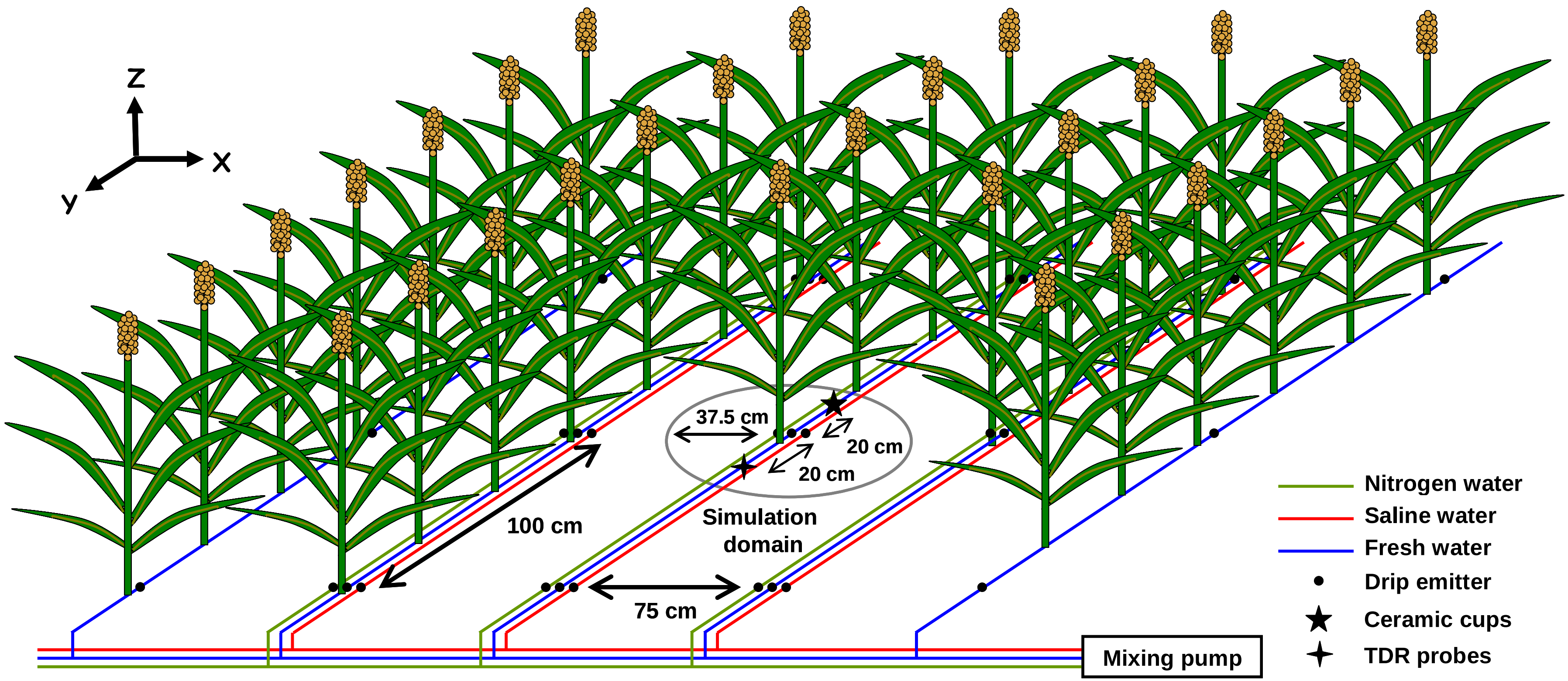
- 56.8 to 0 $g\ m^{-2}\ y^{-1}$
- 95.0 to 0.15 $mmol_c\ L^{-1}$



