Instituto Nacional de Investigação Agrária e Veterinária, I.P.

EJP SOIL
European Joint Programme

PhD course: “Soil Management for Sustainable Agriculture”

Strategies to prevent/contrast Soil Salinization and Alkalization

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1. Measurement
2. Strategies to deal with salt-affected soils
   2.1 Prevention
      Irrigation management and drainage
      Seawater intrusion
      Parent material and groundwater
   2.2. Mitigation
      Chemical remediation of sodicity
      Phyto and bioremediation of sodicity
      Leaching and drainage
   2.3. Adaptation
      Agronomical practices
      Microbial management
      Land-use changes
3. Case Studies




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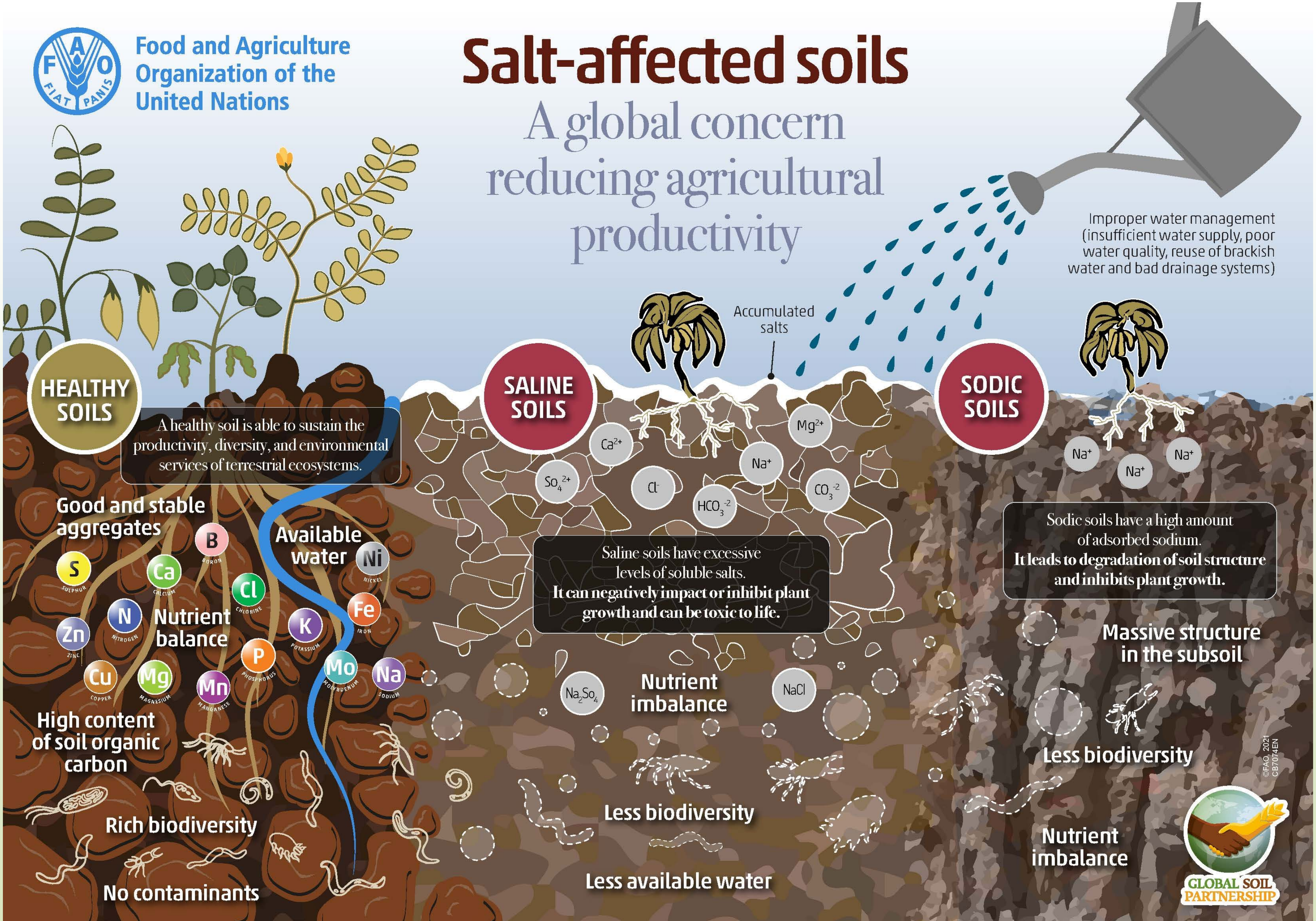

Food and Agriculture Organization of the United Nations
Salt-affected soils
A global concern reducing agricultural productivity
Improper water management (insufficient water supply, poor water quality, reuse of brackish water and bad drainage systems)
Accumulated salts
HEALTHY SOILS
A healthy soil is able to sustain the productivity, diversity, and environmental services of terrestrial ecosystems.
Good and stable aggregates
Available water
Nutrient balance
S Ca B Cl Ni N Zn K Fe P Cu Mg Mn Mo Na
High content of soil organic carbon
Rich biodiversity
No contaminants
SALINE SOILS
Ca2+ So4 2+ Cl- Na+ HCO3 -2 Mg2+ CO3 -2
Saline soils have excessive levels of soluble salts.
It can negatively impact or inhibit plant growth and can be toxic to life.
Na2So4 NaCl
Nutrient imbalance
Less biodiversity
Less available water
SODIC SOILS
Na+ Na+ Na+
Sodic soils have a high amount of adsorbed sodium.
It leads to degradation of soil structure and inhibits plant growth.
Massive structure in the subsoil
Less biodiversity
Nutrient imbalance
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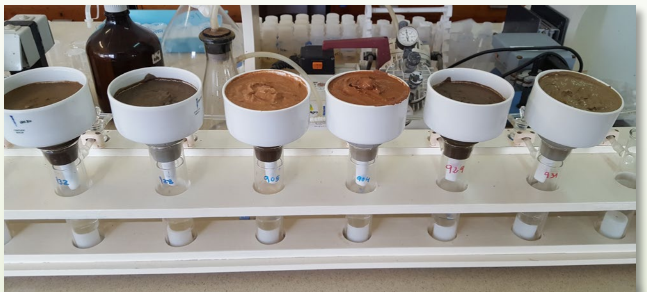
Soil ECe and EC(m:v)

Estimate ECe from EC1:5 of several soil:water extracts from agricultural soils

Saturated paste extract (ECe)



USDA, 1954

Soil:Water Extracts (m:v) in proportions 1:1; 1:2,5; 1:5

ISO 10390 (soil pH)

air dried and sieved at 2mm

749 soil samples

Classification	ECe ($dS\ m^{-1}$)	Nr soil samples
Non saline	0 - 2	579
Slightly saline	2 - 4	113
Moderately saline	4 - 8	36
Strongly saline	8 - 16	21

TABLE 1. Correlation Equations Established by Different Studies to Convert Soil-Water Extracts at Different Ratios ($EC_{1:x}$) to Saturated Paste (EC_e) Equivalents

	Regression Equation[a]				
	With Intercept	**R^2**	**Without Intercept**	**R^2**	**EC_e Range**
USDA (1954)			$EC_e = 3.00\ EC^b_{1:1}$	0.96	N/A[f]
Hogg and Henry (1984)	$EC_e = 1.47\ EC_{1:1} - 0.07^c$	0.96			0.28–25.7
	$EC_e = 2.16\ EC_{1:2} + 0.03^c$	0.94			0.28–25.7
Zhang et al. (2005)	$EC_e = 1.79\ EC_{1:1} + 1.46^b$	0.85	$EC_e = 1.85\ EC^b_{1:1}$	0.85	0.16–108
Ozcan et al. (2006)	$EC_e = 1.93\ EC_{1:1} - 0.57$	0.96			N/A
	$EC_e = 3.30\ EC_{1:2.5} - 0.20$	0.95			N/A
	→ $EC_e = 5.97\ EC_{1:5} - 1.17$	0.94			N/A
Sonmez et al. (2008)	$EC_e = 2.03\ EC_{1:1} - 0.41^c$	0.99	$EC_e = 1.96\ EC^c_{1:1}$	0.99	0.22–17.7
	$EC_e = 3.68\ EC_{1:2.5} + 0.22^c$	0.99	$EC_e = 3.75\ EC^c_{1:2.5}$	0.99	0.22–17.7
	→ $EC_e = 7.36\ EC_{1:5} - 0.24^c$	0.99	→ $EC_e = 7.19\ EC^c_{1:5}$	0.98	0.22–17.7
Khorsandi and Yazdi (2011)	→ $EC_e = 5.37\ EC_{1:5} + 0.57^d$	0.95			0.53–57.1
	→ $EC_e = 5.60\ EC_{1:5} - 4.37^e$	0.97			2.34–59.3
This study	$EC_e = 3.05\ EC_{1:2.5} + 0.41^c$	0.93	$EC_e = 3.34\ EC^c_{1:2.5}$	0.92	0.62–10.3
	→ $EC_e = 5.04\ EC_{1:5} + 0.37^c$	0.93	→ $EC_e = 5.49\ EC^c_{1:5}$	0.92	0.62–10.3

a- EC in dS m^{-1}
b- several soil textures
c- fine textured soils
d- Soils without lime
e- Soils with lime
f- Data non-available

In: Aboukila and Norton, 2017

Soil ECe and EC(m:v)

749 soil samples were used from **27** <u>diferent locations belonging to the irrigation district of Lezíria,</u> Vigia, Campilhas e Alto Sado, Roxo and Alqueva

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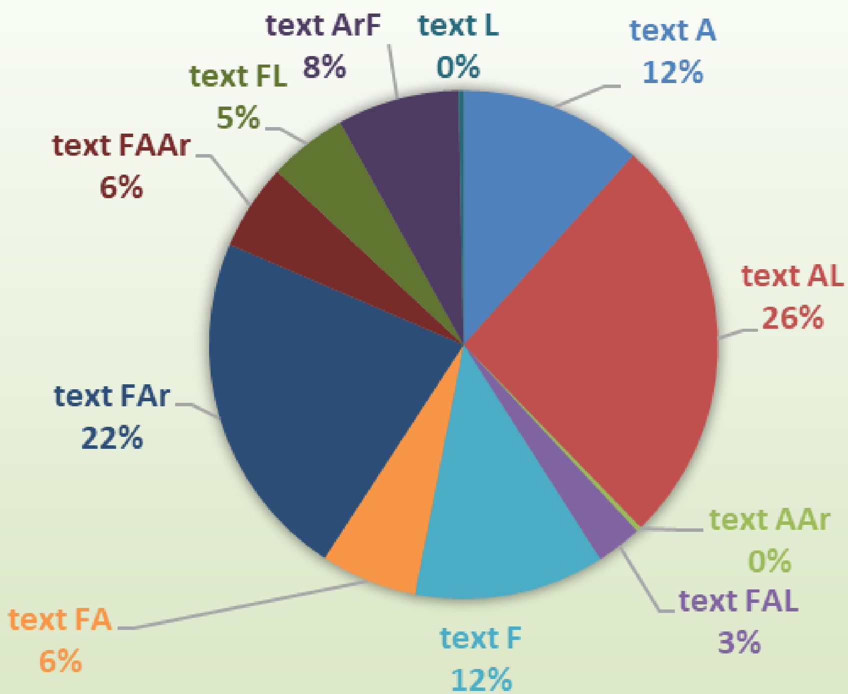
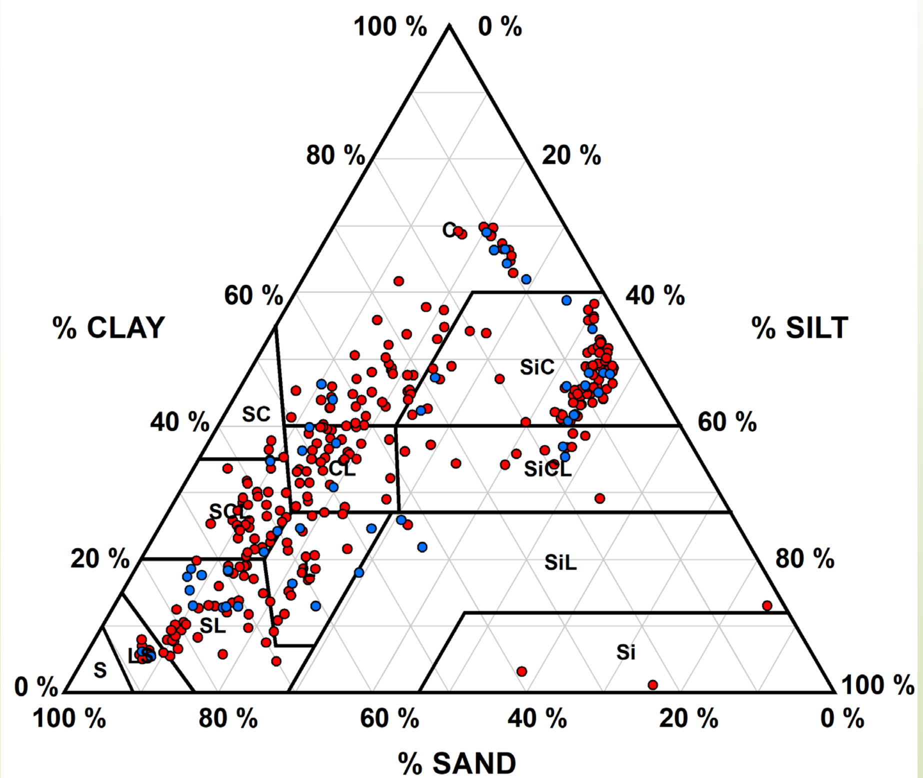
Textural classes



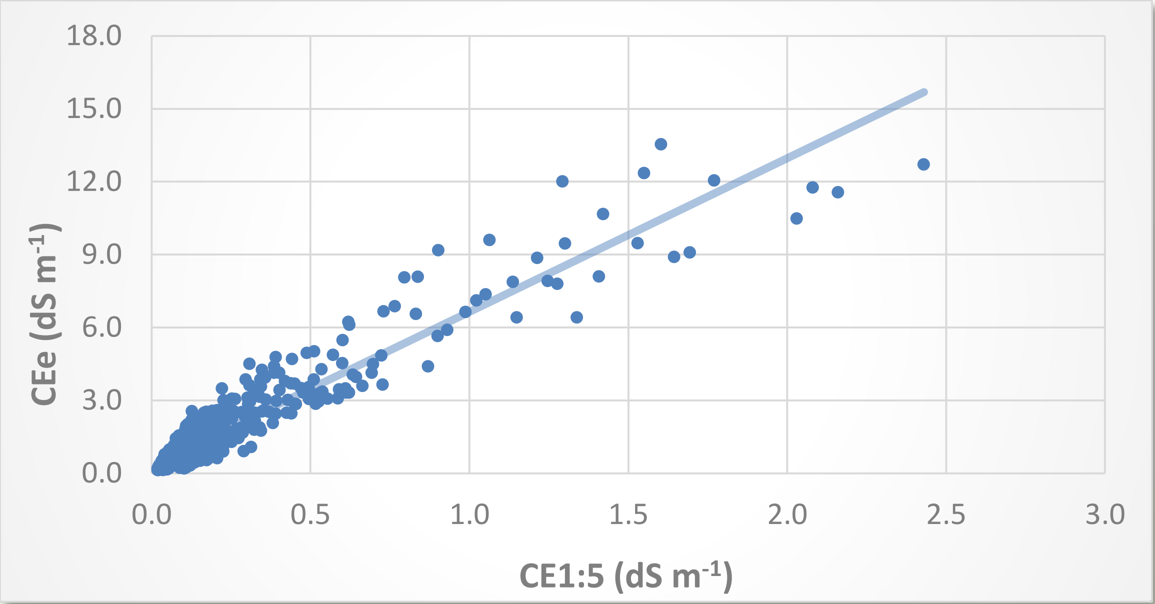


Texture

(pipete method)

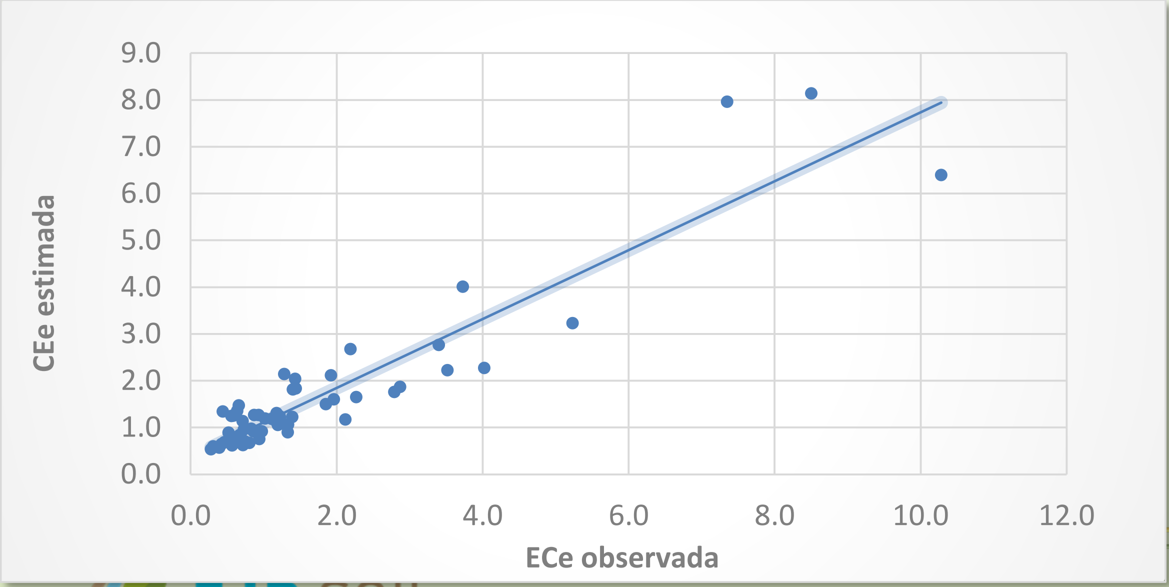
pH, CEC, ESP, BS, SAR

Ece and EC(m:v) - regression



n = 689

$y = 6.3283x + 0.3154$
$R^2 = 0.8891$



Validation with an independent set (n=60)

$R^2 = 0.8611$

RMSE = 0.759 dS m^{-1}
EM = 0.0784 dS m^{-1}
PBIAS = 0.1085 %.

