Salinity - A major agricultural problem: Causes, Impacts & Management

Theoni Karaviti , Efthymia Alexopoulou, Eleni G. Papazoglou

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MARGINAL LANDS, INDUSTRIAL CROPS
AND INNOVATIVE BIO-BASED VALUE CHAINS

Funded by
the European Union

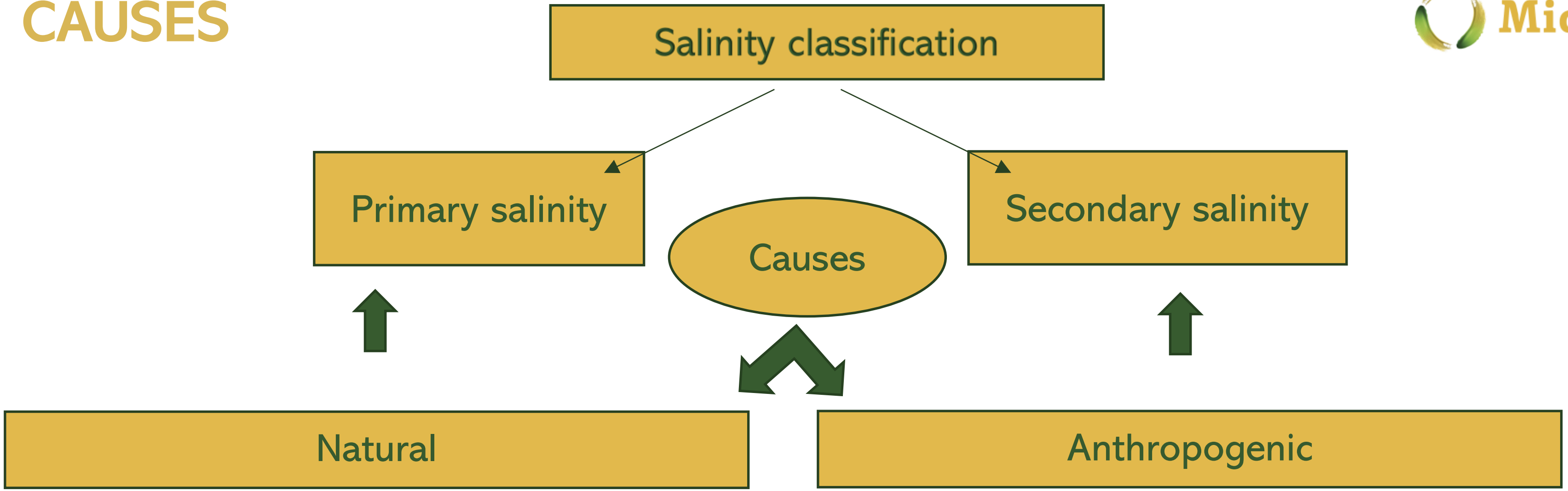
This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101082070.

Soil salinity

DEFINITION

- Salinization is one of the main challenges of contemporary agriculture
- Soil salinity is defined as the accumulation of water-soluble salts in the soil to a level that impacts on agricultural production, environmental health, and economic welfare (FAO, 2011)

CAUSES



- Mineral and salty rocks weathering
- Lands located near coastal regions
- High temperature (↑ evaporation rate)
- Wind and flooding erosion
- Reduced rainfall
- Shallow groundwater

- Extensive irrigation
- Use of imbalanced fertilizers
- Soil / land degradation
- Poor drainage
- Deforestation (soil erosion)
- Mining activities
- Low-quality water

SOIL CLASSIFICATION

- Standard agricultural soils which promote the growth of cultivated crops have salinity level ~ 4 dS m^{-1} (40 mM NaCl)
- Ionic concentration > 4 dS m^{-1} in rhizosphere result in stress conditions
- Most plant species are salt-sensitive (glycophytes)
- Plants known as halophytes can withstand salinity stress up to 100 mM

ECe: Electrical Conductivity
SAR: Sodium Adsorption Ratio

Soil classification	ECe dS m^{-1}	SAR
Saline	> 4	< 13
Sodic	< 4	> 13
Saline-sodic	> 4	> 13

ECe (dS m^{-1})	Soil classification
0 – 2	non-salinized
2 – 4	marginally salinized
4 – 8	moderately salinized
8 – 16	strongly salinized
16 – 32	rigorously salinized
> 32	exceptionally salinized

