SALAD
Saline AgricuLture for ADaptation

Saline Agriculture: from doom and gloom to boom and bloom

Reflections, Future perspectives and Innovations

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ICBA
AGRICULTURE FOR TOMORROW

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Back to June 2012…

Dr. Shoaib Ismail, Ex-Director of Programs (Halophyte Agronomist)

Saline Agriculture

catchy

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Saline Agriculture

Soil

Saline
Sodic
Saline-sodic

Inland
Coastal

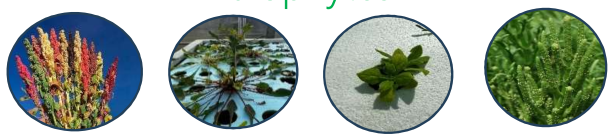
Irrigation water

Brackish groundwater
Drainage water
Seawater
Aquaculture effluents
Reject brine from desalination

Crops

Salt-tolerant cereals, vegetables etc.

Halophytes



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History [edit]

One of the first studies made on soil salinity and plant response was published in the USDA Agriculture Handbook No. 60, 1954.[4] More than 20 years later Maas and Hoffman published the results of an extensive study on salt tolerance.[5] In 2001, a Canadian study provided a substantial amount of additional data.[6] A comprehensive survey of tolerances reported worldwide was made by the FAO in 2002.[7]

Most studies were made with pot or drum experiments or in lysimeters under controlled conditions. The collection of field data under farmers' conditions was rare, probably due to the greater efforts and higher costs involved, the lack of control of plant growing conditions other than soil salinity, and the larger random variation in crop yields and soil salinity. Yet, with statistical methods, it is possible to detect the tolerance level from field data.[1][8][9] Salt Farm Texel, a Dutch-based research company has identified various crops that have considerable amount of salt tolerance.[10]

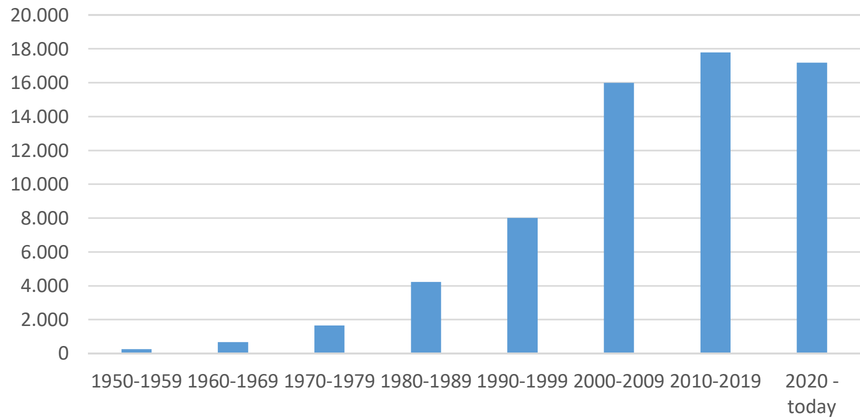
Source: https://en.wikipedia.org/wiki/**Salt_tolerance_of_crops**

IV. HALOPHYTES AS CROPS

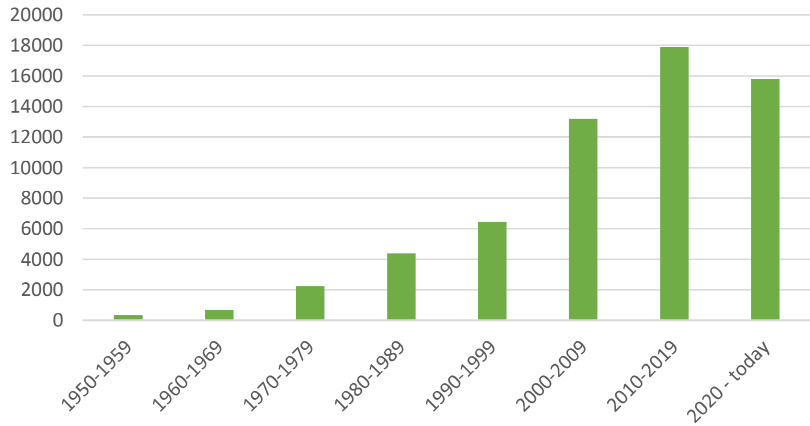
The Israeli scientists Hugo and Elisabeth Boyko were the first modern researchers to attempt to develop high salinity agriculture (Boyko and Boyko, 1959; Boyko, 1966). They demonstrated that some crop plants could be grown on surprisingly high salinity in sandy soil, and pointed to the possibility of crossing crop plants such as wheat with salt-tolerant relatives such as *Agropyrum*, still a topic of

Source: Glenn, E.P., Brown, J.J. and Blumwald, E., 1999. Salt tolerance and crop potential of halophytes. *Critical reviews in plant sciences*, *18*(2), pp.227-255.

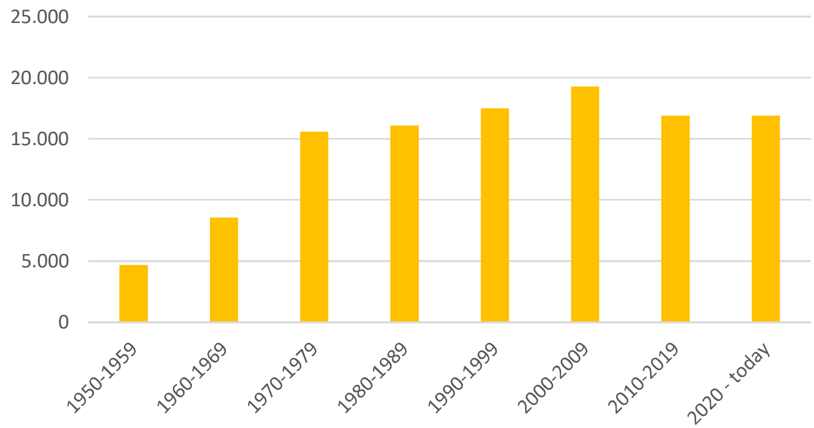
Results from Google Scholar on ***Salt-tolerant crops***



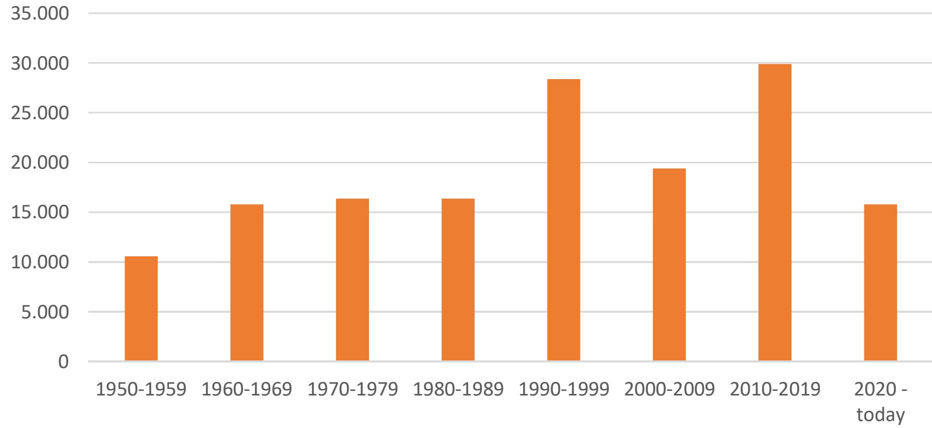
Results from Google Scholar on ***Halophyte(s)***