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Strategies to deal with salt-affected soils

1. Prevention

- Irrigation management and drainage
- Seawater intrusion
- Parent material and groundwater

2. Mitigation

- Chemical remediation of sodicity
- Phyto and bioremediation of sodicity
- Leaching and drainage

3. Adaptation

- Agronomical practices
- Microbial management
- Land-use changes

1. Prevention

ECw, TDS, SAR, and some specific ions that might cause toxicity to the crop

Effects of the salinity and sodicity of the iw are highly dependent:

- soil characteristics
- conditions for **leaching** and **drainage**

Concentration of salts under **the crops' salinity tolerance threshold**

Irrigation water quality

Potential hazards		No restriction	Slight to moderate restriction	Severe restriction
Salinity hazard		$EC_w < 0.7$	$EC_w = 0.7 – 3$	$EC_w \geq 3$
	SAR = 0 – 3	$EC_w > 0.7$	$EC_w = 0.7 – 0.2$	$EC_w \leq 0.2$
	SAR = 3 – 6	$EC_w > 1.2$	$EC_w = 1.2 - 0.3$	$EC_w \leq 0.3$
Sodicity hazard	SAR = 6 - 12	$EC_w > 1.9$	$EC_w = 1.9 - 0.5$	$EC_w \leq 0.5$
	SAR = 12 - 20	$EC_w > 2.9$	$EC_w = 2.9 - 1.3$	$EC_w < 1.3$
	SAR = 20 - 40	$EC_w > 5.0$	$EC_w = 5.0 – 2.9$	$EC_w < 2.9$

Irrigation water-quality guidelines, based on EC and SAR of the irrigation water. Adapted from Ayers and Westcot (1985)

Sodicity – very low ECw soil structure degradation

Na accumulation over sufficient years can result in sodicity

1. Prevention

Irrigation method

Irrigation water quality and crop tolerance

Soil infiltrability and water retention capacity – Salt Leaching

Irrigation systems develop salinity zones in the soil differently

Provide favourable water and salts regimes in the root zone

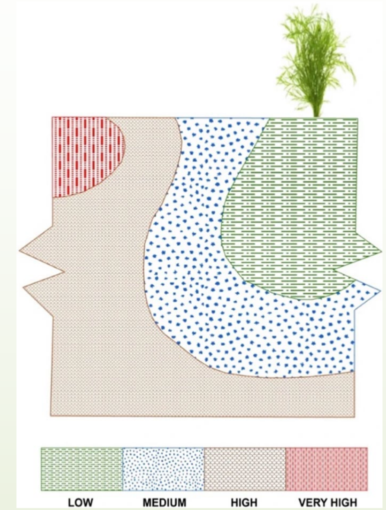
Surface irrigation system (flood, surge, sprinkler, bubbler) - maximum salinity is developed in deeper layers based on the wetting front and the lowest salinity is at the surface

Shahid 2013

1. Prevention

Irrigation method

Irrigation systems develop salinity zones in the soil differently



Drip irrigation is often preferred to sprinkler irrigation for crops highly sensitive to leaf necrosis.
In surface drip irrigation salts concentrate along the perimeters of the expanding wetting soil zone, with the lowest salt concentrations occurring in the immediate vicinity of the water source, the highest at the soil surface, and in the very center of any two drippers, i.e. at the boundary of the volume of wetted soil.

Wetting soil zone (a) and (b) salt accumulation in the center of drip lines where wetting zones meet. *In* Zaman *et al.*, 2018.

1. Prevention

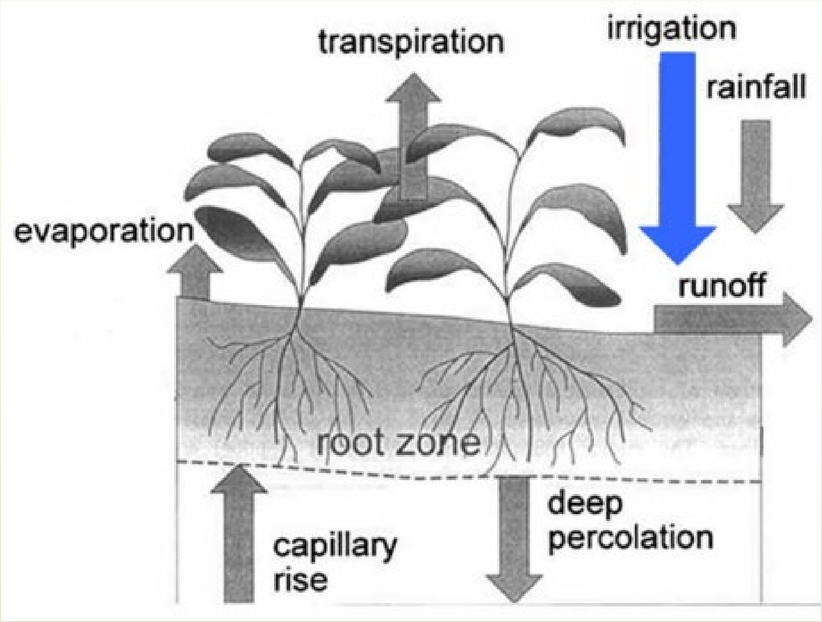
Irrigation scheduling

Meet crop water requirements

Promote salt leaching (depending on soil infiltration)

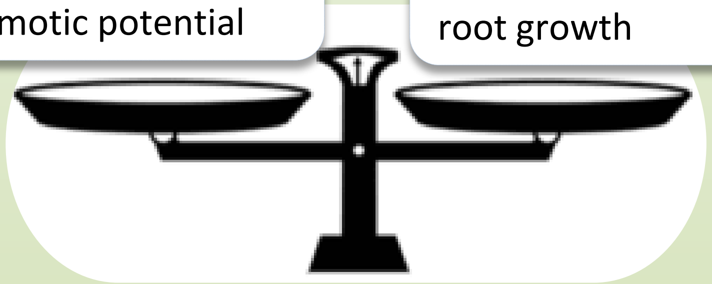
Depends on the type of irrigation system and irrigation frequency and water volumes applied

Root zone



Frequent irrigation ensure matric and osmotic potential

Non-frequent irrigation promotes root growth



1. Prevention

Concept first developed by the US Salinity Lab in Riverside, California.

Fraction of the irrigation water that must be percolated out of the bottom of the root zone in order to prevent average soil salinity from rising above some specifiable level (Richards, 1954)

$$LR = \frac{\mathrm{EC_w}}{5\ \mathrm{EC_e} - \mathrm{EC_w}}$$

where EC_e = crop's salinity tolerance for an acceptable yield of 70%-90%

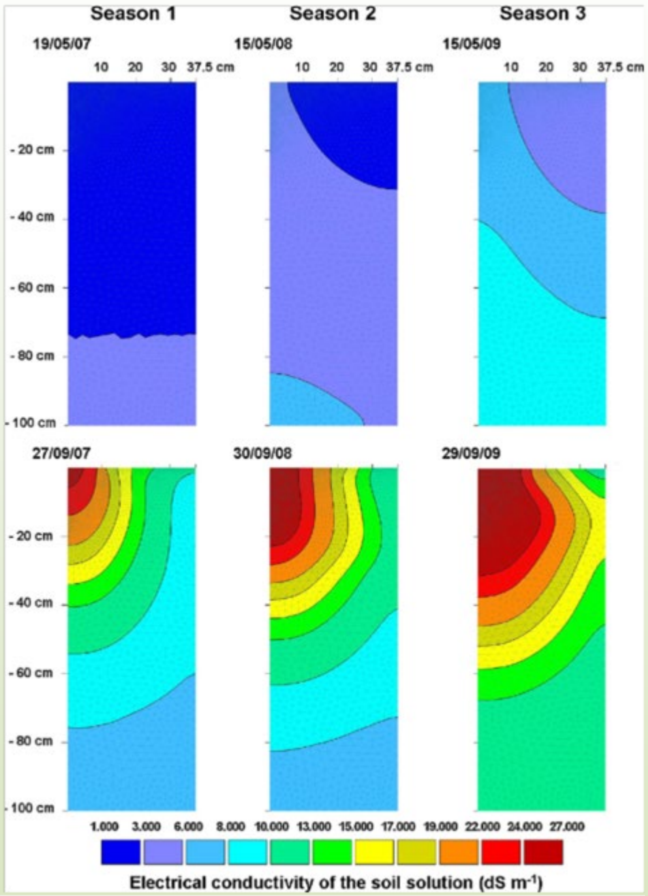
Leaching requirements

- Meet crop water requirements
- Promote salt leaching (depending on soil infiltration apply irrigation water >ET)
- Depends on the irrigation system and irrigation frequency and water volumes applied
- Consider the water table depth

1. Prevention

Irrigation practices with saline waters

- Meet crop water requirements respecting the crop tolerance
- Maybe applied in cycles or blended
- Depends on the irrigation system and irrigation frequency and water volumes applied



Soil water, overall salinity, the major cations, and the fate of N species. *In Ramos et al.*, 2011, 2012

Results showed a build-up of salts along the cropping season in plots irrigated with the blended waters and with fresh waters

Build-up of salts in soil is highly dependent on the annual rainfall, which can be very variable under Mediterranean conditions

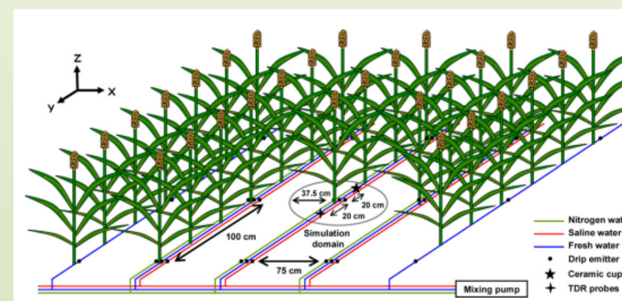


Fig. 3. Location of a point source emitter and monitoring sites in the experimental plot.

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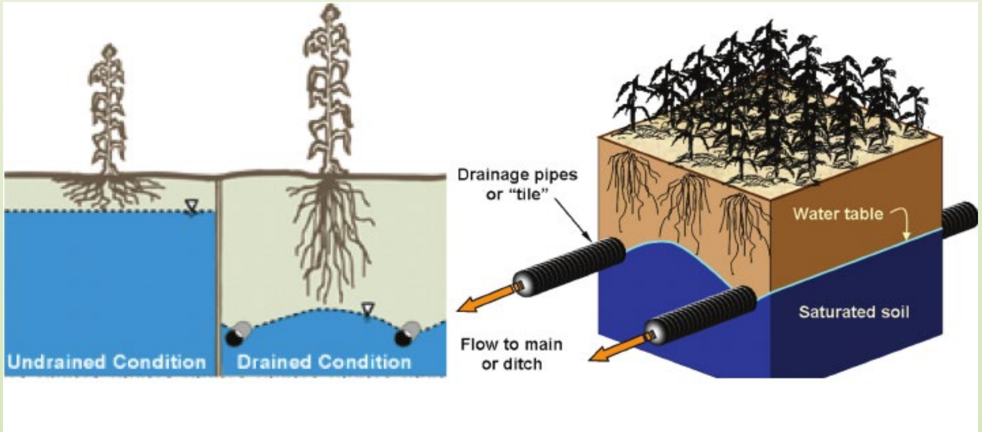
1. Prevention

Drainage

Dependents on soil hydraulic properties

Depends on the irrigation system

Consider depth, distance and type of drains, groundwater, rainfall



Tested the installation of mole drains by sub-soiling, at a depth of 0.7 m and 1.5 m apart, in a Vertisol irrigated with saline-sodic waters, and showed that the mole drains improved leaching of the salts added by the irrigation water by over 20% than without mole drains (Castanheira and Serralheiro, 2010)

1. Prevention

In some regions, such as Northern Europe, soil salinization from coastal flooding is identified as an emerging threat, predicted to increase under future sea level rise (Gould et al., 2021).

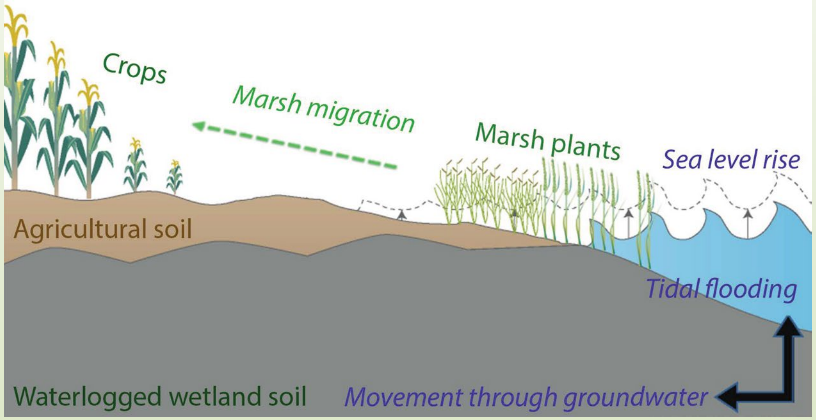


illustration of saltwater intrusion. Image adapted from ian.umces.edu (University of Maryland Center for Environmental Science)

Seawater intrusion

- Climate and geographic location associated
- Depends on the exploitation rates
- Consider upstream flow regulation to reduce the intrusion of seawater in the estuary and the groundwater
- Water abstraction limits can be implemented to maintain freshwater levels in groundwater and help prevent saline rise

Mangrove in coastal areas of Sri Lanka.

