Reuse of Brackish and Produced Water for Crop Irrigation

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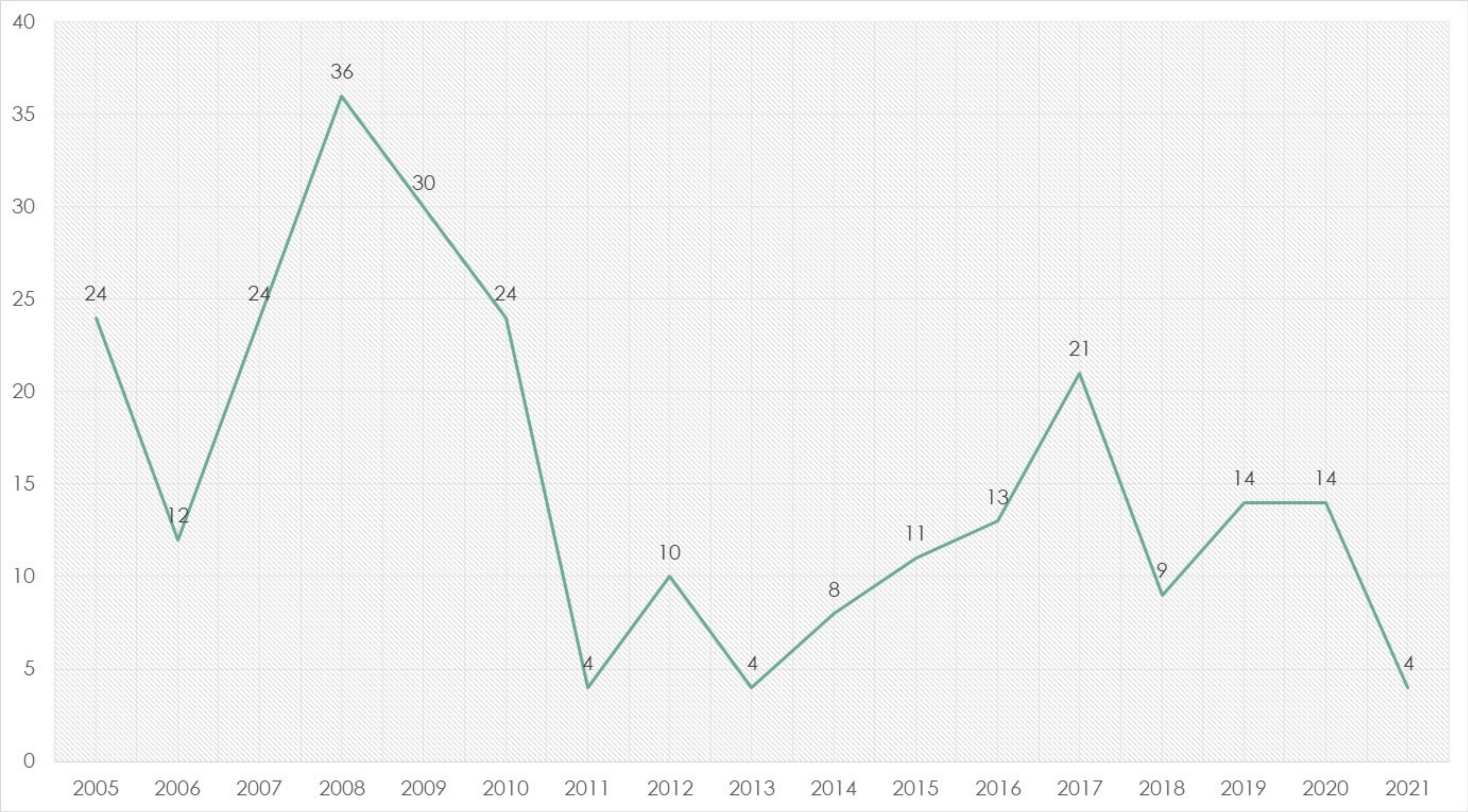
College of Agricultural, Consumer and Environmental Sciences
ACES Global Initiatives Program

