EJP SOIL
European Joint Programme

Towards climate-smart sustainable management of agricultural soils

Summer School

Course N° 1: Soil Management for Sustainable Agriculture

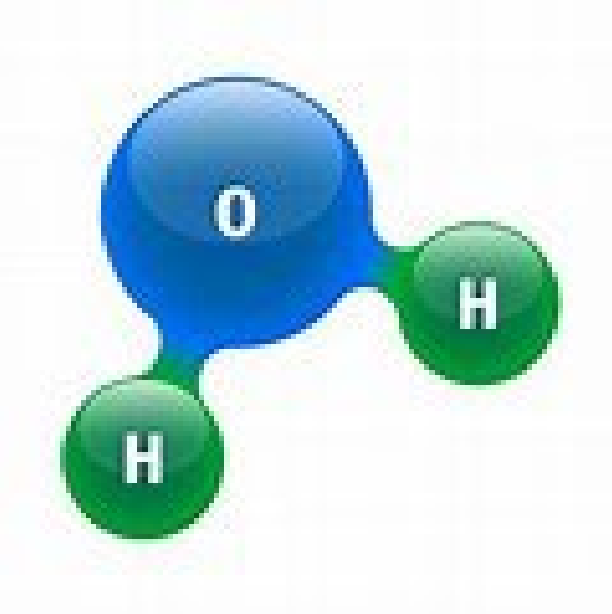
Location: Aula Magna, Department of Agricultural, Food and Forest Sciences.
Viale delle Scienze, 90128 Palermo, Italy

from 24th October 2022 to 28th October 2022
(from 09.00 to 17.00 – including coffee break and lunch time)

Date	Start	topic	Lecturer	n. hours /minutes
28 october Friday	9:00 – 9:50	**Soil Compaction**	Pietro Catania* (IT)	**50'**
	9:50 – 10:00	**Question time**		**10'**
	10:00 – 10:50	**Strategies to prevent and or recover from Soil Compaction**	Pietro Catania* (IT)	**50'**
	10:50 – 11:00	**Question time**		**10'**
	11:00 – 11:20	**Coffee break**		**20'**
	11:20 -12:10	**Soil and Water Quality**	Marcello Mastrorilli* (IT)	**50'**
	12:10 – 12:20	**Question time**		**10'**
	12:20 – 13:20	**Strategies to improve Soil Water Management**	Marcello Mastrorilli* (IT)	**50'**
	13:20 – 13:30	**Question time**		**10'**
	13:30 – 15:00	**Lunch break**		**1h30'**
		Total hours		**35h30'**

*EJP External invited lecturers

H_2O into the soil

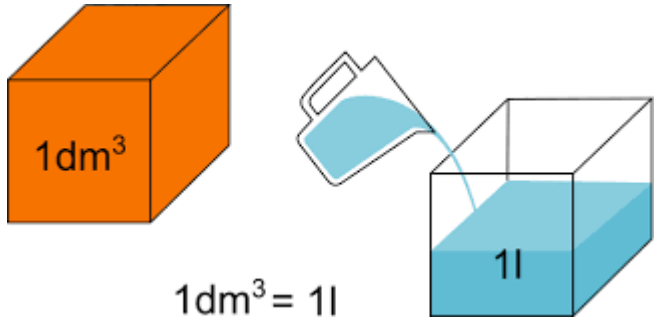


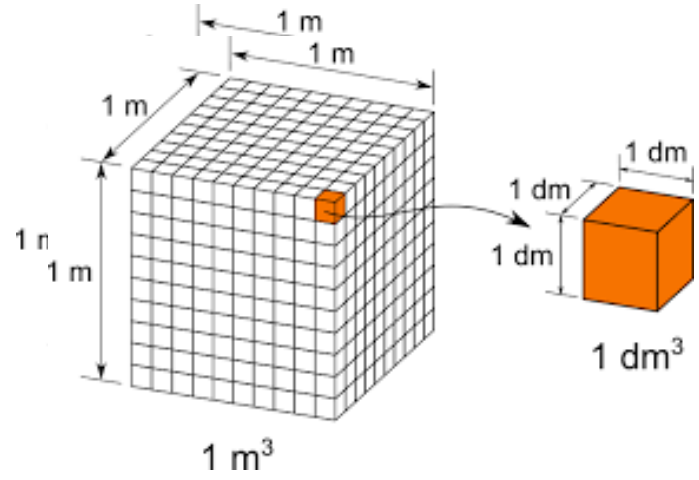
- its extreme purity and the total absence of mineral salts does not benefit the soils
- being so pure it can get to enrich itself with ions of the soil
- in contact with carbon dioxide, H_2O becomes acidic very quickly, even corrosive
- the main damage occurs at the cellular level, where the lack of mineral salts and microorganisms would block the proper soil equilibrium
- pure water in the soil would generate the degradation of organic matter and the de-structuring of soil aggregates

mineral water

170,4 mg of `total dissolved solids` in 1 L

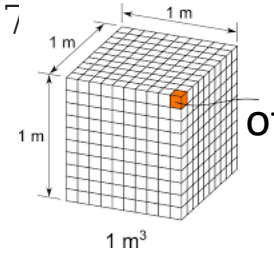
1,23 mg of Na^+ in 1 L





1 m^3 = 1000 dm^3 = 1000 L

`total dissolved solids =17`



(= 0,17 kg)

in of mineral water

170,4 mg of total dissolved solids in 1 L

1,23 mg of Na^+ in 1 L

3 kg of NO_3^-

1 mg/L of Nitrate

6 kg of NO_3^-

Olive irrigation season
3000 m^3 ha^{-1}

511,2 kg of salts

tomato irrigation season
6000 m^3 ha^{-1}

1,02 t of salts

water classification according to electrical conductivity

Class	electrical conductivity dS m^{-1}	Water type
not saline	<0.7	drinking water
slightly saline	0.7-2	irrigation water
moderately saline	2-10	primary drainage and water table
highly saline	10-25	secondary drainage and water table
very saline	25-45	very saline water table
saline	>45	sea

Water Content or Potential?

- Water Content:
  - Total amount of water in the soil
  - Does not indicate how much is available to a plant

Salt affects soil water relationships

Soil Water Content ⟺ **Soil Moisture Content**

Water that may be evaporated from soil by heating at 105^{0}C to a constant weight

$$\text{Gravimetric moisture content (w)} = \frac{\text{mass of water evaporated (g)}}{\text{mass of dry soil (g)}}$$

$$\text{Volumetric moisture content } (\theta) = \frac{\text{volume of water evaporated } (cm^3)}{\text{volume of soil } (cm^3)}$$

$$\theta = w * \frac{\text{bulk density of soil}}{\text{density of water}}$$

$$\frac{cm^3}{cm^3} = \frac{g}{g} \qquad \frac{\frac{g}{cm^3}}{\frac{g}{cm^3}} = \frac{g}{g}\frac{g}{cm^3}\frac{cm^3}{g}$$

$$\text{Bulk density of soil } (\rho) = \frac{\text{mass of dry soil (g)}}{\text{volume of soil } (cm^3)}$$

Water Content or Potential?

- Water Content:
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- Water Potential:
  - The amount of energy needed to extract water from soil
  - Direct measure of how much water is available to a plant

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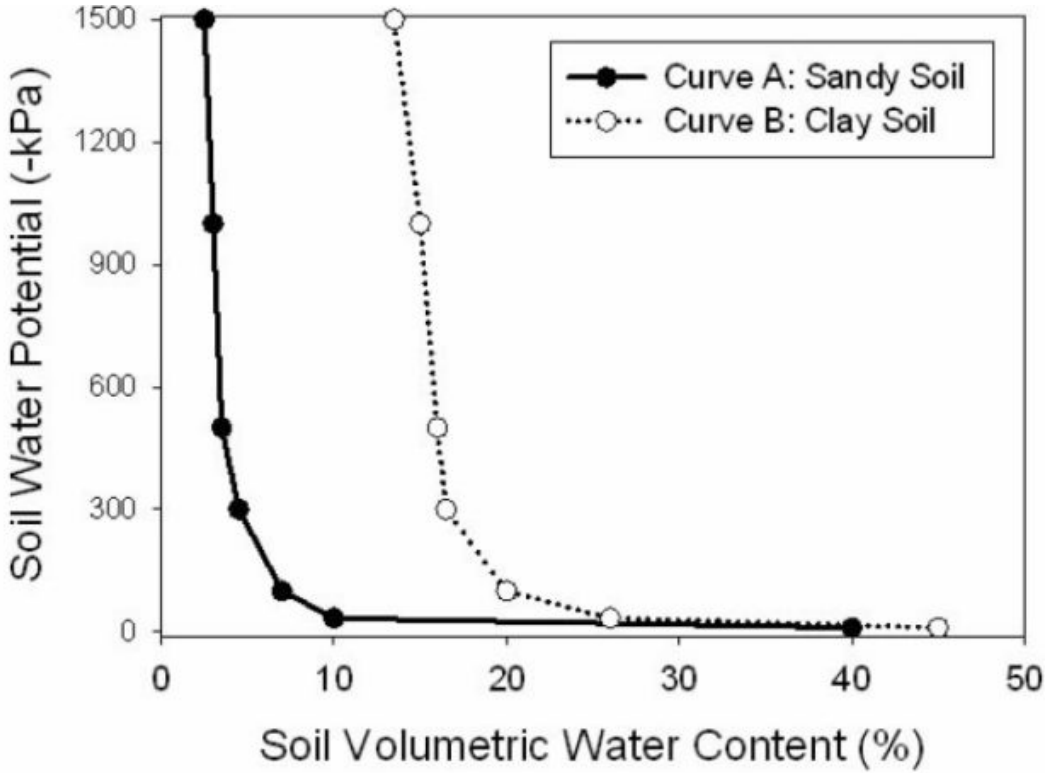

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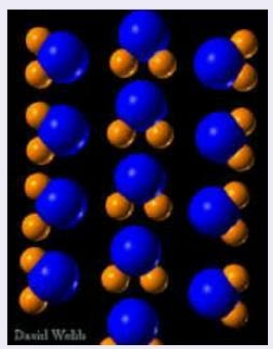
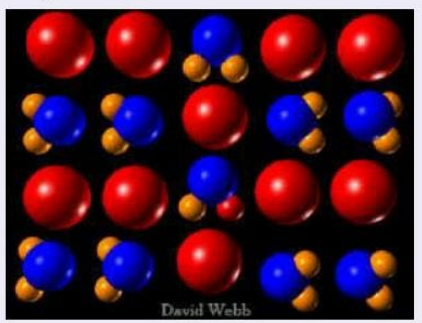
Osmotic potential (OP)

- That portion of the Total Soil Water Potential due to the presence of solutes in soil water
- Salts reduce the water potential by inhibiting the movement of water molecules
- **OP (kPa) ≈ -0.40 x EC (dS/m)**



Pure Water **OP = 0**



Water Diluted by a Solute (Red Spheres)
OP is negative

Water Content or Potential?

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- Water Potential:
  - The amount of energy needed to extract water from soil
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Salinity and Soil Water Potential

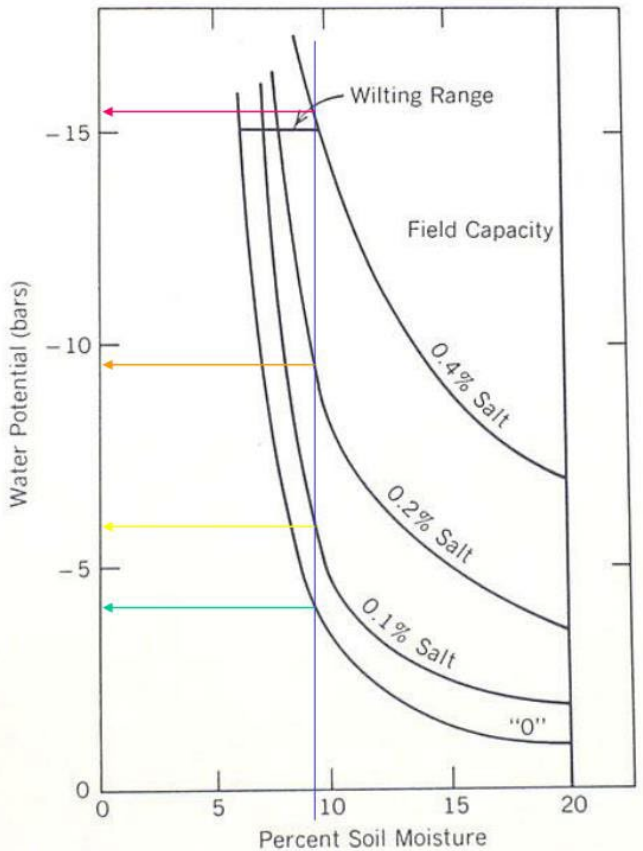
Salt Concentrations

0.1% = 1000 mg/l

0.2% = 2000 mg/l

0.3% = 3000 mg/l

0.4% = 4000 mg/l



compared to soil not affected by salinity, water (in terms of soil water content) is there, but it is less available to crops

EFFECT OF SALINITY ON WATER STRESS, GROWTH, AND YIELD OF MAIZE AND SUNFLOWER

N. Katerji[1], J.W. van Hoorn[2], A. Hamdy[3], F. Karam[3], M. Mastrorilli[4]

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Agricultural Water Management, 30 (1996) 237-249