Corn in Cheasepeake Bay, USA

1. Prevention

Parent material

Soils naturally rich in soluble salts due to the weathering of parent rock constituents such as carbonate minerals and/or feldspar

- Climate and geographic location associated
- If weathering rocks rich in Na, sodicity can arise
- Soil movements (preparing the fields, namely deep ploughing and slope reshaping)
- Irrigation can mobilize salts from parent materials (including Na)

Vineyards in contour, Portugal (Carlos *et al.*, 2019)

Soils with good hydraulic conductivity with gypsum in the profile impeded sodification, irrigation with low ECw was able to desalinate the profile and allowed rice cultivation.
Other soils absent in gypsum, low ECw converged to cause soil particle dispersion leading to land abandonment after some years of irrigation (Herrero and Castañeda, 2018)

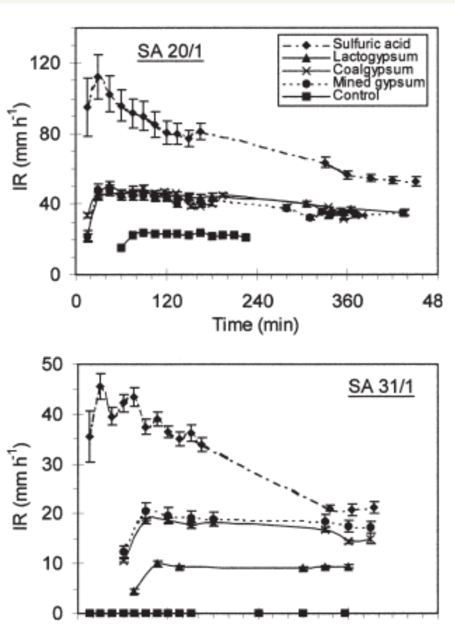
2. Mitigation

Chemical remediation of sodicity

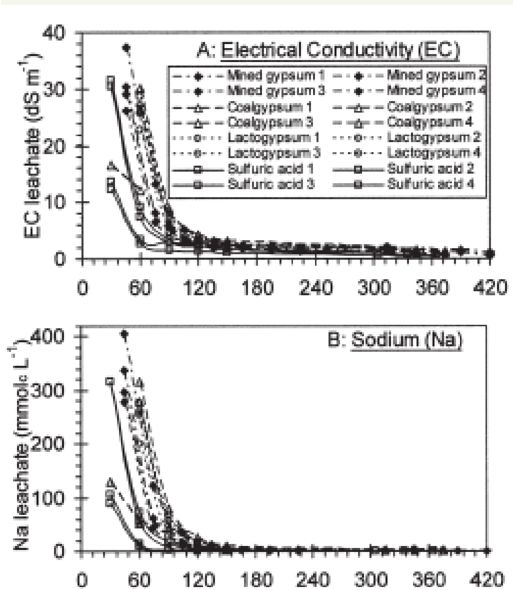
Soil sodicity can be remediated with Ca chemical amendments

Ca exchanges with the Na adsorbed in the soil's exchange complex. When in the soil solution, Na can be leached from the soil profile.

Most used are gypsum amendments (Ca sulphate) and gypsum-like by-products. Others such as Ca chloride and Ca nitrate (highly soluble), maybe used but usually are more expensive solutions.



Infiltration Rate of two calcareous soils (non-sodic and sodic)



EC and Na - Sodic calcareous soil

All amendments were effective in crusting prevention (IR) but sulfuric acid was the most efficient, leading to quicker reduction of soluble salts and Na in the soil leachates. The 3 gypsum-materials were equally effective in the reclamation process (Amezketa et al., 2005)

mined-gypsum, coalgypsum (a by-product from coal power plants), lactogypsum (a by-product from lactic acid and lactates), and sulfuric acid

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2. Mitigation

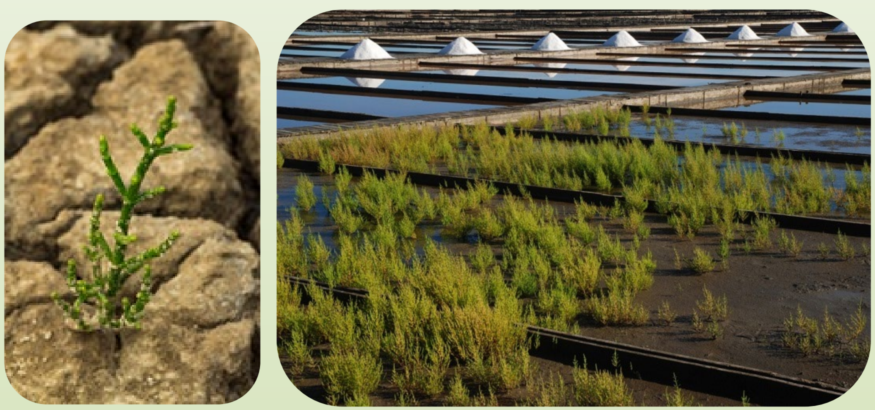
Phyto and bioremediation of sodicity

- Ca available to change with the Na adsorbed in the soil's exchange complex
- Plants increase the CO_2 level in the root zone, which enhances the dissolution of calcite
- Soil microbiome participates in increasing CO_2 level

Na can be removed by phytoremediation or bio accumulated in plants biomass

Requires presence of calcite in soils

Soil microbiome participates in increasing remediation process



Salicornia in Ria de Aveiro, Portugal

Review of 17 phytoremediation studies:

- approach can have similar or improved results compared to chemical remediation (gypsum), but it requires specific and more complex planning (crop rotation, crop type, irrigation timings)
- overall better plant nutrient availability in the soil, as a result of root exudates.

Qadir et al., 2007

2. Mitigation

Leaching and drainage

Practices favouring the water movement in the soil and improving leaching are a strategy for remediation of salt-affected soils

Increase soil structural stability with **PAM** and polysaccharides. PAM molecules are adsorbed by the clay surface causing a physicochemical change at the clay surface and acting as a bridge between soil particles

- Climate associated (arid regions with irrigation and semi-arid regions with rainfall)
- Monitor and control the drainage effluent to minimize downstream effects
- Soil strategies that enhance soil infiltration rates are necessary

PAM applied with sprinkler irrigation significantly improved the soil infiltration rate and reduced runoff (reducing soil crusting and erosion). Bjorneberg *et al.*, (2003) showed that PAM applied in single or multiple applications, at a rate of 1 kg ha-1 (10 mg L-1), with sprinkler irrigation, reduced cumulative runoff for the irrigation season by 38%, 15%, and 22% of the applied irrigation water for the control, single, and multiple treatments, respectively. (silty loam and sandy loam Fluvisols)

3. Adaptation

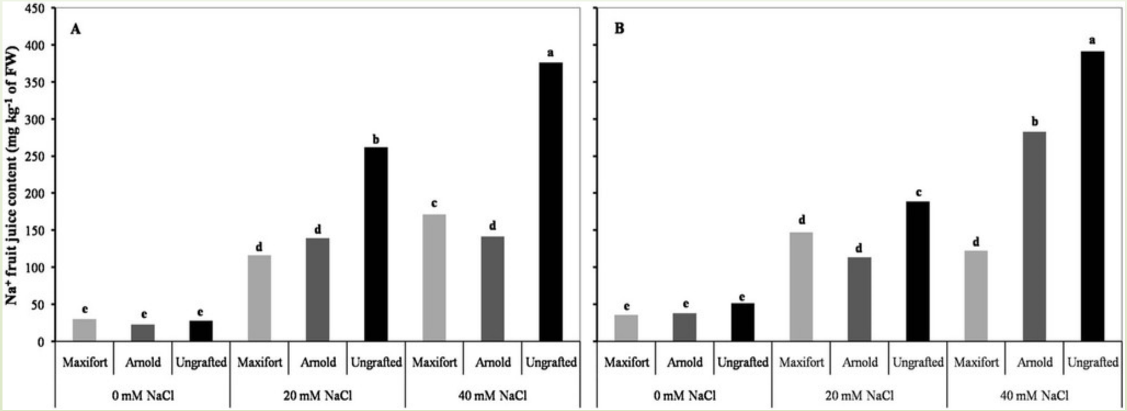
Agronomic practices

Use crops and crop rotations tolerant to salinity

Use cover crops to help extract salts from the soil

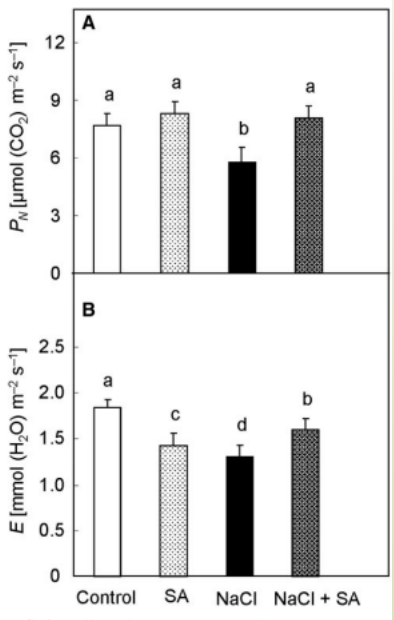
Decrease of foliar transpiration through foliar application of SA

grafting a salt-sensitive tomato variety into a more resistant tomato rootstock improved salinity tolerance of the salt-sensitive cultivar and maintain its organoleptic properties



Effects of salinity level and grafting combinations on the juice Na^+ content of 'Cuore di Bue' tomato fruits. Goia et al., 2013. 10.21273/HORTSCI.48.7.855

Effect of exogenous SA application on mean net photosynthetic rate (PN) (A) and transpiration rate (E) (B) of tomato plants grown for 17 days in nutrient solution with 100 mM NaCl and/or 0.01 mM salicylic acid. Mimouni *et al.*, 2016



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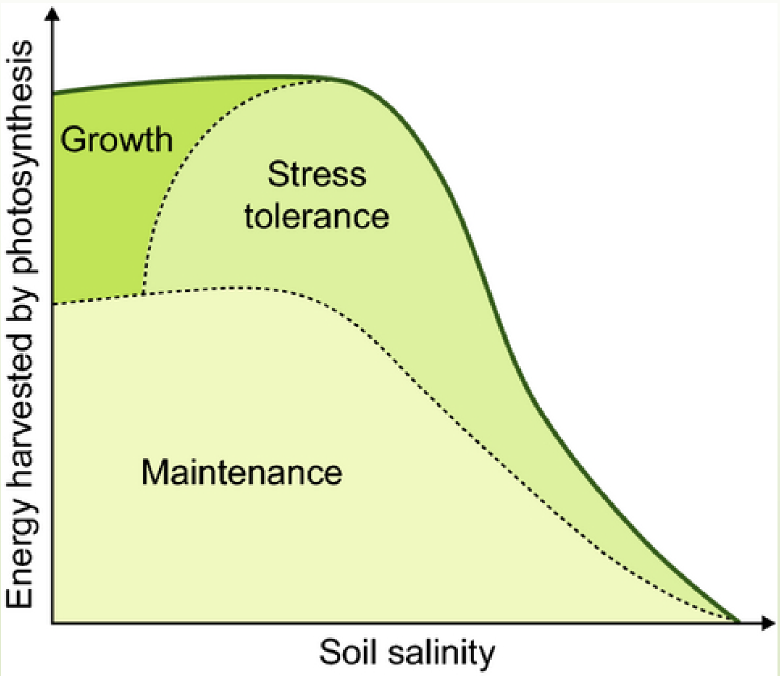
3. Adaptation

Crops with a productivity reduction of only 10% at EC_e > 4 dSm^{-1} (Weil and Bradley, 2017)



Scheme of energy gain and use of a crop plant under salinity stress. Maintenance - biomass, protein turnover, synthesis of lipids and carbohydrates, maintaining ion gradients, gaining nutrients and source to sink transfer. *In* Munns and Gilliham, 2015. Adapted from a concept by A. H. Millar and H. Lambers

Agronomic practices

Use crops and crop rotations tolerant to salinity

The majority of energy acquired by photosynthesis and fixed into C compounds is used by plants in general <u>maintenance</u> (Amthor, 2000; Jacoby *et al*., 2011).

Only a small proportion (10–40%) - used directly for biomass accumulation even under optimal conditions.

<u>Stress can be defined in terms of energy costs</u>

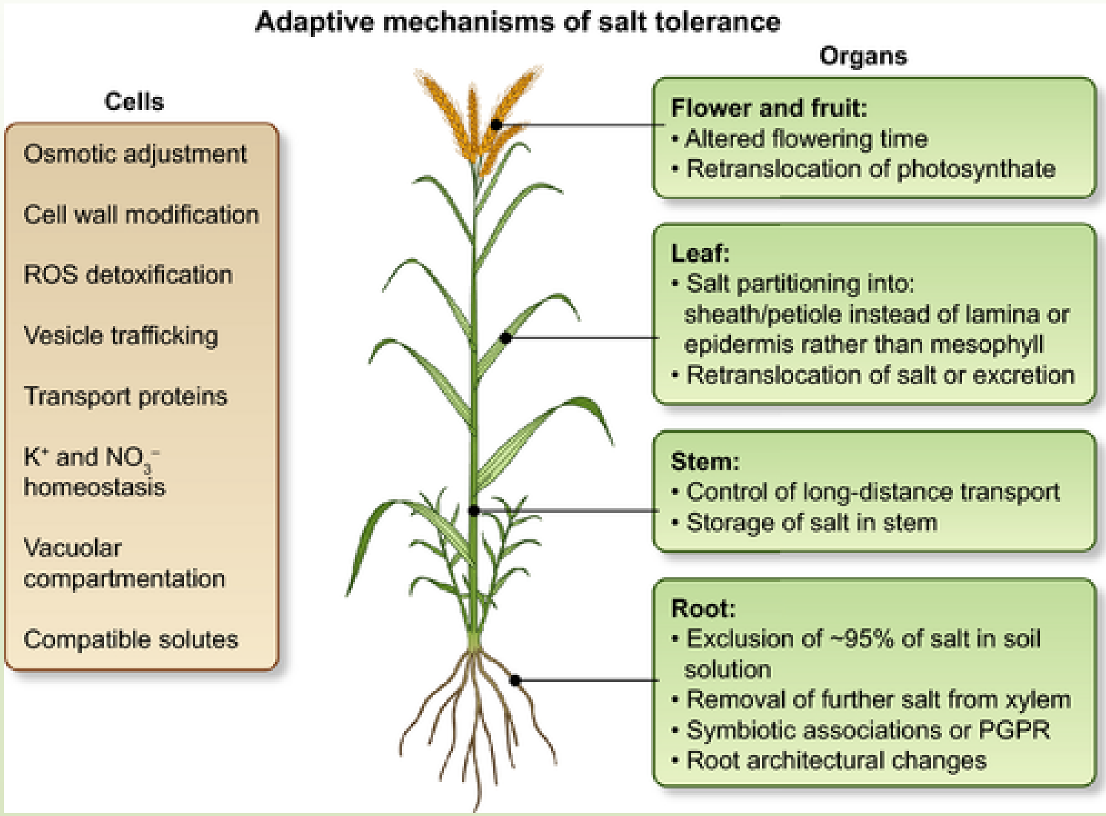
1. when the amount of energy acquired by plants is reduced (because of a reduction in photosynthesis rate or leaf area)

and/or

2. when energy is redistributed from growth into stress defence

3. Adaptation

Agronomic practices



In Munns and Gilliham, 2015.

Reactive oxygen species:
act as a signal
can also damage plant root and shoot tissue (perturbing enzyme, cell wall and membrane)
Overexpression of genes involved in ROS scavenging has resulted in lower cellular damage, the maintenance of photosynthetic energy capture, and an improvement in shoot and root growth under saline conditions

Root system architecture
Energy costs – real effects on crops

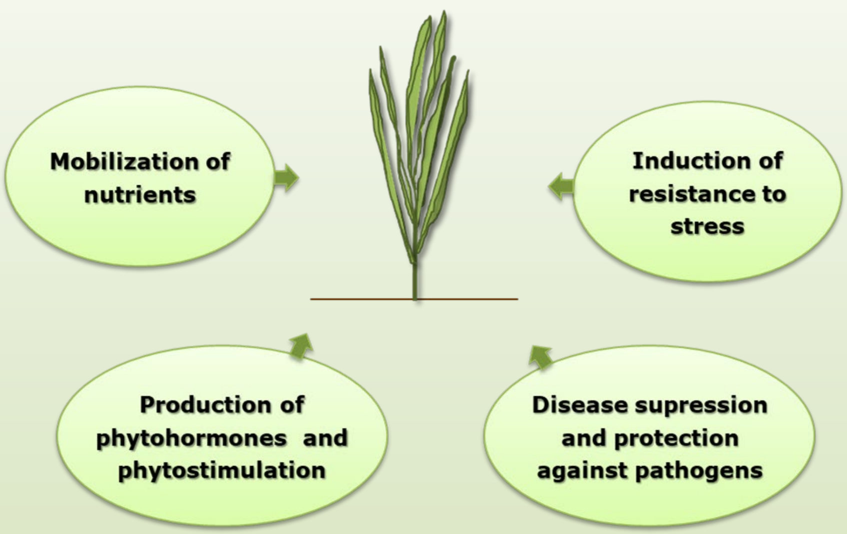
3. Adaptation

Microbial management

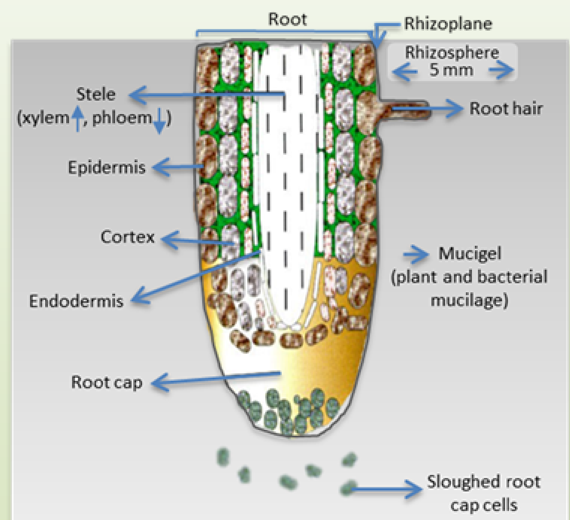
Crop host dependent

Sensitive to management techniques (tillage, fertilization, etc.)