HYDRUS-2D SIMULATIONS

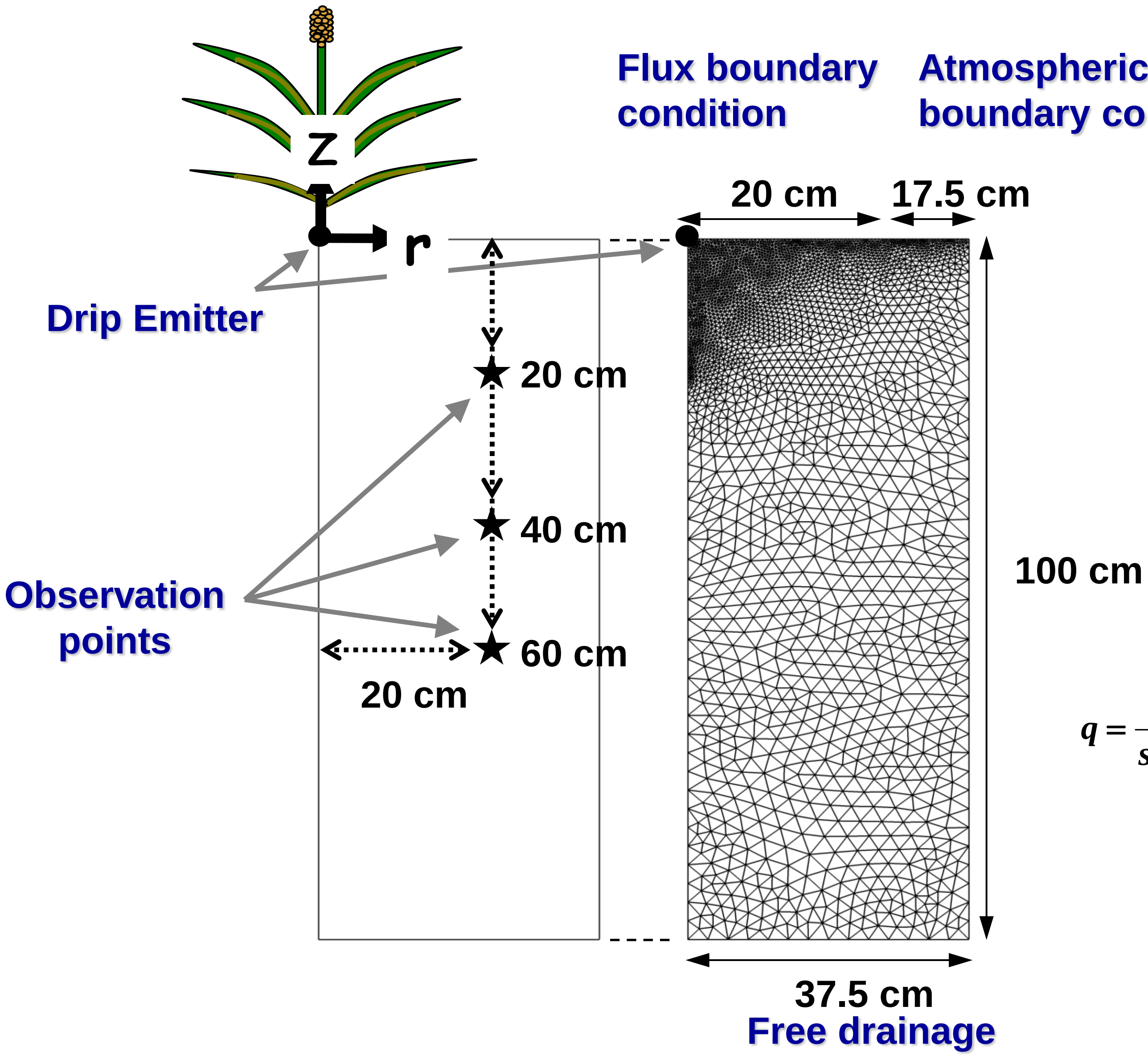


HYDRUS-2D SIMULATIONS



Location of a point source emitter and monitoring sites in the experimental plot

AXISYMMETRICAL DOMAIN GEOMETRY



$$q = \frac{volume\ of\ \ water\ applied}{surface\ wetted\ area \times duration}$$

Monitoring irrigation and leaching cycles (20, 40, and 60 cm)

- Soil water content (TDR)
- Electrical conductivity from soil solution (ceramic cups)
- Soluble ions from soil solution (ceramic cups)

INPUT DATA

Measured in representative soil profile at 20, 40 and 60 cm

Soil Initial Conditions

- Soil water content, TDR
- Dry bulk density
- Electrical conductivity of the soil solution (EC_{sw})

Soil Hydraulic Properties

- Suction tables
- Pressure Plate
- Evaporation Method
- Hot Air Method

Described with Mualem-van Genuchten equations

Solute Transport Parameters

- Chloride Breakthrough Curves
- CXTFIT 2.1

TIME-VARIABLE BOUNDARY CONDITIONS

- Rainfall (daily) / Irrigation water
- Daily ET_0 (Penman-Monteith)
- $ET_c = (K_{cb} + K_e)\ ET_0$ (dual Kc approach from FAO 56)
- $K_{cb\ mid} = K_{c\ min} + (K_{cb\ full} - K_{c\ min})^{(1-e(-0.7\ LAI))}$

  (Leaf Area Index measured every week)

MODELING APROACH

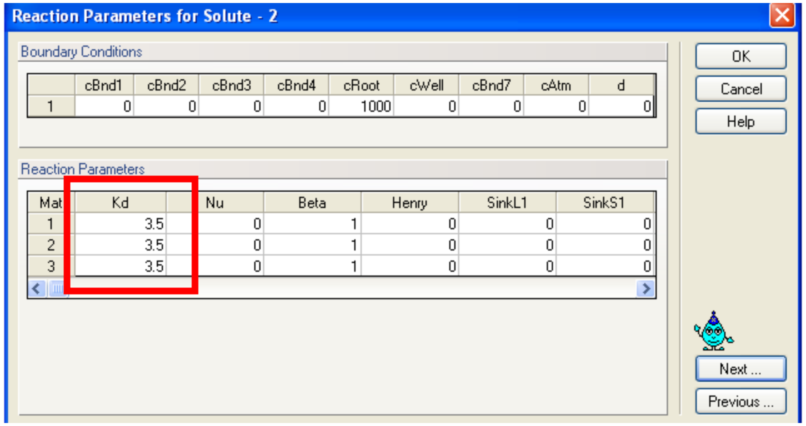
Linear Adsorption Isotherm

$$\overline{c_k} = K_{d,k}\, c_k$$

$K_{d,ECsw}$ = 0 cm^3 g^{-1}

$K_{d,NH4+}$ = 3.5 cm^3 g^{-1}

$K_{d,NO3-}$ = 0 cm^3 g^{-1}



Reaction Parameters for Solute - 2

Boundary Conditions

	cBnd1	cBnd2	cBnd3	cBnd4	cRoot	cWell	cBnd7	cAtm	d
1	0	0	0	0	1000	0	0	0	0

Reaction Parameters

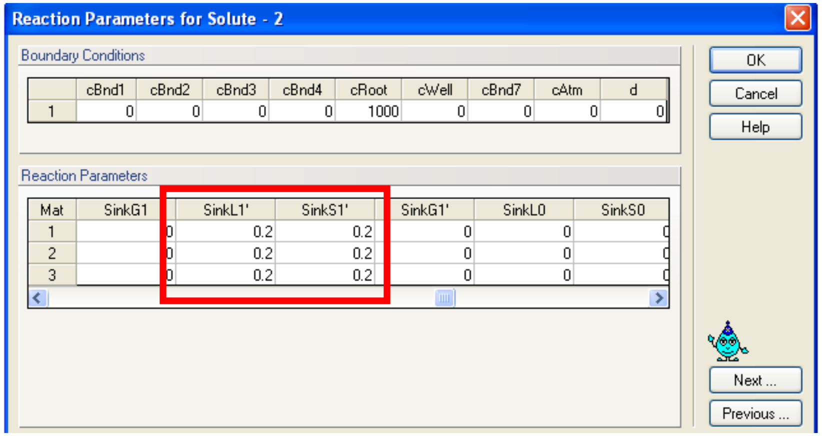
Mat	Kd	Nu	Beta	Henry	SinkL1	SinkS1
1	3.5	0	1	0	0	0
2	3.5	0	1	0	0	0
3	3.5	0	1	0	0	0