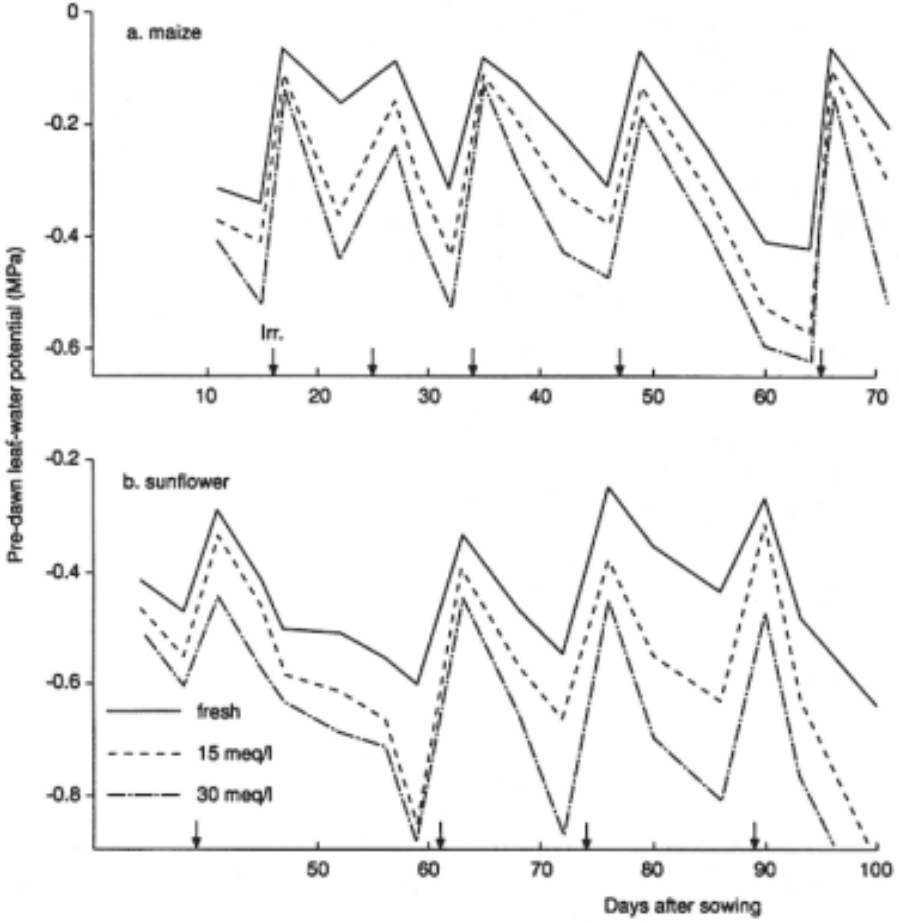
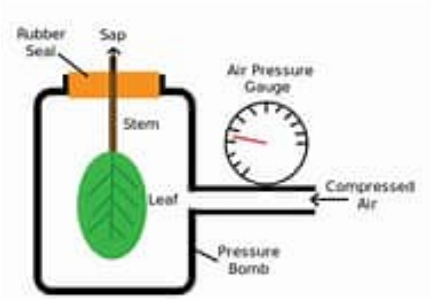


Fig. 1. *Predawn leaf-water potential vs. days after sowing on loam*



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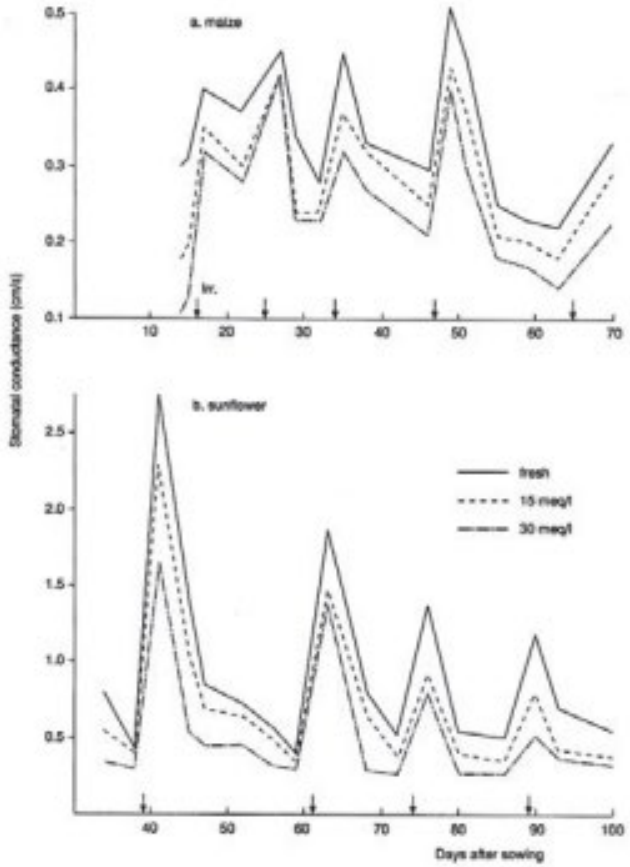

***Fig.* 2.** *Stomatal conductance of maize and sunflower vs. days after sowing on loam*

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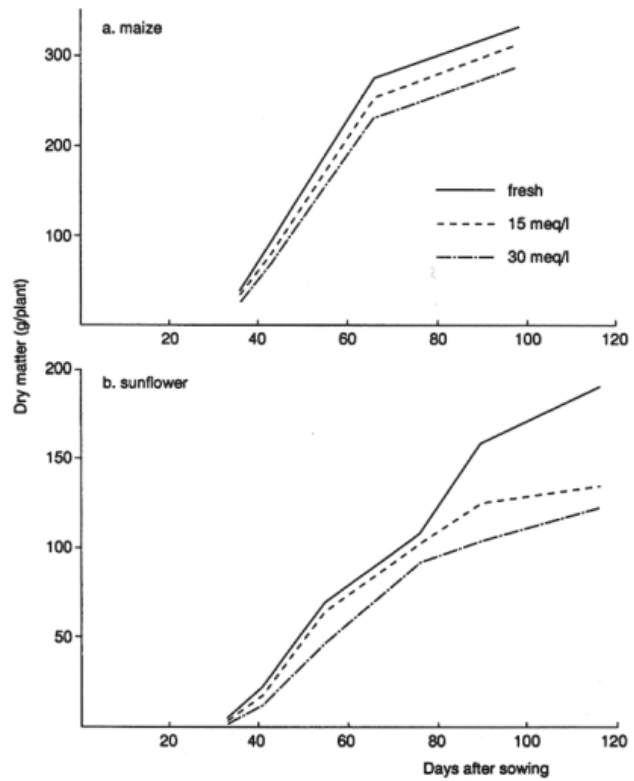

Fig. 5. Canopy dry matter of maize and sunflower vs. days after sowing on loam

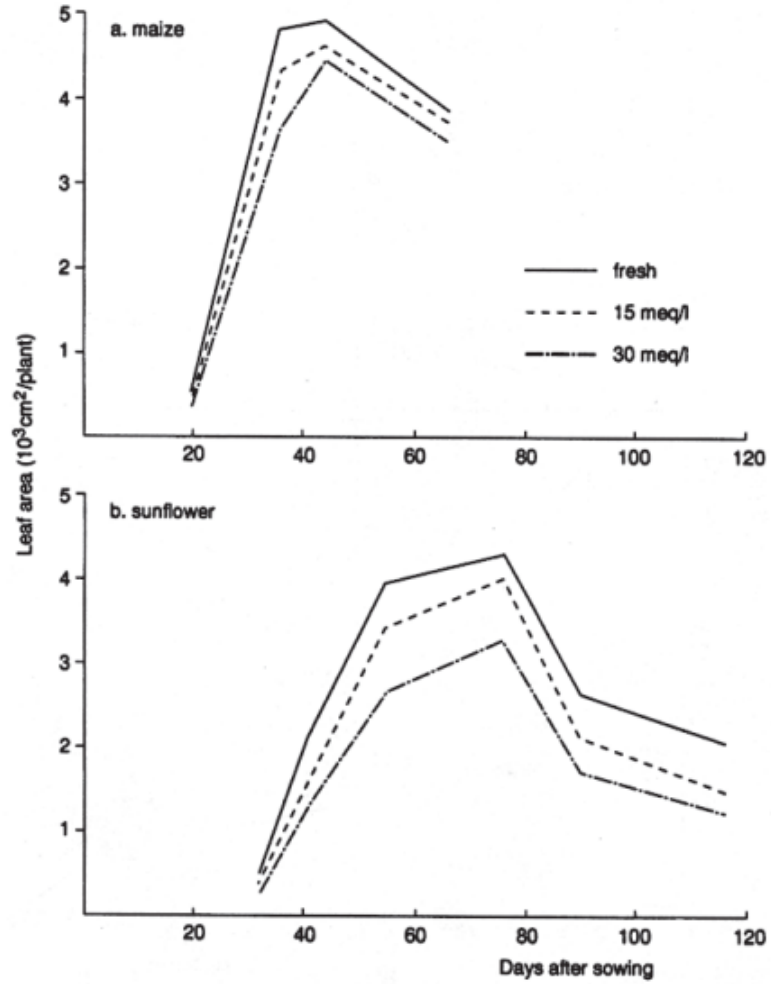

Fig. 4. Leaf area of maize and sunflower vs. days after sowing on loam

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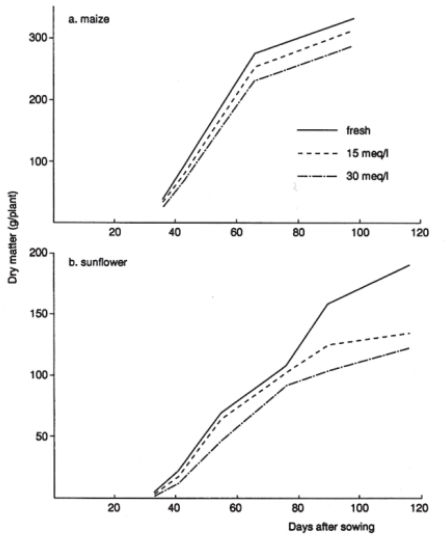

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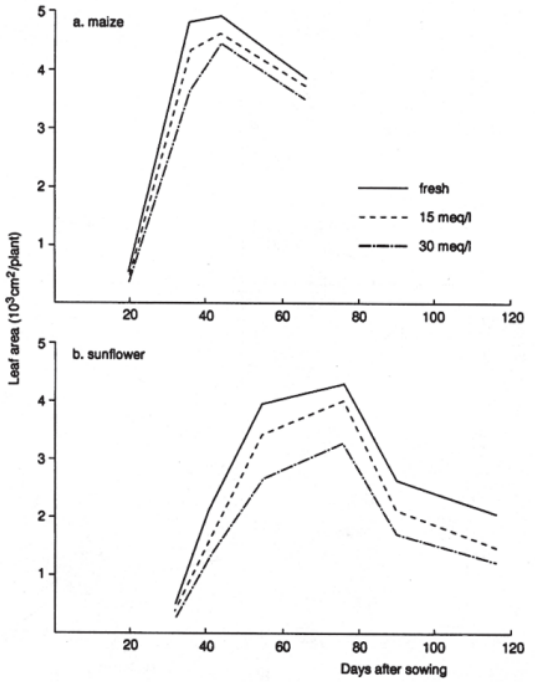

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grain yield reduction in clay ≈ **25%**

grain yield reduction in clay ≈ **40%**

-21%

-24%

Table 3. Yield of maize and soil salinity

	Loam			Clay		
	Fresh	15 meq l^{-1}	30 meq l^{-1}	Fresh	15 meq l^{-1}	30 meq l^{-1}
Grain yield (kg m^{-2})	0.678	0.674	0.533	0.548	0.486	0.414
Total canopy dry matter (kg m^{-2})	1.466	1.387	1.269	1.324	1.192	1.133
Ears/plant	1.20	1.24	1.03	1.06	1.00	1.00
Grains/ear	522	487	505	526	486	441
Weight of 1000 grains (kg)	0.244	0.254	0.232	0.221	0.226	0.212
EC_e (dS m^{-1})	0.8	1.8	3.0	0.8	1.9	3.7

-30%

Table 4. Yield of sunflower and soil salinity

	Loam			Clay		
	Fresh	15 meq l^{-1}	30 meq l^{-1}	Fresh	15 meq l^{-1}	30 meq l^{-1}
Grain yield (kg m^{-2})	0.351	0.291	0.263	0.216	0.193	0.154
Total canopy dry matter (kg m^{-2})	1.039	0.818	0.744	0.597	0.514	0.385
Grains/plant	1280	1183	1159	950	926	831
Weight of 1000 grains (kg)	0.062	0.056	0.051	0.051	0.047	0.042
EC_e (dS m^{-1})	0.8	2.7	3.8	0.8	2.0	3.9

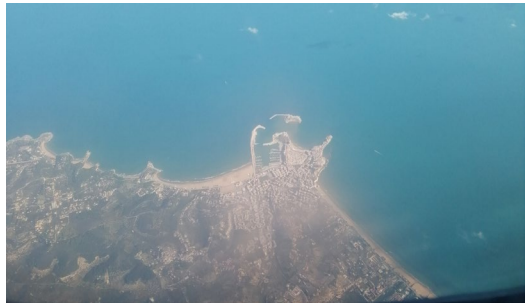
-25%

several million *ha* of agricultural land are deemed to be affected by salinisation

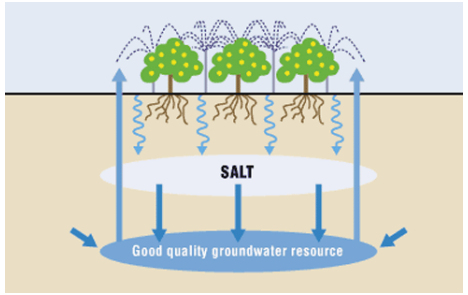
Daliakopoulos *et al.*, 2016

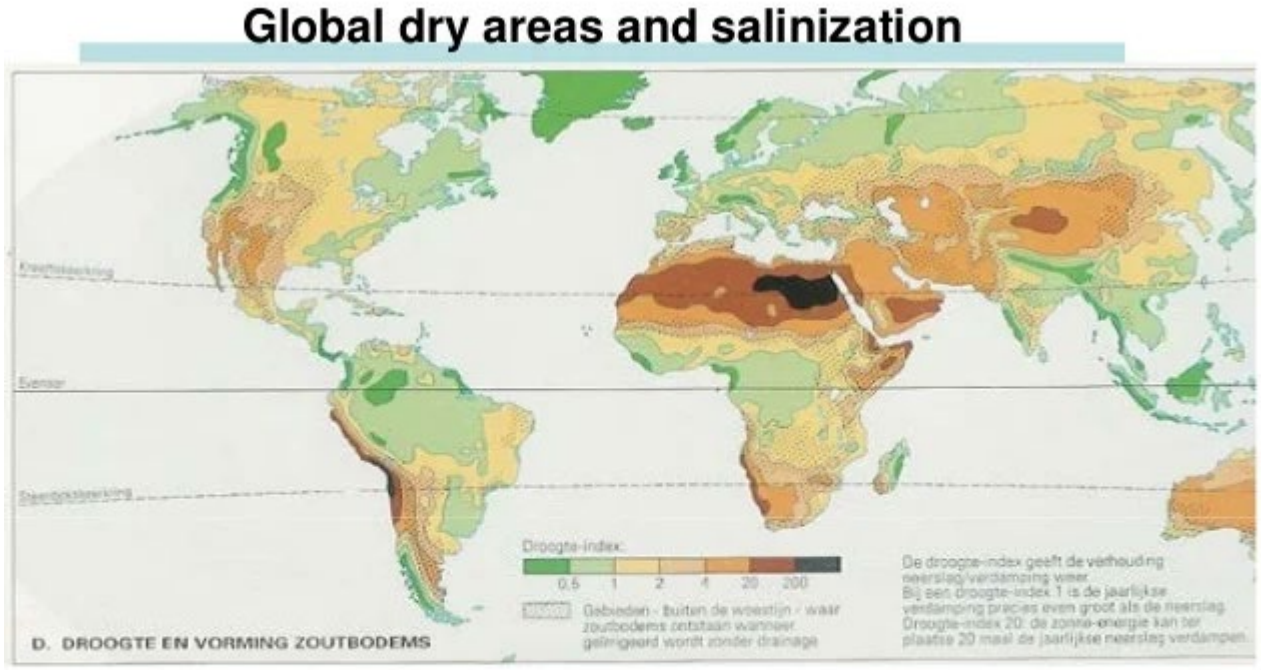
accumulation of salt

- coastal areas
  - sea water intrusion



- internal and continental lands
  - salt rich parent materials
  - saline layers can occur in the soil profile