Plant Growth Promoting Bacteria: benefits for the host plant



In Castanheira et al., 2018



The rhizosphere and its different components.

Root Exudates

- Organic acids
- Sugars
- Amino acids
- Vitamins
- Nucleic acids
- Mucilage
- Sloughed root cap cells

Nutrients + energy for microorganisms

Figure adapted from Maier *et al.* 2000, Environ Microbiol

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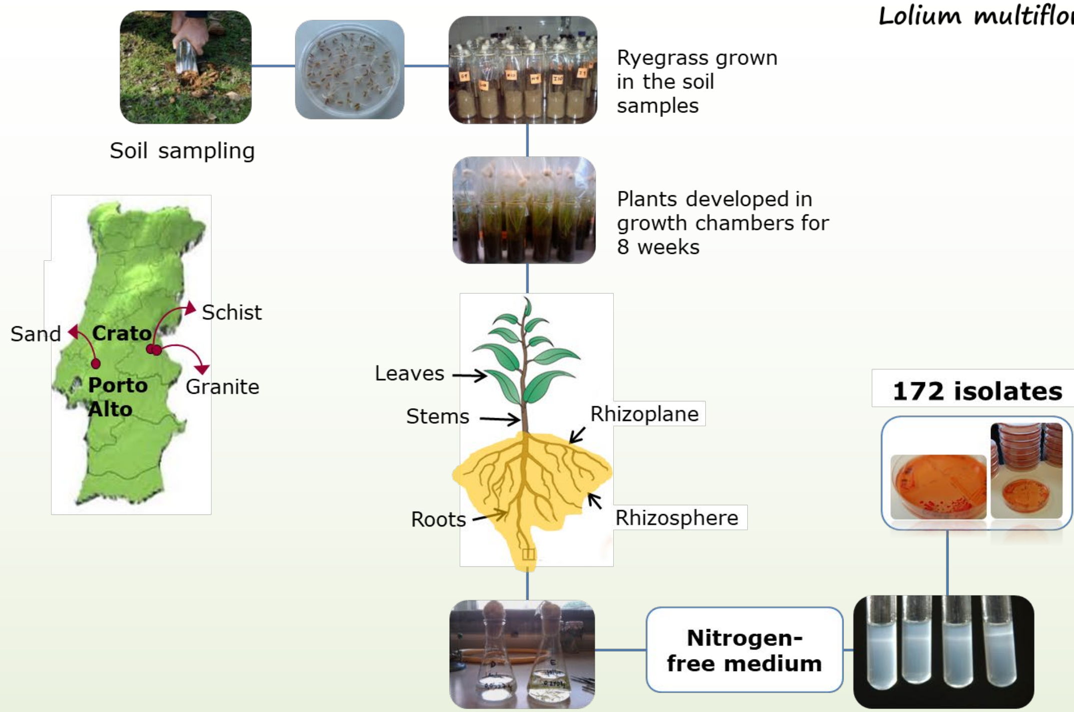
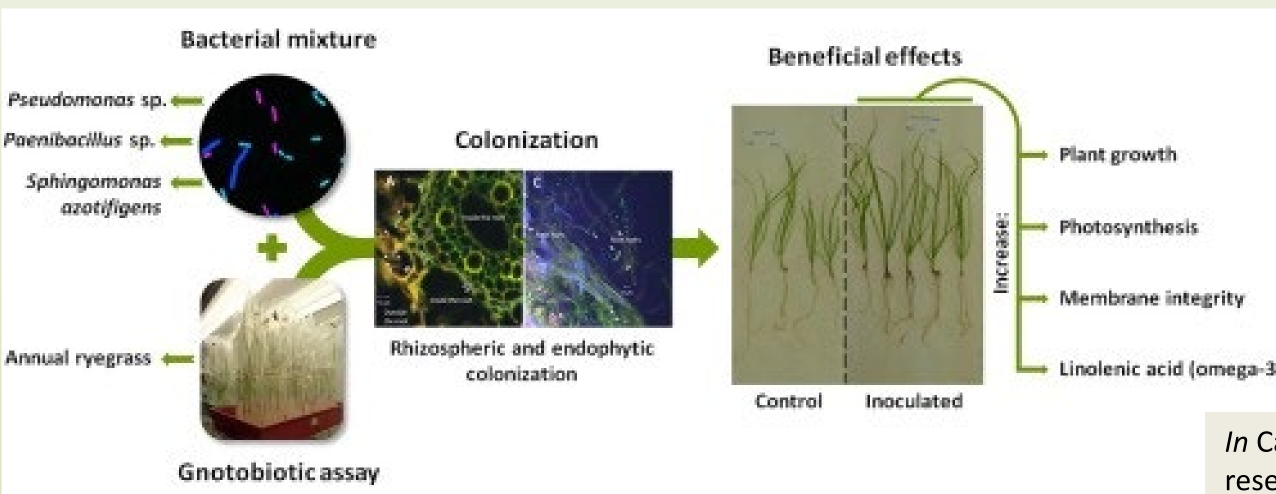
3. Adaptation

Surveyed annual ryegrass-associated bacteria in Portuguese soils - reported novel strains able to increase the biomass of annual-ryegrass plants in gnotobiotic conditions

In Castanheira *et al.*, 2018

Lolium multiflorum





In Castanheira *et al.*, 2017. Microbiological research. https://doi.org/10.1016/j.micres.2017.01.009.

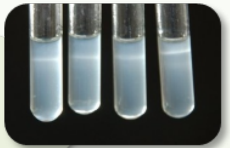
3. Adaptation

Plant growth promotion

Phytohormone production (Auxins)

37 isolates produced > 20 μg IAA ml^{-1} culture

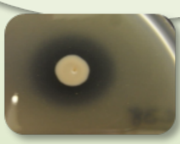
Nitrogen fixation



*nif*H gene screening

Solubilization of mineral phosphate

11 isolates positive



Siderophore production

11 isolates positive

Hydrolysis of plant polymers

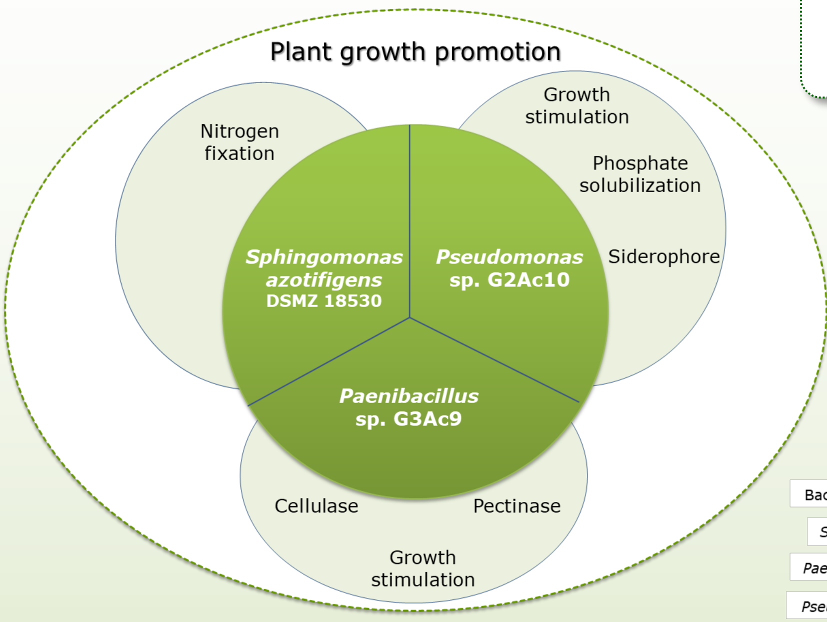
27 isolates positive

celullose

pectin

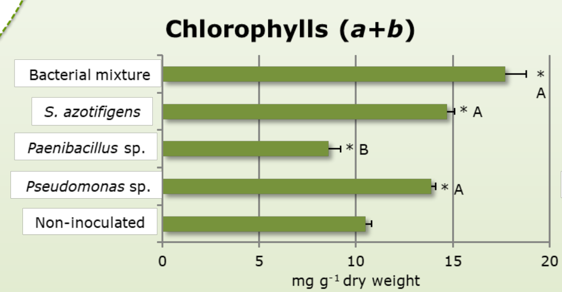
In vitro activities performed by plant growth promoting bacteria

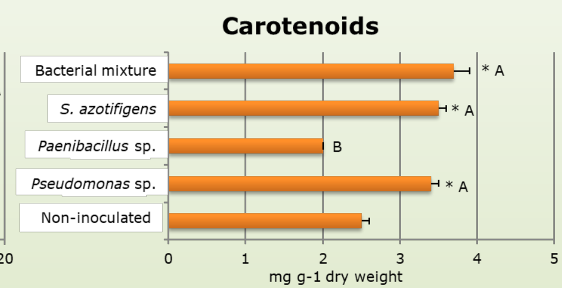
3. Adaptation

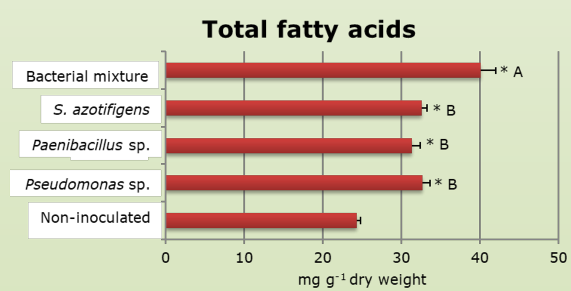


Microbial management

Complete plant growth medium







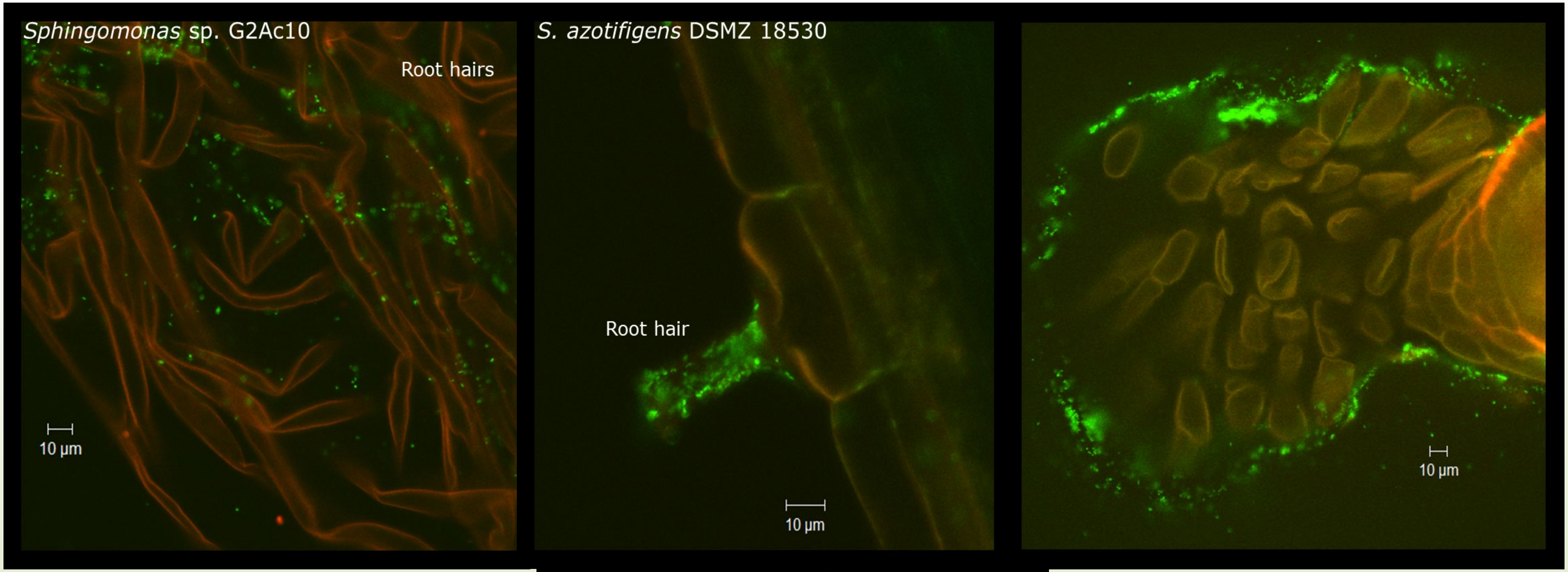
* Significant differences from non-inoculated controls

Chlorophylls (*a+b*): > 67%
Carotenoids: > 48%
Total fatty acids: > 65%
DBI: < 8% (not significant)
Electrolyte leakage: < 45%

In vivo

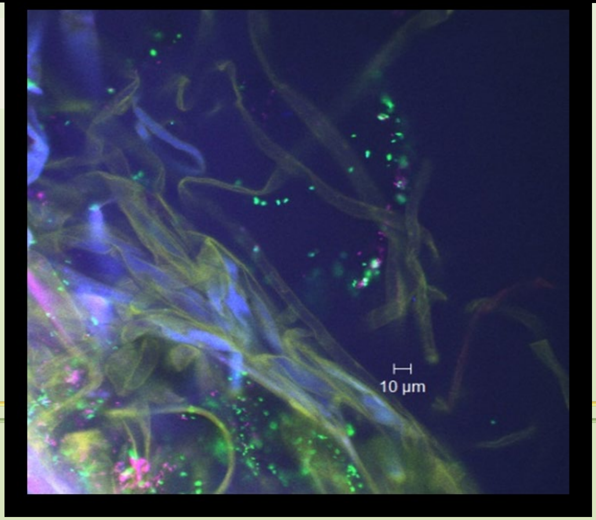
In Castanheira *et al.,* 2017. Microbiological research. https://doi.org/10.1016/j.micres.2017.01.009.

3. Adaptation



In Castanheira *et al.*, 2017. Microbiological research. https://doi.org/10.1016/j.micres.2017.01.009.

In vivo



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3. Adaptation

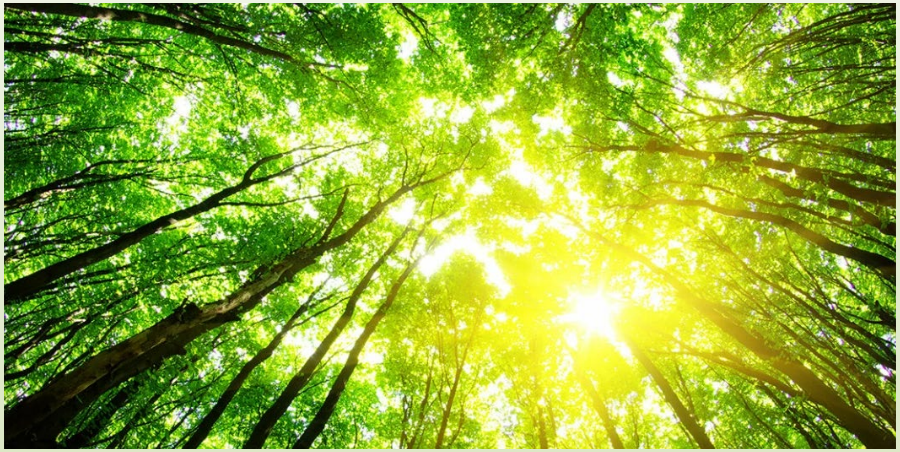
Land-Use changes

Evaluate the best use for the soil

Access land suitability and degradation susceptibility

converting into recreation and ecotourism areas, cultural heritage, or natural protection areas

Lezíria, Portugal 2018



Predominant regional biophysical cooling from recent land cover changes in Europe. NTNU - Norwegian University of Science and Technology 2020

Soil Salinity/Sodicity

Destruction of soil structure as a result of excess sodium (Source: Soil Atlas of Europe)

Lezíria

Located approximately 25 km northeast of Lisbon, Portugal, between January 2017 and December 2019. The area is a small peninsula (13,000 ha), limited to the west by the Tagus River and to the east by the Sorraia River.