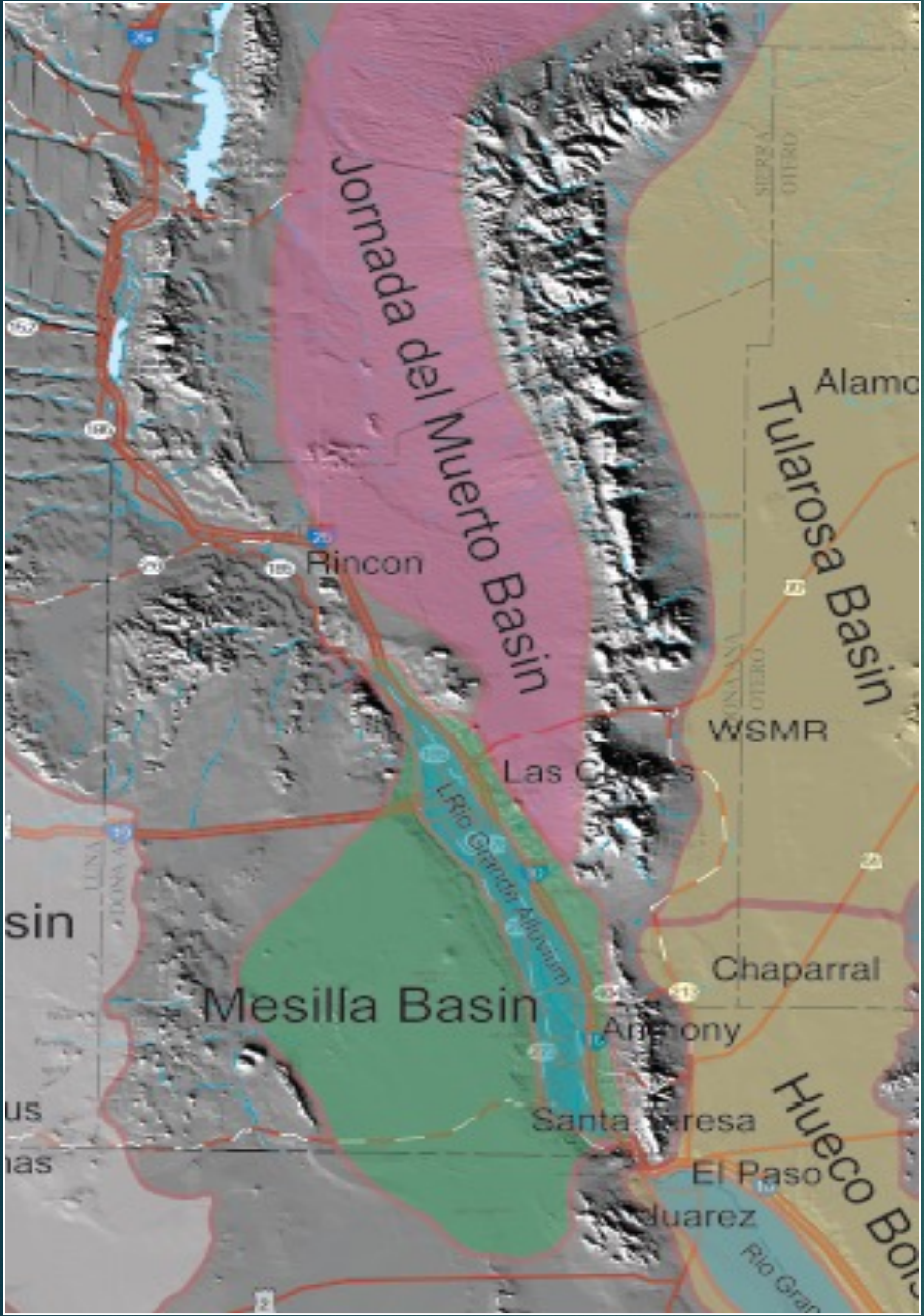
Elephant Butte Reservoir; T OR C, New Mexico

August 2016

100 acre-inch = 1.028 ha-m



* 36 acre-inches per acre is considered the full allotment. Less than adequate for most years



Total aquifer volume in New Mexico = 20 billion acre-feet

75% is > 2000 mg/L

Desalination?