40% of the earth surface is arid and inclined to salinization

Overall, 40 to 60% of irrigated soils of the Aral Sea Basin, which receives water from the Amu and Syr Darya river systems and occupies approx. 150 million hectares are salt-affected, with 29% of them having a strong to moderate degree of salinity (Qadir et al. 2009, Toderich et al, 2010, Carlo Carli, unpublished data).

several million ha of agricultural land are deemed to be affected by salinisation

Daliakopoulos et al., 2016

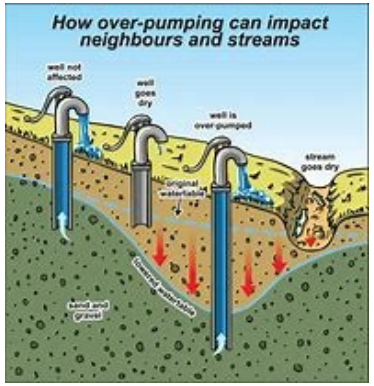
1. primary salinisation
   lands naturally affected by salinisation

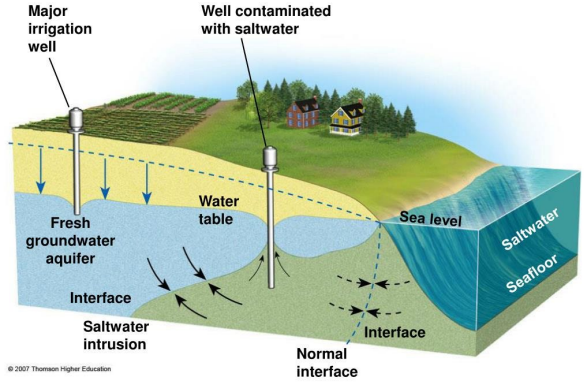
2. secondary salinisation
   soil salinisation is enhanced by human activities

The adoption of improper agricultural practices

Stolte *et al.*, 2016

overpumping





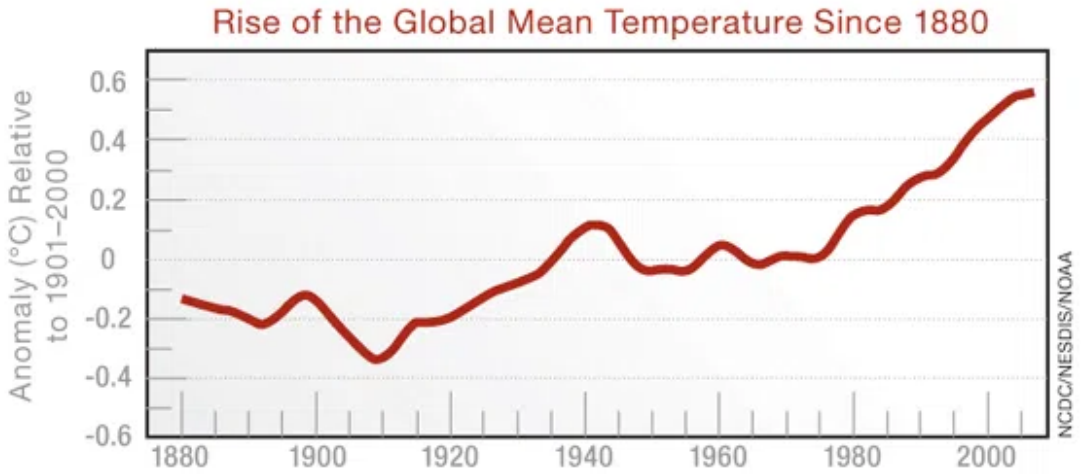
irrigation with poor quality waters

…… and their frequency is deemed to be on increase

raise of temperature

- growth of the water evapotranspiration demand

- boost the risk of soil salinisation in many parts of Europe

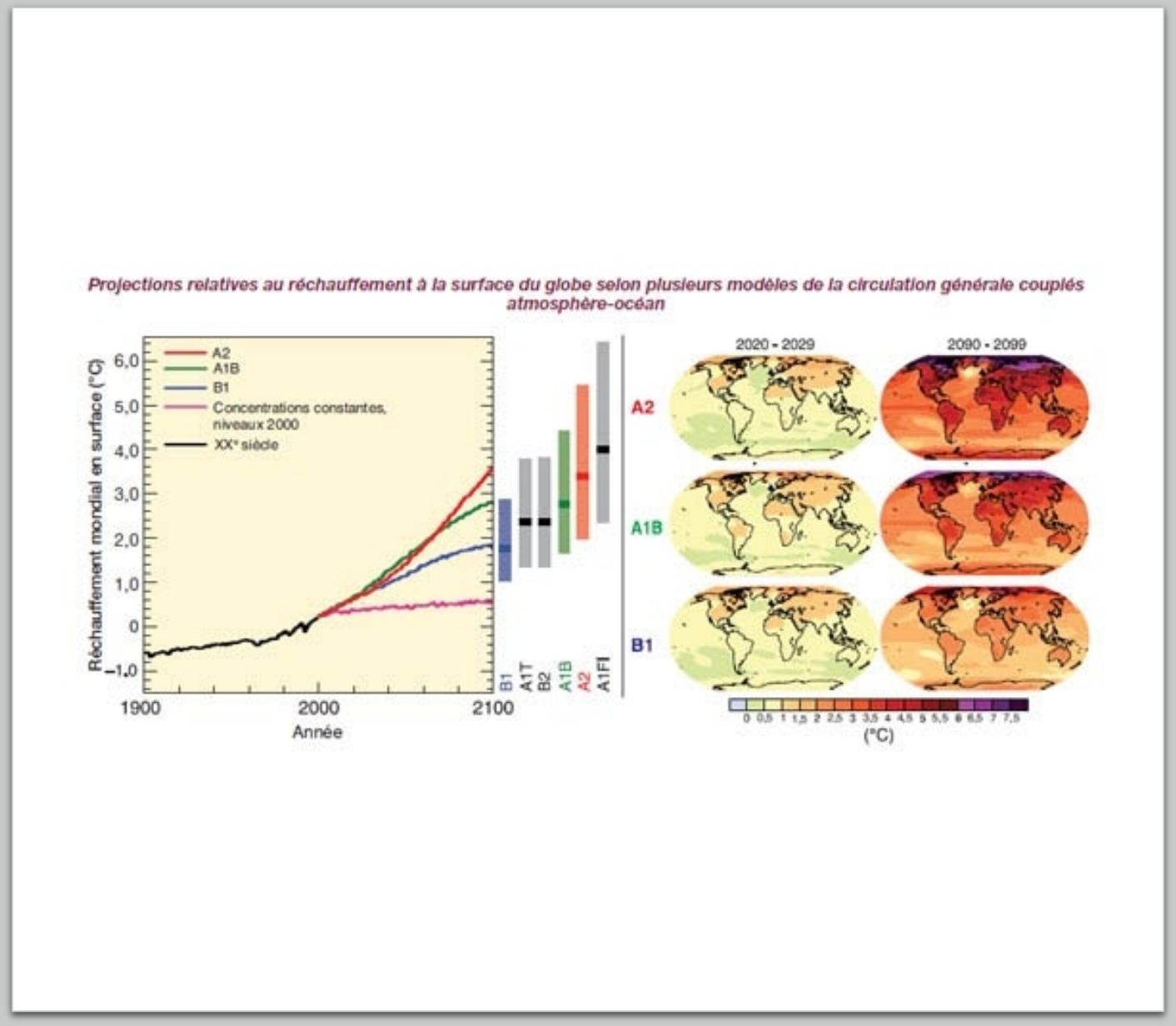


For over a century, the National Climatic Data Center has been gathering temperatures from thousands of sites worldwide on land and sea. By carefully approximating temperatures of inaccessible areas, the NCDC has produced a very reliable approximation of changes in the earth's temperature.

raise of temperature

- The projections for the future climatic conditions and their consequences on soils are alarming

Trnka *et al.,* 2003



raise of temperature

- The projections for the future climatic conditions and their consequences on soils are alarming

- soil salinisation is assumed to further increase in the future, as a consequence of
  - current climate
  - land use
  - management changes

Trnka *et al.,* 2003

raise of temperature

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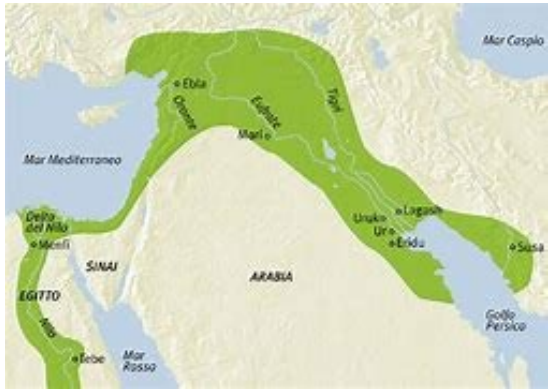
an old story