EXAMPLES OF SALT-TOLERANT PLANT SPECIES

Common name	Scientific name
Swiss chard	*Beta vulgaris* L.
Asparagus	*Asparagus officinalis* L.
Cotton	*Gossypium hirsutum* L.
Kenaf	*Hibiscus cannabinus* L.
Rapeseed	*Brassica* sp.
Barley	*Hordeum vulgare* L.
Rye	*Secale cereale* L.
Triticale	X Triticosecale Wittmack
Wheat, semidwarf	*Triticum aestivum* L.
Wheat, durum	*Triticum turgidum* L. var. durum Desf.
Bermuda	*Cynodon dactylon* (L.) Pers.
Wheatgrass, tall	*Agropyron elongatum* (Hort) Beauvois
Wheatgrass, fairway crested	*Agropyron cristatum* (L.) Gaertn.
Date Palm	*Phoenix dactylifera* L.
Hemp	*Cannabis sativa* L.
Sweet sorghum	*Sorghum bicolor* (L.) Moench
Switchgrass	*Panicum virgatum* L.
Elephant grass	*Miscanthus x giganteus*
False flax	*Camelina sativa* (L.) Crantz
Athel tree	*Tamarix smyrnensis* Bunge
Common reed	*Phragmites australis* (Cav.) Trin. ex Steud.
Castor bean	*Ricinus communis* L.
Nettle	*Urtica dioica* L.
Safflower	*Carthamus tinctorius* L.
Salicornia	*Salicornia* sp.

SALT TOLERANCE LIMIT OF HALOPHYTES SPECIES

Plant species	Salt tolerance limit
Aster tripolium	40 mM
Atriplex lentiformis	500 mM
Atriplex triangularis	150 mM
Batis maritima	500 mM
Salicornia europaea	500 mM
Salicornia persica	100 mM
Sarcocornia fruticosa	100 mM
Aster tripolium	300 mM
Atriplex hortensis	>250 mM
Batis maritima	200 mM
Cochlearia officinalis	100 mM
Crambe maritima	>100 mM
Crithmum maritimum	150 mM
Diplotaxis tenuifolia	~150 mM
Inula crithmoides	400 mM
Mesemyranthenum crystallinum	400 mM
Plantago coronopus	250 mM
Portulaca oleracea	<140 mM
Salicornia sp.	>500 mM
Sarcocornia sp.	>500 mM
Tetragonia tetragonioides	174 mM

SALT-AFFECTED SOILS IN THE WORLD

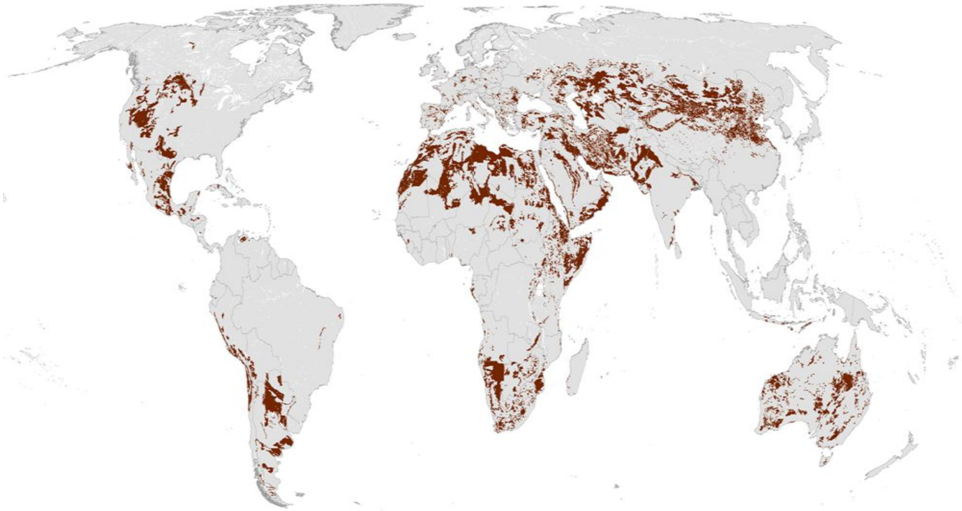


Fig. 1 All salt-affected (saline and saline-sodic) land using the Ecocrop data (>4 dS/m) (Negacz et al., 2022)

