Integration of Hydroponic Controlled Environment Agriculture with Brackish Water Resources

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Controlled Environment Agriculture Platform for Cultivation of Salt-Tolerant Crops with Integrated Saline Water Irrigation and Salinity Management.

USDA-NIFA-SAS. $10M (*USDA NIFA SAS CAP # 2023-69012-39038)*

Water (re)sources for agricultural irrigation

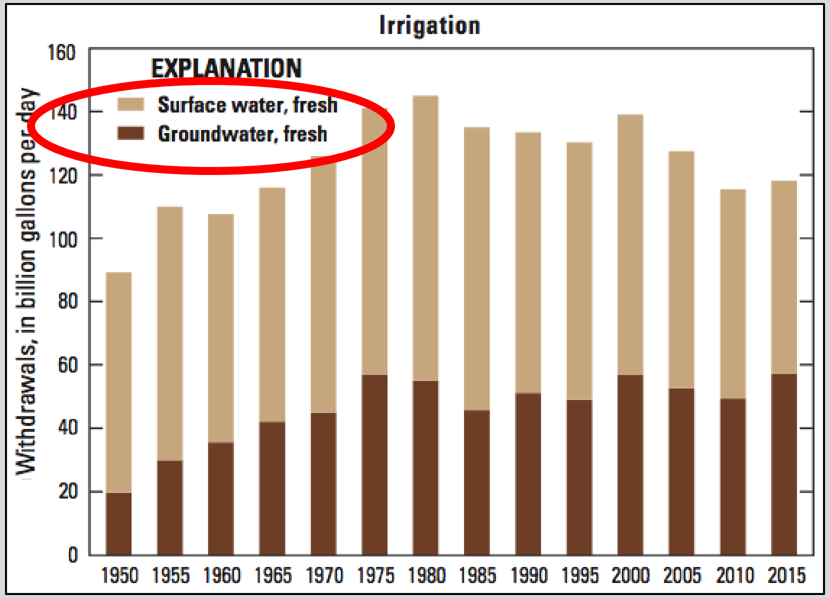
Conventional sources

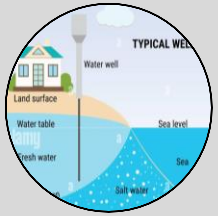
- Freshwater from surface and groundwaters
- Increasingly impacted by regional droughts

Non-conventional (marginal quality) sources

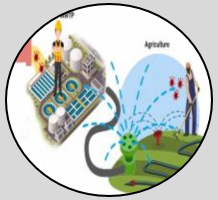
- **Saline and brackish surface and groundwaters**
    - Seawater impacted coastal surface and groundwaters
    - Inland groundwater
    - Overall salinity: problematic and beneficial salts
- Reclaimed municipal wastewater
    - Human pathogens, organic micropollutants (OMPs)
    - Attribute: *in situ* presence of plant nutrients (P & N)
- Urban stormwater (urban and peri-urban)
    - Heavy metals, hydrocarbons, pesticides, fertilizers