Nitrification

Sequential first-order decay chain:

$$\phi = -\mu_{w,N-NH_4^+}\theta c_{N-NH_4^+} - \mu_{s,N-NH_4^+}\rho \overline{c}_{N-NH_4^+}$$

$$\phi = \mu_{w,N-NH_4^+}\theta c_{N-NH_4^+} + \mu_{s,N-NH_4^+}\rho \overline{c}_{N-NH_4^+}$$



Reaction Parameters for Solute - 2

Boundary Conditions

	cBnd1	cBnd2	cBnd3	cBnd4	cRoot	cWell	cBnd7	cAtm	d
1	0	0	0	0	1000	0	0	0	0

Reaction Parameters

Mat	SinkG1	SinkL1'	SinkS1'	SinkG1'	SinkL0	SinkS0
1	0	0.2	0.2	0	0	0
2	0	0.2	0.2	0	0	0
3	0	0.2	0.2	0	0	0

μ_w = 0.2 d^{-1}

μ_s = 0.2 d^{-1}

Hanson et al. (2006)

MODELING APROACH

Root Water Uptake

Water stress

Feddes et al. (1978)

Salinity stress

Maas's (1990) threshold and slope function

$$\alpha_2(h_\phi) = 1 - (EC - EC_T)\,0.01s$$

$$EC_e \times k_{EC} = EC_{sw}$$

K_{EC} = 2

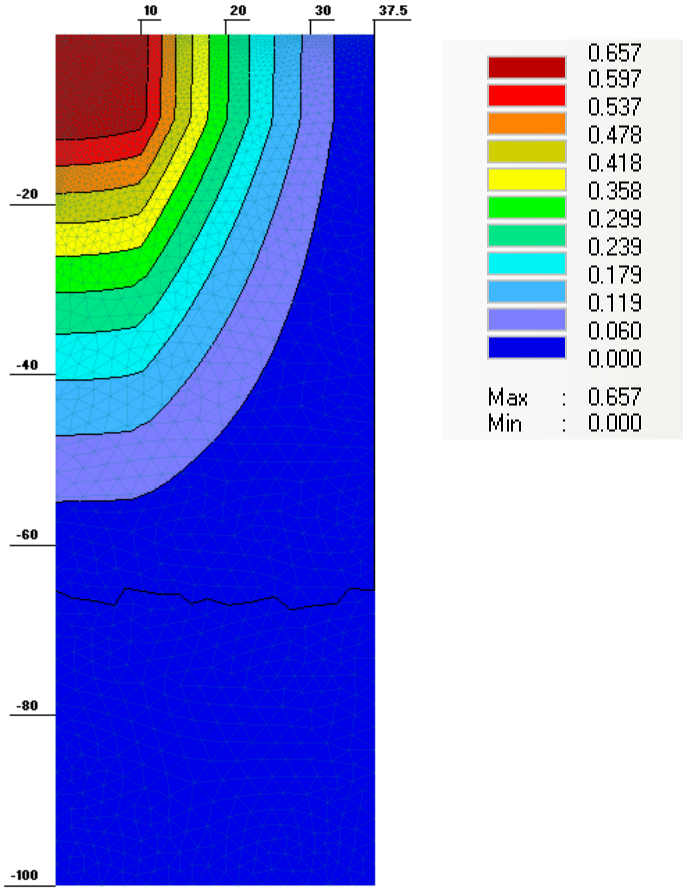
Nutrient uptake

Only considering passive nutrient uptake

$$c_{root}(r,z,t) = \min[c(r,z,t), c_{max}]$$

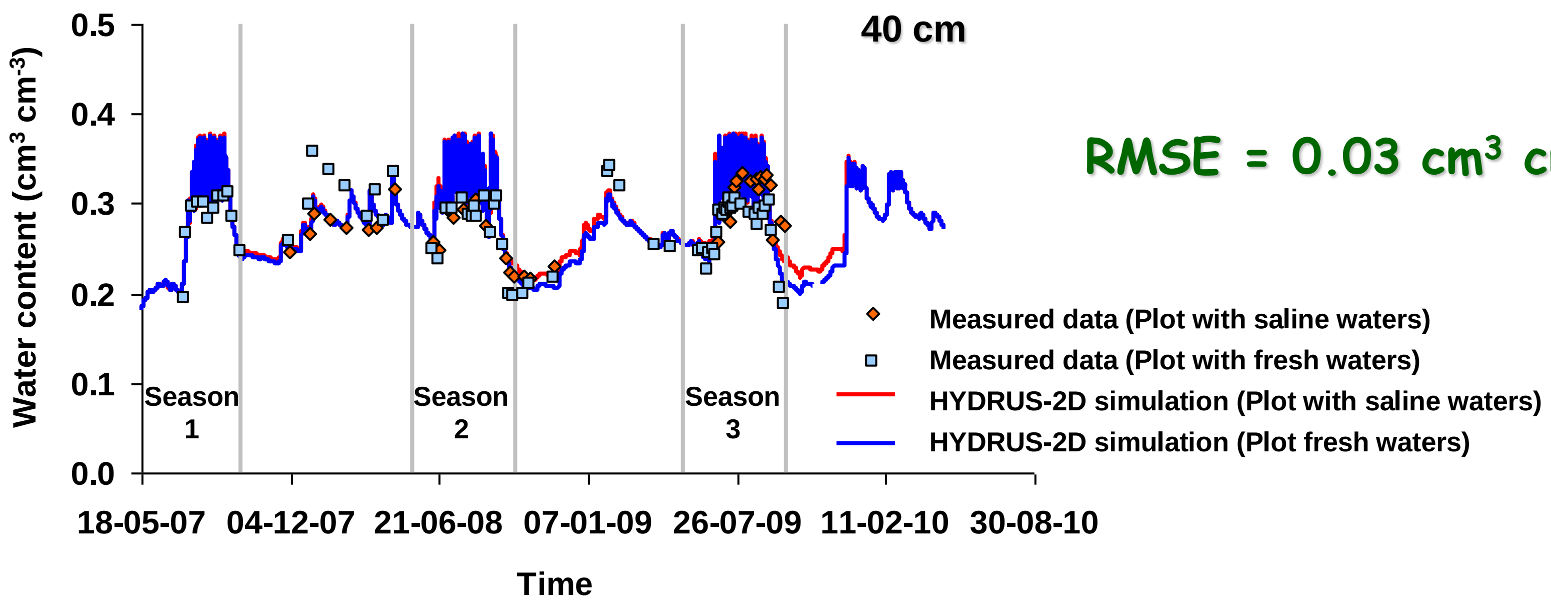
C_{max} is the maximum concentration of the root uptake