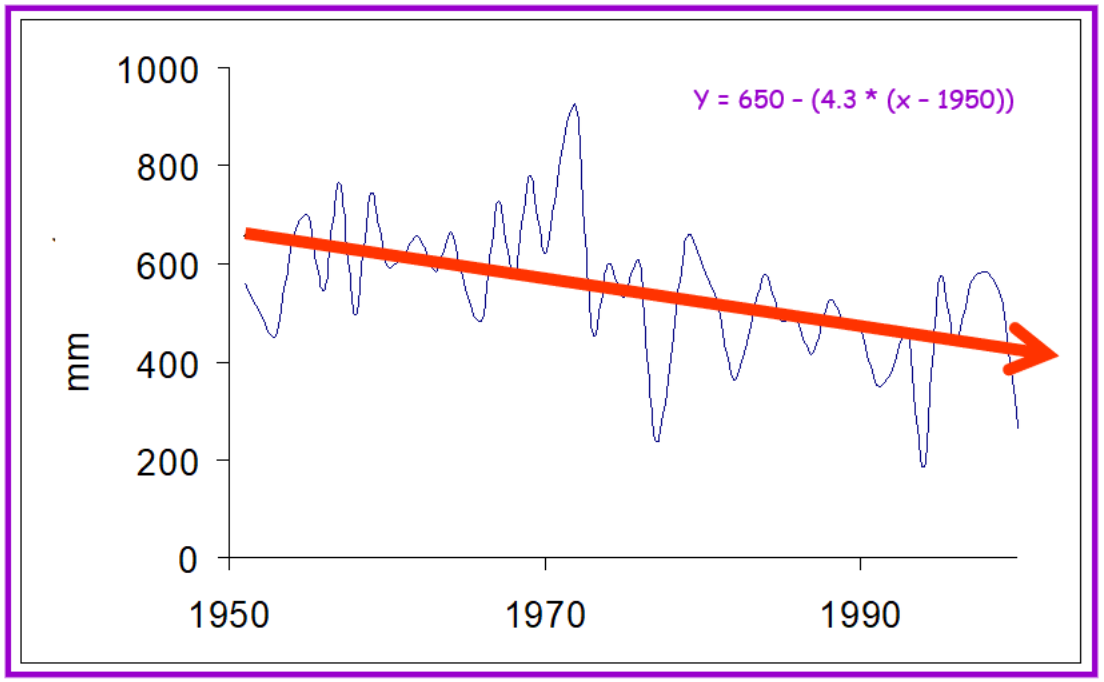
Trnka *et al.,* 2003

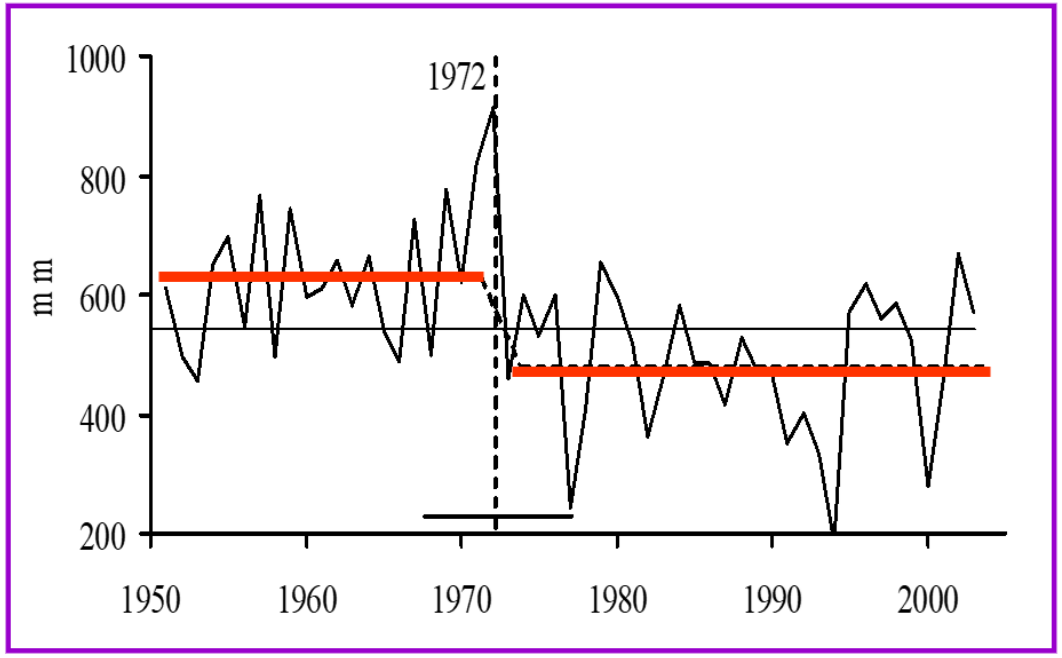


soil salinisation is assumed to further increase

Trnka *et al.*, 2003

annual rainfall in Foggia





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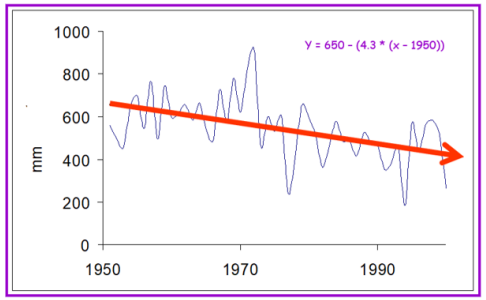
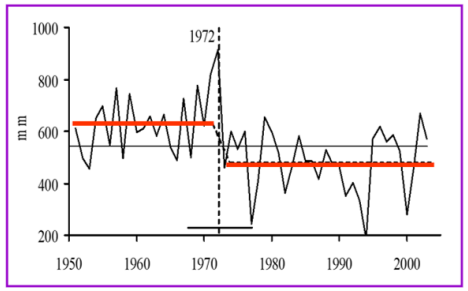
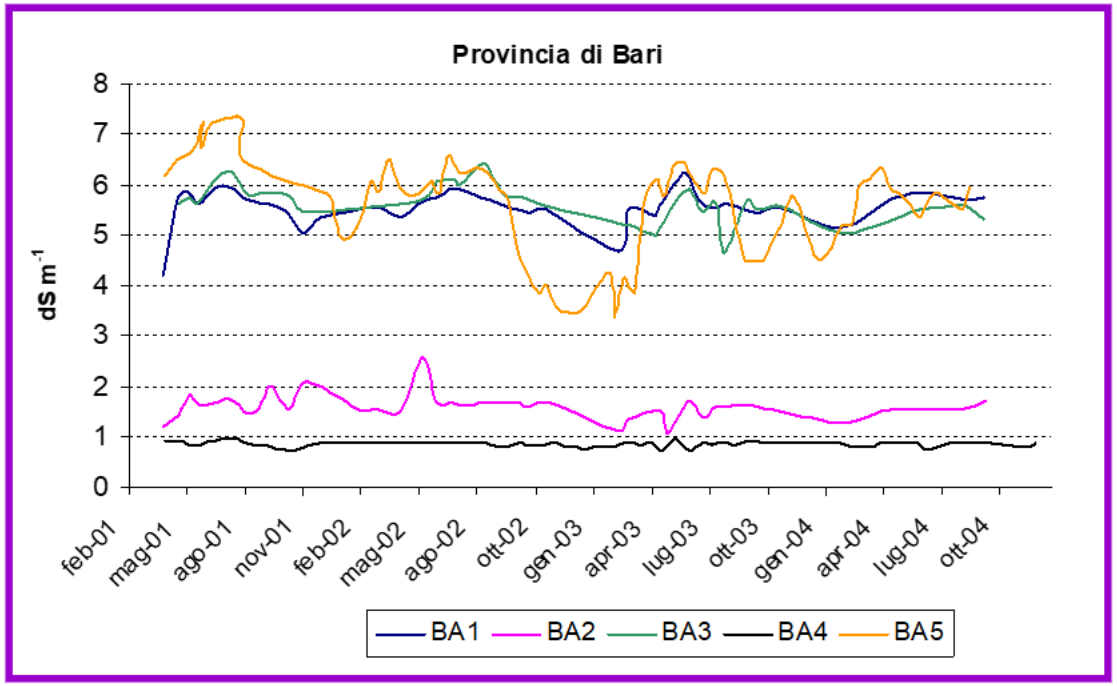




Consequences on the quality of groundwater reserves



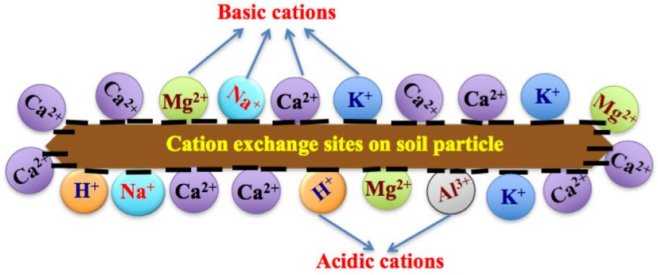
shallow
< 30 m

deep
> 150 m

soil salinity refers to:

1. Salinisation
   accumulation of water-soluble salts in the soil profile
   - Chloride
   - Sulphate
   - Carbonate and bicarbonate
     - Sodium
     - Magnesium
     - Calcium
     - Potassium

2. Sodification
   progressive saturation of the exchange complex with sodium
   (mainly from sodium carbonate)



3. Alkalinisation
   increase in pH reaction in the soil solution over 8.5

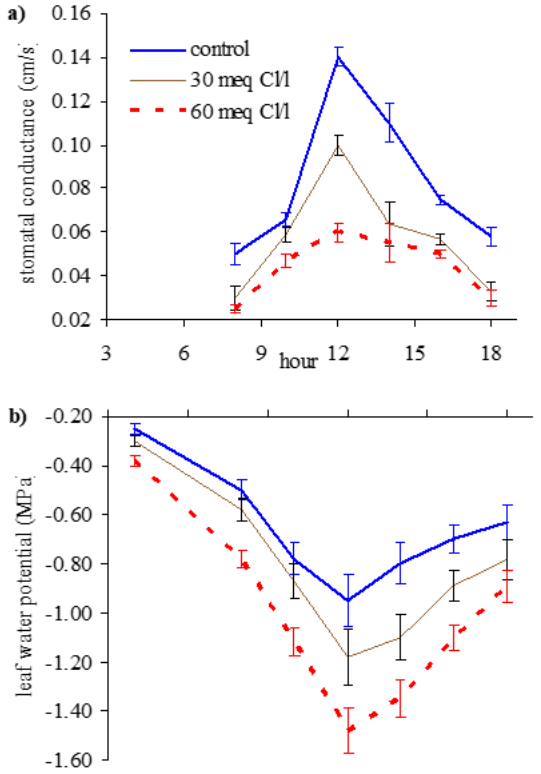
Salinity increases the osmotic potential of the soil water solution

limits the plant capacity to absorb water

nutritional imbalances

toxicity due to the presence of specific ions

Daily course of leaf water potential and stomatal conductance of maize



Salinity increases the osmotic potential of the soil water solution

limits the plant capacity to absorb water

nutritional imbalances

toxicity due to the presence of specific ions

Boron Effects on Crops

Salinity increases the osmotic potential of the soil water solution

limits the plant capacity to absorb water

nutritional imbalances

toxicity due to the presence of specific ions

- N surplus vegetative-productive imbalances

- calcium deficiency
  - excess of Na
  - excess of Mg

- Fe & P deficiency
  - pH
  - pot.redox

Salinity increases the osmotic potential of the soil water solution

limits the plant capacity to absorb water

nutritional imbalances

toxicity due to the presence of specific ions

Leaf spots due to fluoride toxicity

Symptoms (leaf) of chloride (Cl) toxicity

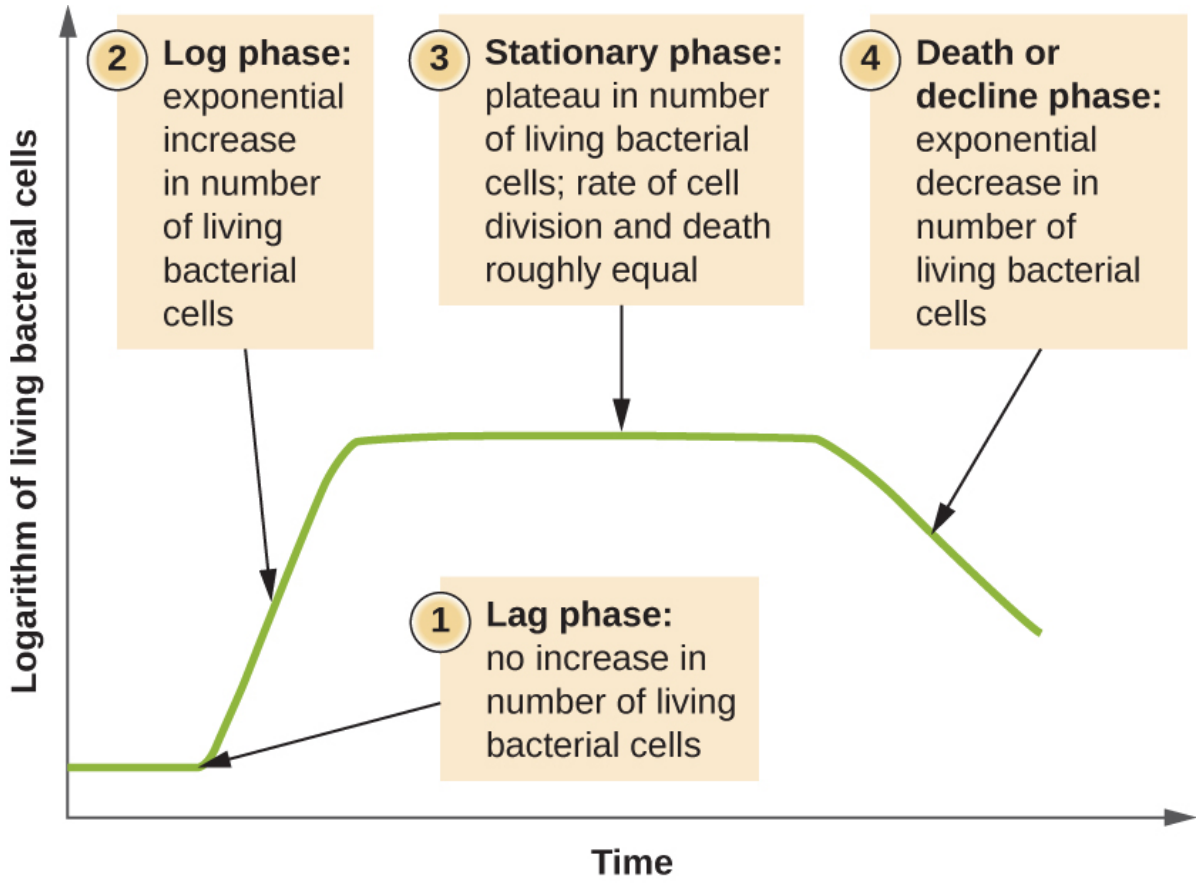
Salinity increases the osmotic potential of the soil water solution

limits the plant capacity to absorb water

nutritional imbalances

toxicity due to the presence of specific ions

and has a direct negative effect on soil biology



Salinity increases the osmotic potential of the soil water solution

limits the plant capacity to absorb water

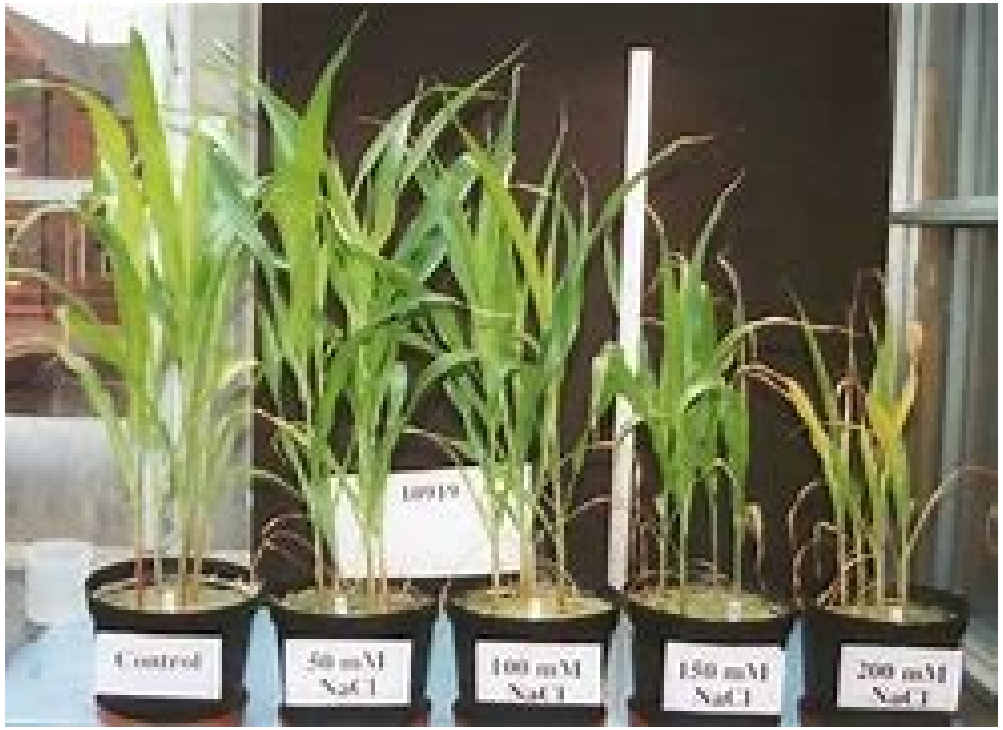
nutritional imbalances

toxicity due to the presence of specific ions

and has a direct negative effect on soil biology

excess of Na^{+} and Mg^{2+}

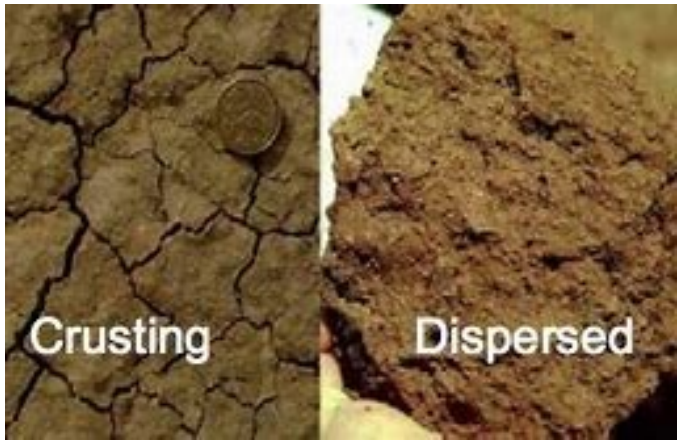
- destroy cell morphology
- restrain plant photosynthesis
- reduce chlorophyll production