Irrigation water withdrawals in US, 1950-2015





Saline/brackish surface and groundwater



Reclaimed municipal wastewater

Urban stormwater

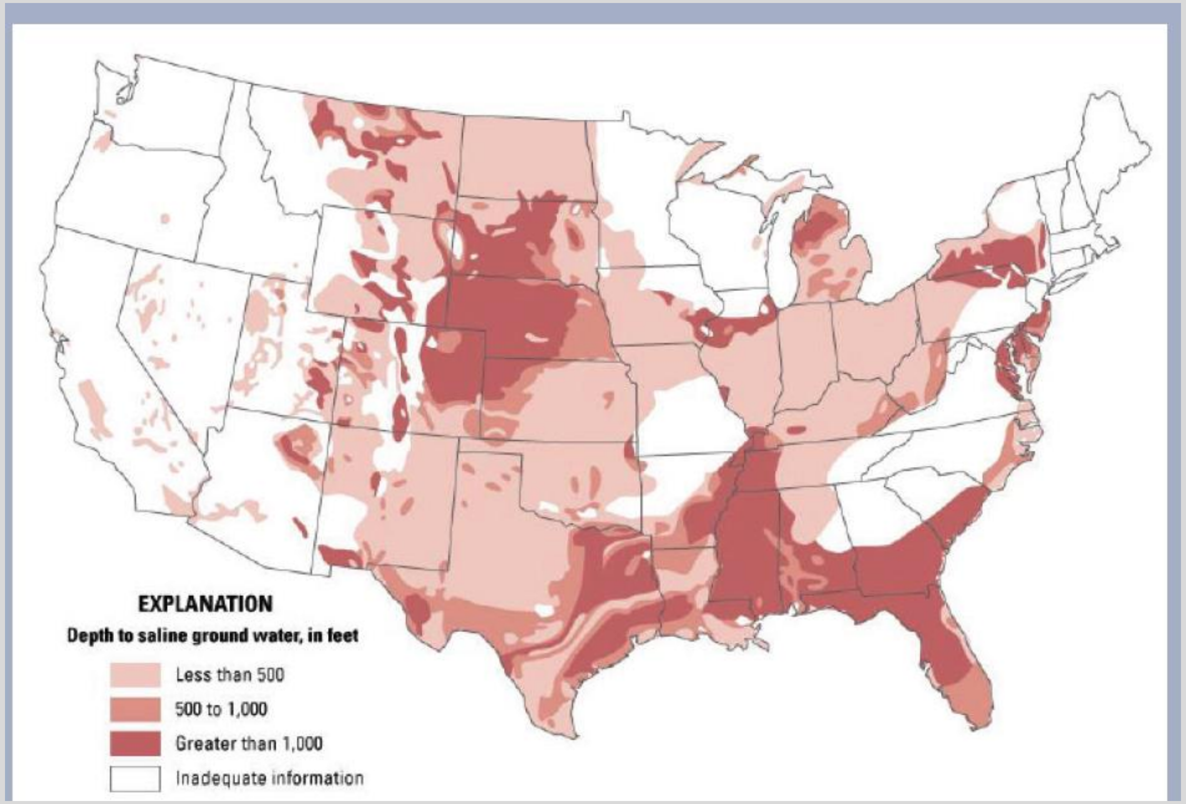
Water quality challenges – saline & brackish water

Abundance of saline and brackish waters

- Bays, estuaries, river deltas, coastal & inland groundwaters, geothermal brines, etc.

Salinity (TDS) and specific ions

- Brackish: 1,000 - 10,000 ppm TDS;
- Saline: 10,000 - 35,000 ppm (seawater)
- Problematical ions (e.g., Cl^-, $H_2BO_3^-$)
- Beneficial ions (e.g., K^+, Ca^{2+})