Root distribution



RESULTS

WATER FLOW

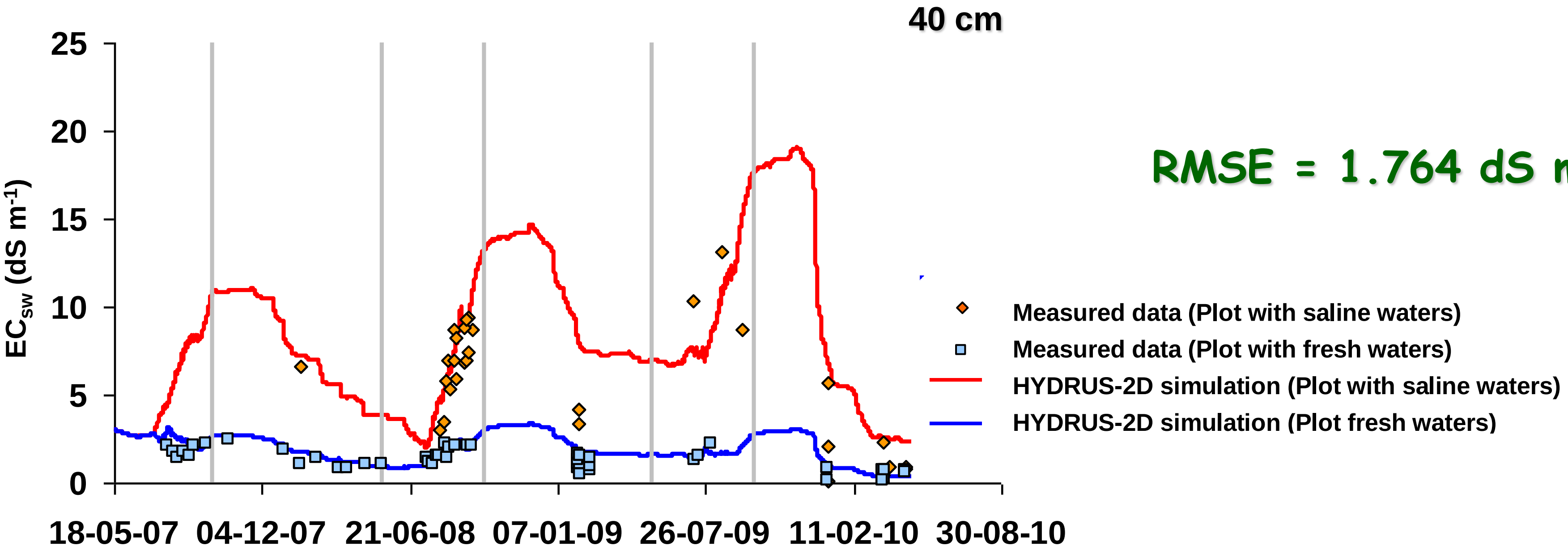


RMSE = 0.03 cm^3 cm^{-3}

- Tp: 360 - 457 mm
- Ta: 264 - 364 mm
- Tp reductions due to water stress: 21.9 – 27.4 %

Water stress was a function of the irrigation schedule during each season

EC_{sw}



RMSE = 1.764 dS m^{-1}

- Tp reductions due to water and salinity stress:

  24.2 – 33.3 % (plots with saline waters)

SALINITY DISTRIBUTION

Salinity stress:

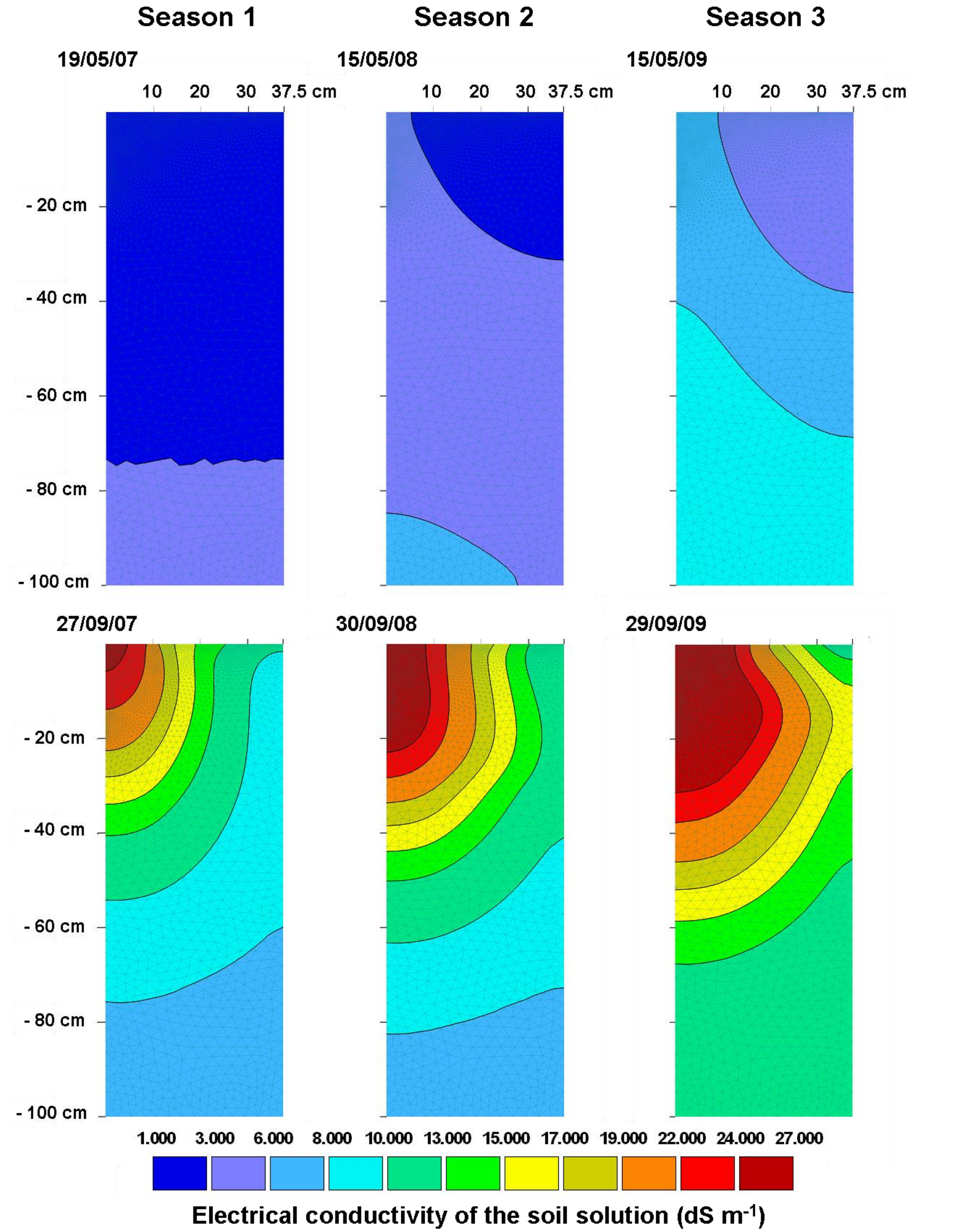
2007: 0 %

2008: 2.3 - 4.7 %

2009: 4.6 – 7.0 %

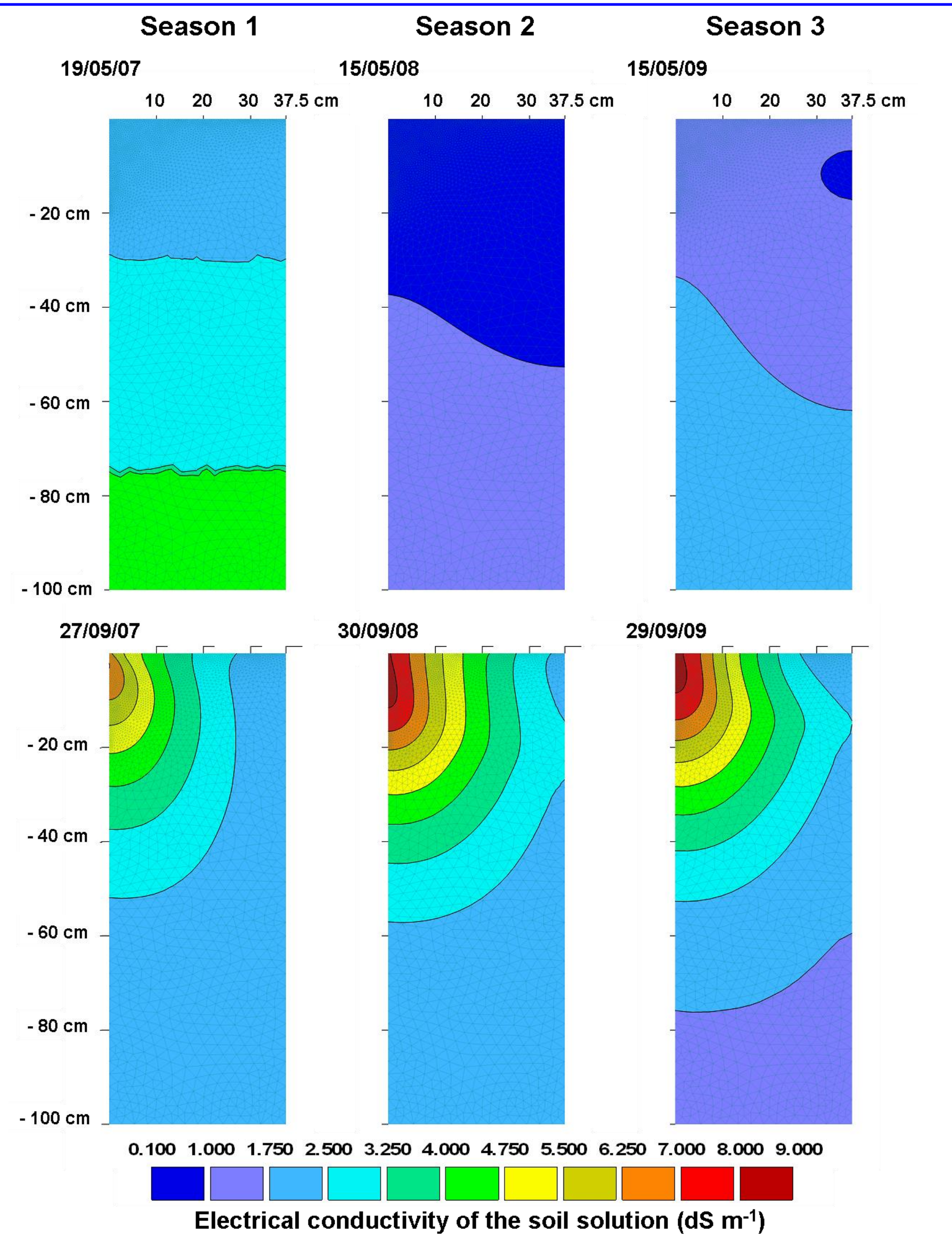
Sweet sorghum showed to be tolerant to the use of saline waters during one crop season.