Sodification and alkalinisation lead to the destruction of the soil structure

through the swelling and dispersion of the clay particles

formation of low permeability layers



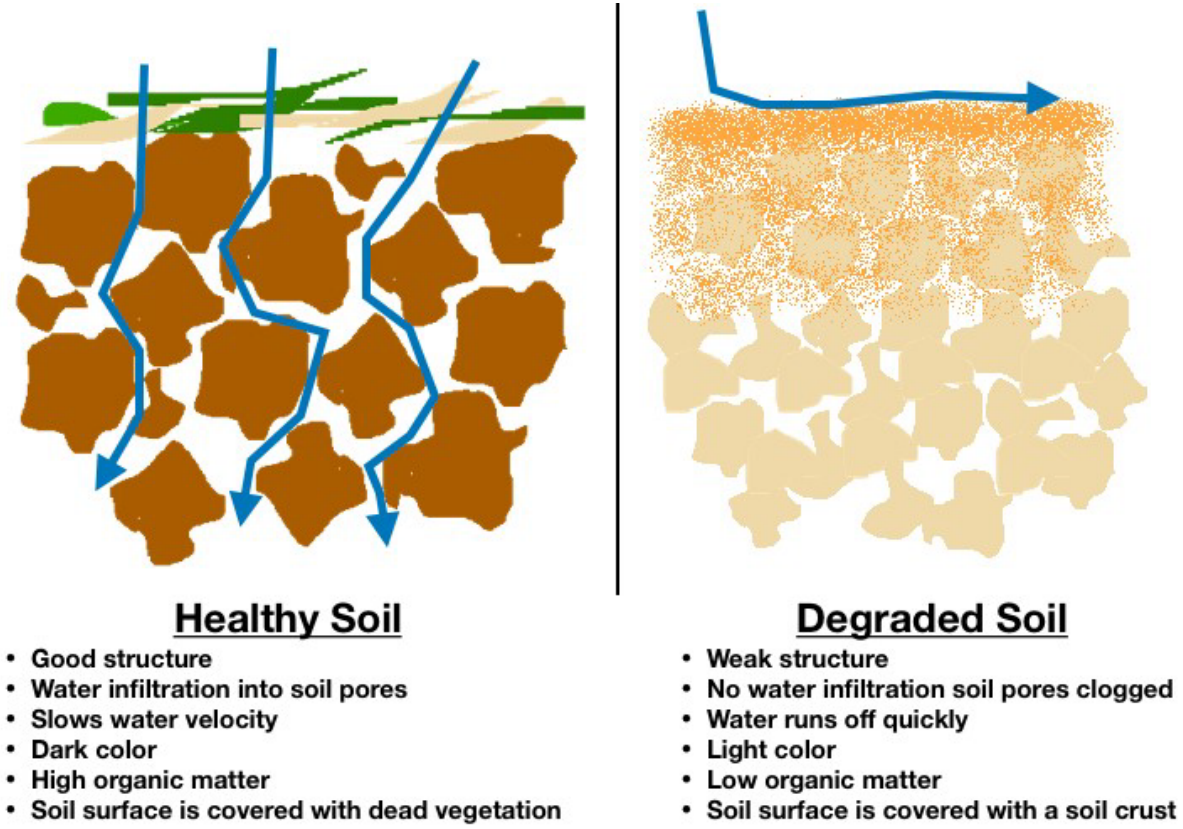
that restrict root growth

Clay dispersion also reduces:

water infiltration throughout the soil profile

plugs pipe drainages

enhance surface and subsurface soil erosion



(Stolte et al., 2016)

Clay dispersion also reduces:

water infiltration throughout the soil profile

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enhance surface and subsurface soil erosion

(Stolte et al., 2016)

Clay dispersion also reduces:

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(Stolte et al., 2016)

excessive soil salinity reduces the yield of crops

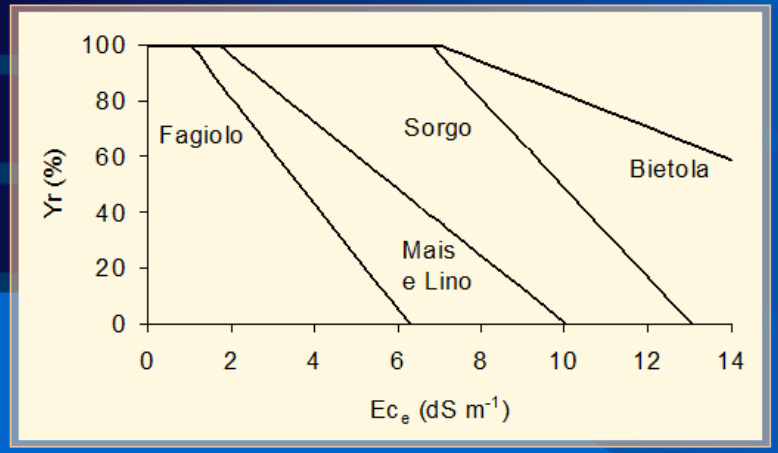
threshold value above which deleterious effects occur can vary depending on:

plant species and variety

soil water regime

climatic condition

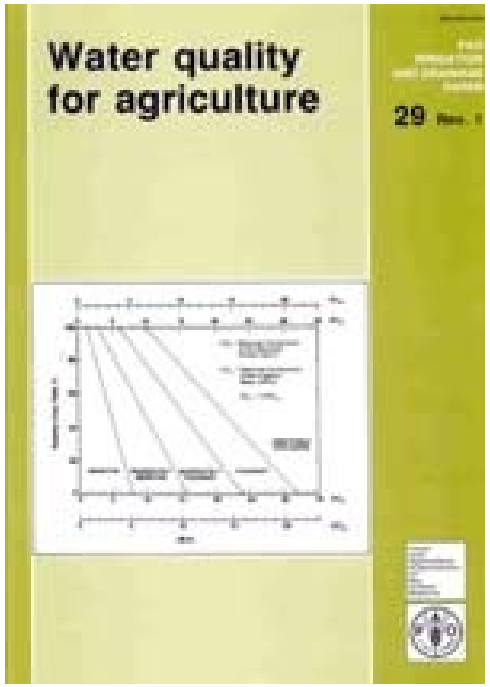
- Yield function (salt/no salt) $Yr = 100 - b\,(Ec_e - a)$



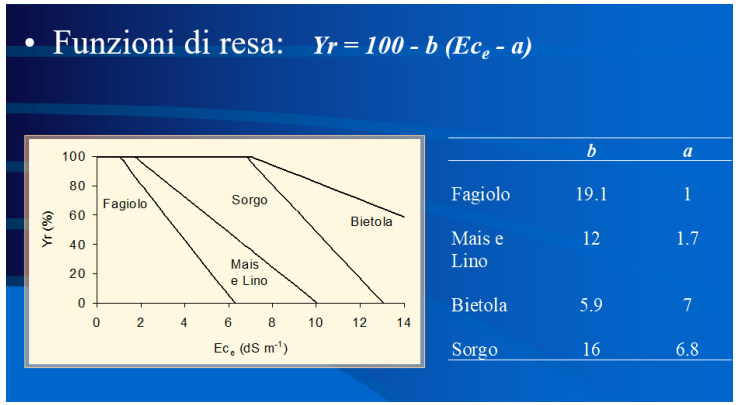
	b	*a*
bean	19.1	1
corn & flax	12	1.7
beat	5.9	7
sorghum	16	6.8

(Maas EV, Hoffman GJ, 1977. *Crop salt tolerance-current assessment*)

excessive soil salinity reduces the yield of crops



Water quality for agriculture
by
R.S. Ayers
Soil and Water Specialist (Emeritus)
University of California
Davis, California, USA
and
D.W. Westcot
Senior Land and Water Resources Specialist
California Regional Water Quality Control Board
Sacramento, California, USA
FAO IRRIGATION AND DRAINAGE PAPER
29 Rev. 1
Reprinted 1989, 1994



	b	a
Fagiolo	19.1	1
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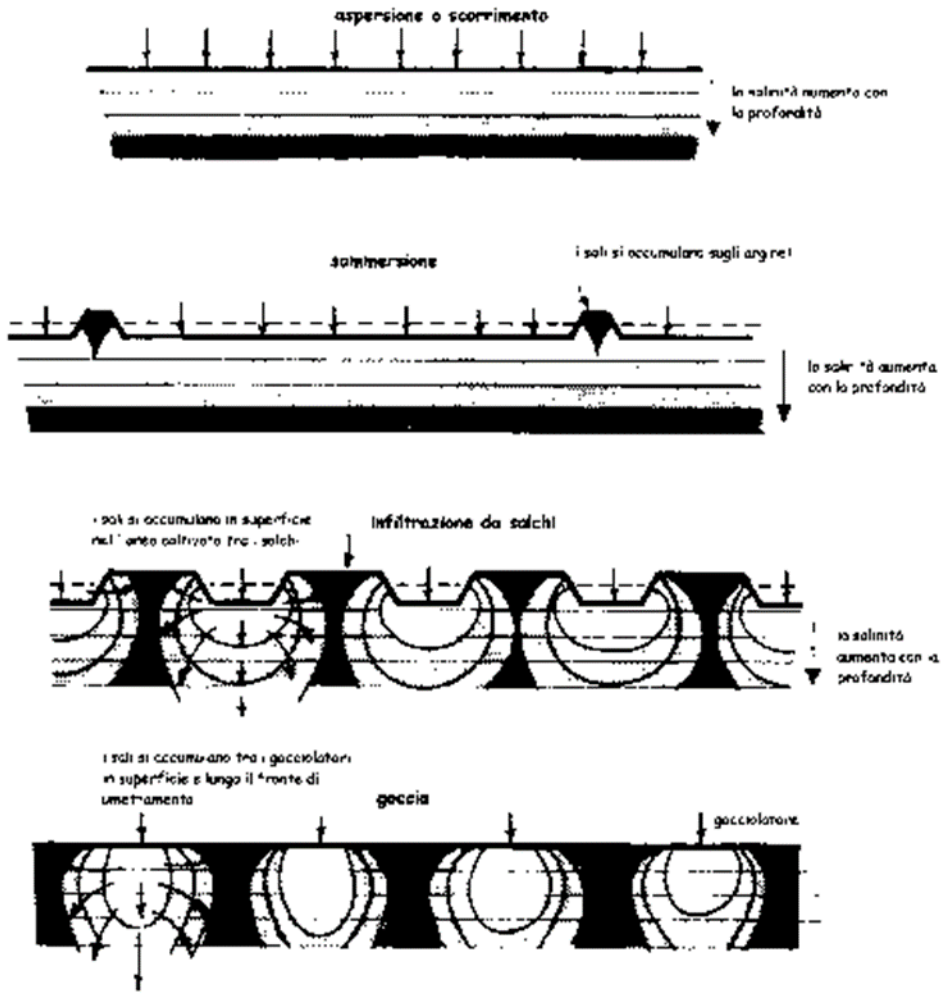


Irrigation methods and salinity

sprinkling or flowing

Salinity increases in deeper layers

ponding

Salinity increases in deeper layers

farrow

Salinity increases in deeper layers
+
accumulates on the soil surface
and between the furrows

drip

Salts accumulates near drippers

- on the soil surface
- following the wetting front

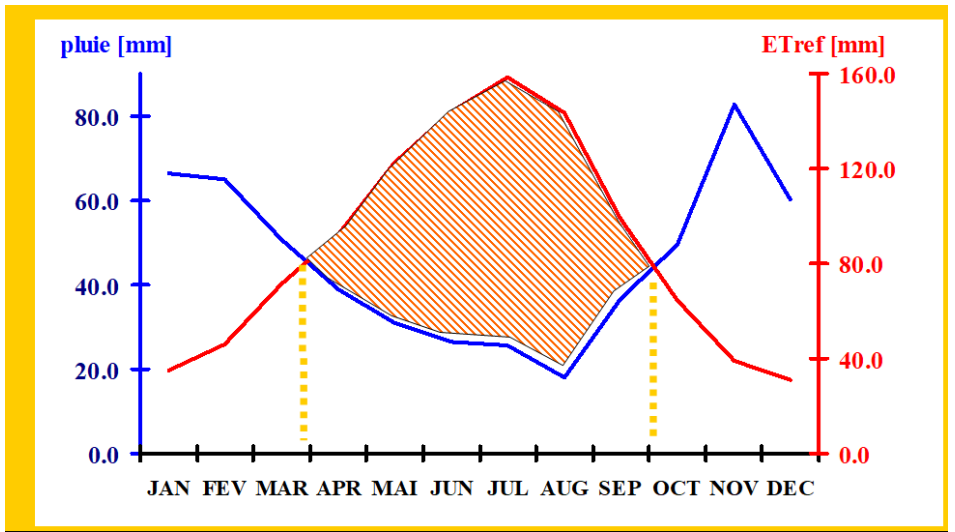
excessive soil salinity reduces the yield of crops

threshold value above which deleterious effects occur can vary depending on:

plant species and variety

soil water regime

climatic condition



excessive soil salinity

in early stages

- affects the metabolism of soil organisms
- reduces soil productivity

in advanced stages

- kills all vegetation
- transforms fertile and productive land to barren land

most important row crops

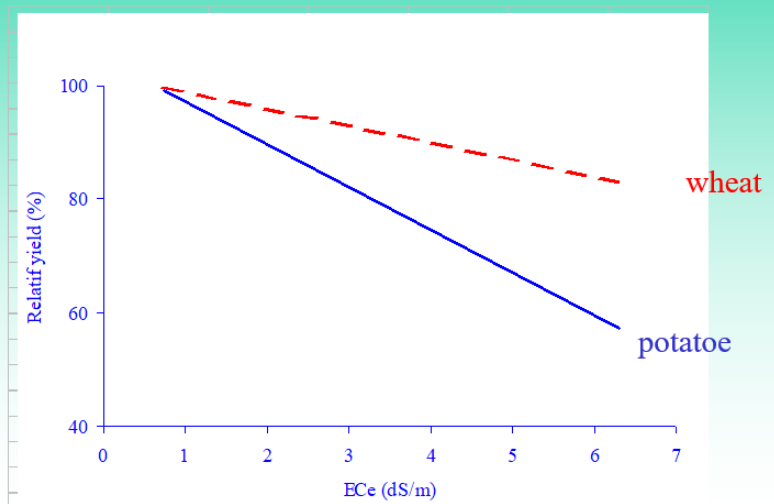
tolerant
- Barley
- Rye
- Rice
- Sunflower
- Potato
- Sugar beet