Fig. 1. Location of the study area.

Soil salinization risks

Lezíria Grande de Vila Franca de Xira

Ricardo Lopes, Público 2018

Primary risks:
- Costal area with tidal influence
- existence of alluvial and marine soils
- presence of saline surface water table (with 12-30 dS m^{-1} at about 1-2 m depth)
- ascending capillary flow

Secondary risks:
- quality and quantity of water available for irrigation, particularly in dry years

Fluvisol and Solonchak
(according to IUSS Working Group WRB, 2014)

Salt-affected soils field monitoring - ECa

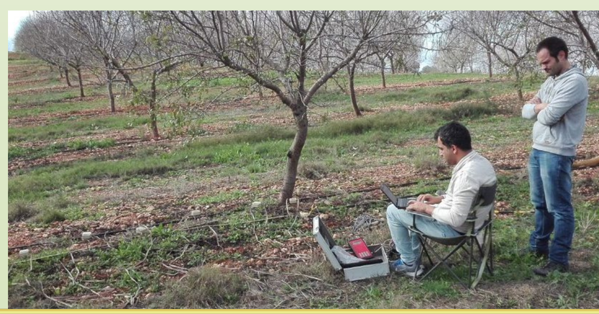
EC_a (dSm^{-1})	Apparent soil electrical conductivity

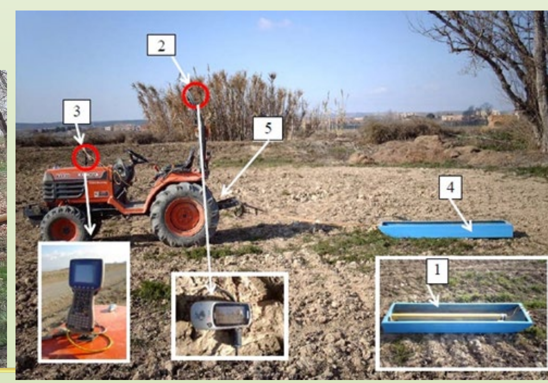
The presence of dissolved salts in the soil is likely to dominate ECa, can be correlated to ECe and ECsw by establishing local-specific calibrations

Several variables influence: bulk density, percentage of sand, silt, and clay, plant-available water content, cone index, and saturated hydraulic conductivity, chemical parameters (i.e., extractable P and K, pH, CEC, OM, and micronutrients) presented different strengths of the correlations (Bang, 2005)

EC_a measurements should be performed with soil water content above half the field capacity, in order to ensure that the salts are dissolved (Rhoades, 1999)

EM38 Geonics Ltd.





Georeferenced Dualem -1S sensor with 5 components: (1) EM sensor, (2) GPS unit, (3) data acquisition system, (4) non-metallic sledge and (5) vehicle. Adapted from (Urdanoz *et al.*, 2008).

Salt-affected soils field monitoring - ECa

ECa represents a depth weighted average of the soil EC and it **does not reflect the real variation of EC with depth**

ECa collected at multiple soil depths by placing the sensor at different heights from the soil surface

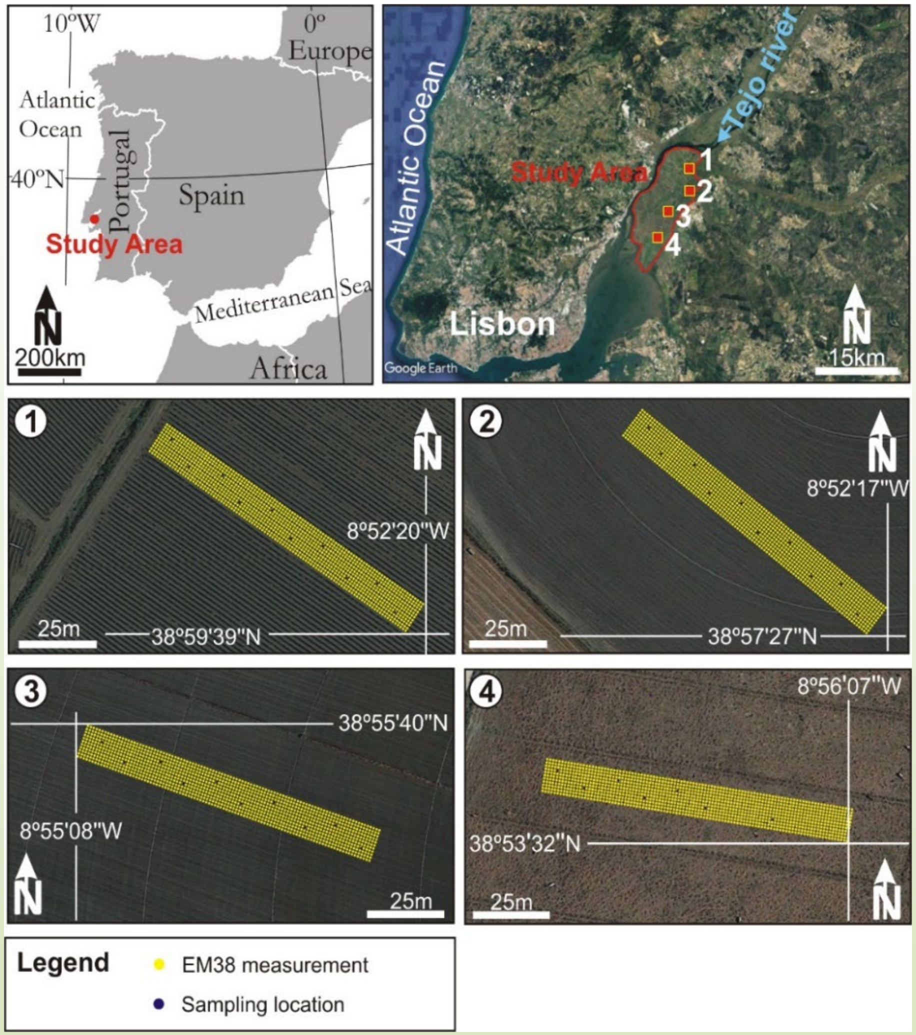
Numerical inversion of ECa data to find the spatiotemporal distribution of soil EC (σ) at each depth

Calibration - regression between σ and ECe, SAR, ESP

Conversion of spatiotemporal distribution of σ into salinity and sodicity cross sections using the obtained calibration equations

Lezíria

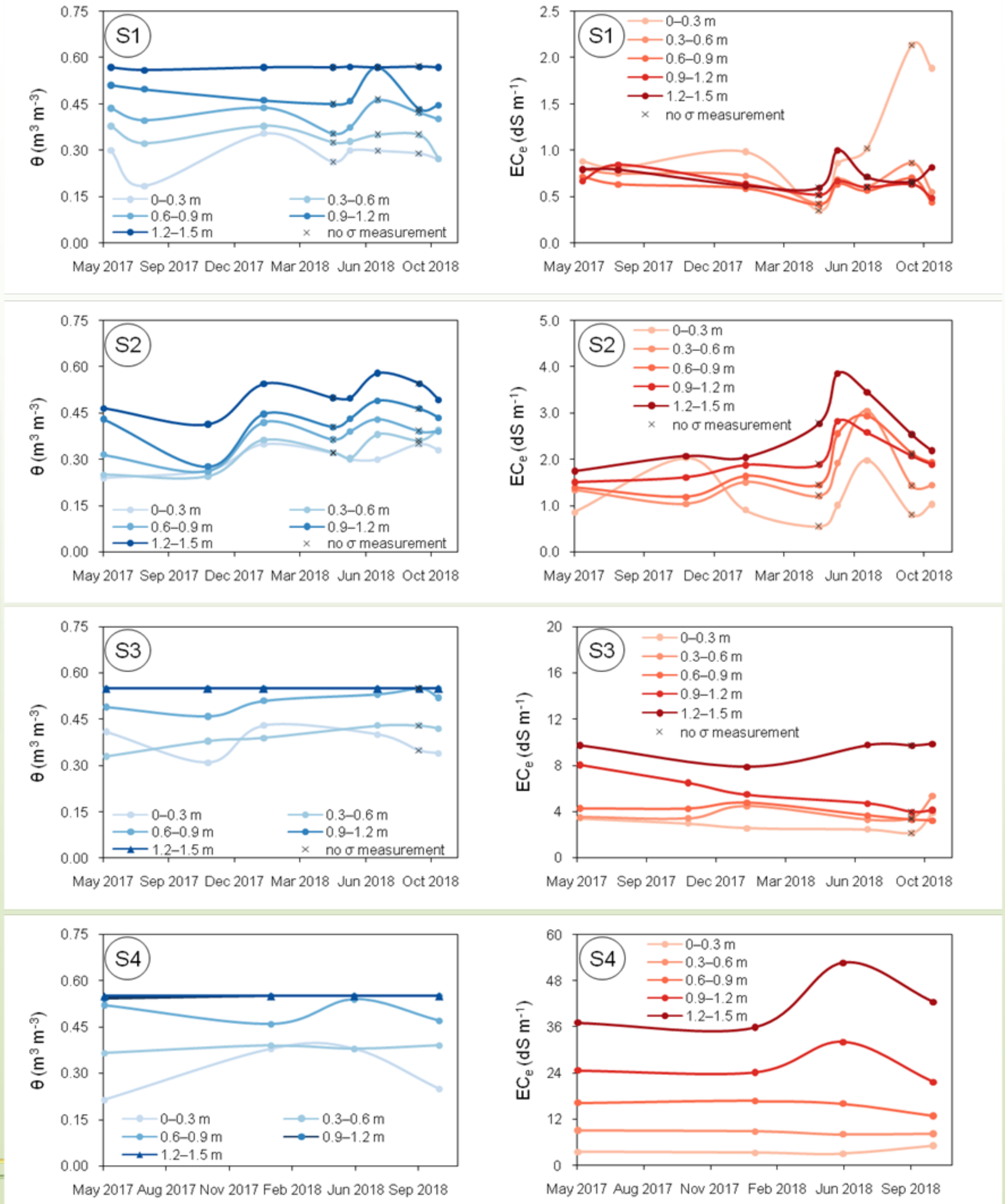
Study area of Lezíria Grande de Vila Franca de Xira (Lisbon, Portugal), and locations 1, 2, 3, and 4 where the EMI transects and sampling were conducted.



Temporal variation of soil θ and ECe

ECe peaks in summer when irrigation occurs:

- salts probably added by fertigation (S2)
- influence of the saline and shallow water table (S3 and S4)

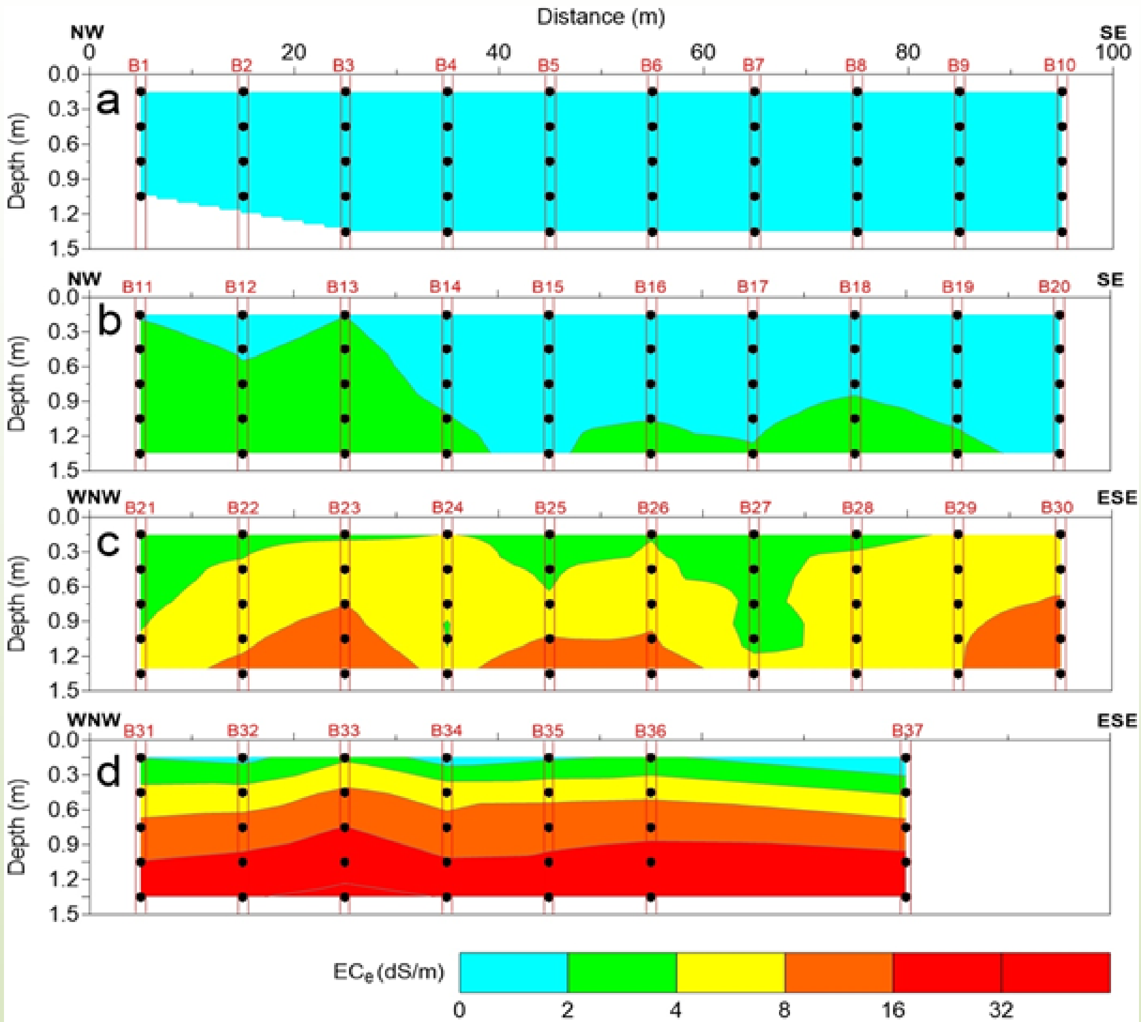


Period of May 2017–October 2018, variation of volumetric water content (θ – $m^3\ m^{-3}$), and electrical conductivity of the soil saturation extract (ECe – $dS\ m^{-1}$), in the topsoil (0–0.3 m), subsurface (0.3–0.6 m), upper subsoil (0.6–0.9 m), intermediate subsoil (0.9–1.2 m), and lower subsoil (1.2–1.5 m), measured at S1, S2, S3, and S4 sites, at locations 1, 2, 3 and 4 respectively.