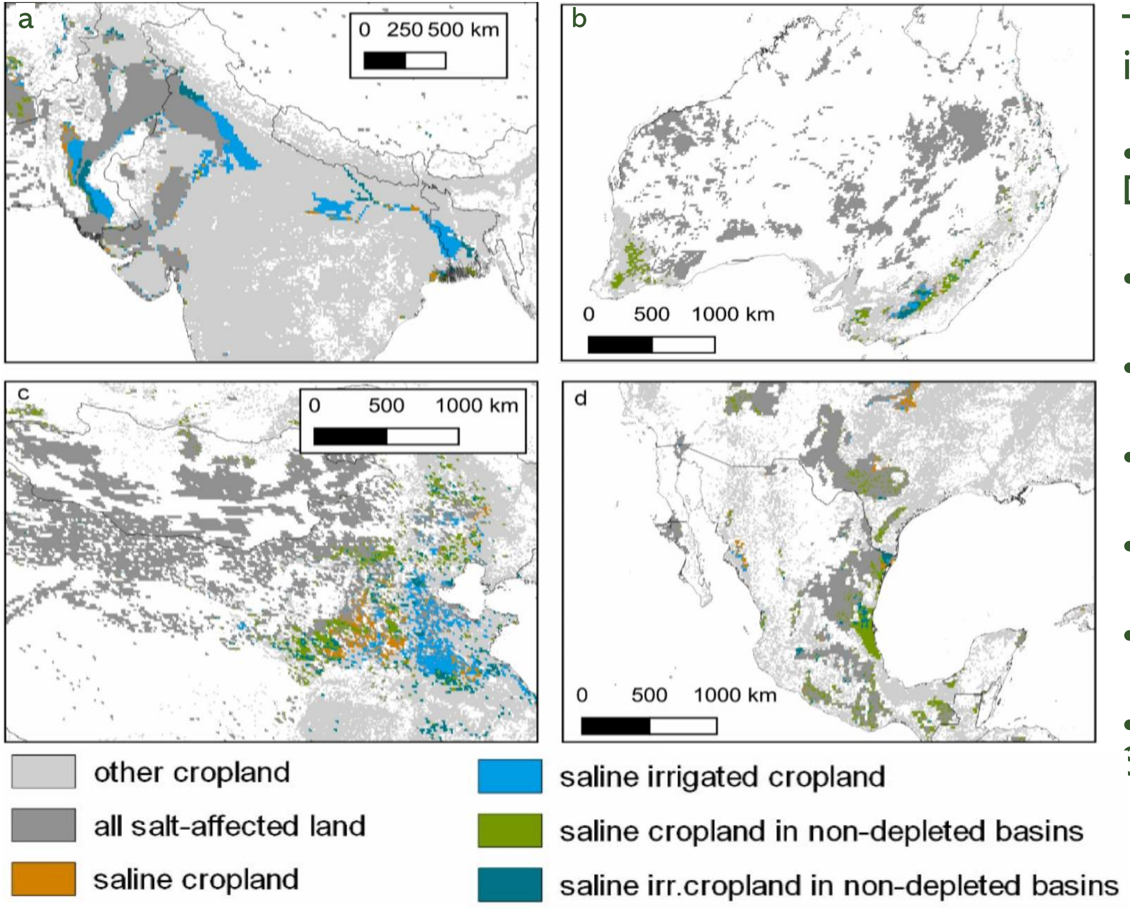
About 20–33% of the cultivated and irrigated land throughout the world is affected by salinity ~ 17 million km^2

- ✓ The global area of salt-affected soils covers 424 million hectares of topsoil (0–30 cm) and 833 million hectares of subsoil (30–100 cm) (based on 73% of the land mapped so far) (FAO, 2021a)
- ✓ The rate of expansion of soil salinization worldwide is expected to increase due to climate change
- ✓ Potential of 10 to 16 % increase/year (Aydemir & Sünger 2011)

Region	Salt-affected area (Mha)	Sodic-affected area (Mha)
Africa	122.9	86.7
South Asia	82.3	1.8
North and Central Asia	91.5	120.2
Southeast Asia	20.0	–
South America	69.5	59.8
North America	6.2	9.6
Mexico/Central America	2.0	–
Australasia	17.6	340.0

Country	Area (km^2)
China	1.840.300
Australia	1.255.100
Kazakhstan	1.037.200
United States	999.500
Argentina	792.000
Libya	748.600
Algeria	732.900
Iran	658.100
Mongolia	588.300
Namibia	471.500

Fig. 2 Hot-spots of saline areas: a) Bangladesh, India and Pakistan b) Australia c) East and Central China d) Mexico (Negacz et al., 2022)



The most known regions where salt-induced land degradation takes place:

•Aral Sea Basin (Amu-Darya and Syr-Darya River Basins) in Central Asia

•Indo-Gangetic Basin in India

•Indus Basin in Pakistan

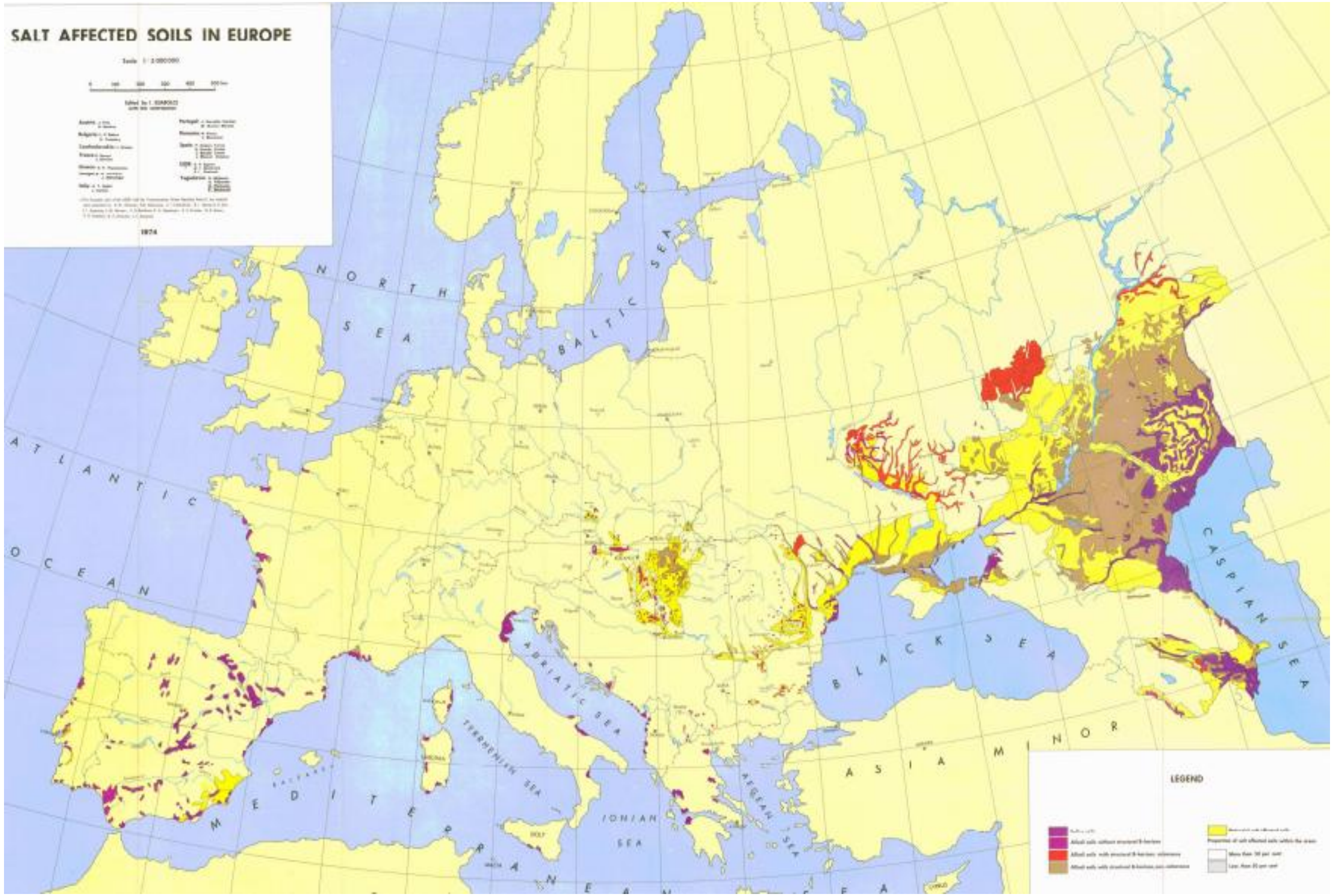
•Yellow River Basin in China

•Euphrates Basin in Syria and Iraq

•Murray-Darling Basin in Australia

•San Joaquin Valley in the United States

SALT-AFFECTED SOILS IN EUROPE



Saline soils

Alkali soils without structural B-horizon

Alkali soils with structural B-horizon, calcareous

Alkali soils with structural B-horizon,non-calcareous

Potential salt affected soils

More than 50 per cent

Less than 50 per cent

Fig. 3 Map of salt-affected soil in Europe (Bloem et al., 2007)

GENERAL IMPACT

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- Soil/land degradation
- Change root zone chemistry and alter hydro-physical and biological behavior
- Prone to formation of surface crusts
- Water stagnation
- Infiltration reduction
- Anoxic conditions
- Unsaturated hydraulic conductivity
- Deterioration of soil structure
- Water movement restriction
- Difficulties in tillage and sowing operations