sensitive
- Maize
  in early development stages

higher sensitivity →
- Vegetables

exceptions
- asparagus
- artichoke
- red beet
- zucchini squash

relationship between
relative yield versus soil salinity $Y_r = Y/Y_m$



Variety *cv*
Soil
Climate
Management

fruit trees and soil salinity

limits
- tree growth
- fruit yield

sensitive
- stone fruits
- citrus

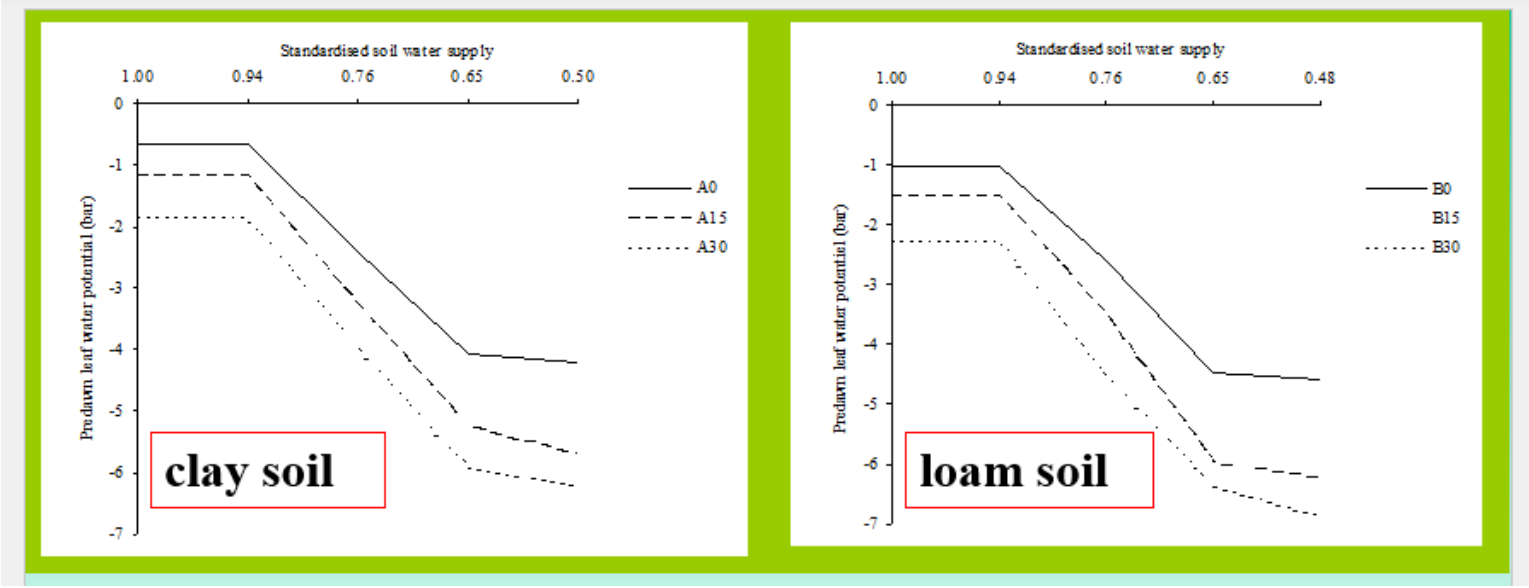
exceptions
- olive tree
- grapes

can be moderately tolerant

Variety *cv*
Soil
Climate
Management
+ Rootstock

Crops may demonstrate different salt tolerance depending on:

- soil properties
- types of rhizobacteria
- growth stage
- agronomical practices
- salt-resistant rootstocks



Mastrorilli *et al.,* 2003
Using the CERES-maize model in a semi-arid Mediterranean environment.
Europ. J. of Agron., 19 (2), 125-134

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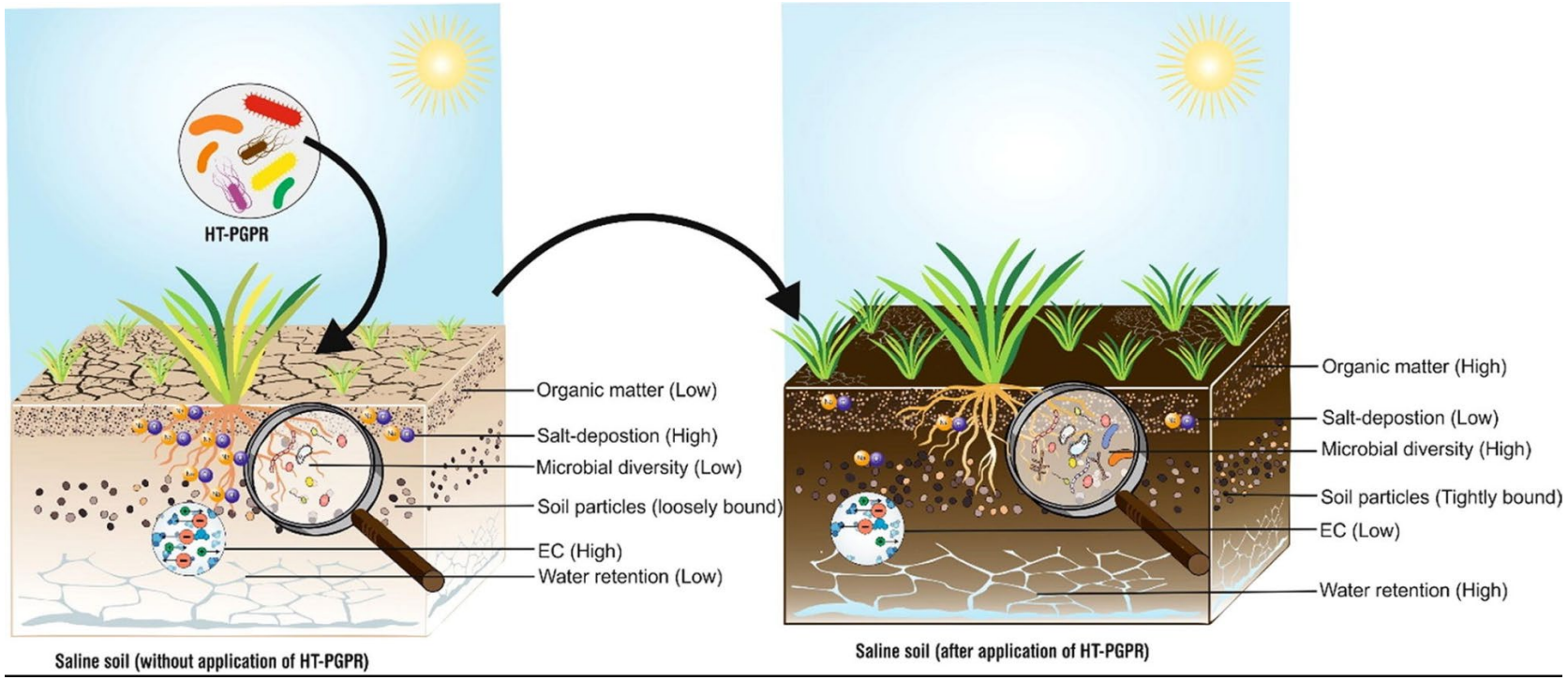

Journal of Advanced Research
Volume 26, November 2020, Pages 69-82

Halo-tolerant plant growth promoting rhizobacteria for improving productivity and remediation of saline soils

Crops may demonstrate different salt tolerance depending on:

- soil properties
- types of rhizobacteria
- growth stage
- agronomical practices
- salt-resistant rootstocks

seeds are exposed to a higher salinity than during later growth stages
- delay with increasing salinity
- lower emergence percentage

Crop	Time (days)	Cl^- concentration of irrigation water (meq./l)				
		3.7	15	30	45	60
Maize	3	62	64	49	46	41
	4	81	78	67	65	60
	6	95	94	88	86	82
Sunflower	4	60	58	54	51	40
	7	77	74	71	67	61
	10	94	91	86	80	75

- hard soil crust
- salinity increases in the top layer of the soil
  - plants during germination and emergence are more sensitive than later on

Katerji, N., van Hoorn, J.W., Hamdy, A., Karam, F., Mastrorilli, 1994.
Effect of salinity on emergence and on water stress and early seedling growth of sunflower and maize.
Agric. Water Manage., 26, 81-91.

Crops may demonstrate different salt tolerance depending on:

- soil properties
- types of rhizobacteria
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Figure 1: Dhaincha *in-situ* green manuring in cotton

Figure 2: Sunhemp *in-situ* green manuring in cotton

HARIT DHARA 1(1) July – December, 2018 Soil Health/Fertility Management

GREEN MANURING: A PANACEA FOR THE RECLAMATION OF SALINE AND SODIC SOILS

A O SHIRALE, B P MEENA, A K BISWAS, PRIYA P GURAV and ANKUSH L KAMBLE
ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh

Crops may demonstrate different salt tolerance depending on:

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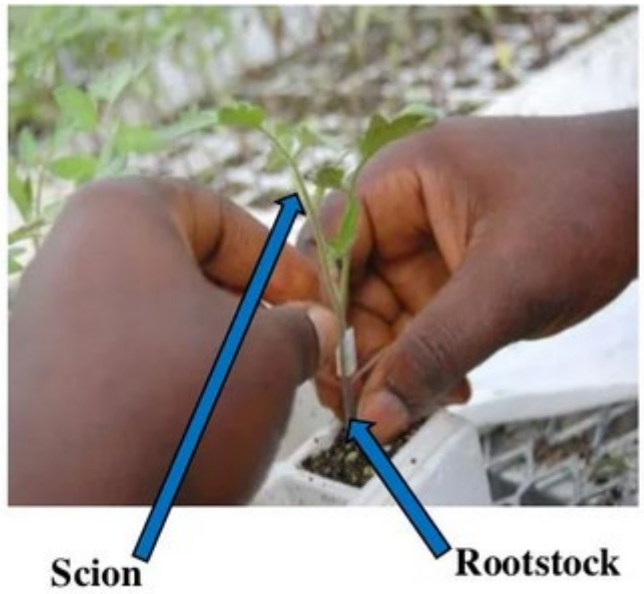
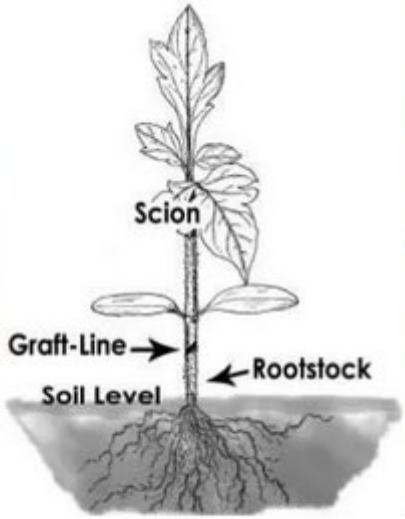




Scion

Rootstock

Desirable aboveground traits

Desirable belowground qualities

Beside on food production, salinisation has an effect on:

other soil ecosystem services:

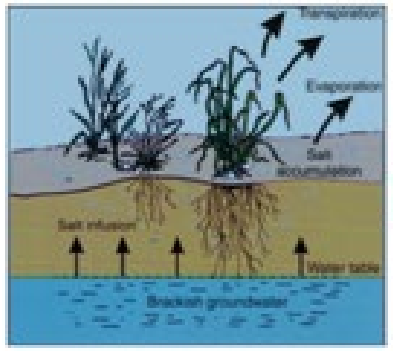
- provision of freshwater for
  - livestock
  - wild animal
  - plants
- regulation of groundwater quantity and quality
- soil erosion
  - water
  - wind

Positive effects

- supporting habitats and also on recreational areas
- aesthetic value of the landscape

Stolte *et al.*, 2016

ecosystem services modifications caused by salinity



Salinisation

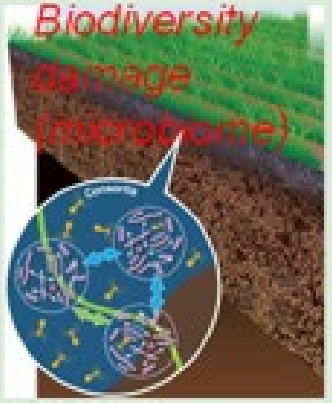
Stunted plant growth

Coarse texture (sand)

Coarse texture (sand)

Fine texture (clay)

OTHER EFFECTS



European areas affected by soil salinization

- along the coasts
- inland

- 19 irrigated
- 6 rainfed

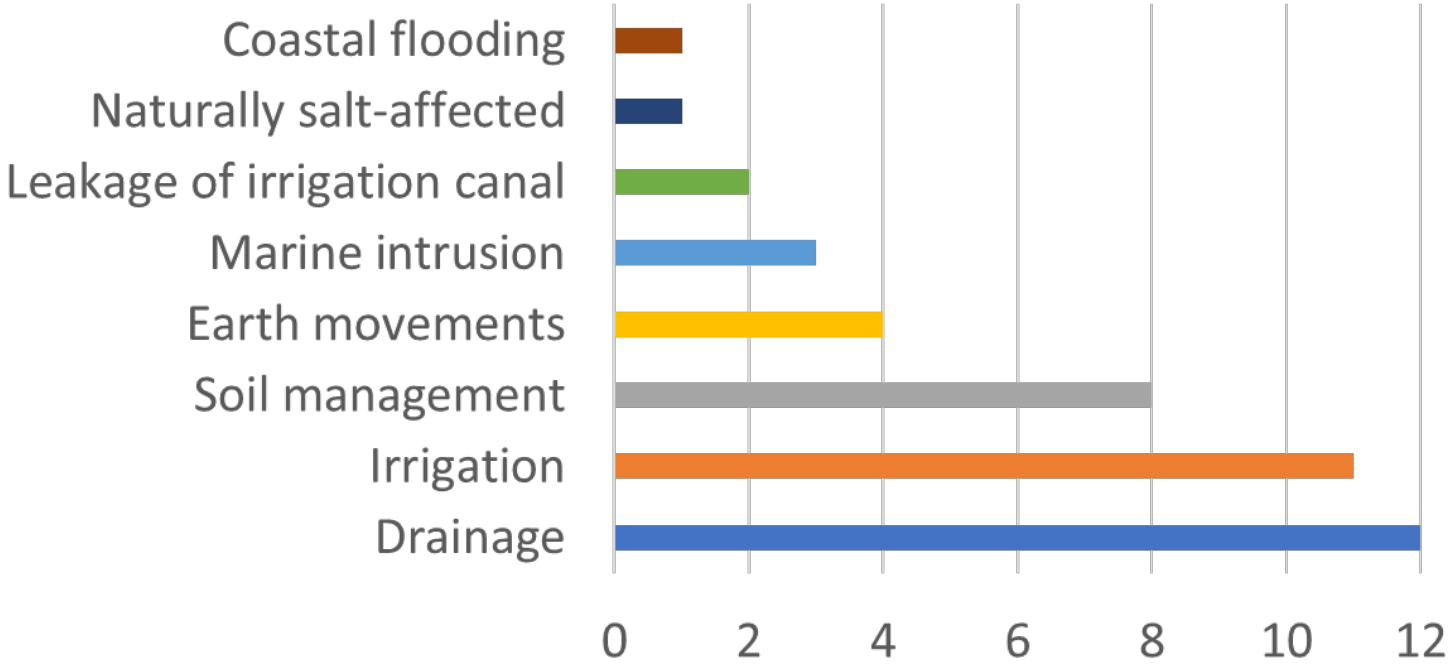
- 18 from a Mediterranean type of climate
- 5 under Temperate
- 2 continental