Results from Google Scholar on ***Saline Farming***



Results from Google Scholar on ***Saline Agriculture***



 Source: Google Scholar access, 14th of April 2024


SUSTAINABILITY
ECONOMIC
SOCIAL
ENVIRONMENT

ENVIRONMENT

Natural resources degradation when using saline water for irrigation

SALAD
Saline AgricuLture for ADaptation

Sustainability factor improves…

Halophytes

Inland areas
- High water salinities
- Less productive soils

Salt-tolerant cereals, vegetables etc.

- Lower water salinities
- More productive soils

Halophytes

- Coastal areas

Implementation farms in Abu Dhabi

TABLE 11.2
The Characteristics of the Eight Farms in Abu Dhabi Emirate. EC_{GW} Is the Electrical Conductivity of the Groundwater; $EC_{RO\text{-}BRINE}$ Is the Electrical Conductivity of the Reject Brine from RO-desalination

Farms with Salicornia and Tilapia Component

Farm 453

$EC_{GW} = 22.3$ dS/m
$EC_{RO\text{-}BRINE} = 40.2$ dS/m

Farm 17

$EC_{GW} = 28.7$ dS/m
$EC_{RO\text{-}BRINE} = 30.0$ dS/m

Farm 79

$EC_{GW} = 20.2$ dS/m
$EC_{RO\text{-}BRINE} = 24.9$ dS/m

Farm 168

$EC_{GW} = 12.9$ dS/m
$EC_{RO\text{-}BRINE} = 28.6$ dS/m

Farms with Salicornia Component Only

Farm 211

$EC_{GW} = 26.8$ dS/m
$EC_{RO\text{-}BRINE} = 36.8$ dS/m

Farm 658

$EC_{GW} = 12.7$ dS/m
$EC_{RO\text{-}BRINE} = 20.8$ dS/m

Farm 136

$EC_{GW} = 21.5$ dS/m
$EC_{RO\text{-}BRINE} = 31.0$ dS/m

Farm 364

$EC_{GW} = 20.0$ dS/m
$EC_{RO\text{-}BRINE} = 21.7$ dS/m

Source: Lyra, D.A., Lampakis, E., Al Muhairi, M., Tarsh, F.M.B., Dawoud, M.A.H., Al Khawaldeh, B., Moukayed, M., Plewa, J., Cobre, L., Al Masjedi, O.S. and Al Marzouqi, K.M., 2021. From Desert Farm to Fork: Value Chain Development for Innovative Salicornia-Based Food Products in the United Arab Emirates. In *Future of Sustainable Agriculture in Saline Environments* (pp. 181-200). CRC Press.

What is happening in the soil salinity after irrigating with saline water?

TABLE 11.4

Electrical Conductivity of the Soil Saturation Extract (EC_e) Collected from the Top 30 cm in All Eight Farms

		EC_e (dS/m)		Increase or Decrease of EC_e
	Farm	**October 2019**	**July 2020**	**between the two Samplings (%)**
Salicornia and Tilapia component	Farm 453	16.8	47.4	182
	Farm 17	18.3	12.0	–34
	Farm 79	15.2	14.8	–2.6
	Farm 168	33.8	38.9	15
Salicornia component only	Farm 211	14.7	22.7	54
	Farm 658	14.2	43.6	207
	Farm 136	2.3	13.0	465
	Farm 364	5.6	12.2	118

Source: Lyra, D.A., Lampakis, E., Al Muhairi, M., Tarsh, F.M.B., Dawoud, M.A.H., Al Khawaldeh, B., Moukayed, M., Plewa, J., Cobre, L., Al Masjedi, O.S. and Al Marzouqi, K.M., 2021. From Desert Farm to Fork: Value Chain Development for Innovative Salicornia-Based Food Products in the United Arab Emirates. In *Future of Sustainable Agriculture in Saline Environments* (pp. 181-200). CRC Press.

Table 8

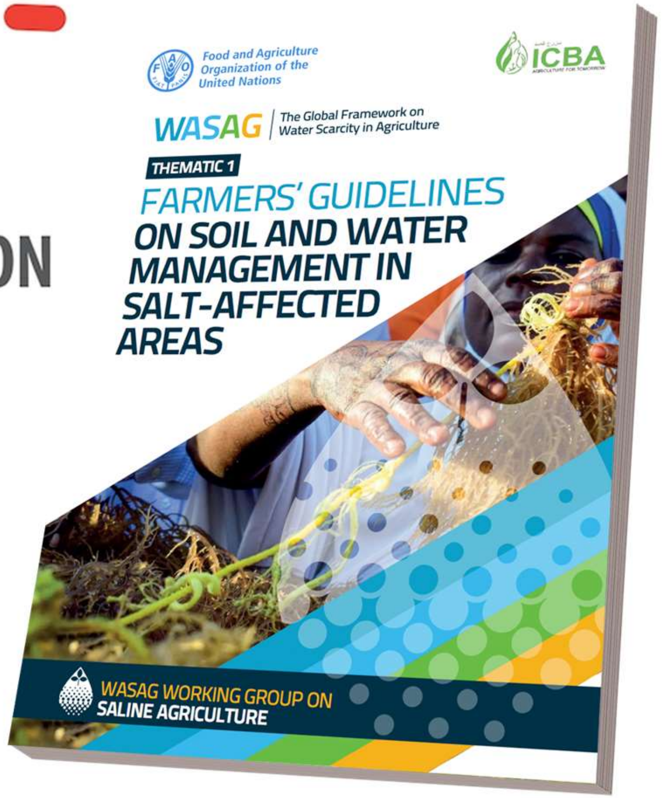
The salt added in the irrigation water for the three emitter-device types of bubbler (BUB), dripper (PCD) and subsurface tape (SUB) for each of the three waters aquabrine (AQ), reverse osmosis brine (RO) and groundwater (GW), in relation to the leachate losses of salt measured by the tension drainage flux-meters. The measured losses were calculated using the measured electrical conductivity in the leachate, and the modelled drainage. Modelled drainage (Al Tamimi et al., 2022) was used because of the high variability in the measured values (Fig. 5).