Environmental impact

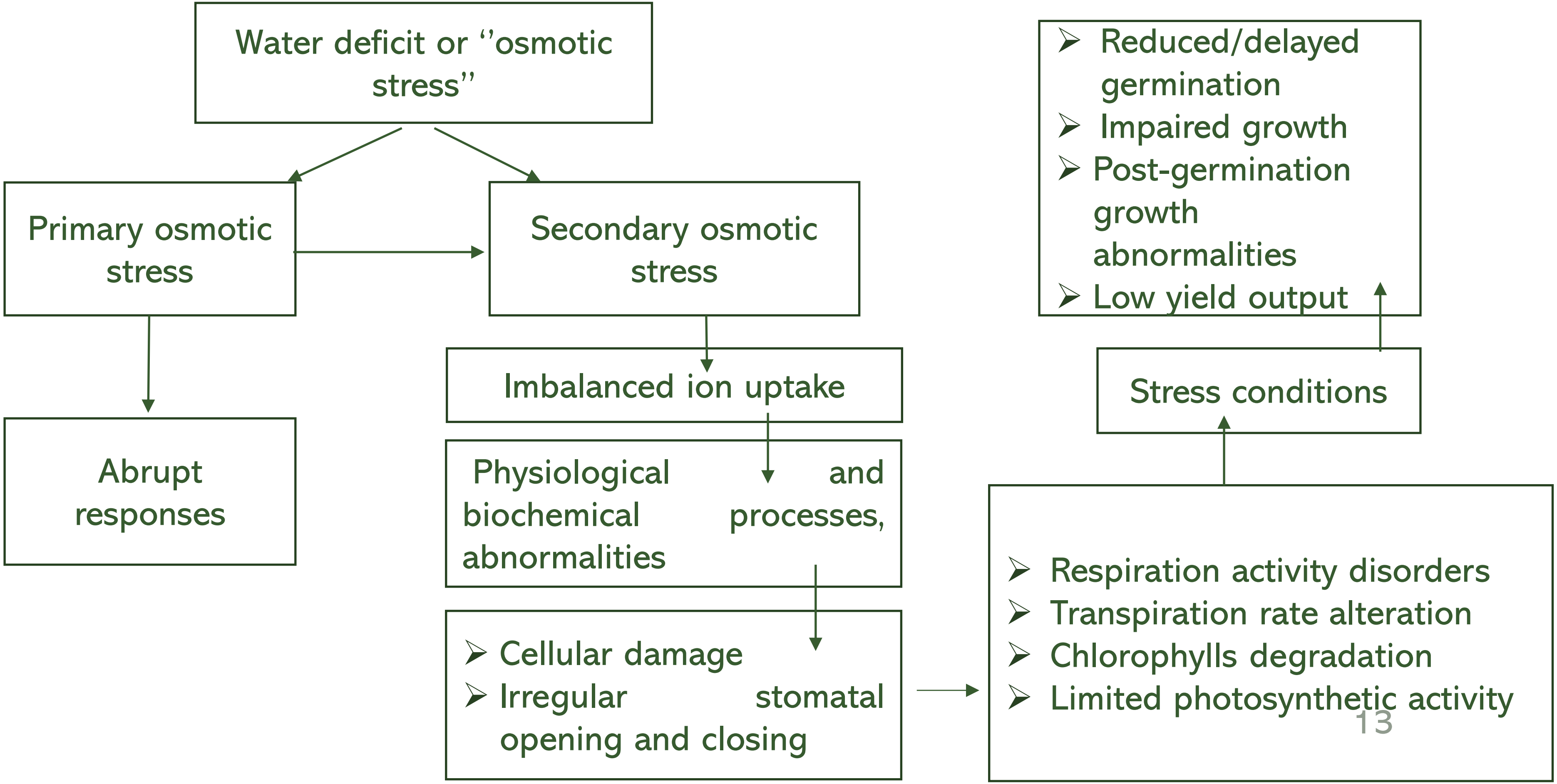
Agricultural impact

- Reduce water uptake (Water deficit/osmotic stress) in plants
- Imbalanced accumulation of specific ions, e.g. Cl, Na, etc., in plants
- Reduced germination
- Root growth inhibition
- Root water extraction restriction
- Plant growth inhibition

- Leading limiting factor responsible for growth and production decline
- About 20% (45 million ha) of irrigated land, producing one-third of the world's food, is salt-affected
- The global annual cost is estimated to be US$ 27.3 billion related to lost crop production.

Economic impact

IMPACT ON PLANTS



Soil salinity: Management

AGRONOMIC PRACTICES - Irrigation

- ❑Irrigation Method → increasing water-use/nutrient-use efficiency
- ✓Surface drip irrigation (DI)
- ✓Subsurface drip irrigation (SDI)
- ✓Furrow irrigation
- ✓Sprinkler irrigation
- ✓Low energy precision application (LEPA) irrigation, installation of tube wells
- ❑Irrigation frequency
- ✓Appropriate irrigation scheduling
- ✓Deficit irrigation (DI): optimization strategy in which the application of water is smaller than the full crop evapotranspiration requirements (scarce irrigation water)
- ❑Water quality

AGRONOMIC PRACTICES – Leaching & drainage

❑Maintenance leaching

✓When sufficient natural drainage

✓Low soil moisture content, deep groundwater table

✓Leaching fraction (LF) 15-20%, frequency ~ 2-3 times/per week (drip irrigation)

❑Artificial drainage

✓Water removal equipment

✓Avoid water table rise

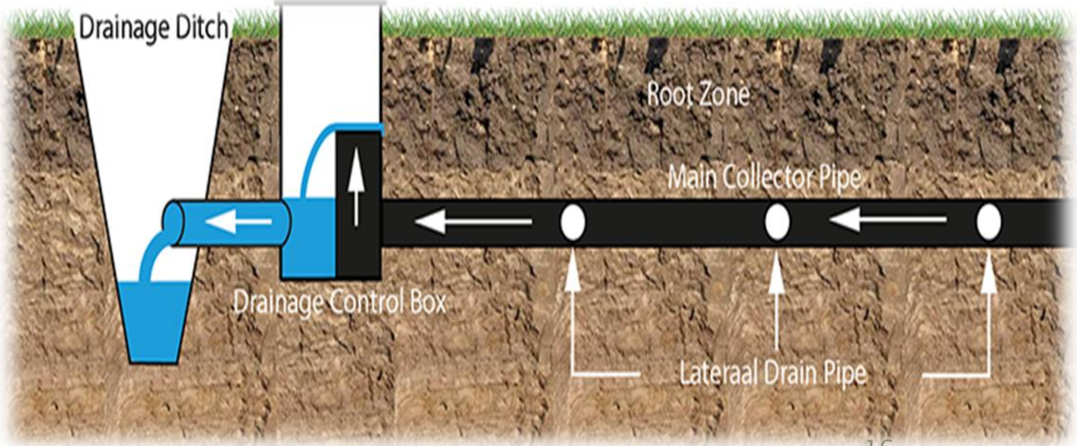


Fig. 4 Climate Adaptive Drainage (CAD), with drains merging into a collector pipe, that discharges into a control box (Van Der Zee et al., 2017).