Requires

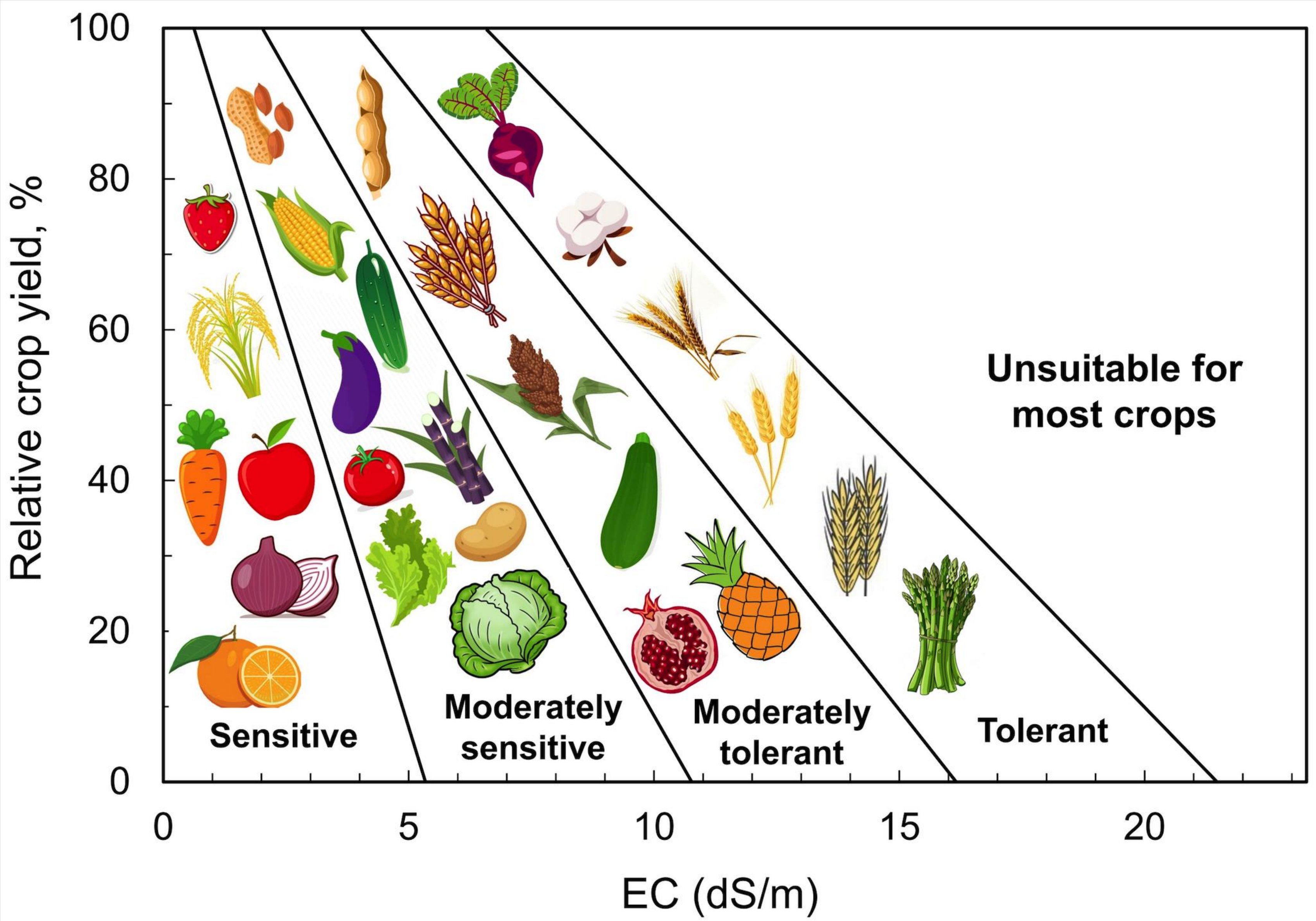
salt tolerant crops (halophytes) or
enhanced salt tolerance through breeding (e.g., mustard greens) or grafting (e.g., tomatoes)

Risk of soil salinization in conventional agriculture…

Controlled Environment Agriculture (CEA)

- Greenhouses or modular containers
- Controlled water, light, temperature, humidity, ventilation
- Deployment: Rural, peri-urban, and urban CEA
- Hydroponic (soilless) or soil based
- Nutrient solution (e.g., nutrient film technique (NFT))
- Leafy greens, tomatoes, cucumbers, melons, strawberries
- **Greater Control for Non-Conventional Water Sources**