Water Source	Emitter-Type	Salt Added, kg m^{-2}	Measured Salt Loss, kg m^{-2}
Aquabrine	Bubbler	164.4	195.0
	Dripper	48.8	23.3
	Sub-surface	53.2	36.1
RO Brine	Bubbler	152.7	169.3
	Dripper	52.6	13.6
	Sub-surface	45.9	22.3
Groundwater	Bubbler	120.1	135.0
	Dripper	42.2	21.0
	Sub-surface	36.4	17.8
	Average	79.6	70.4

For example: a salt loading of 75 kg m^{-2}, would result in an annual salinity rise of 2.6 dS m^{-1} y^{-1} for an aquifer of saturated depth of 100 m.

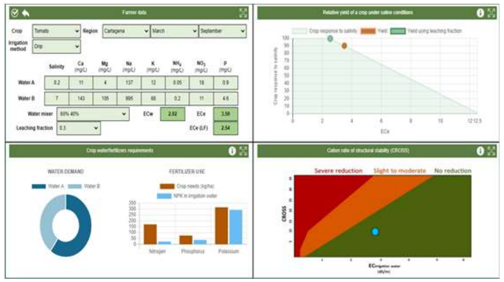
Source: Al-Tamimi, et al. 2023. Drainage, salt-leaching impacts, and the growth of Salicornia bigelovii irrigated with different saline waters. *Agricultural Water Management*, *289*, p.108512.

INNOVATION



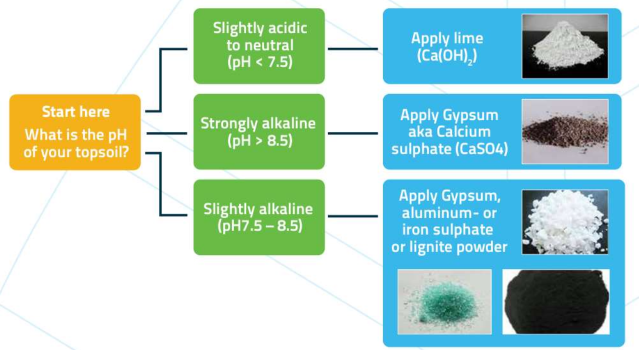
Source: https://www.fao.org/documents/card/en/c/cc4200en

- Selecting suitable irrigation systems
- Proper drainage
- Precision tools to support irrigation scheduling sustainable water management such as "Irriweb" and others
- Soil management (adding compost, green manure, mulching, gypsum etc.)



https://app.agri.gov.il/AnswerApp/
https://answerapp.agri.gov.il/

Figure 21. Decision tree of soil chemical amendments based on topsoil pH



SOCIAL

Acceptance

CONSUMERS

FARMERS

- What is the yield and profit?

- Why should I purchase a halophytic product or the produce from a salt-tolerant crop?
- What is the nutritional value?

CONSUMERS

- Why should I purchase a halophytic product or the produce from a salt-tolerant crop?

CONSUMERS

Source: Hammami, Z., Mahmoudi, H., Al Janaahi, A. and Singh, R.K., 2024. Evaluation of date palm fruits quality under different irrigation water salinity levels compared to the fruit available in the market. *Frontiers in Sustainable Food Systems*, *7*, p.1322350.

- What is the nutritional value and palatability

TABLE 1 Date palm material tested, names, general description and origin.

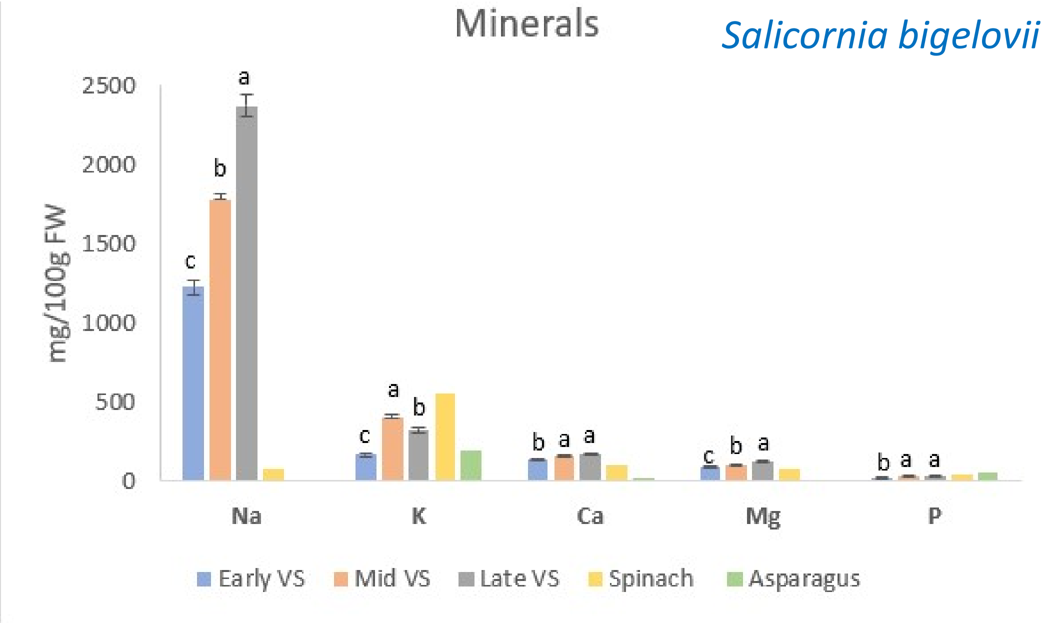
Date palm varieties	General description	Effect of salinity on fruits
FARD	This variety is considered to be commercial. It has an oval and elongated shape with a pinkish-yellow color. The tamer is brown, the dates are dark brown, and the flavor is both sweet and pungent. The flesh is medium-thick with white pulp that has low fiber and pigments. The seed is small, and the fruit weighs an average amount. It is a semi-dry variety that is best eaten when it is in the tamer stage. The yield potential for this fruit is approximately 70–90 kg/tree. For tolerant to salinity, 50 reduction in yield will be noted if the electrical conductivity of the water exceeds 9 dS m^{-1} ECw. The distribution in the UAE: All UAE	
LULU	This variety is commonly used for commercial purposes. The fruit is oval-shaped and has a bright yellow color. When ripe, the rutab has an amber color and the tamer has a brown color. The flesh is thick, with less fibrous texture, and has a sweet and soft flavor. The seeds are small. The fruit has a medium weight on average and can be eaten at the rutab and tamer stages. The approximate yield potential per tree is between 70–90 kilograms. Salinity tolerance: 50% yield reduction at 12 dS m – 1 ECw. The distribution in the UAE: All UAE	
KHALAS	This is a popular variety in Gulf countries. The fruit is bright yellow in color, and the rutab stage fruit has a deep amber to reddish-brown color, while the tamer stage is light brown. The flesh is tender, translucent, and thick with a white color and slight yellowness. It is free from fiber and pigments and has a melting texture. The flavor is rich and delicious, which makes it an excellent quality fruit that can be eaten at both the rutab and tamer stages. Approximative yield potential kg/tree: 40–60. Salinity tolerance: 50% yield reduction at 8 dS m^{-1} ECw. The distribution in the UAE: all UAE	