NMWRRI Trans-boundary Aquifer Assessment (Hawley and Kennedy, 2004)

On going drought and water scarcity

- Is it sustainable to use brackish water for agriculture?
- Is desalination needed? RO?
- What to do with the generated concentrate?
- Reuse for Ag?

➢ Glycophytes: Chile peppers, Tomato Pecans

Ion concentrations of irrigation waters

Ion Concentrations						
dSm^{-1}	-----------	----------------	meq L^{-1}	---------------	----------------	
Salinity	Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	SAR
< 0.7	2.53	2.59	0.79	5.33	57.2	1.95
4	15.87	20.4	16.54	6.74	697.7	3.69
8	30.09	34.88	30.12	14.0	892.7	5.28
10	84.35	19.81	16.05	19.1	3024.3	19.92

- Tap water as control from the greenhouse (EC= 0.7 dS/m)
- Brackish groundwater (EC=4 dS/m) from BGNDRF
- RO concentrate (conc.) (EC= 8 dS/m) from BGNDRF
- BGW+ NaCl (EC=10 dS/m) irrigation

Chile

Table 3. Regression statistics for two response functions applied to yield responses of five chile pepper cultivars against soil salinity.

	Piecewise Linear Function				
	a (dS m^{-1})	*b* (dS m^{-1})$^{-1}$	r^2	*RSS*	*N*
AZ1904	1.19	0.044	0.88	0.21	32
NuMex Joe E. Parker	1.04	0.045	0.90	0.24	32
Numex Sandia Select	1.12	0.045	0.89	0.25	32
Paprika LB25	1.33	0.046	0.85	0.25	32
Paprika 3441	1.09	0.038	0.89	0.17	32
All cultivars	1.10	0.043	0.87	1.18	160
	Sigmoid non-linear function				
	c_{50} (dS m^{-1})	*p*	r^2	*RSS*	*N*
AZ1904	12.22	2.110	0.89	0.18	32
NuMex Joe E. Parker	11.61	1.633	0.91	0.19	32
Numex Sandia Select	10.75	1.262	0.89	0.32	32
Paprika LB25	12.01	1.761	0.87	0.16	32
Paprika 3441	13.55	1.537	0.90	0.12	32
All cultivars	12.11	1.618	0.88	0.94	160

a: salinity (EC_e) threshold; *b*: slope; c_{50}: EC_e at which yield is reduced by 50%; *p*: regression constant for sigmoid function.

horticulturae

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Article

Water Use and Yield Responses of Chile Pepper Cultivars Irrigated with Brackish Groundwater and Reverse Osmosis Concentrate

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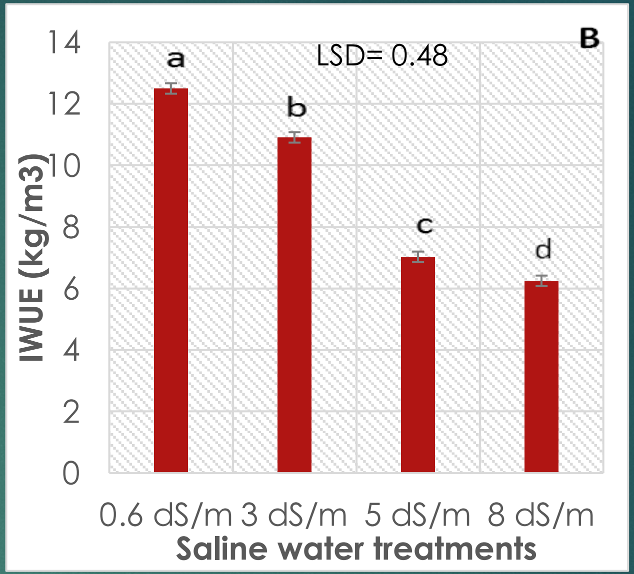