The continuous use of synthetic saline irrigation waters led to soil salinization over the years and to transpiration reductions

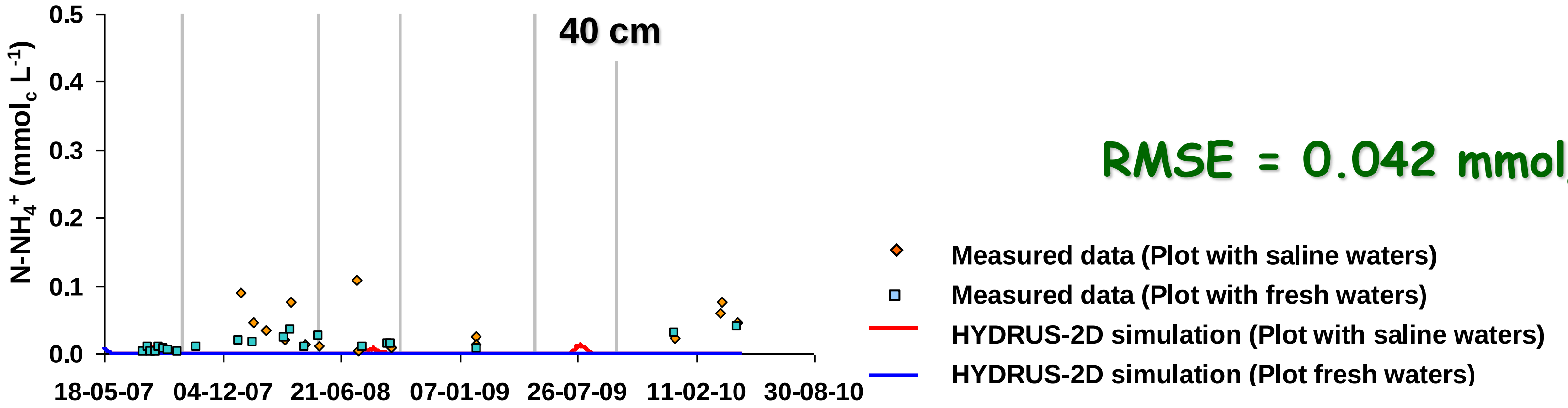


SALINITY DISTRIBUTION

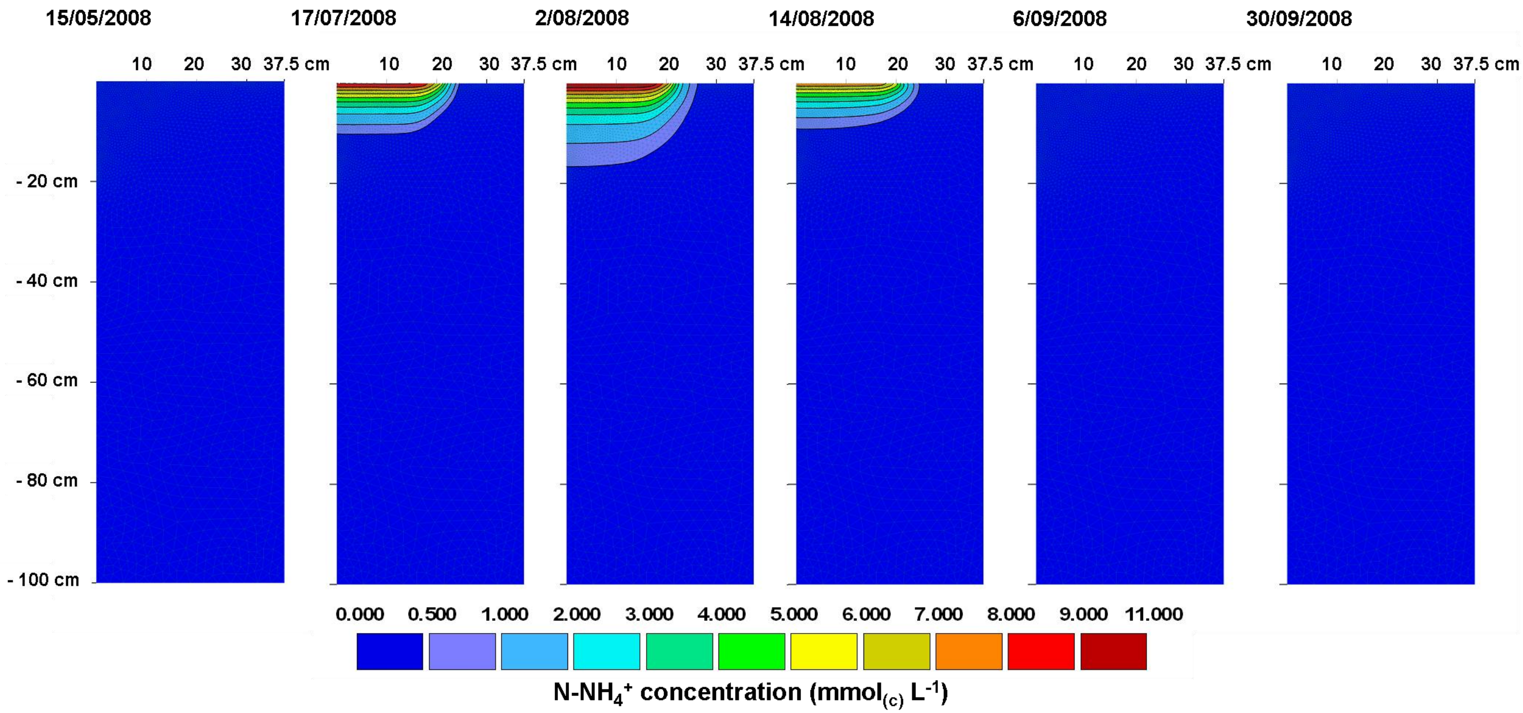
Transpiration in plots with fresh irrigation waters were not affected by the osmotic stress