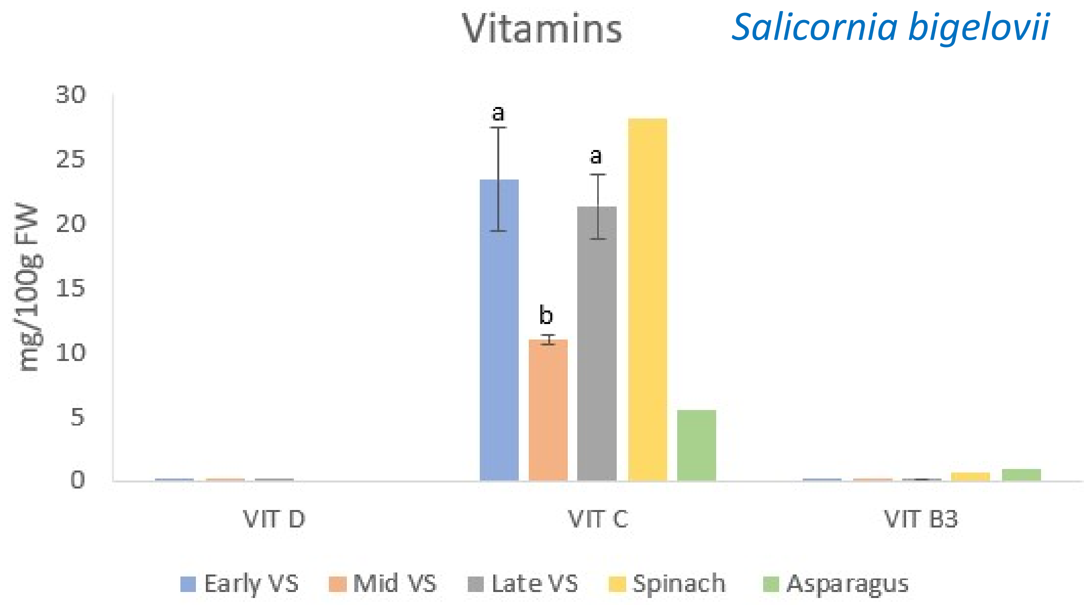
TABLE 2 Salinity and variety effect on fruit length (FL), fruit width (F. width), fruit weight (FW), fruit volume (FV), firmness (Fr), degree of sweetness (brix), seed flesh percentage (F/s), protein, sucrose, glucose, fructose, sugars, phenols, sodium (Na) and potassium (K).

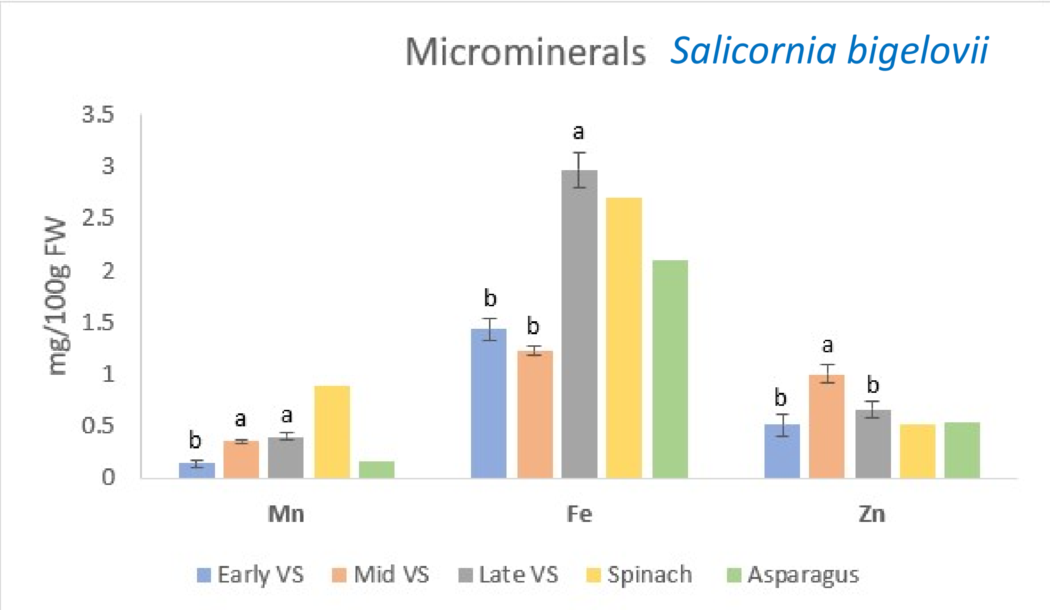
Source of variation		FL (mm)	F. width (mm)	FW (g)	FV (mL)	Fr (kgf/ cm²)	Brix (% Brix)	F/s (ratio)	Protein (g/100 g)	Sucrose (g/100 g)	Glucose (g/100 g)	Fructose (g/100 g)	Sugars (g/100 g)	Phenols (mg GAE/100 g)	Na (mg/ kg)	K (mg/ kg)
Salinity																
5 dS m⁻¹		32.29a	23.20a	7.67a	7.67a	6.18b	70.44a	9.57b	2.73a	–	32.26a	30.94a	68.08a	374.80a	283.30c	6622.16b
10 dS m⁻¹		28.74b	23.26a	6.73b	6.73b	4.98c	69.12a	12.19a	2.86ab	–	31.24b	30.78a	68.06a	372.44a	306.92b	7239.01ab
15 dS m⁻¹		32.11a	22.27b	6.20c	6.20c	7.47a	66.40b	11.76a	2.92b	–	31.95a	30.33a	66.89b	344.04a	339.82a	7488.93a
Variety																
AJWA-TUL-MADINAH		29.52c	22.82b	7.11b	7.11b	6.02b	66.36ab	14.52a	2.96a	–	33.55b	31.65c	65.20c	422.86a	265.20d	8294.92a
FARD		33.44b	20.10c	5.89c	5.89c	3.96c	73.33a	10.23b	2.43ab	–	34.16b	34.84d	69.01a	322.80b	332.59b	7045.84bc
KHALAS		38.00a	23.51b	7.22b	7.22b	6.03b	65.89ab	8.54c	3.13b	–	35.82a	32.99b	68.81a	388.56a	274.09c	7455.17ab
LULU		20.82d	25.31a	6.00c	6.00c	6.65b	71.58ab	11.44b	2.90b	–	34.16b	33.76b	67.91ab	294.06b	470.41a	6356.58c
SUKKARI		33.44b	22.81b	8.11a	8.11a	8.39a	65.44b	11.13b	2.79b	22.88	21.39c	20.17d	67.45b	390.53a	207.78e	6431.01c
ANOVA	DF															
Variety (V)	4	375.1***	31.63***	7.744***	7.744***	22.715***	136.2^{ns}	42.98***	0.6064***	–	311.94***	322.9***	20.965***	25560***	89968***	5750459***
Salinity (S)	2	60***	4.59^{ns}	8.267***	8.267***	23.147***	102.5^{ns}	29.72***	0.1409*	–	4.06*	1.5^{ns}	6.898*	4,395^{ns}	12084***	2985656*
V × S	8	55.1***	4.12*	1.794***	1.794***	15.875***	195.5**	10.68***	0.1234*	–	1.71*	1.3^{ns}	8.557***	3,461^{ns}	5359***	1,631,344^{ns}
Residuals	30	4.1	1.52	0.311	0.311	2.228	79.3	2.65	0.0441	–	0.79	0.9	2.152	2,652	75	800,881