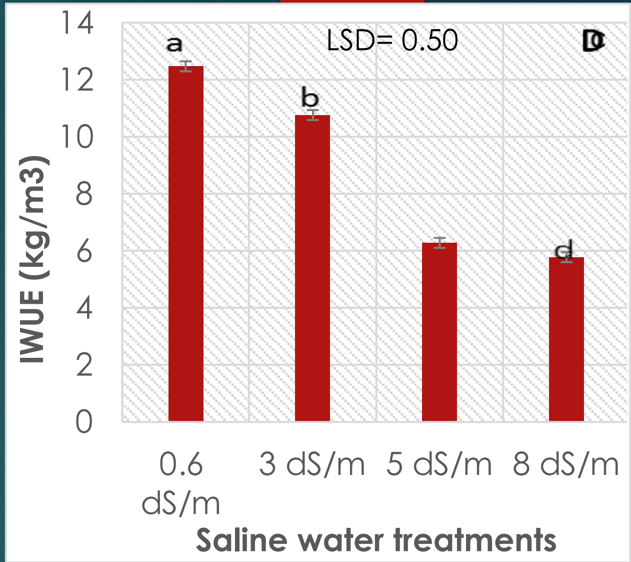

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ELSEVIER

Irrigation water salinity influences at various growth stages of *Capsicum annuum*

CrossMark

Gurjinder S. Baath [a], Manoj K. Shukla [a,*], Paul W. Bosland [a], Robert L. Steiner [b], Stephanie J. Walker [c]

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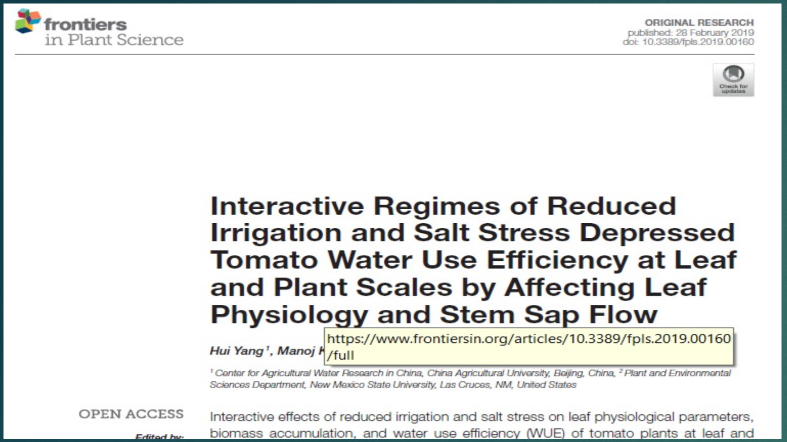
ABSTRACT

Availability of fresh surface water for irrigation is declining in southern New Mexico, and saline ground-water is increasingly used for irrigation. This study evaluates the effects of irrigation using saline water

Tomato


frontiers in Plant Science

ORIGINAL RESEARCH
published: 28 February 2019
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Interactive Regimes of Reduced Irrigation and Salt Stress Depressed Tomato Water Use Efficiency at Leaf and Plant Scales by Affecting Leaf Physiology and Stem Sap Flow