Crop salinity tolerance



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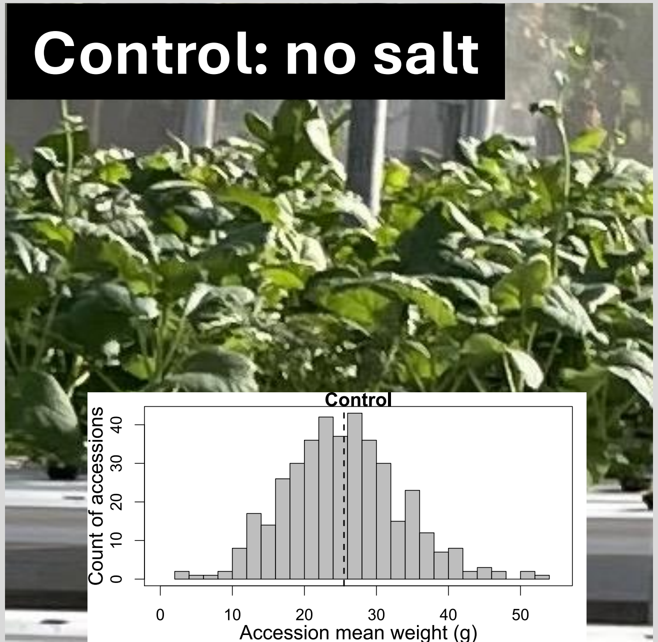
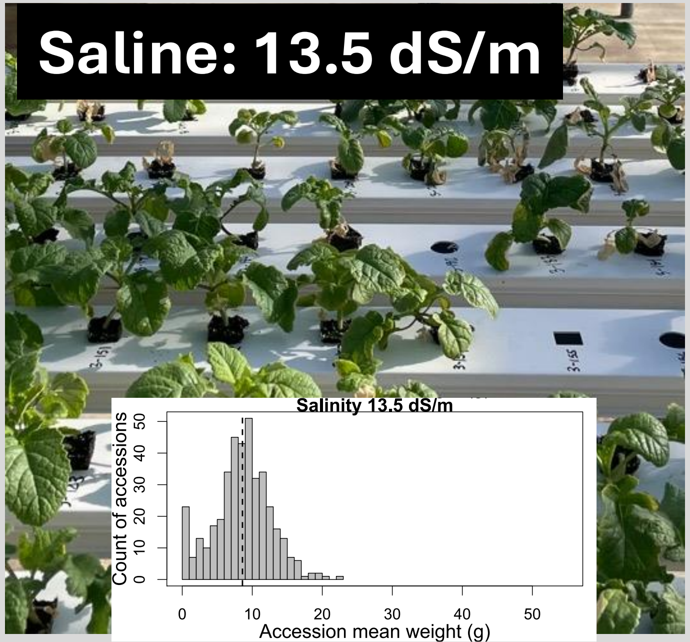
Pre-breeding & phenotyping: Mustard greens

Salinity screening in NFT system

464 USDA *B. juncea* (mustard greens) accessions

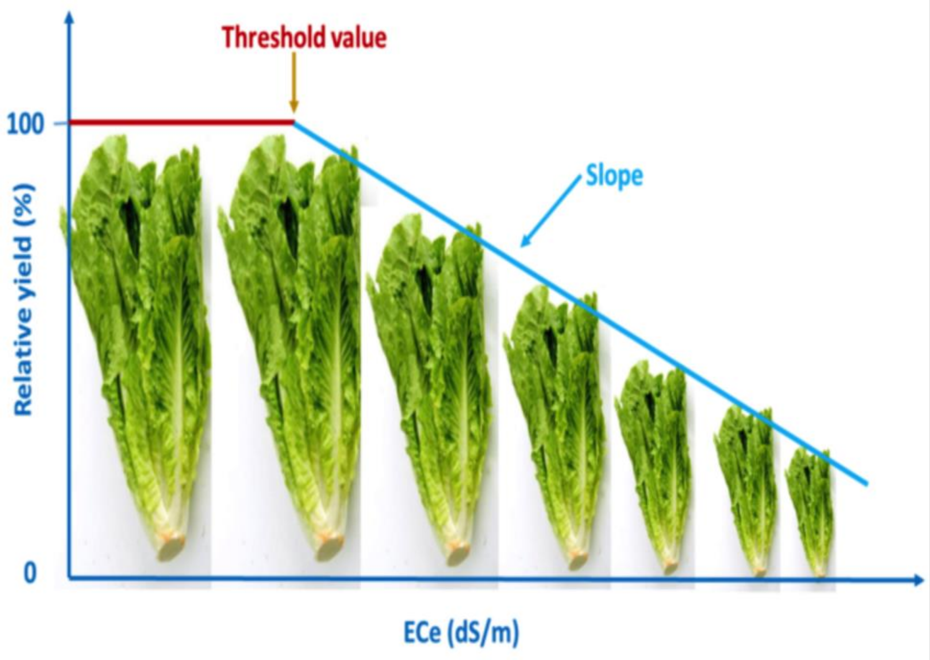
- Self-pollinate to S2 generation
  - Increase homozygosity
  - Generate seed for salinity screening
  - Plants phenotyped & sequenced





Partial desalting: A new paradigm for agricultural sector

Tailored-quality irrigation water for cultivation of salt-tolerant crops: match salinity with salt tolerance