Spatiotemporal variability of ECe – EMCIs

Electromagnetic conductivity images (EMCIs by the IDL-UL team) provide volume specific distribution of the soil bulk electrical conductivity (σ)

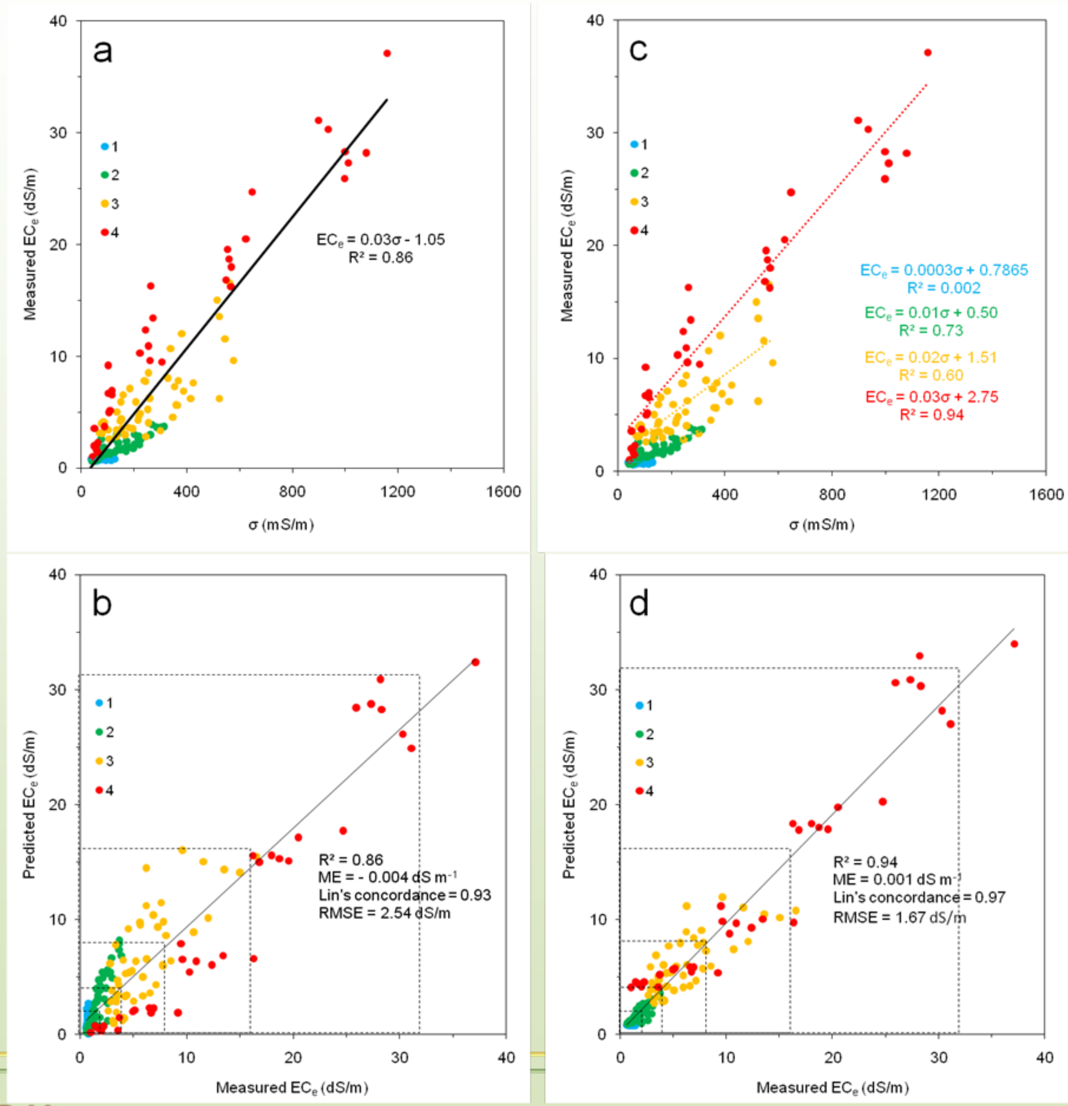
Using a one-dimensional (1-D) laterally constrained inversion algorithm (Monteiro Santos, 2004), generated EMCIs in order to evaluate the soil salinization.
The subsurface model consists of a set of 1-D models distributed according to the locations of the Eca measurements.



Contour plots of the measured electrical conductivity of the saturation soil paste extract (ECe, dS m^{-1}) for the four locations, including (a) 1, (b) 2, (c) 3, and (d) 4

Calibration σ and ECe

Regional calibration | **Location-specific calibration**

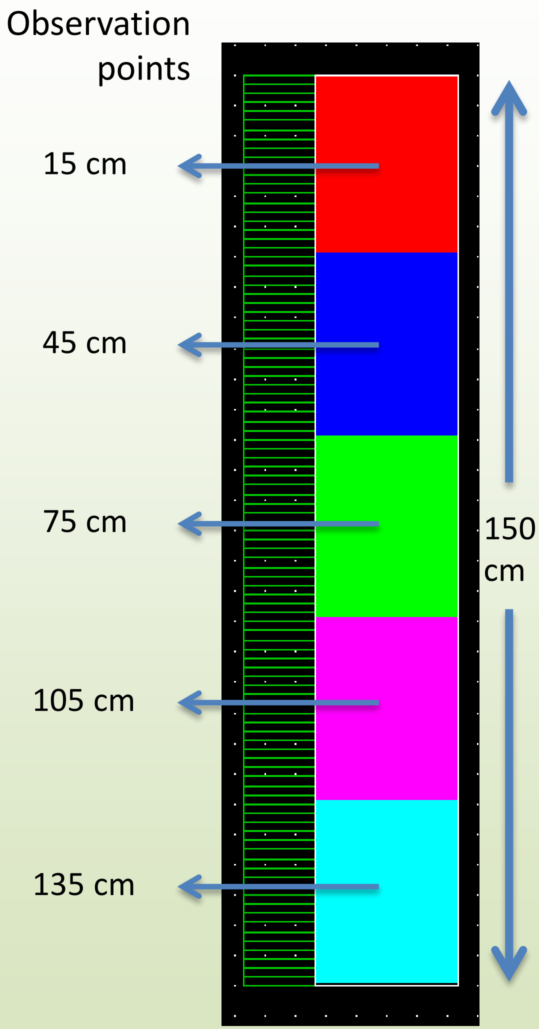


The comparison of the regional and location-specific approaches in terms of ability to predict EC_e

$R^2 = 0.86$
ME = -0.004 dS m^{-1}
RMSE = 2.54 dS m^{-1}

$R^2 = 0.94$
ME = 0.001 dS m^{-1}
RMSE = 1.67 dS m^{-1}

Soil water and salts dynamics – Hydrus 1D



Frontier conditions

Soil surface: Meteorological with water fluxes

With temporal variation:

- Rainfall and irrigation (daily)
- Reference evapotranspiration (daily) - ET_0 (Penman-Monteith)
- Crop evapotranspiration: $ET_c = ET_0 \times K_c$ (Crop coeficient) (FAO 56)
- Crop transpiração: $T = ET_c \times SCF$ (Surface Cover Fraction estimated with LAI)
- Soil evaporation: $E = ET_c - T$

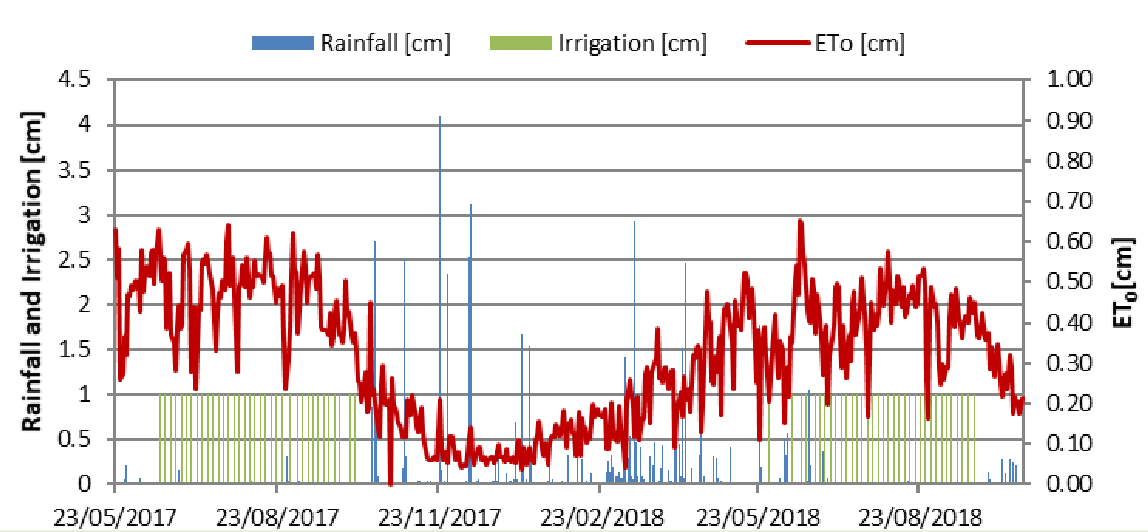
Bottom: Water table with variable depth

Soil water and salts dynamics – Hydrus 1D

Input data:

- Soil initial conditions
- Soil water content
- Ec_e converted in TDS_{sw} (gL^{-1}) = (EC_e x K)/1000

  where K = 640 if ECe between 0.1-5 dSm^{-1} or K = 800 if ECe > 5 dSm^{-1} (Richards, 1954)
- Soil hydraulic properties
- Transport of solute parameters
- Root growth



Water and solutes absorption by the roots:

- Water Stress: Feddes *et al.* (1978)
- Saline stress: Maas's (1990) (tolerance in function of the limits and slope)
- Passive solute absorption

Lezíria

Zea mays, L.

Lolium multiflorum, Lam

Fluvisol with clay-loam texture

Irrigation with center pivot

Crop rotation: maize and ryegrass

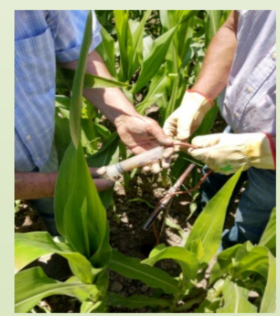
Irrigation water: ECw = 0.48 dS m^{-1}

2 irrigation cycles:

2017 - 3600 m^3ha^{-1} ➡ 79% ET_c

2018 - 3600 m^3ha^{-1} ➡ 76% ET_c

Depth (cm)	**0-30**	**30-60**	**60-90**	**90-120**	**120-150**
Texture	Silty-Clay-loam	Clay-loam	Clay-loam	Clay-loam	Clay-loam
EC_e (dS m^{-1})	1.85	2.87	2.97	3.01	3.86
SAR (meq L^{-1})$^{0.5}$	7.03	9.86	12.41	19.32	23.48
ESP (%)	7.99	8.92	11.37	14.60	15.52
pH (H_2O)	7.12	8.01	8.55	8.69	8.56
CEC ($cmol_{(c)}$ kg^{-1})^c	22.35	22.17	24.93	26.46	23.25
Classification (Richards 1954)	Nonsaline and nonsodic	Nonsaline and nonsodic	Nonsaline and nonsodic	Sodic	Sodic



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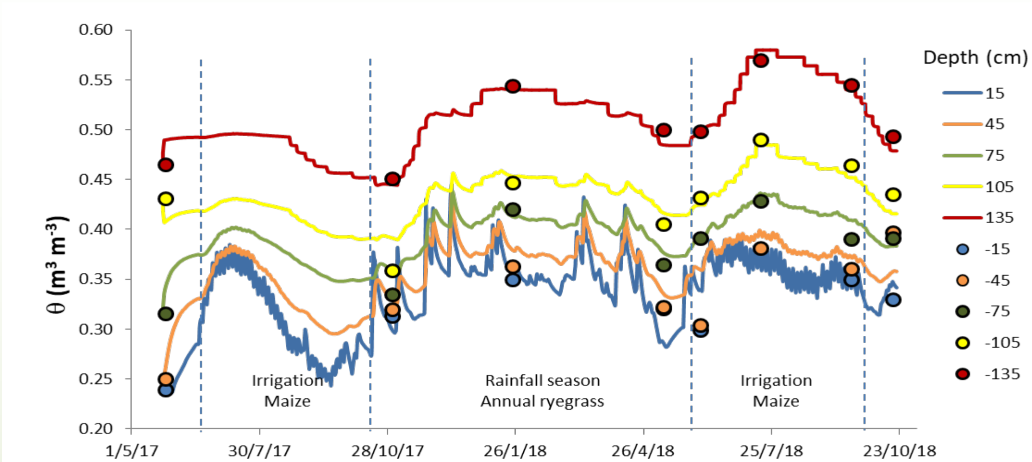
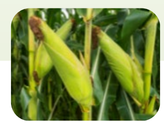
Model calibration



Hydrus-1D model calibration for soil water flow and solute transport with observed field data and considering the presence of a saline water table

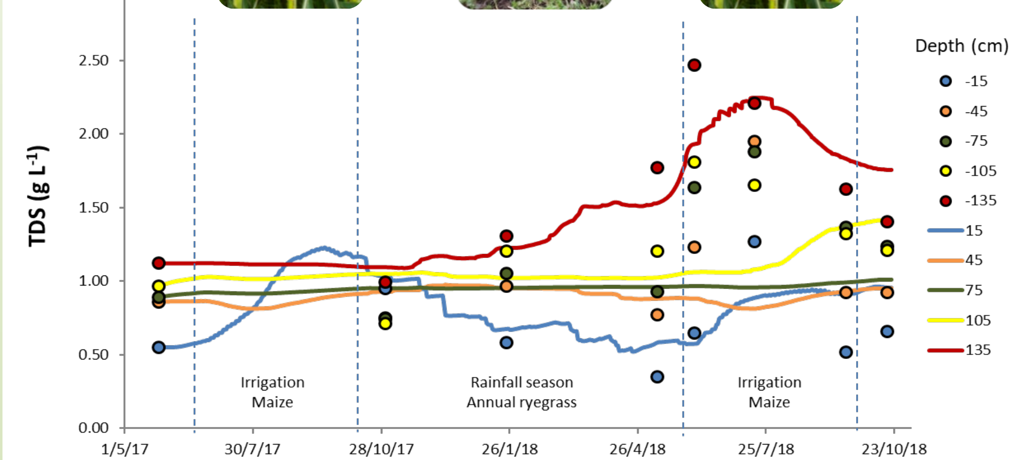
RMSE = 0.022 $m^3\ m^{-3}$ (0.23-0.58 $m^3\ m^{-3}$);

R^2 = 0.94



Simulated

Measured



RMSE = 0.212 $g\ L^{-1}$ (0.35-2.47 $g\ L^{-1}$);

R^2 = 0.77

In Castanheira *et al.* 2020.
https://doi.org/10.19084/rca.19646

Predict irrigation-induced risks of soil salinisation

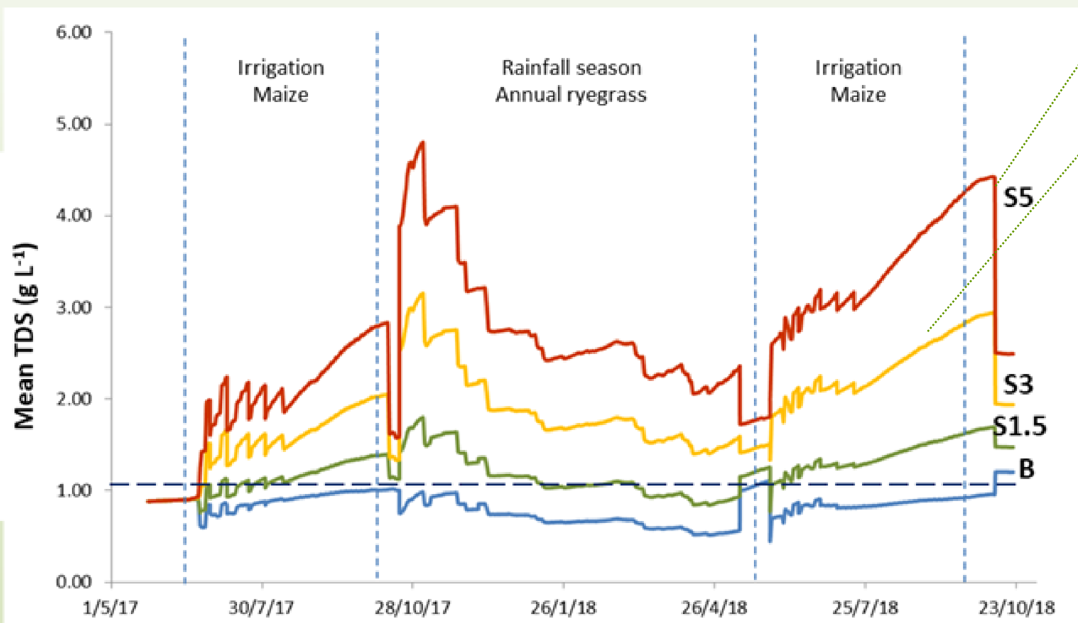
Threshold tolerance to salinity :

Maize: ECe 1.7 $dSm^{-1} \approx 1.09$ $g\ L^{-1}$ → Moderately sensitive

Ryegrass: ECe 6 $dSm^{-1} \approx 3.84$ $g\ L^{-1}$ → Moderately tolerant

In scenarios ECw 3 and 5 dS m^{-1} the mean concentration of solutes in the root zone increased to levels above the threshold tolerance of maize

Mean solute concentration in the root zone



ECw 5 dSm^{-1}

ECw 3 dSm^{-1}

ECw 1.5 dSm^{-1}

Baseline ECw 0.48 dSm^{-1}

Root zone [salts] increases 2.7 and 4.5 x

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In Castanheira *et al.* 2020. https://doi.org/10.19084/rca.19646

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SoilSalAdapt

Preadapting soil biology for increased tolerance to elevated salinities

UNIVERSITY OF LINCOLN

Norwegian University of Life Sciences

Instituto Nacional de Investigação Agrária e Veterinária, I.P.