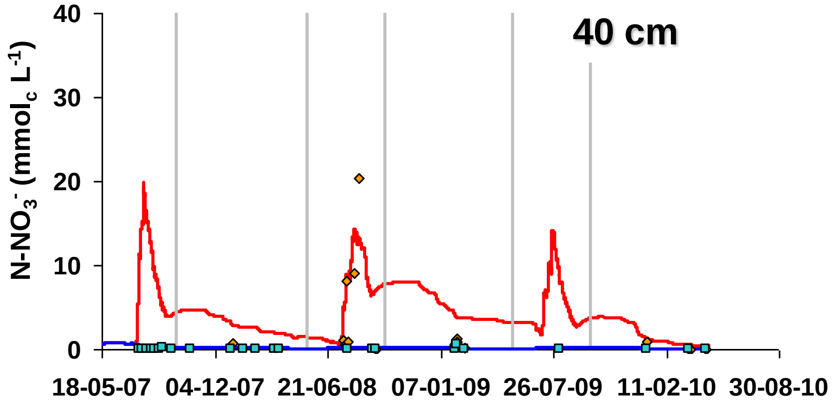
$N\text{-}NH_4^+$



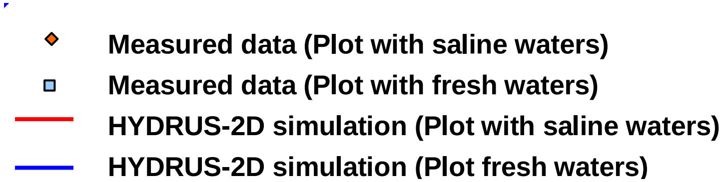
RMSE = 0.042 $mmol_c\ L^{-1}$

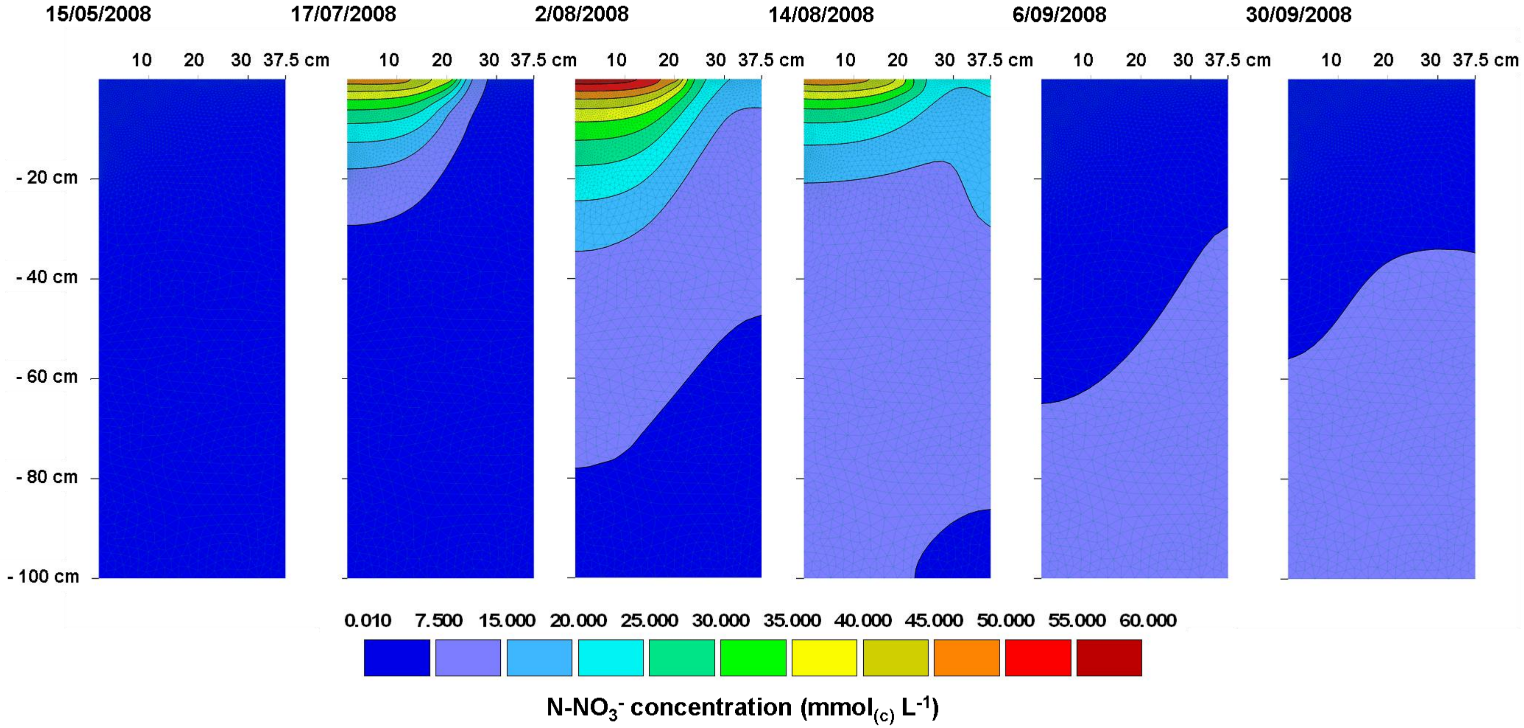


$N\text{-}NO_3^-$



RMSE = 3.078 $mmol_c\ L^{-1}$





NITROGEN BALANCE

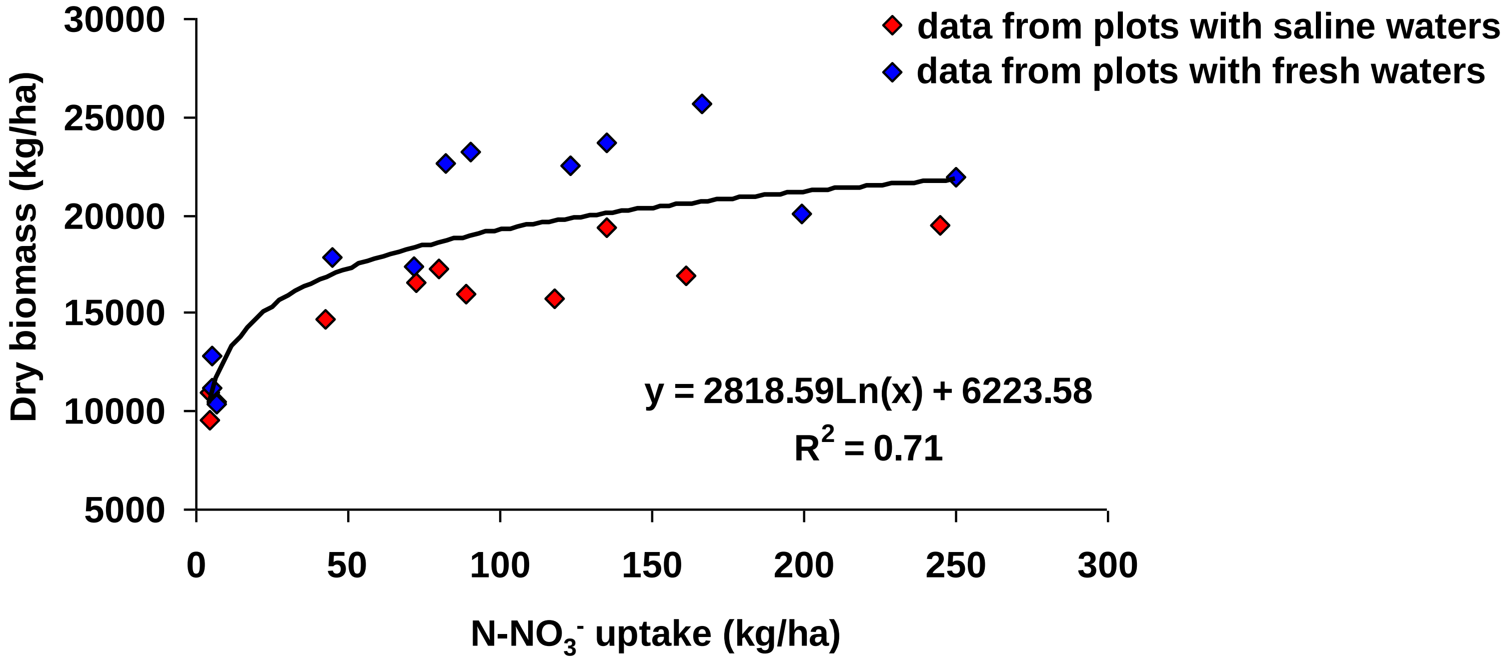
- Fertigation events:
  - 2007: 4
  - 2008: 6
  - 2009: 3
- $N\text{-}NO_3^-$ leaching:
  - 2007: 51 - 53 %
  - 2008: 41 %
  - 2009: 68 - 70 %
- $N\text{-}NO_3^-$ uptake:
  - 2007: 37 %
  - 2008: 39 - 42 %
  - 2009: 23 - 25 %

- The leaching of N out of the root zone depended closely on drainage, the amount of N applied, the form of N in the fertilizer, and the time and number of fertigation events.

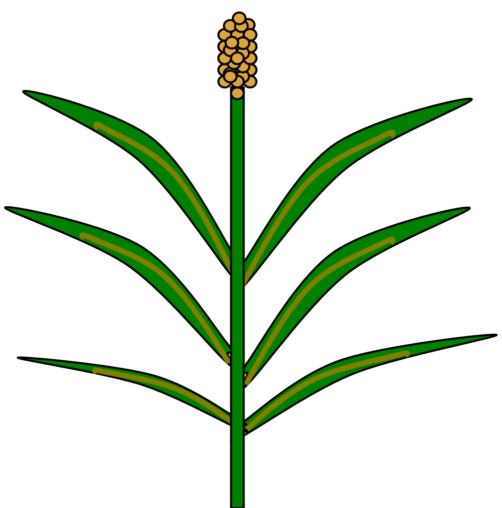
- The effects of the salinity stress on nutrient uptake (and inversely on nutrient leaching) was relatively small since sweet sorghum has a medium to high tolerance to salinity

YIELD FUNCTION

An additional incremental change of $N\text{-}NO_3^-$ uptake produced diminishing returns in the total dry biomass response with optimum levels being reached at 130-180 kg/ha



CONCLUSIONS



CONCLUSIONS

- HYDRUS-2D successfully estimated the fate of nitrogen in field plots grown with sweet sorghum in Alentejo.

- Saline waters can be viewed as an important source of irrigation water during drought seasons, the use of marginal waters showed viability for irrigating sweet sorghum during a limited time period (one crop season).

- The relatively low water needs (360-457 mm) and N requirements (130-180 kg/ha) of sweet sorghum makes it a good alternative when compared to other traditional crops grown in the region.

- The modeling approach helped us understand the best irrigation and fertigation management practices to be adopted in future practical applications for increasing nutrient uptake and reducing nutrient leaching.