University of California - Salinity Management

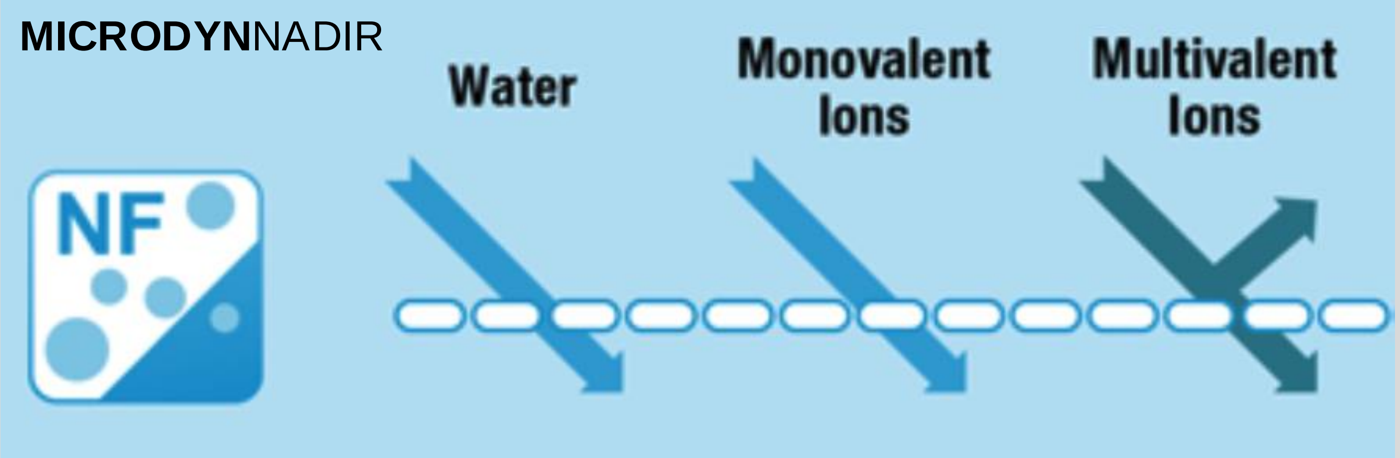
Potential membrane processes

- Nanofiltration (NF); Pressure-driven process;
  Ion removal based on ion size and/or charge
- Electrodialysis (ED); Electrically-driven process;
  Ion removal based on ion size and/or charge
- Range of NF and ED membranes and different-objective operating conditions

Besides overall salinity

- Ions detrimental to plant growth (e.g., Na^+, Cl^-, $H_2BO_3^-$)
- Ions beneficial to plant growth (e.g., K^+, Ca^{2+}, Mg^{2+})

Nanofiltration (NF)



Membrane separation based on ion size and charge

Ion *fractionation*, e.g., mono- vs. di-valent ions in product versus concentrate, respectively

Operational Parameters: Pressure, Flux (flow/area), Recovery (product/feed)

Membrane Properties: Water permeability, Pore Size or MWCO, Surface charge (- or +)

NF process simulation results
(Feed water: diluted seawater @ 10,000 ppm; feed pressure: 20 bar; 1-stage; 8 elements/pressure vessel)

Membrane	Recovery (R, %)	Permeate TDS (ppm)	SEC (kWh/m^3)
NF 270	90	9,000	0.7
NF200	85	5,500	0.8
NF90	70	1,500	1.0
BW30	55	250	1.3

Notes:
- SEC: Specific Energy Consumption
- Tradeoffs between Recovery and SEC
- High Recovery: *Lower Brine Management*
- Osmotic Pressure of Feed: 6.3 bar

Electrodialysis (ED)