AGRONOMIC PRACTICES – Fertilization

❑Fertilizer characteristics

✓Application of high-purity, chloride-free and low-saline fertilizers

✓Addition of different nutrients

✓Addition of NO_3^-, Ca^{2+}, K^+, P, salicylic acid (SA), and silicon (Si) in foliar application

❑Fertilization scheduling

✓Excessive nutrient applications must be avoided

AGRONOMIC PRACTICES – Fertilization

❑Application method

✓Application of fertilizers through irrigation water (**fertigation**)

✓Fertigation improves fertilizer efficiency use, increases nutrient availability and timing of application, and the concentration of fertilizers are easily controlled

✓Fertigation allows frequent applications of very low fertilizer rates which adjusts nutrient supply to plant requirements

Fig. 5 Surface drip irrigation (DI) in Kenaf cultivation

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SEED PRIMING

- ❑Pre-germination soaking of seeds with different solutions for the different duration is termed as "seed priming"
- ❑Seed preparation for better performance under stressful environment
- ❑Solutions for seed priming can be pure water, salts, hormones, and natural metabolic substances.

➢ Halo priming (treatment of seeds with different concentration of salts)

➢ Hydropriming (water treatment)

✓ Low cost and easy availability of soaking gents

PLANT GROWTH PROMOTING BACTERIA (PGPB)

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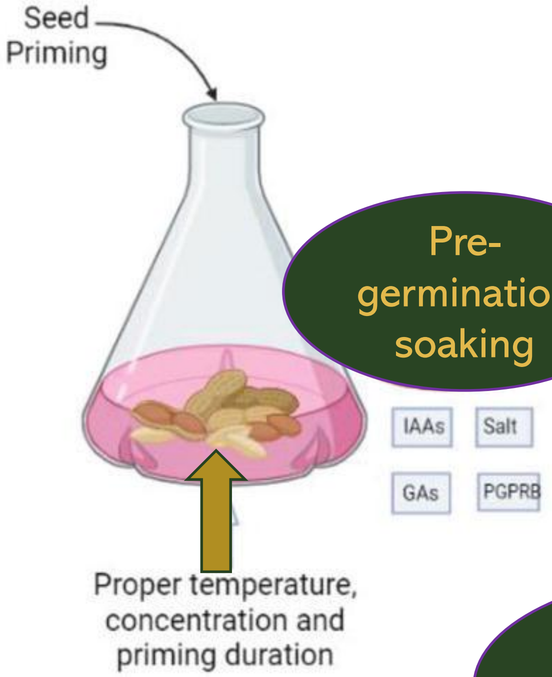
- ❑Priming compounds induce defense and stress tolerance
- ❑PGPB improve stress responses by several mechanisms



Pre-germination soaking

1

Bio-priming with plant growth promoting bacteria

2

- ✓ Enhanced seed germination
- ✓ Viability and vigor
- ✓ Uniform germination
- ✓ Abiotic stress tolerance
- ✓ Enhanced crop yield

PHYTOREMEDIATION OF SALT-AFFECTED SOILS

- Phytoremediation of salt-affected soils is a technology that utilizes salt-tolerant and salt-removing plant species to decrease the salt content in saline soils and enhance their sustainability.
- Plants selected for soil salt phytoremediation are salt tolerant or halophytes with high biomass production and economic importance.

Excluders	➢ Prevent salts from entering their tissues	✗
Accumulators	➢ Uptake and accumulate salts in their tissues	✓
Conductors	➢ Conduct salts from the soil into the air	?