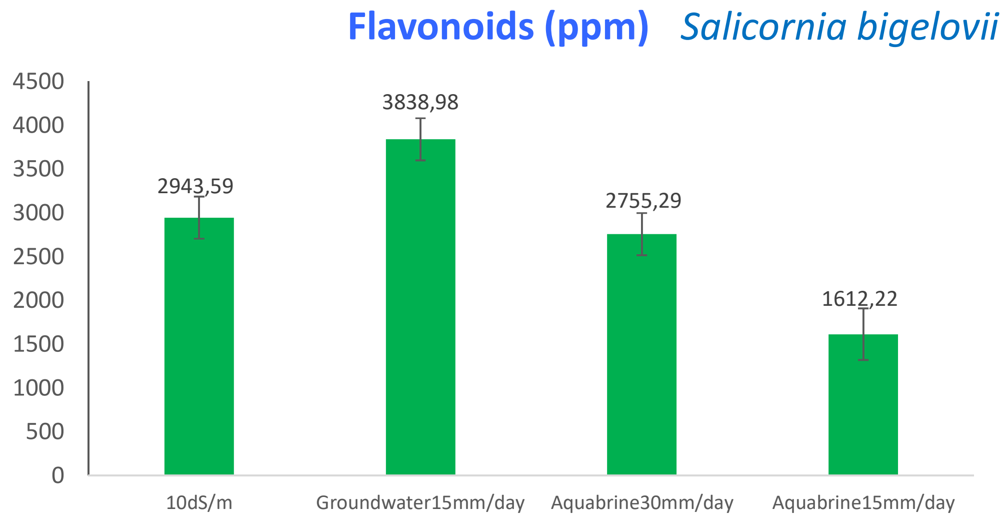
Different letters in the same line indicate significant differences at 0.05 by Duncan's LSD test. Asterisks indicate significance at *$p<0.05$, **$p<0.01$, and ***$p<0.001$, and ns indicates no significance ($p>0.05$). DF, degrees of freedom; kgf/cm², kilogram-force per square centimeter; GAE, gallic acid equivalents.

Source: Hammami, Z., Mahmoudi, H., Al Janaahi, A. and Singh, R.K., 2024. Evaluation of date palm fruits quality under different irrigation water salinity levels compared to the fruit available in the market. *Frontiers in Sustainable Food Systems*, *7*, p.1322350.


Minerals
Salicornia bigelovii
mg/100g FW
2500
2000
1500
1000
500
0
Na
K
Ca
Mg
P
Early VS
Mid VS
Late VS
Spinach
Asparagus

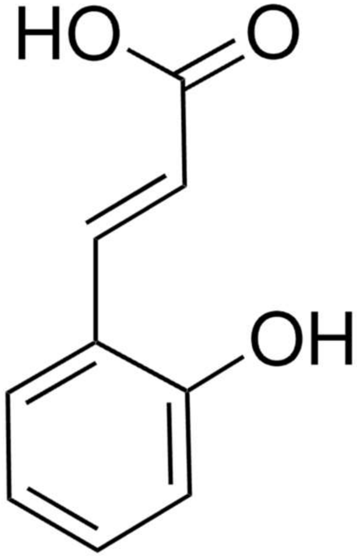

Vitamins
Salicornia bigelovii
mg/100g FW
30
25
20
15
10
5
0
VIT D
VIT C
VIT B3
Early VS
Mid VS
Late VS
Spinach
Asparagus


Microminerals
Salicornia bigelovii
mg/100g FW
3.5
3
2.5
2
1.5
1
0.5
0
Mn
Fe
Zn
Early VS
Mid VS
Late VS
Spinach
Asparagus


Flavonoids (ppm)
Salicornia bigelovii
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2943,59
3838,98
2755,29
1612,22
10dS/m
Groundwater15mm/day
Aquabrine30mm/day
Aquabrine15mm/day

High salt content in halophytes

a functional characteristic of vascular dysfunction [19]. Consistent with the findings of previous reports, our study showed that high salt intake induced vascular dysfunction; however, the SE did not induce vascular dysfunction, even when the salt concentration was the same as that in the high salt intake condition. This result suggested that some component in SE confers protective effects against high salt-induced vascular dysfunction. The composition analysis revealed that SE mainly contained 5-(hydroxymethyl)furfural, *p*-coumaric acid, *trans*-ferulic acid, and other unknown compounds. Among these, *trans*-ferulic acid is responsible for the vascular protective effect of SE. Although *p*-coumaric acid and *trans*-ferulic acid induced slight vasodilation by themselves (10.92% and 19.76% relaxation at 0.1 mmol/L, respectively), *trans*-ferulic acid significantly ameliorated the high salt-induced vascular dysfunction. Similarly, Suzuki et al. have reported that *trans*-ferulic acid restored endothelium-dependent vasodilation in the aortas of SHR, but showed no effect on aortas from normotensive Wistar Kyoto rats [15]. A previous report suggested that high salt consumption



Trans-ferulic acid

Source: Zhang, S., Wei, M., Cao, C., Ju, Y., Deng, Y., Ye, T., Xia, Z. and Chen, M., 2015. Effect and mechanism of *Salicornia bigelovii* Torr. plant salt on blood pressure in SD rats. *Food & function*, *6*(3), pp.920-926.

Source: Panth, N., Park, S.H., Kim, H.J., Kim, D.H. and Oak, M.H., 2016. Protective effect of Salicornia europaea extracts on high salt intake-induced vascular dysfunction and hypertension. *International Journal of Molecular Sciences*, *17*(7), p.1176.

Functional food and feed

ECONOMIC

- What is the yield and profit?