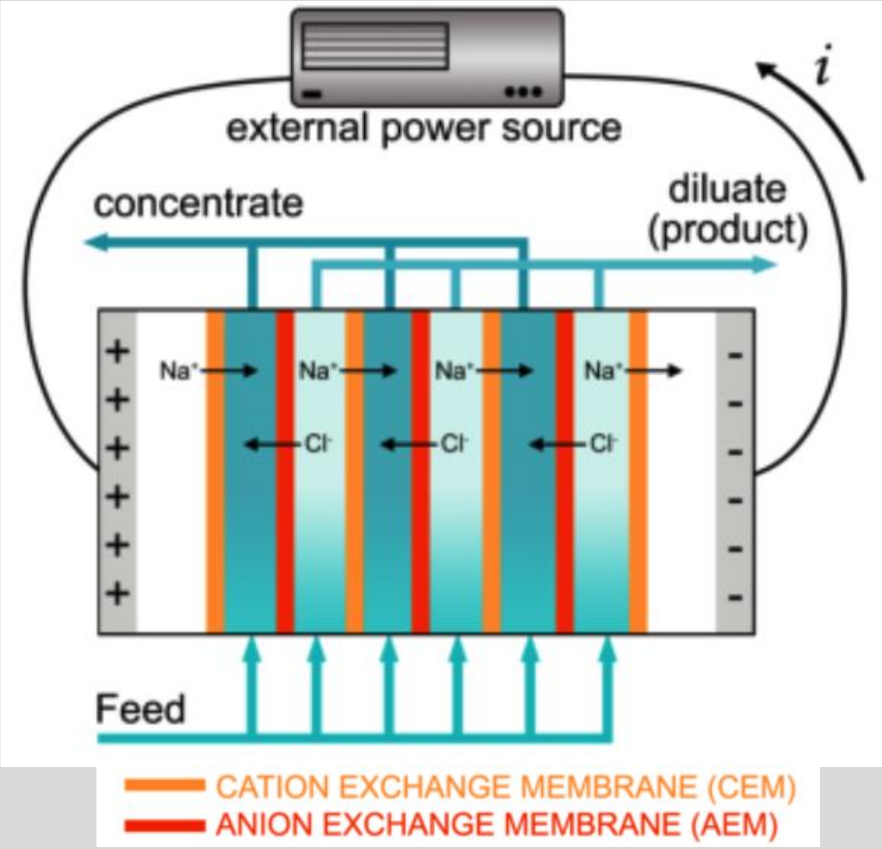
Separation based on cation- and anion-exchange membranes in electrical field between electrodes; alternating *dilute* and *concentrate* channels

Process Stack: Array of membrane pairs between electrodes

Process Stages: Series of stacks

Operating Parameters: Voltage, Current Density, Flow, Residence Time, Recovery, Cell Pairs, Membrane Area

Membrane Properties: Permeability, Resistance, Thickness



Tedesco et al., J. Membrane Science 510:370 (2016)

ED Process Simulation Results

(Feed water: diluted seawater; recovery fixed at 90 %)

ED Membranes	# of Stages	Feed TDS (ppm)	Permeate TDS (ppm)	SEC (kWh/m^3)
Conventional	3	10,000	5,000	2.25
Conventional	4	10,000	5,000	1.95
Conventional	4	10,000	2,500	3.38
Conventional	5	10,000	2,500	3.08
Conventional	2	5,000	2,500	1.01
Conventional	3	5,000	2,500	0.84
Thin	3	10,000	5,000	2.08
Thin	4	10,000	2,500	3.07

Notes:

- SEC values approach Seawater RO (2.5 kWh/m^3)
- Improved SEC with lower feed TDS
- Improved SEC with increasing # of stages but higher capital cost
- Thinner ED membranes lowered SEC

Comparison of NF, ED, and Blending (with RO)

Specific energy consumption (kWh/m³): NF outperformed ED; ED performance improved at lower feed TDS

RO with source blending: compares favorably with NF alone to achieve an energy consumption below 1 kWh/m³, *but much lower recovery for RO (more brine)*