- 13 saline soils
- 9 saline-sodic
- 3 sodic

25 sites

eip-agri_fg_soil_salinisation_final_report_2020_en.pdf (europa.eu)

Engineering mistakes



25 European areas affected by soil salinization

Improper management of soil and water are the main drivers of soil salinisation

irrigated meadows on Haplic Phaeozems (Endocalcaric, Sodic, Clayic) near Sofia

Most of saline soils in inland areas are associated with irrigation

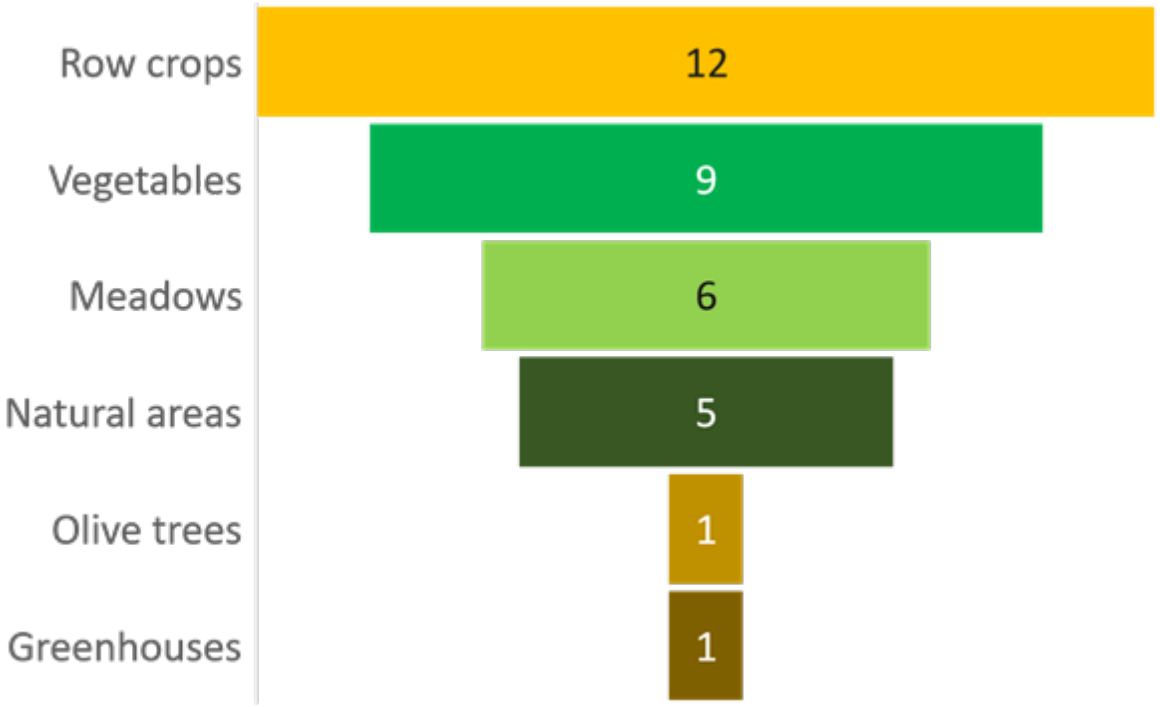
Leaking of irrigation channels and wells
raising the saline water table through excessive irrigation

Water management is the most important issue to control soil salinity. The degree to which water movement can be managed determines the feasibility of facing the salinity problem

drainage

Currently, crop selection is the main practice that farmers use to cope with soil salinity problems in the affected area

crop selection



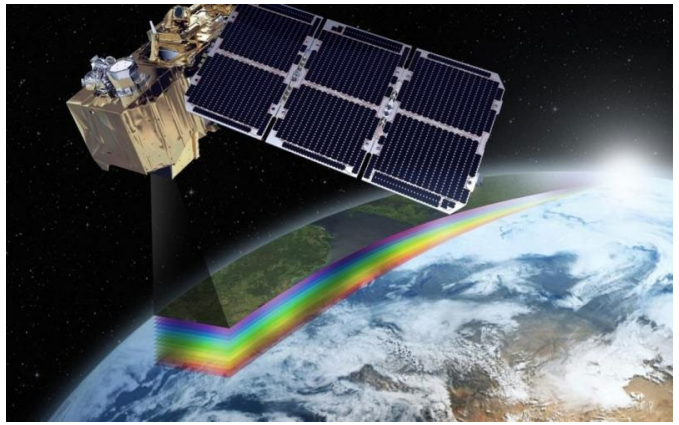
Main crops in the areas with salinization problems

needs for research & ideas to generate the knowledge

major knowledge gaps for the proper management of soil salinity:

- **updated assessment of the extent, magnitude, and development of the process of soil salinisation**
  at the different scales

- **how to get the most out of tools**
  proximal
  remote
  ICT



Monitoring and mapping soil salinisation

The acreage of soil affected either on surface and/or in depth by salinization is still uncertain

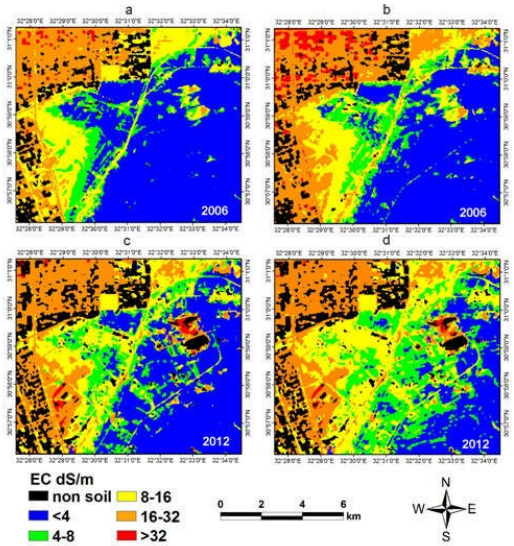
Is observed increasing trend of soil salinisation in the last decades, as a consequence of:

- current climate
- land use
- management changes

Monitoring and mapping soil salinity is practiced for a number of years, however

problem in the monitoring of saline soils is determined by dependency of salinity values on:

- weather
- local soil variability
- land subsidence
- variable quality and quantity of irrigation water



Remote Sens. **2014**, *6*(11), 10813-10834; **https://doi.org/10.3390/rs61110813**

Monitoring and mapping soil salinisation

The acreage of soil affected either on surface and/or in depth by salinization is still uncertain

- typical short-term change is the appearance/disappearance of salt efflorescence caused by an upward seepage of saline water in dry periods

- farmers may little appreciate the effects of soil salinisation in the short run, especially when they have to face incipient, seasonal, or periodic salinity

Funct Plant Biol. 2012 Sep;39(8):689-698. doi: 10.1071/FP12152.

Seasonal and multiannual effects of salinisation on tomato yield and fruit quality

Stefania De Pascale [1], Francesco Orsini [2], Rosanna Caputo [1], Maria Antonella Palermo [1], Giancarlo Barbieri [1], Albino Maggio [1]

Monitoring and mapping soil salinisation

soil salinity can be detected with different methodologies in:

- laboratory
- field

Electrical conductivity values
are the standard international laboratory method for interpreting soil salinity

The standard method is the electrical conductivity measurement of the extract obtained from a saturated soil paste (EC_e at 25°C, dS m^{-1})

However, the preparation of the saturated extract is

- labour-intensive
- time-consuming
- not well-suited to processing large number of samples

Electrical conductivity values

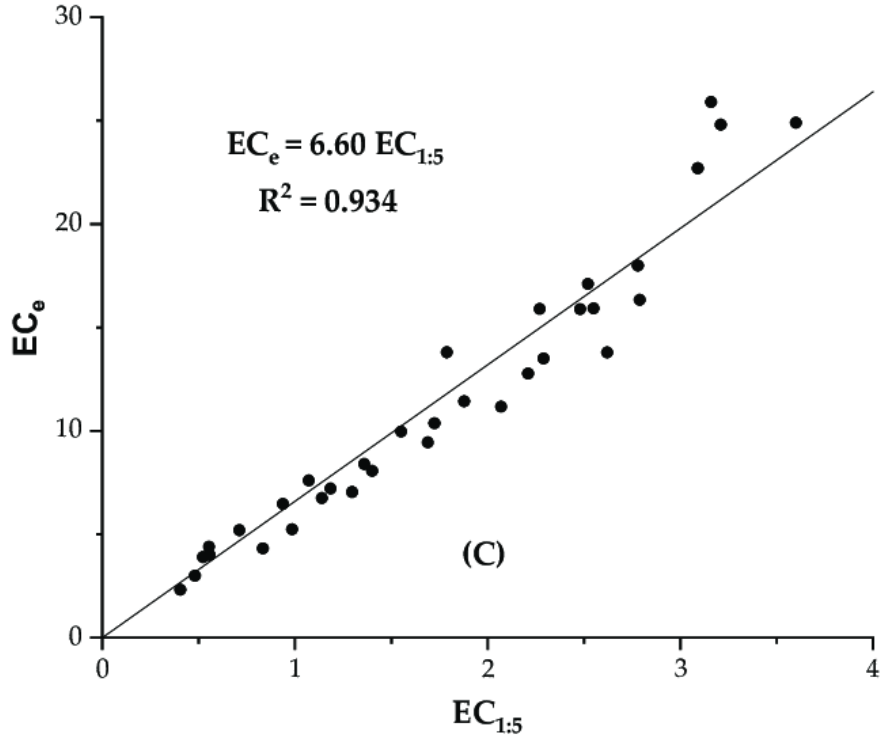
To make the analysis easier, there are

- many empirical relationships
  assumed to relate the value of saturated paste to that in different suspensions of soil and water

- a number of methods that can be used for field measurements of soil salinity.
  - ceramic cup suction samplers installed directly in the field
  - hand-held electrometer

Comparison of Soil EC Values from Methods Based on 1:1 and 1:5 Soil to Water Ratios and ECe from Saturated Paste Extract Based Method

April 2020 · Water 12(4):1010
DOI:10.3390/w12041010



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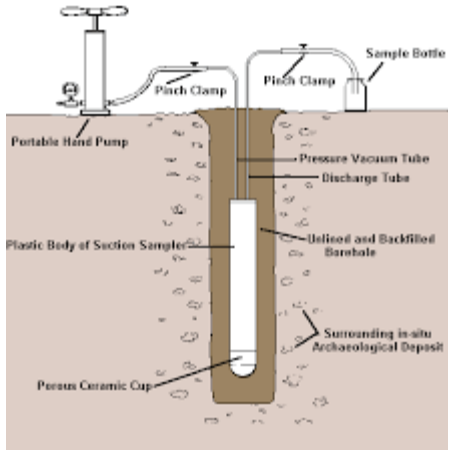


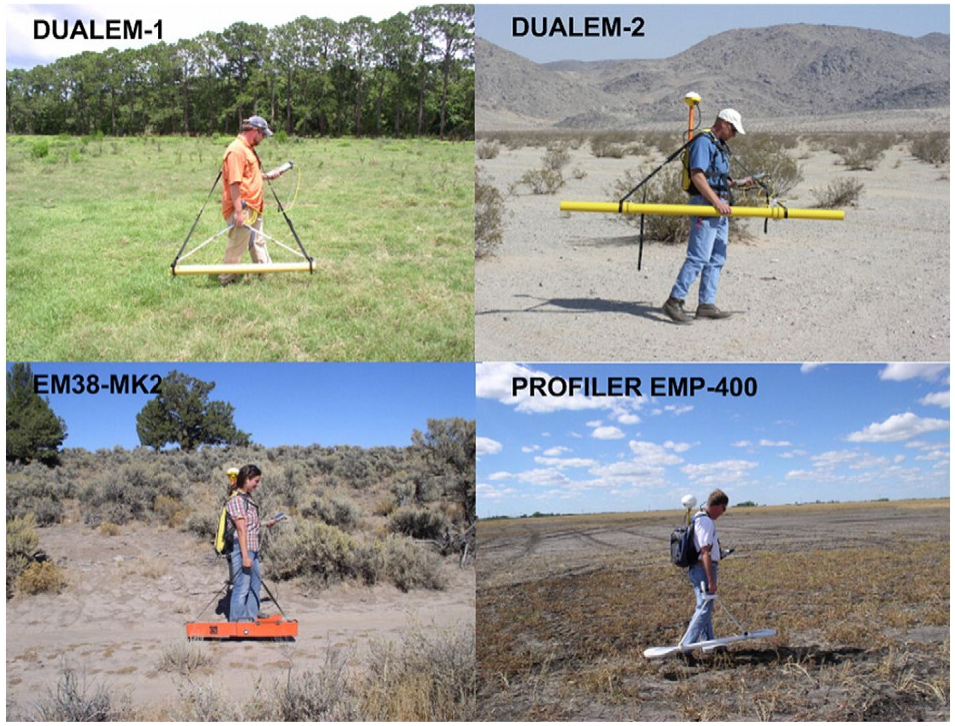
promising methods of analysing and monitoring soil salinity at the farm level

proximal sensors
in contact with the soil or close to it (within 2 m)

- electrical resistivity sensors
- dielectric sensors
- electromagnetic induction (EMI) sensors