PHYTOREMEDIATION

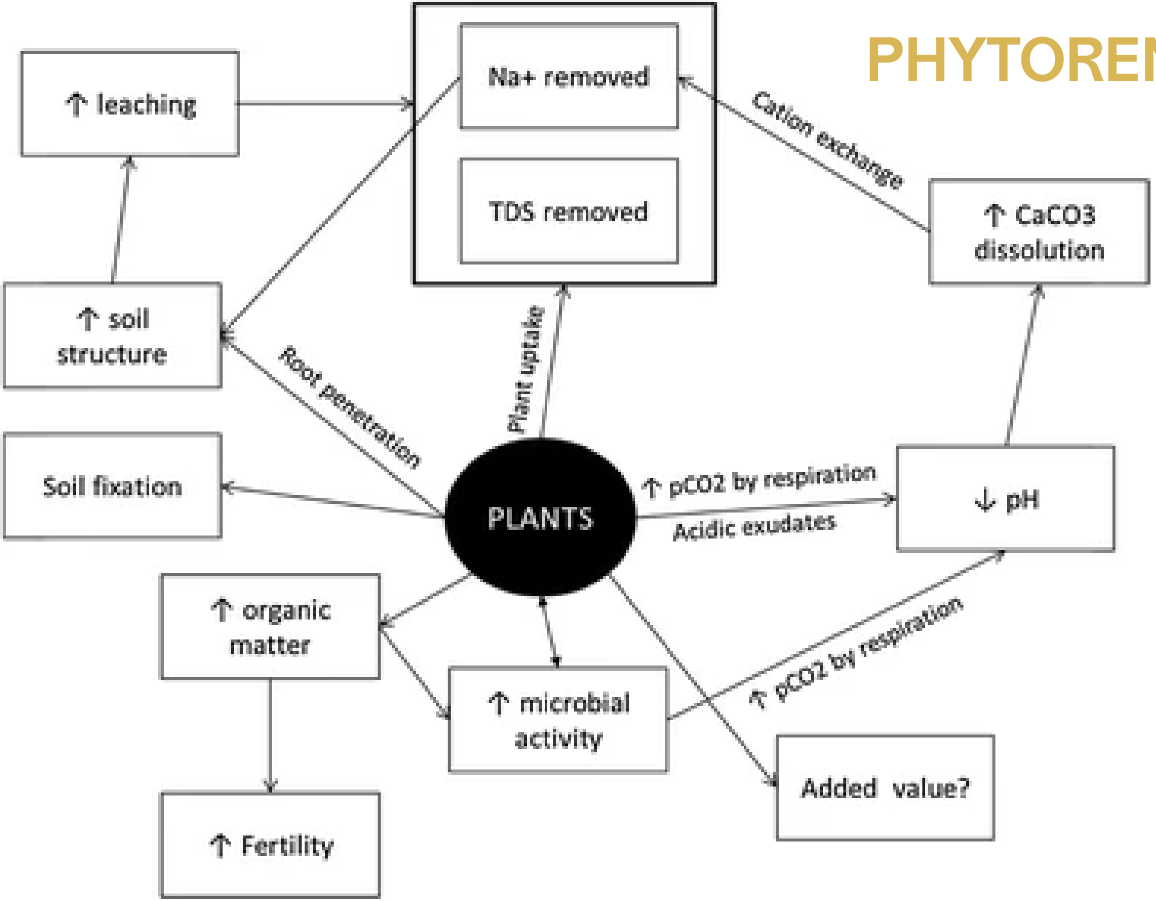


Fig. 6 Role of plants in salt-affected soil remediation and possible variations in soil properties as a result of this process (based on Qadir et al. 2000; Qadir et al. 2006; Rabhi et al. 2009)

$CaCO_3$ dissolution is the main mechanism for saline soil remediation

SELECTED PLANTS – HYPERACCUMULATORS & HALOPHYTES

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- ✓ Halophytes are key players for phytoremediation of saline soils.
- ✓ Plants able to remove the maximum quantity of salts (hyperaccumulators) by producing higher biomass with economic importance are mainly selected for phytoremediation.
- ✓ Halophytic herbs *Suaeda maritama* (sea-blite) and *Sesuvium portulacastrum* (sea purslane) exhibit the highest accumulation of salts and can be grown easily. These two halophytes can remove 504 and 474 kg of NaCl, respectively, from t1 ha saline land in 4 months.
- ✓ *Sesuvium portulacastrum* accumulate nearly 30% of Na^+ content in shoot in170 days
- ✓ *Suaeda salsa* produces about 20 tons dry weight ha^{-1} containing 3–4 tons of salt
- ✓ *Alfalfa* sp. readily decrease salt content in saline soils
- ✓ *Portulaca oleracea* (common purslane) accumulate up to 497 kg per hectare (16% of removed salt) and it does not require any irrigation when water table is 1.1 m
- ✓ *Glycyrrhiza glabra*, commonly known as liquorice, has been used for phytoremediation of saline soils.

SELECTED PLANTS

Plant species (Shrubs)	Root zone salinity causing 50% yield reduction	
	ECe (dS m^{-1})	% salt
Suaeda fruticosa	48	3.07
Kochia indica	38	2.43
Atriplex nummularia	38	2.43
Atriplex amnicola	33	2.11
Atriplex lentiformis	23	1.47
Atriplex undulate	22.5	1.44
Atriplex crassifolia	22.5	1.44
Sesbania Formosa	21.4	1.37
Beta vulgaris	19	1.22
Lotus carniculatus	16.7	1.07
Trifolium alexandrinum	15.8	1.01
Sesbania aculeate	13	0.83
Hasawi rushad	12.5	0.8
Medicago sativa	13.2–12.2	0.84–0.78
Sesbania rostrata	12	0.77
Macroptilium atropurpureum	12	0.77
Trifolium resupinatum	11.6	0.77

Several plant species including shrubs are being used for phytoremediation of salinized soils

SELECTED PLANTS

Plant species (Grasses)	Root zone salinity causing 50% yield reduction	
	ECe (dS m^{-1})	% salt
Leptochloa fusca	22.0–14.6	1.41–0.93
Sporobolus arabicus	21.7	1.39
Cynodon dactylon	21.0–13.2	1.34–0.84
Hordeum vulgare	19.5–10.0	1.25–0.64
Sorghum. vulgare	16.7–15.0	1.07–0.96
Panicum antidotale	16	1.02
Echinochloa crusgalli	15.9	1.02
Polypogon monspeliensis	13.7	0.88
Avena sativa	11.8–9.1	0.76–0.58
Lolium multiflorum	11.2	0.72
Echinochloa colona	11.2	0.72
Desmostachya bipinnata	9	0.64
Panicum maximum	9.0–8.5	0.58–0.54
Sorghum halepense	7	0.45