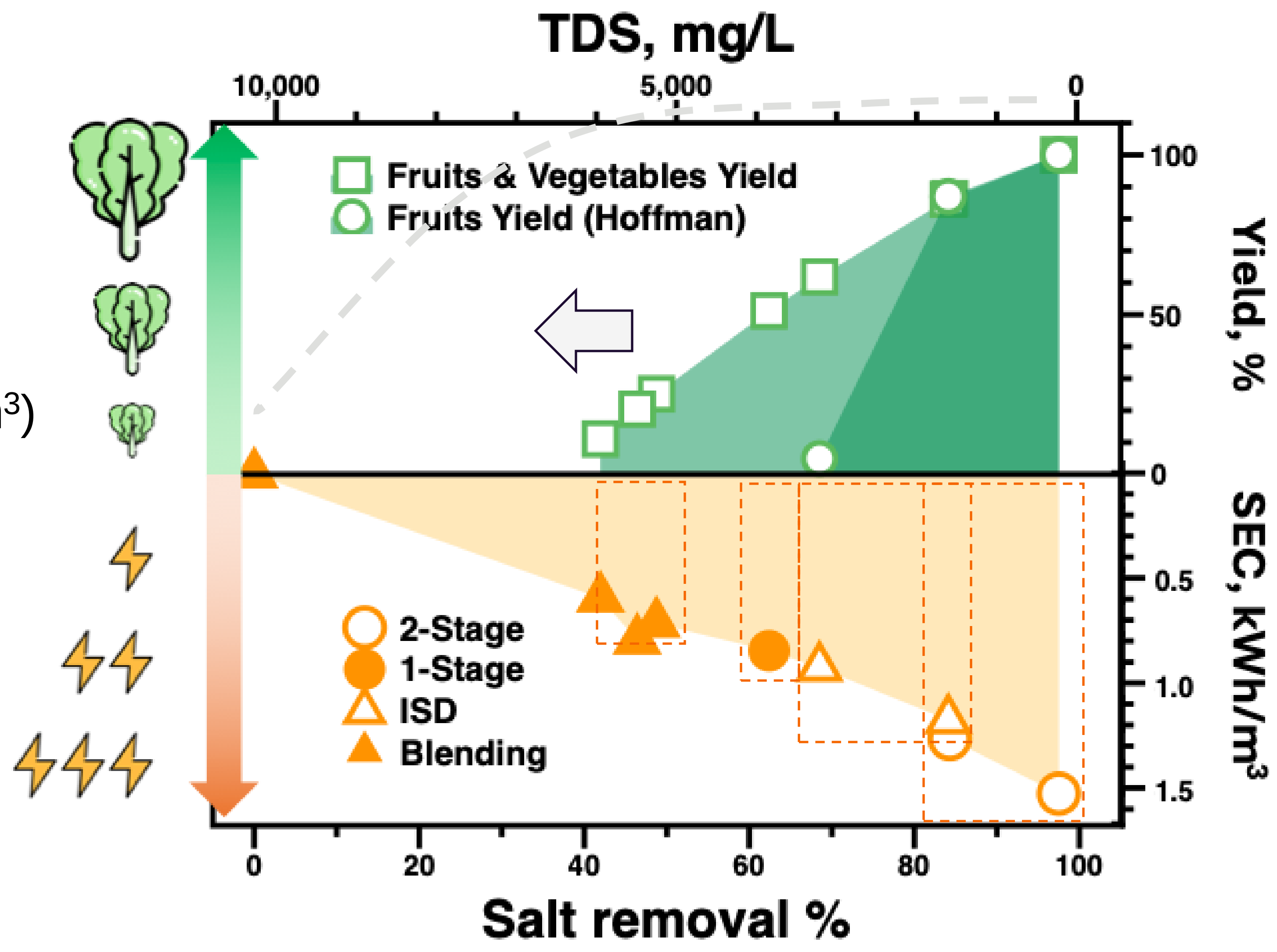
Both NF and ED with conventional CEX and AEX membranes: preferentially remove di-valent over mono-valent ions.

ED using monovalent ion selective (MIS) membranes: potential application - a product water containing beneficial ions such as Ca^{2+} and Mg^{2+} and a waste stream containing problem ions (e.g., Cl^- and Na^+)