SALAD
Saline AgricuLture for ADaptation

FARMERS

- Proper salt-tolerant germplasm
- Landraces / local varieties salt-tolerant
- Molecular breeding programs to accelerate the development of salt-tolerant varieties
- Package of best management practices

Crops adapted to salt-affected areas

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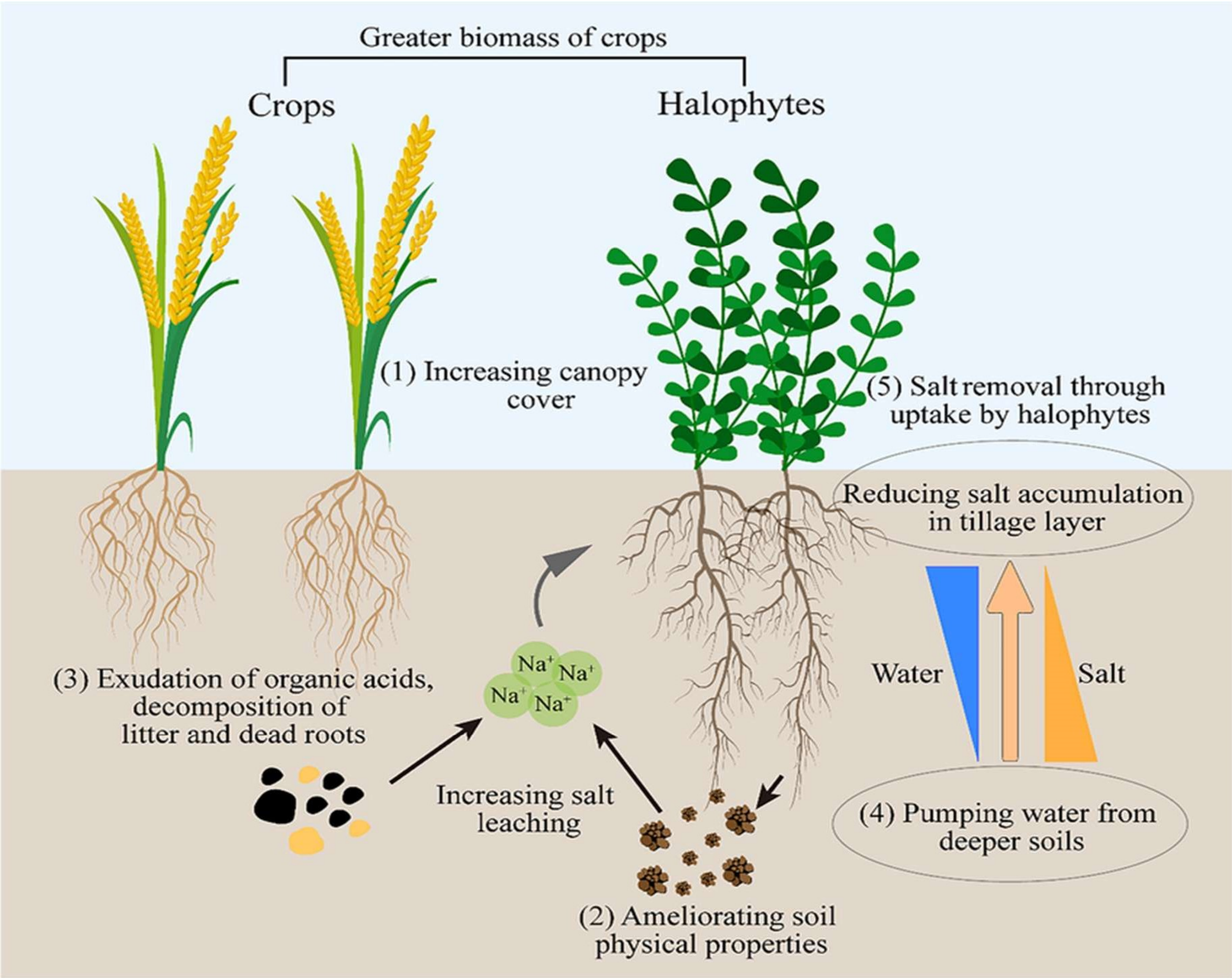
Saline AgricuLture for ADaptation



SA practices might enhance crop salt tolerance:

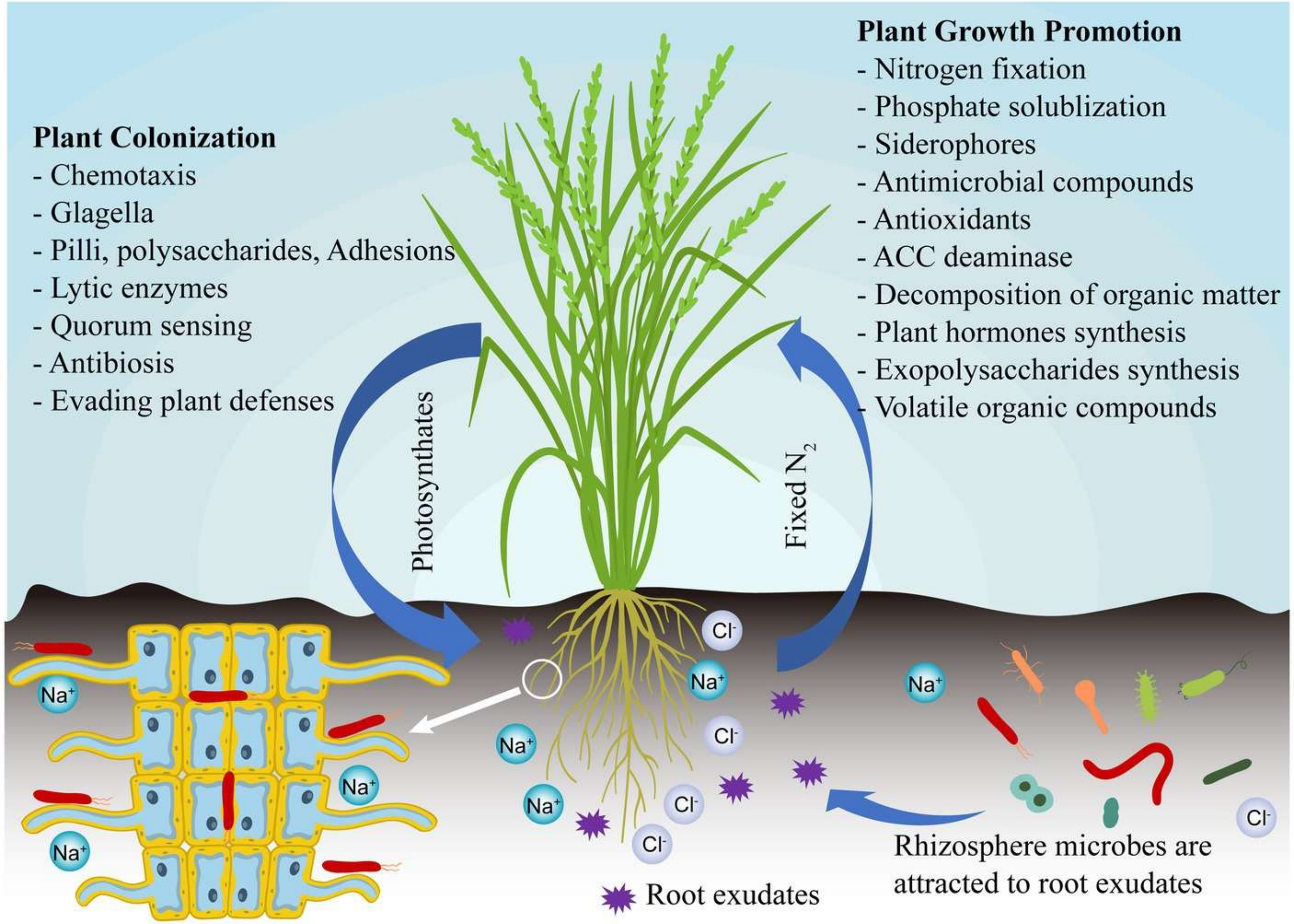
- Start with healthy seedlings (plants more sensitive in early stages)
- Mulching, compost, right fertilizers, rotations...
- Heat and salt tolerant crops (EC_e 2 –15 dS/m) for the dry season
  - Rice paddies into quinoa/wheat/amaranth fields?
  - Salt tolerant & high yielding varieties of vegetables: carrots, potatoes, cabbage, red beet, *atriplex spp*...
- Adapt crop cycles to seasonal fluctuations
- Possibility to produce off-season (profitably)