Several plant species including grasses are being used for phytoremediation of salinized soils

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SELECTED PLANTS

Plant species (Vegetables)	Root zone salinity causing 50% yield reduction	
	ECe (dS m^{-1})	% salt
Aster tripolium	31.7	2.03
Brasssica napus	19.5	1.25
Trigonella foenum–graceum	19.2	1.23
Spinacea oleracea	14.8	0.94
Medicago falcata	13.4	0.86
Brassica carinata	12.5	0.8
Brassica juncea	12.4–8.44	0.79–0.54
Lactuca sativa	9.9	0.63
Brassica campestris	9.8	0.63
Eruca sativa	9.4	0.6
Coriandrum sativum	5.7	0.37

Several plant species including vegetables are being used for phytoremediation of salinized soils

Plant species (Trees)	Root zone salinity causing 50% yield reduction	
	ECe (dS m^{-1})	% salt
Acacia sclerosperma	38.7	2.48
Acacia ampliceps	35.7	2.28
Prosopis juliflora	35.3	2.26
Prosopis chilensis	29.4	1.88
Casuarina obesa	29.2	1.86
Acacia victoriae	28.3	1.81
Eucalyptus microtheca	27.9	1.78
Acacia nilotica	27.9	1.78
Acacia acuminate	27.7	1.77
Acacia cambagei	27.7	1.77
Eucalyptus striaticalyx	26.2	1.68
Acacia salicina	24.5	1.57
Prosopis cineraria	24.4	1.56
Casuarina glauca	24.4	1.56
Prosopis tamarugo	22.7	1.45
Acacia calcicola	19.9	1.27
Acacia coriacea	18.2	1.16
Cassia nemophila	16.8	1.07
Cassia sturtii	15.8	1.01
Acacia saligna	15.7	1
Acacia bivenosa	13.7	0.88
Acacia subtessarogna	13.7	0.88
Leucaena leucocephala	12.4	0.79
Acacia kempeana	11	0.7
Acacia aneura	9.5	0.61
Acacia cunnighamii	9.4	0.6
Acacia holosericea	9	0.78
Acacia adsurgens	4.3	0.27
Acacia validinervia	1.7	0.11

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SELECTED PLANTS

Several plant species including trees are being used for phytoremediation of salinized soils

SELECTED PLANTS

- Salt-tolerant plants are also suitable for phytoextraction and phytostabilization of heavy metals in saline soils.
- Examples of salt-tolerant plants suitable for phytoremediation of heavy metals and saline soils include:
- *Tamarix smyrnensis* is a highly salt-tolerant plant with ability to accumulate high concentration of lead and cadmium in saline environments
- Common plants such as *Brassica* sp. can also used for phytoremediation of heavy metals and saline soils
- *Chenopodium album* species produce high dry biomass and can be used as a rehabilitating and reclamating agent for the saline soils

Phytoremediation: Pros & Cons

ADVANTAGES

- ✓ Cost-effective option
- ✓ Environmental friendly
- ✓ Well adaptation and economic value
- ✓ Biomass obtained can be used for bioenergy or cellulose production
- ✓ Changes in Soil Physical Characteristics
  - soil porosity
  - soil hydraulic permeability (Kfs)
  - bulk density
  - soil water retention
  - soil structural stability

ADVANTAGES

- ✓Changes in Soil Chemical Characteristics
  - soil pH
  - electrical conductivity (EC)
  - sodium adsorption ratio (SAR)
  - soil organic matter
- ✓Improvement in Soil Fertility
  - availability of nutrients to the subsequent crop increase
- ✓Plants may be used to lower the water table and enhance drainage.
- ✓Salt uptake into the shoots prevents their leaching to groundwater

LIMITATIONS

- Plants unsuitable for food or fodder use
  - Most of the plants used for phytoremediation of salt-affected soils are fodder plants
  - High salt content
  - Plants may contain toxic substances
- Long-term method
  - Extremely slow technique because of the slow growth of plants
  - Phytoremediation may take years and even decades to get clarified
- Leaching prevention
  - Leaching takes place in underground water, which makes this technique less efficient and less desirable as these metals and salts ions may affect the fertility and productivity of soil again after years

CONCLUSIONS

- Salinization is one of the main challenges of contemporary agriculture
- Leading limiting factor responsible for growth and production decline of agricultural crops throughout the world
- About 20–33% of the cultivated and irrigated land throughout the world is affected by salinity
- The adverse effects are expected to reach to 50% in the year 2050

- Phytoremediation of salt-affected soils is an emerging technology which is
  - ✓ Low-cost
  - ✓ Environmentally friendly
  - ✓ Sustainable

- Further research and knowledge is required to commercialize this technique on a large scale

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Funded by the European Union

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101082070. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.