Site-specific seeding using multi-sensor and data fusion techniques: A review

M.A. Munnaf, ... A.M. Mouazen, in Advances in Agronomy, 2020



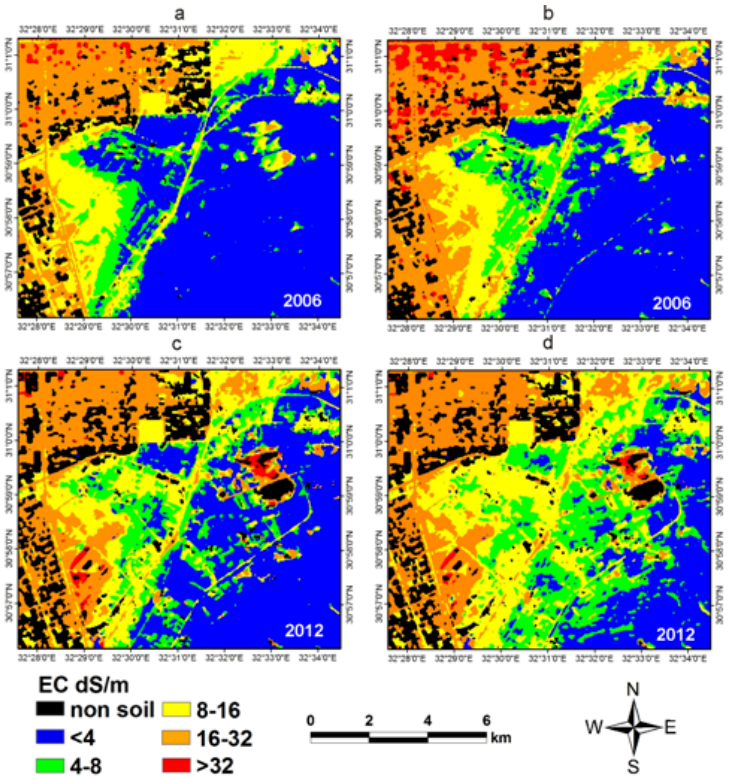
Measuring, mapping and monitoring of soil salinity by means of remote sensors

Air-borne sensors
- helicopters
- light aircraft
- drones

satellite-borne sensors
reduce time-consuming and costly field surveys

Images obtained with sensors that measure
- different wavelengths of the light reflected by the earth surface
- reflectance (and ratios) of various reflectance values

information of the soil surface (**not from the soil profile**)



Modeling and Mapping of Soil Salinity with Reflectance Spectroscopy and Landsat Data Using Two Quantitative Methods (PLSR and MARS)

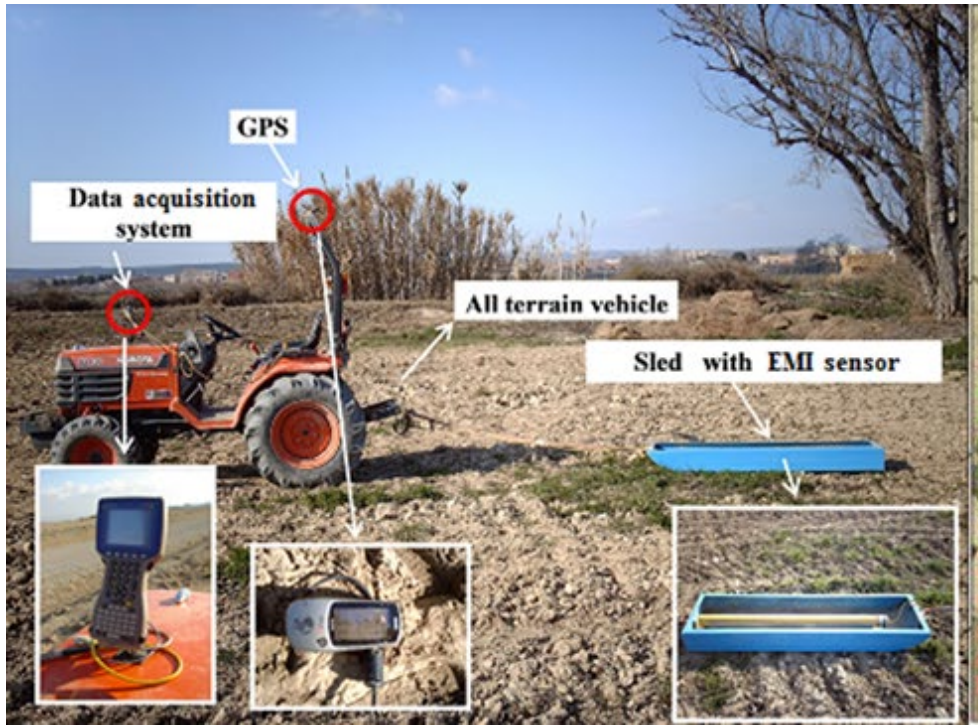
by Said Nawar [1,2,*], Henning Buddenbaum [3], Joachim Hill [3] and Jacek Kozak [1]

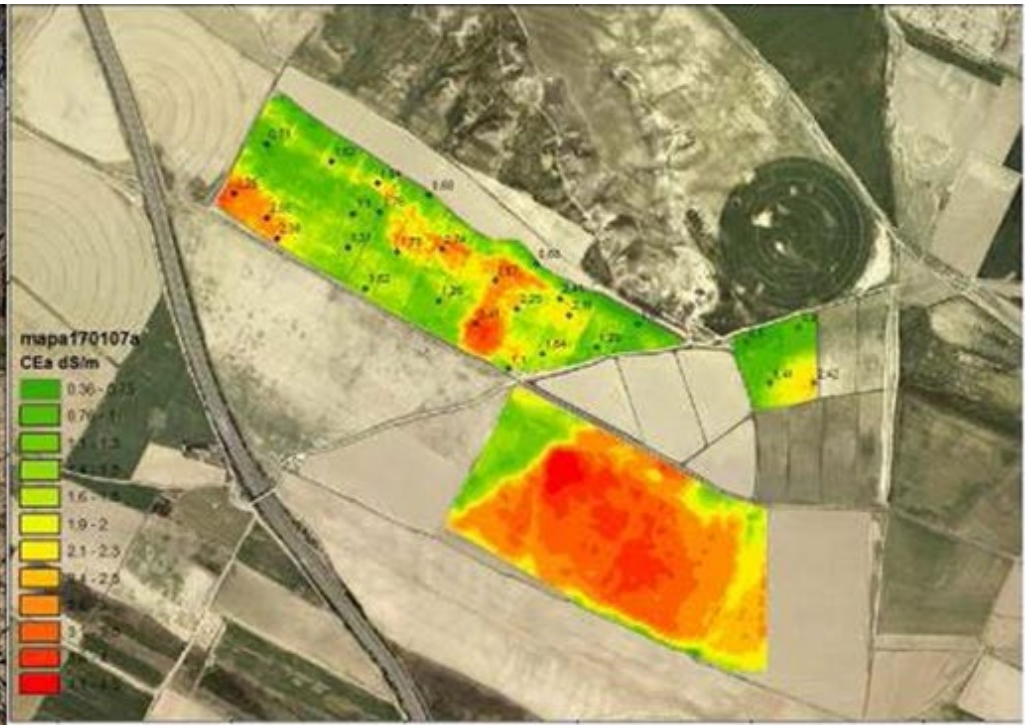
[1] Institute of Geography and Spatial Management, Jagiellonian University, Krakow 30-387, Poland
[2] Faculty of Agriculture, Suez Canal University, Ismailia 41522, Egypt
[3] Environmental Remote Sensing and Geoinformatics, Trier University, 54286 Trier, Germany
[*] Author to whom correspondence should be addressed.

Remote Sens. **2014**, *6*(11), 10813-10834; **https://doi.org/10.3390/rs61110813**

Innovation in monitoring soil salinisation: proximal on-the-go sensors and digital mapping

+ models



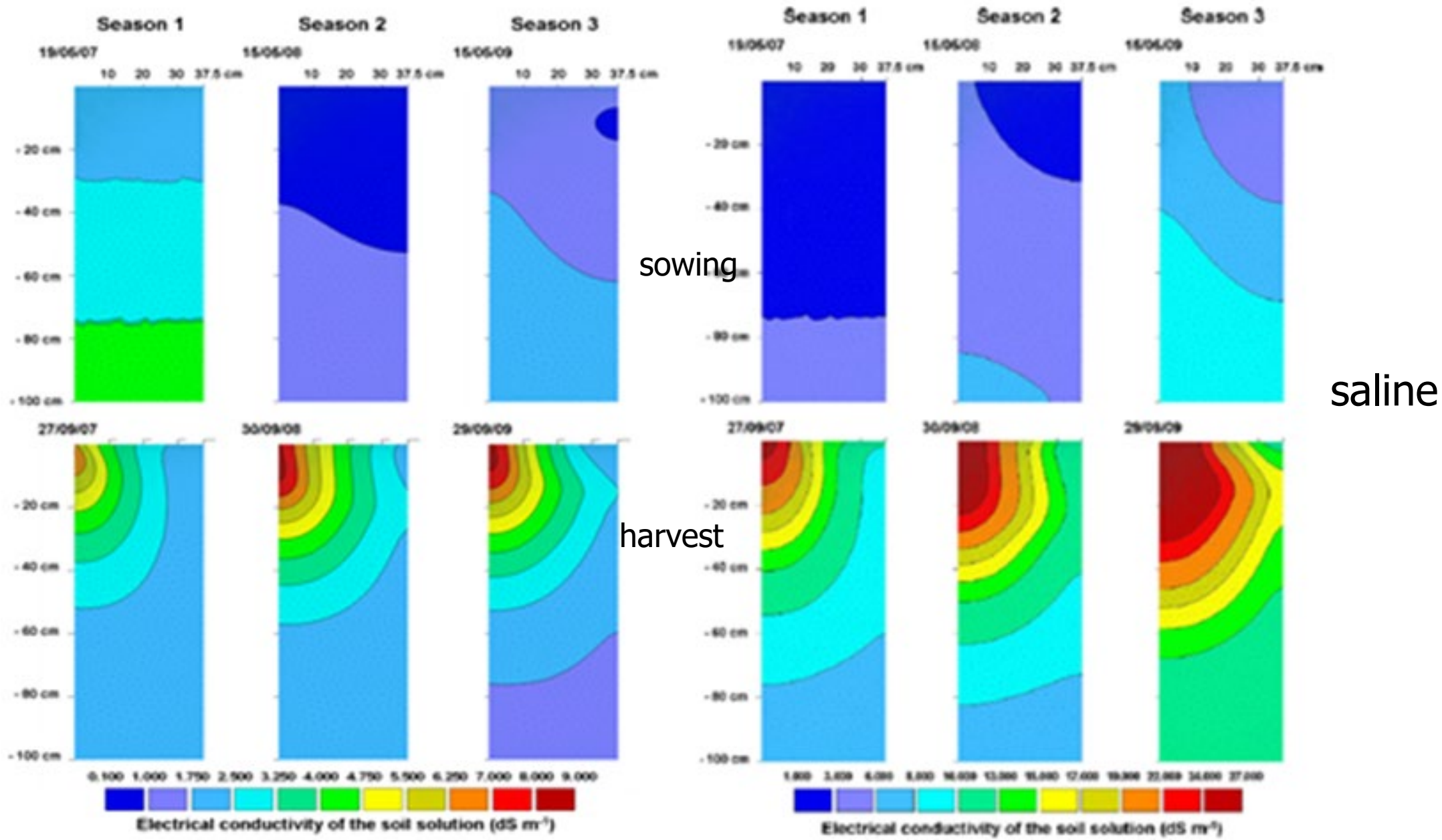


portable EMI sensors +
Global Positioning Systems (GPS) +
data-loggers

resulting map
displays the spatial patterns of soil salinity

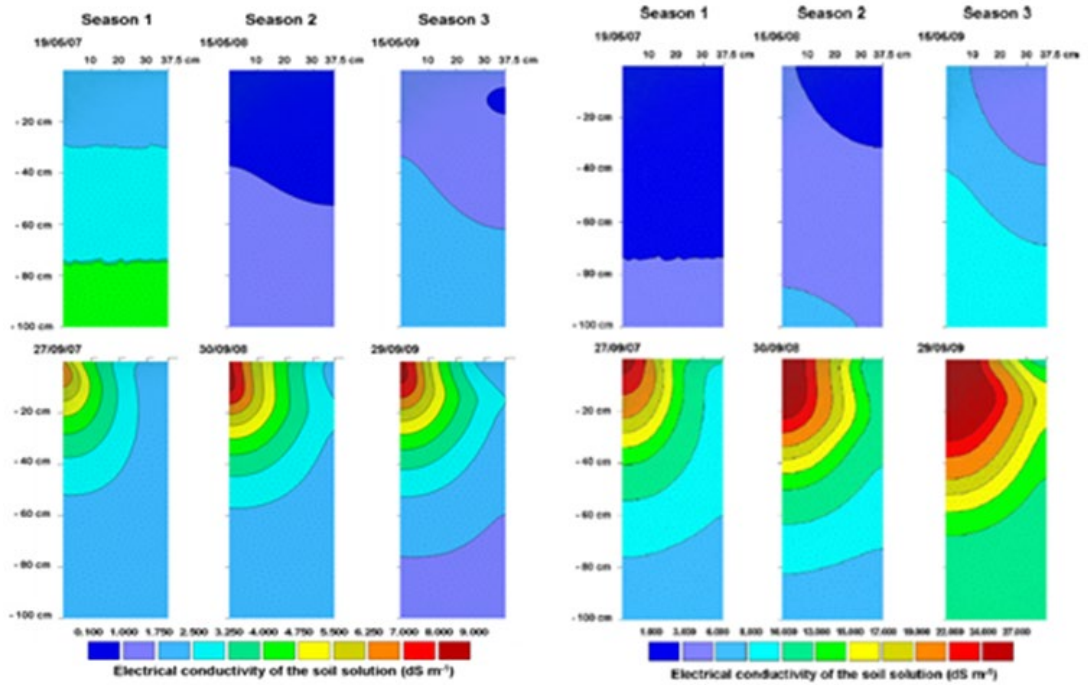
to identify and rank salinity affected areas
slightly……. moderately……severely- affected

Simulated distribution of the electrical conductivity of the soil solution



Simulated distribution of the electrical conductivity of the soil solution

fresh



saline

Modeling is a processes integration tool, which favors the comparison of different scenarios

However, a real challenge is

- dominating spatial variability
  upscaling soil properties from plot scale to larger areas