Crops/halophytes Intercropping

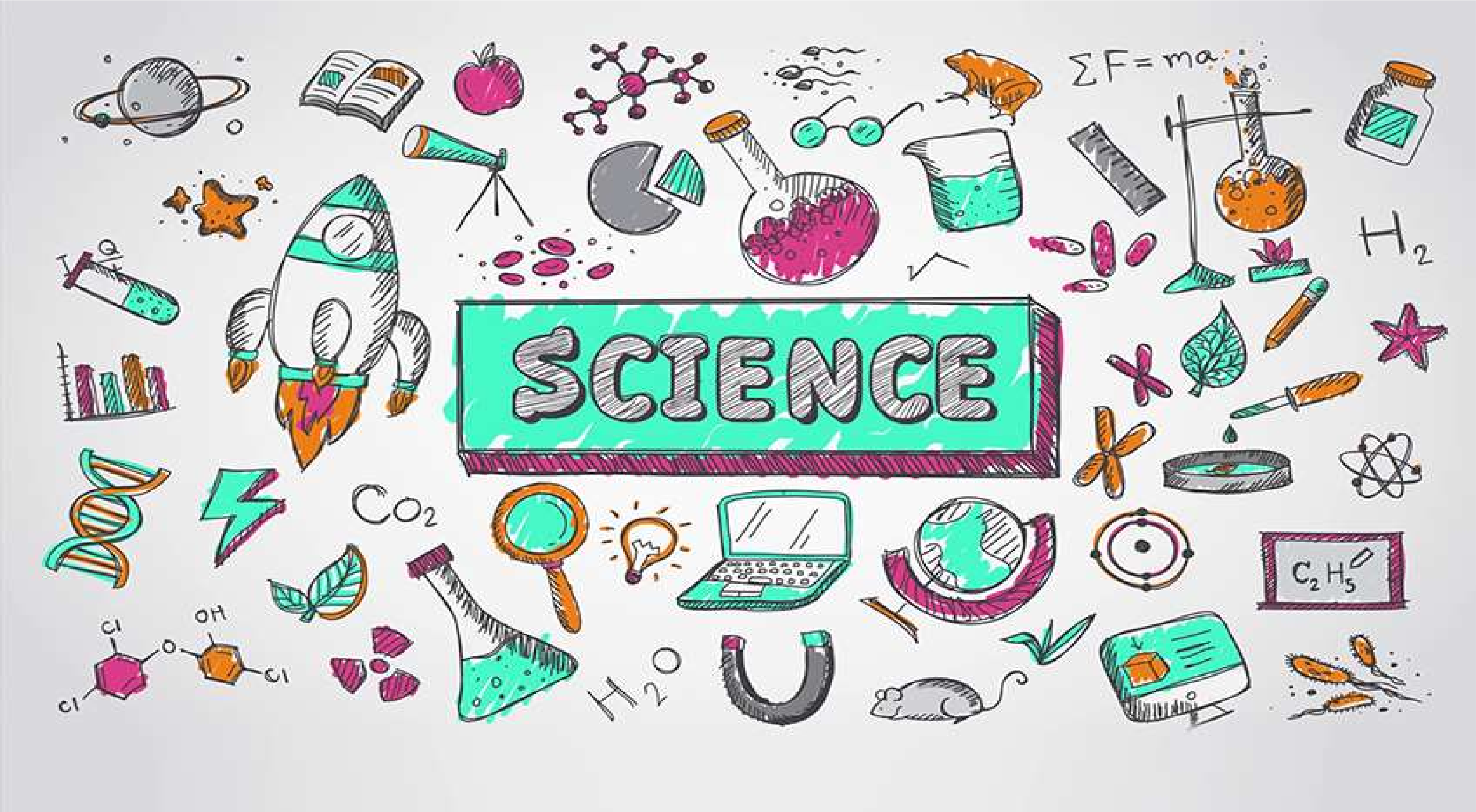
Source: Zhang, W.P., Surigaoge, S., Yang, H., Yu, R.P., Wu, J.P., Xing, Y., Chen, Y. and Li, L., 2024. Diversified cropping systems with complementary root growth strategies improve crop adaptation to and remediation of hostile soils. *Plant and Soil*, pp.1-24.

Salinity Tolerance Induced by Plant Growth Promoting Bacteria



Source: Peng, M., Jiang, Z., Zhou, F. and Wang, Z., 2023. From salty to thriving: plant growth promoting bacteria as nature's allies in overcoming salinity stress in plants. *Frontiers in Microbiology*, *14*, p.1169809.

Common Scientific language



Crop Salt Tolerance

Based on "threshold-slope model" (Maas and Hoffman, 1977)

Water

OR

Salinity

Soil

Soil analysis conducted in Uzbekistan

№	Date of analyses	Depth, cm	Dry Residue %	Hydrogen pH	Total bicarbonate HCO_3 %/mg/eq	Chlorine Cl %/mg/eq.	SO_4 Sulphate %/mg/eq	Calcium Ca %/mg/eq	Magnesium Mg %/mg/eq	Anions-cations, %/mg/eq	Na+K separately		Sum of components %	Type salinisation	Degree salinity
											mg/eq	%			
1	20.04.2023	0-30	0,94	6,9	0,03	0,24	0,12	0,05	0,03	10,1	15,1	0,34	0,9	Chlorine-Sulphate	Very strong
					0,6	7,0	2,5	2,5	2,5						
2	08.06.2023	0-30	6,2	6,9	0,488	3,124	0,048	0,08	0,06	97,0	87,5	2,1	5,9	Chlorine	Very strong
					8,0	88	1,0	4,0	5,5						
3	19.07.2023	0-30	1,59	5,6	0,152	0,266	0,6	0,125	0	22,5	16,25	0,37	1,516	Chlorine-Sulphate	Very strong
					2,5	7,5	12,5	6,25	0						