1. Research focused on effects on soil physical and chemical properties: salinity damages soil structure, reduces SOM availability, fertility and crop yields.
2. Bacteria and fungi: key drivers of soil nutrient cycles and fertility -> **effects of changes in salinity on soil biological communities are not well understood**
3. Limited work shows short term negative effect in soil microbial respiration and activity

Soil DNA metagenomics very powerful: aware of only 4 relevant previous studies, and these show:

- bacterial salt tolerance correlated with the salinity of the soil they derived from in Australia (ISME J 2019 13, 836–846)
- experimental manipulation the Swedish grassland soils salinities showed a significant effect of 7 dSm^{-1} salinity on bacterial communities and selection for Firmicutes in the short term (40 days) (mBio 2019 10:e01607-19)
- soil samples from the Yellow River Delta in East China across a natural gradient from to 1 to 34 dSm^{-1} had significant differences in bacterial and fungal communities (Sci Rep 2021 11:12870; Microbiol.2020 11:594284)

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Experimental evolution: adaptation of fungi to increased salinity

Goddard shown:

Short term 3 month – soil microbiome changes due to salt

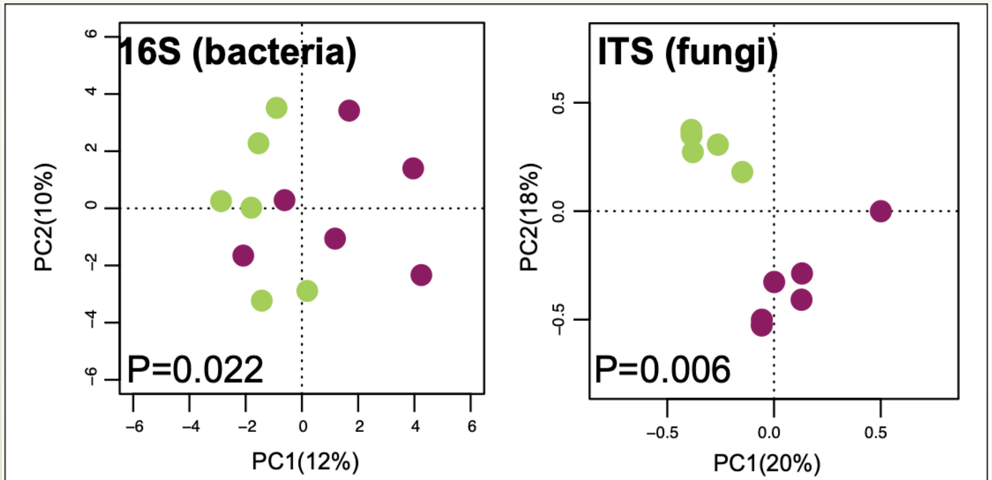
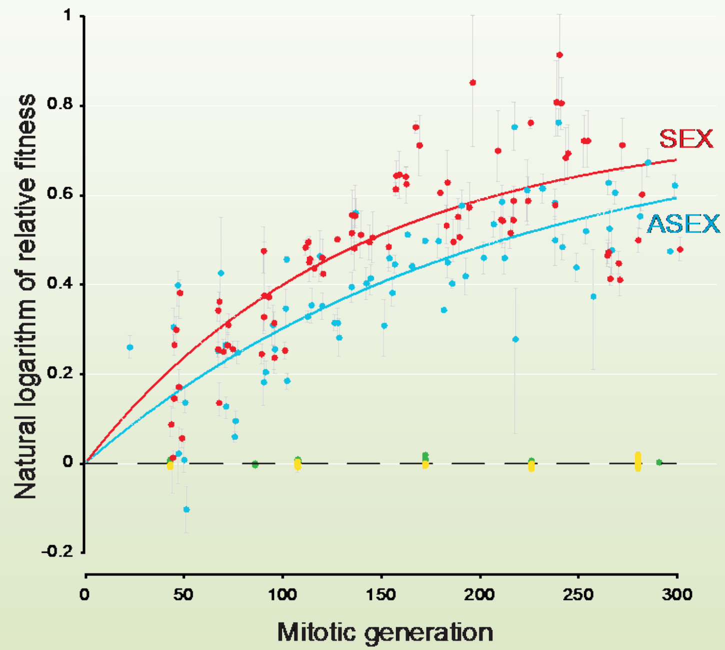


Fig 2. PCA plots showing the difference in types of bacterial and abundances of fungal species in soils irrigated with tap (green) or 3 dS/m saline (purple) water based on Jaccard distances.



Others shown similar for bacteria and nematodes

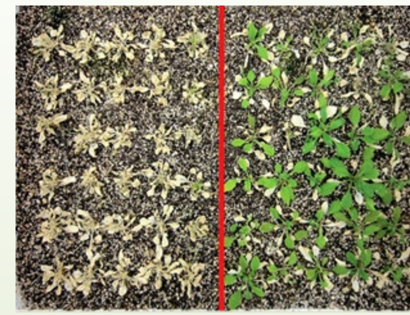
SoilSalAdapt

UNIVERSITY OF LINCOLN

Norwegian University of Life Sciences

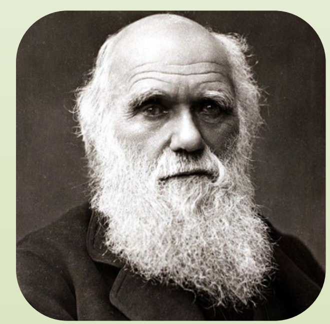
Instituto Nacional de Investigação Agrária e Veterinária, I.P.

Hypothesis:
the deliberate sustained use of part-saline irrigation across the growing season will apply selection pressures resulting in soil and rhizosphere biological **communities becoming pre-adapted** to be more robust and resilient to increased salinities in drought periods later in the season



Trends in Plant Science 2015 20(9):586–594

A potential solution:
Use of Darwinian selection processes to naturally **<u>pre-adapt</u>** soil and rhizosphere biological communities



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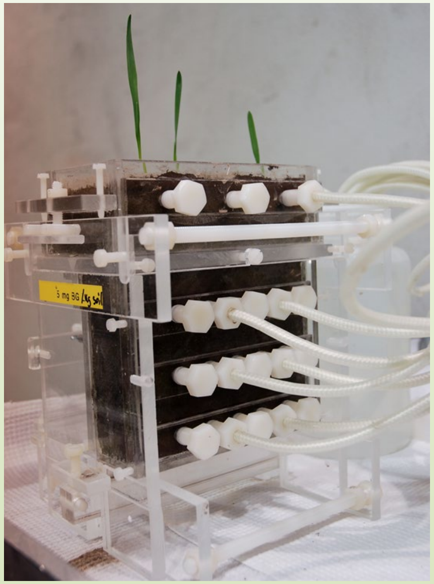
- to test this management approach to protect soils and enhance their performances
- to increase understanding of how changes in salinity affects soil biological communities (how these communities may become ecologically and physiologically adapted to this)

At different scales:
1. experimental microcosms

2. pot-scale mesocosms

3. field trials

Assess the affect on soil biology (R/DNA sequencing), soil properties, and crop growths/yields



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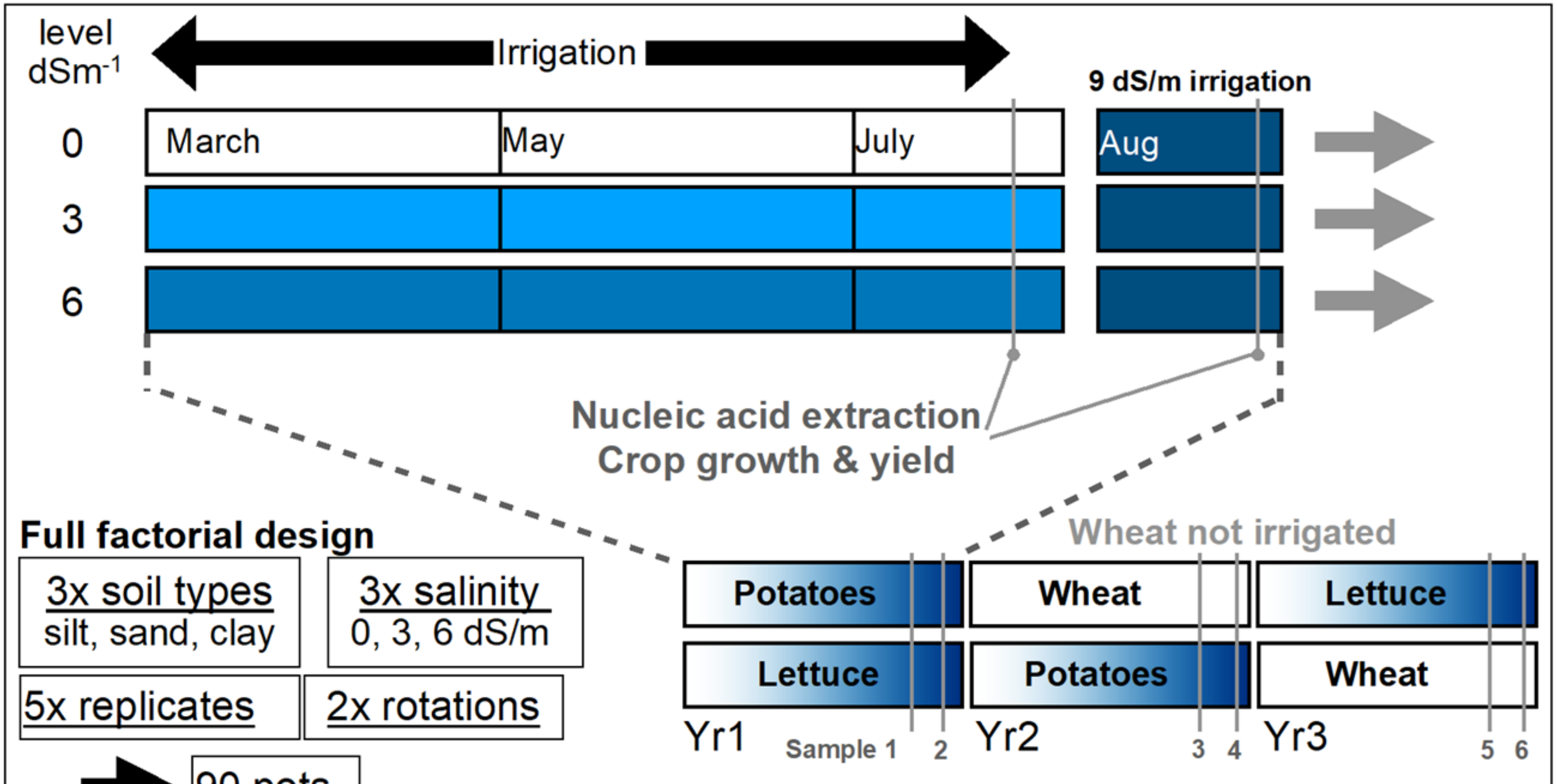
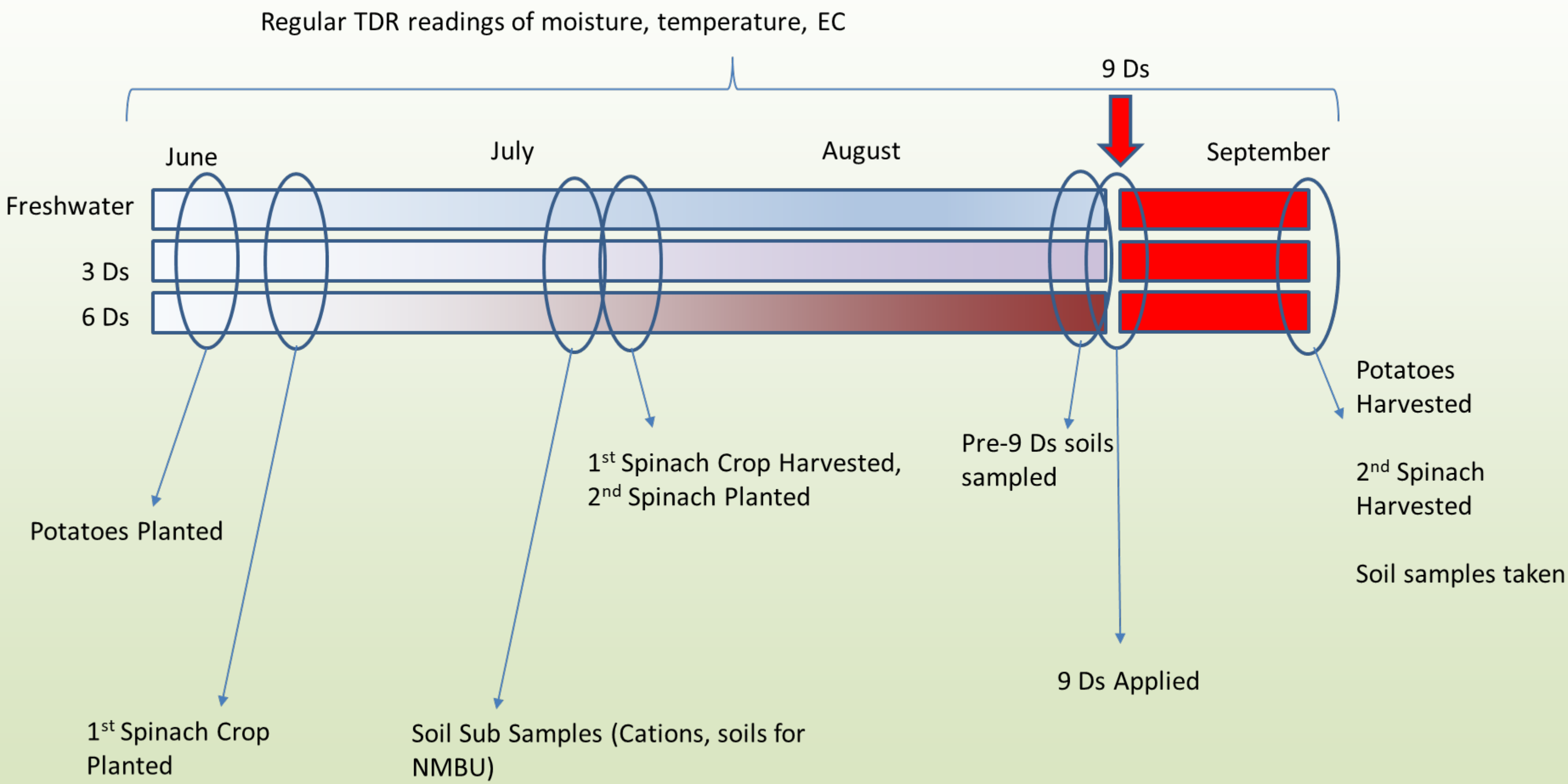


Fig 5: Mesocosm experimental design

SoilSalAdapt

Mesocosm Trials UK

SoilSalAdapt



Soil salinity - remote sensing


Agricultural Water Management 241 (2020) 106387

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Soil salinity assessment using vegetation indices derived from Sentinel-2 multispectral data. application to Lezíria Grande, Portugal

Tiago B. Ramos[a,*], Nádia Castanheira[b], Ana R. Oliveira[a], Ana Marta Paz[b], Hanaa Darouich[c], Lucian Simionesei[a], Mohammad Farzamian[b], Maria C. Gonçalves[b]