Crop Yield, Water Quality (TDS) & SEC of different desalting scenarios

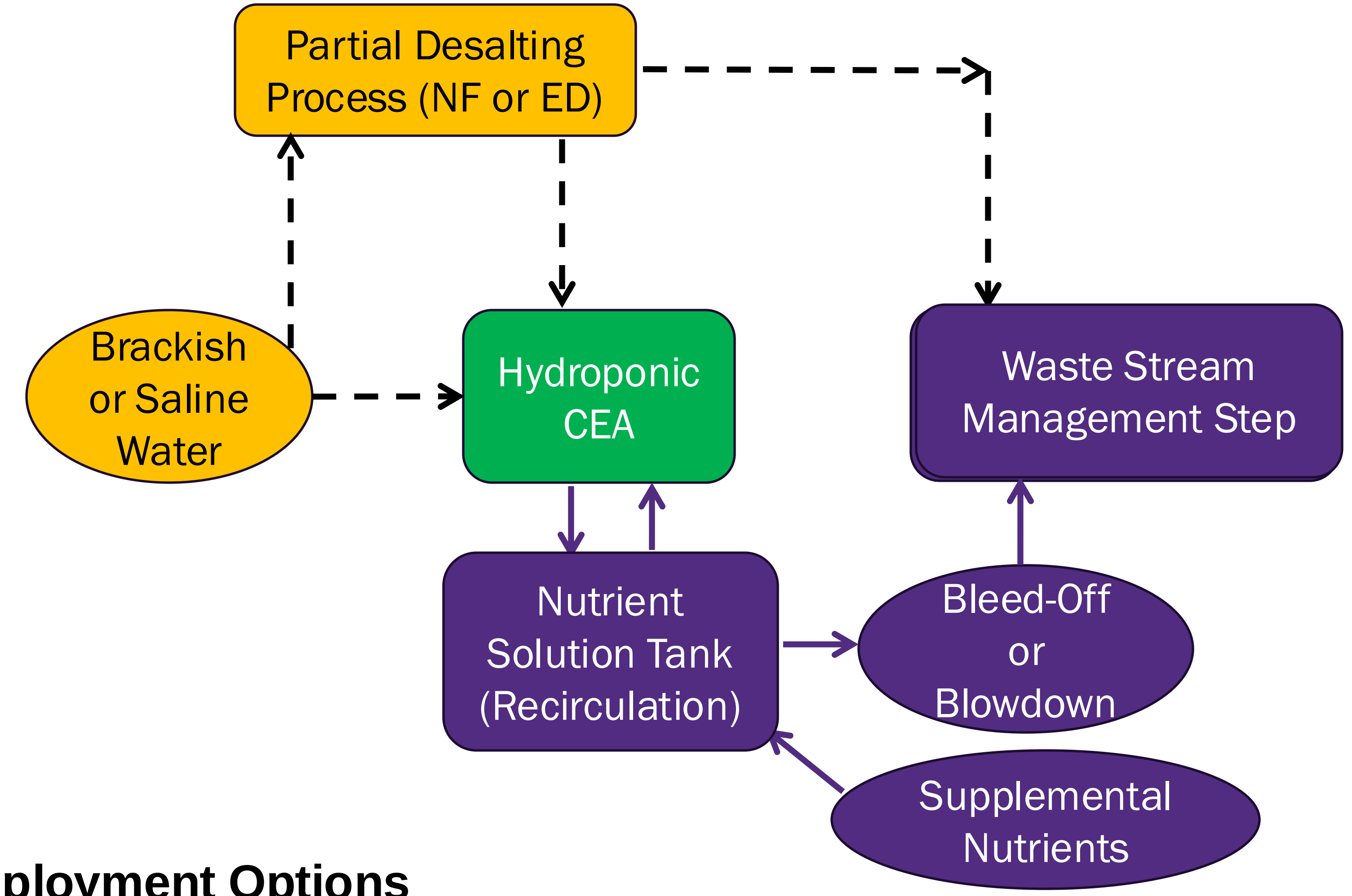
Tradeoff between
crop revenue ($/kg)
&
desalting costs ($/m³)

Identify salt-tolerant
cultivars
and/or
enhance salinity
tolerance



(Fruits and vegetables yield obtained from (Maas and Hoffman, 1977; Wallender and Tanji, 2011) and International Center for Bio-saline Agriculture (ICBA, 2004). SEC of each water treatment is from this study.)

Hydroponic CEA with Integrated Brackish/Saline Water



Brine Management
(Higher recovery: lower brine)

- Sewer discharge
- Deep well injection
- Evaporation pond
- Salt gradient solar pond

Deployment Options
Direct partial desalting (NF or ED)
Source Blending RO; Higher SEC

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