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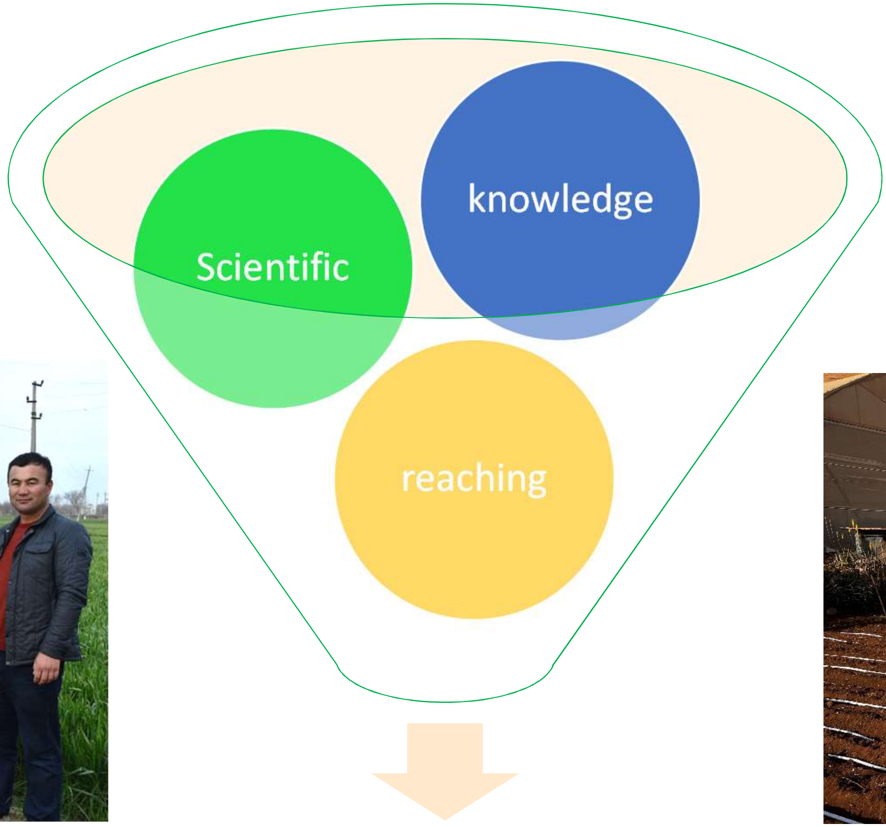

Training in Uzbekistan
18-22 March 2024

Training in Cabo Verde
2-4 April 2024

FARMERS

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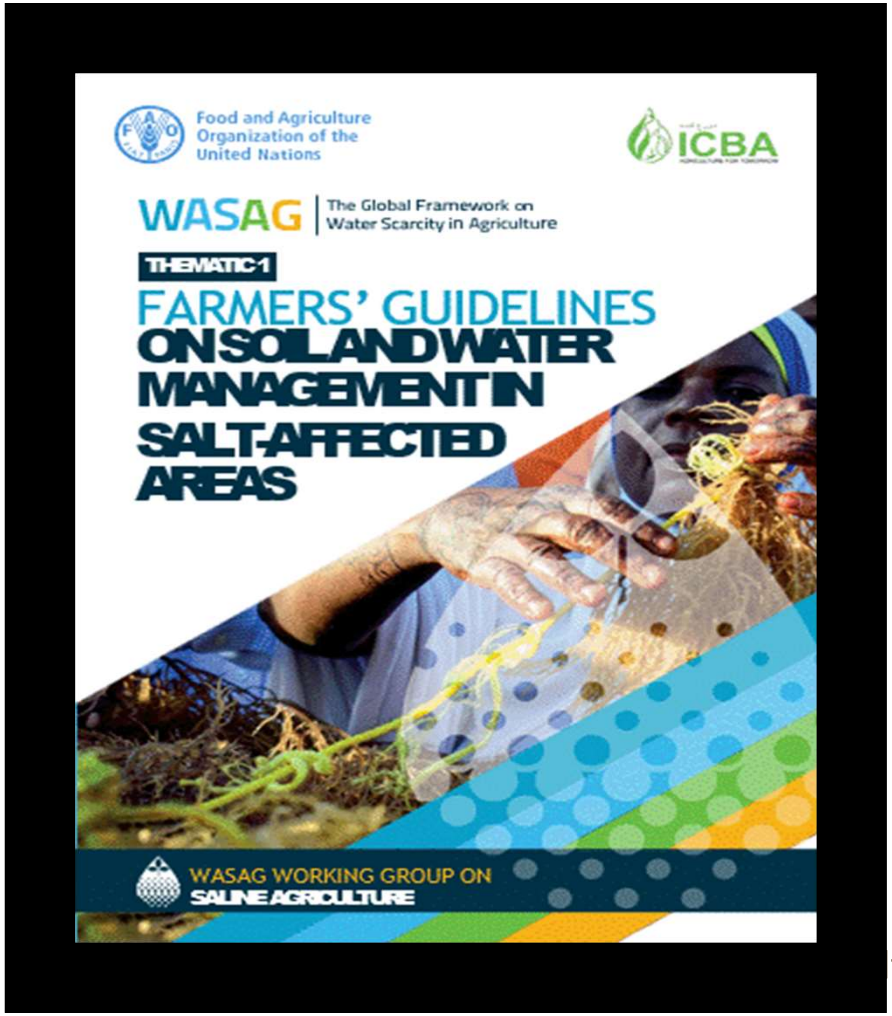
A resource for all…

- https://www.fao.org/wasag/working-groups/saline-agriculture/en/



… and the fruit of collaboration


Dr. Fatma Rekik


Dr. Bas Bruning


Dr. Francisco Pedrero Salcedo


Dr. Gergely Tóth


Dr. Ahmed Attia


Dr. Marco Arcieri


Dr. Tommaso Letterio


Dr. Alon Ben-Gal


Dr. Angelika Kaus

Scan and follow:

ICBA
ICID•CIID
The Salt Doctors
UNIVERSITY OF SUSSEX
CEBAS
CSIC
Interreg North Sea Region
CONSORZIO DI BONIFICA DI SECONDO GRADO PER IL CANALE EMILIANO ROMAGNOLO
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FAO/WASAG – Saline Agriculture Working group

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CONCLUSIONS

1) Saline Agriculture (SA) has great potential with salinity emerging as increasing threat in many areas

2) SA requires SMART Approach: Structured - Multidisciplinary – Achievable – Realistic – Targeted

3) SA is a package of: crops, BMP, environmental considerations

4) SA touches upon the whole value chain

5) Effective capacity building programs to support farmers on the ground on how to adapt to salinity and take the proper decisions when it comes to farming crops etc.

6) Scientific clarity

7) Work ethics, team values, strong and visionary leadership

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Thank you!

SALAD
Saline AgricuLture for ADaptation

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