T.B. Ramos, et al. *Agricultural Water Mana*

A - Montalvo

drip irrigation
tomato/ryegrass

B - Corte Lobo

sprinkler irrigation
maize/ryegrass

C - Ermida

sprinkler irrigation
maize/ryegrass +
cloverleaf + lucerne

D - Polvarista

Rainfed
pasture

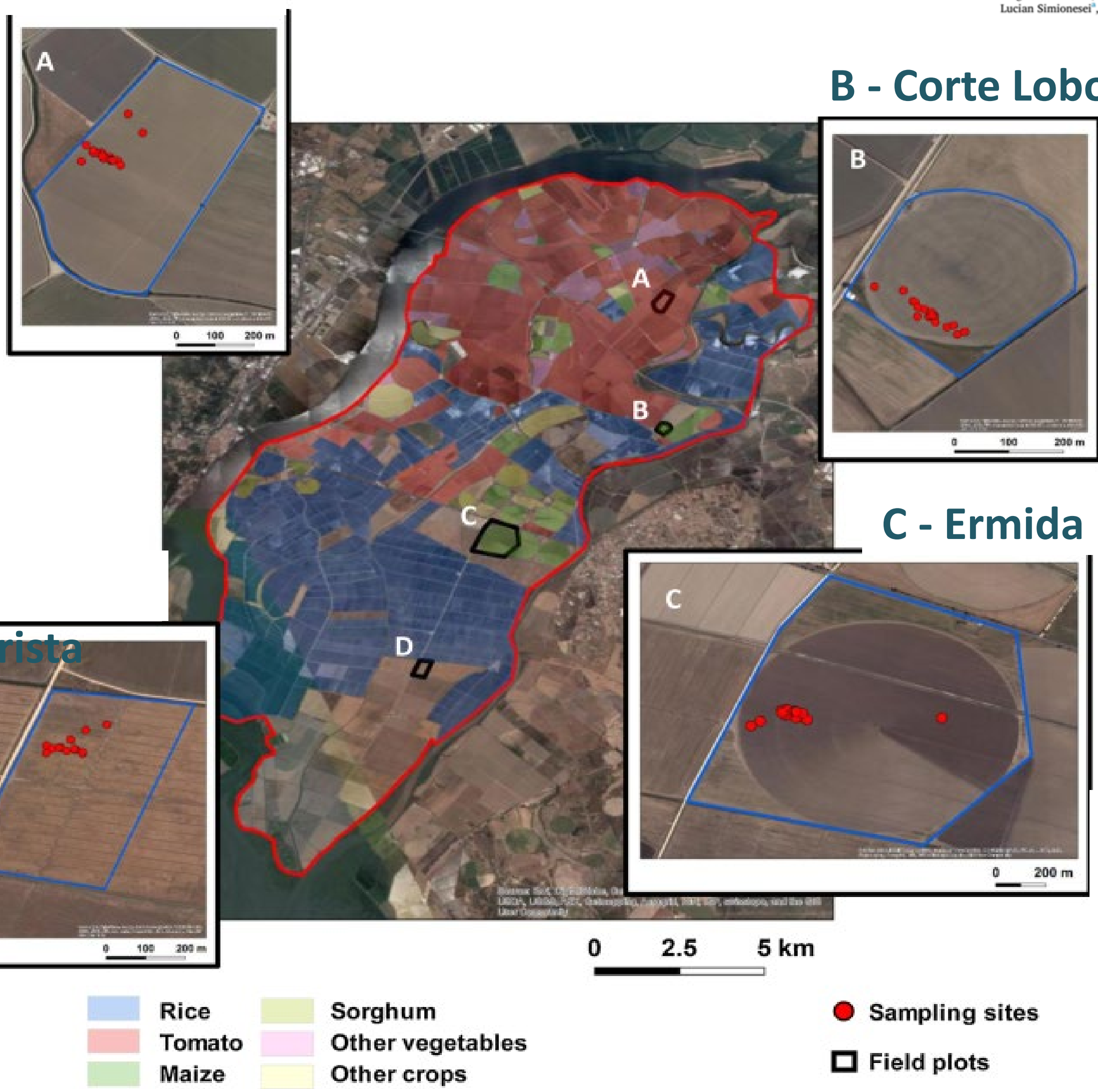


Fig. 2. Main land uses (ABLGVFX, 2017) and location of the field plots (A, B, C, and D) and sampling points.

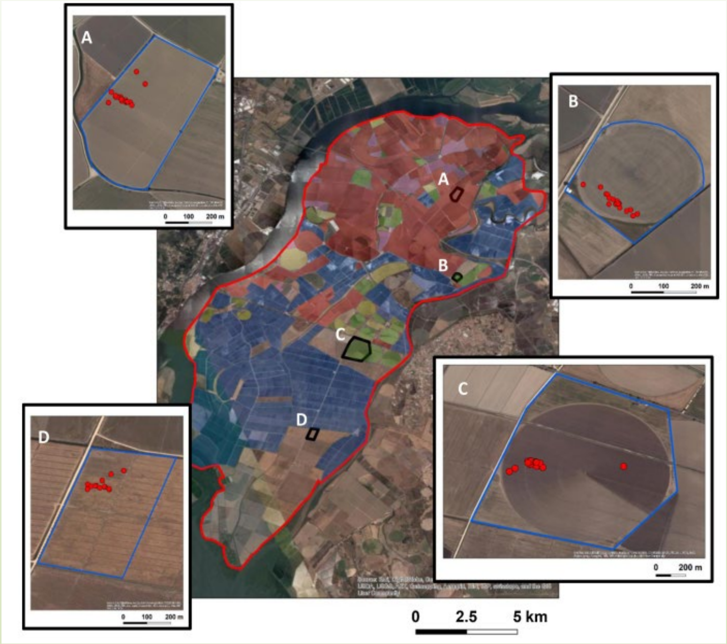
Soil salinity - remote sensing

Sentinel-2 satellite sensor (European Space Agency, EU), offers cost-free multispectral imagery from 10 to 60 m resolution

Viable alternative for better describing soil salinity variability and landscape heterogeneity at the regional scale?

Several vegetation indices exist for large scale assessment of multiple crop characteristics (LAI, biomass) and for stresses (water, nutrient, plagues and diseases)

Saline stress: Crop canopy reflectance has shown to be a good indicator



Soil salinity assessment - remote sensing

Vegetation indices evaluated in this study

Index	Formulation	References
Canopy Response Salinity Index	$CRSI=\sqrt{\frac{(NIR\times R)-(G\times B)}{(NIR\times R)+(G\times B)}}$	Scudiero et al. (2014a, 2015)
Enhanced Vegetation Index	$EVI= g\times\frac{(NIR-R)}{(NIR+c1\times R-c2\times B+l)}$	Huete et al. (2002)
Green Atmospherically Resistant Vegetation Index	$GARI=\frac{NIR-(G+\gamma\times(B-R))}{NIR+(G+\gamma\times(B-R))}$	Gitelson et al. (1996)
Generalized Difference Vegetation Index	$GDVI_x=\frac{(NIR^x-R^x)}{(NIR^x+R^x)}$	Wu et al. (2014)
Normalized Difference Salinity Index	$NDSI=\frac{(R-NIR)}{(R+NIR)}$	Khan et al. (2005)
Normalized Difference Vegetation Index	$NDVI=\frac{(NIR-R)}{(NIR+R)}$	Rouse et al. (1973)
Salinity Index	$SI=\sqrt{G\times R}$	Aldakheel et al. (2005)
Normalized Difference Index	$NDI=\frac{(SWIR_2-RE_3)}{(SWIR_2+RE_3)}$	Wang et al. (2019)
Three-Band Index	$TBI=\frac{(SWIR_2-G)}{(G-SWIR_1)}$	Wang et al. (2019)

Sentinel-2 spectral bands: B, blue (B2); G, green (B3); R, red (B4); RE_3, red edge (B7); NIR, near-infrared (B8); $SWIR_1$, short wave infrared (B11); $SWIR_2$, short wave infrared (B12).
Aerosol and soil correction parameters: g (2.5), c_1 (6.0), c_2 (7.5), l (1.0), and γ (0.9).
x, power value ranging from 1 to 4.

1. Sentinel-2 scenes with than 10 % cloud cover (downloaded from the Copernicus Open Access Hub)
2. 10 spectral bands were used
3. Atmospheric correction of the downloaded scenes performed using Sen2cor software (ESA, 2020)

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Ground-truth salinity (ECe mean) data vs predicted salinity (ECp) data

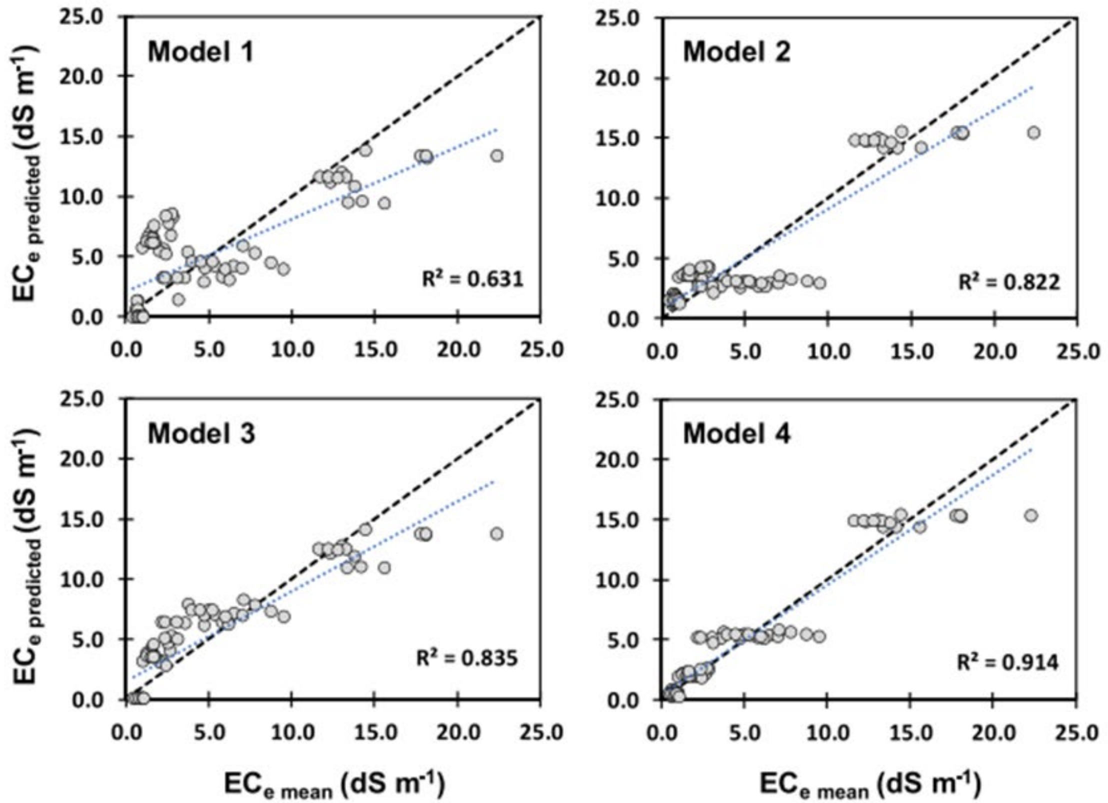

Fig. 5. Scatterplot of ground-truth salinity ($EC_{e\ mean}$) data vs. predicted salinity data ($EC_{e\ predicted}$) with regression models 1, 2, 3 and 4.

A total of 400 samples from 80 locations were collected.
The soil samples were analyzed: particle size distribution, pH, CEC, and ECe.

Regression models for soil salinity assessment in Lezíria based on the relationship between **multi-year crop reflectance data** derived from Sentinel-2 multispectral imagery and root zone salinity.

Table 8
Regression models for soil salinity assessment in Lezíria Grande.

Model	Equation	R^2 (-)	RMSE (dS m^{-1})	NRMSE (-)	PBIAS (%)
1	$EC_{e\ mean}$ = 223.154–257.450 CRSI	0.63 (0.11)	3.26 (1.24)	0.07 (0.07)	−2.04 (26.91)
2	$EC_{e\ mean}$ = 71.171–80.207 CRSI + 9.588 VEG	0.82 (0.11	2.26 (0.62)	0.05 (0.05)	0.35 (10.08)
3	$EC_{e\ mean}$ = 161.958–187.998 CRSI + 4.955 SOIL	0.83 (0.06)	2.25 (0.84)	0.05 (0.04)	−5.83 (13.02)
4	$EC_{e\ mean}$ = 53.466–61.013 CRSI + 7.765 VEG + 3.773 SOIL	0.91 (0.04)	1.63 (0.70)	0.03 (0.04)	0.20 (9.07)

R^2, coefficient of determination; RMSE, root mean square error; NRMSE, ratio of the root mean square error to the standard deviation of observed data; PBIAS, percentage bias; $EC_{e\ mean}$, soil salinity; CRSI, canopy response salinity index; VEG, vegetation type (1 for cultivated areas and 0 for areas under fallow); SOIL, soil type (0 for Fluvisols and 1 for Solonchaks).
Values in brackets correspond to the standard d
testing datasets.

Regression models based on the relationship between multi-year maxima of vegetation indices computed from Sentinel-2 multispectral imagery and rootzone salinity (0–1.5 m depth).

Canopy Response Salinity Index (CRSI) and the Green Atmospherically Resistant Vegetation Index (GARI) were able to reasonably describe the effect of soil salinity on crop health status

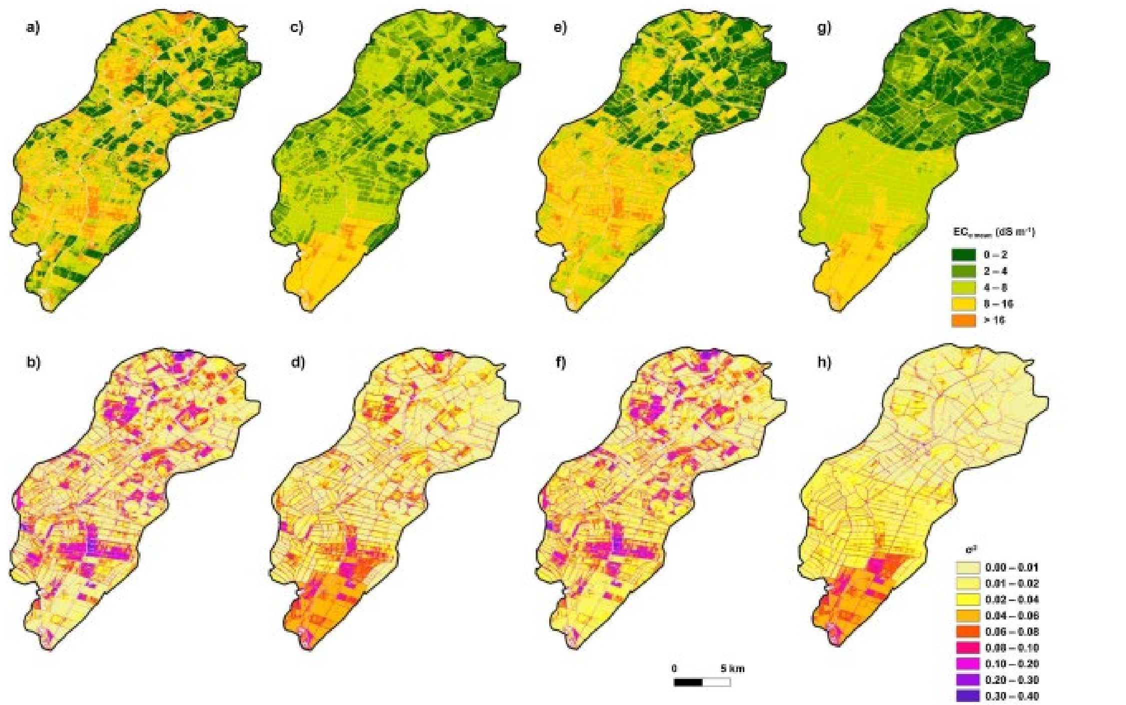

Fig. 6. Soil salinity ($EC_{e\ mean}$; top) predictions and respective variance (σ^2; bottom) maps using regression models 1 (a and b), 2 (c and d), 3 (e and f) and 4 (g and h).

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