Hui Yang[1], Manoj K

https://www.frontiersin.org/articles/10.3389/fpls.2019.00160/full

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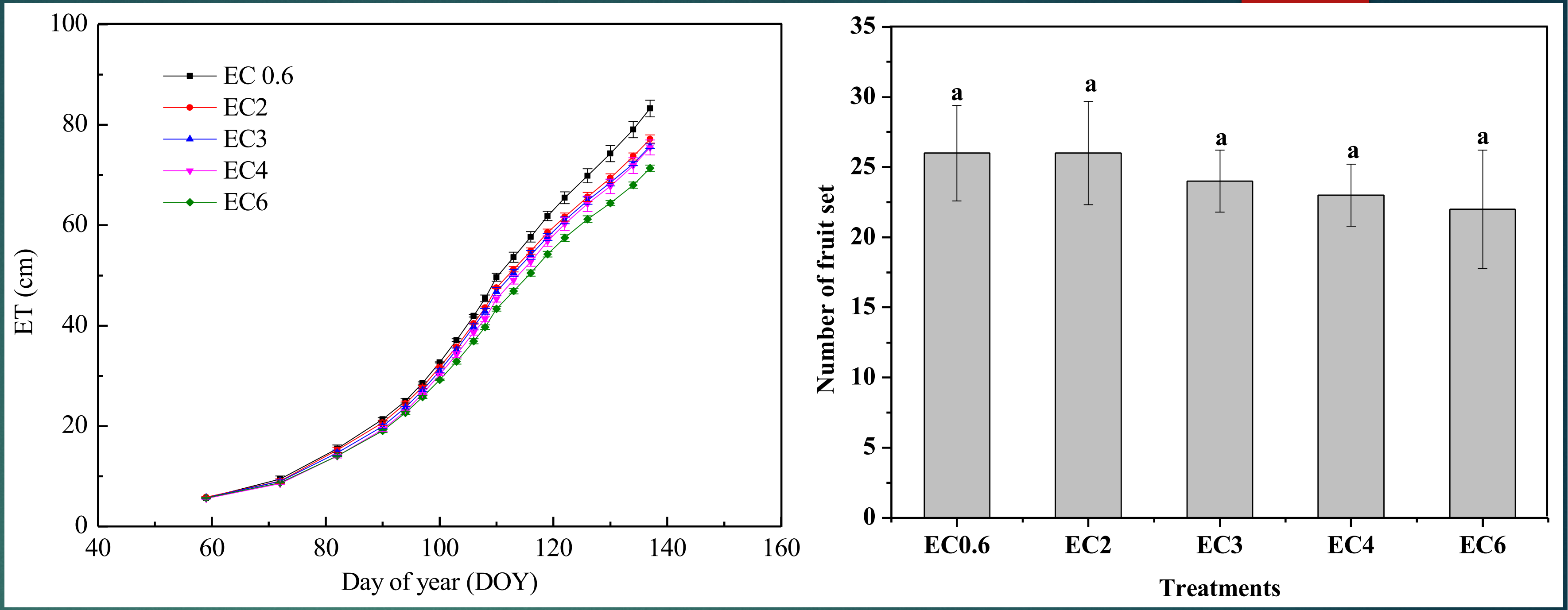
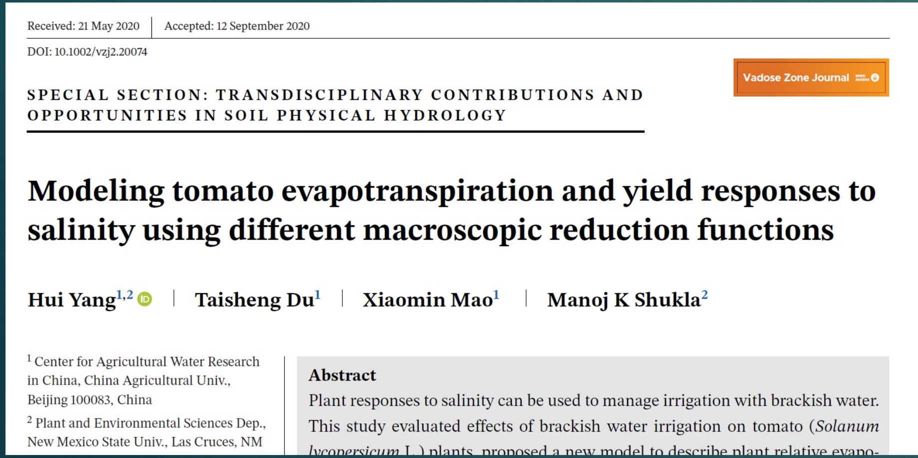
OPEN ACCESS

Interactive effects of reduced irrigation and salt stress on leaf physiological parameters, biomass accumulation, and water use efficiency (WUE) of tomato plants at leaf and

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Vadose Zone Journal

SPECIAL SECTION: TRANSDISCIPLINARY CONTRIBUTIONS AND OPPORTUNITIES IN SOIL PHYSICAL HYDROLOGY

Modeling tomato evapotranspiration and yield responses to salinity using different macroscopic reduction functions

Hui Yang[1,2] | Taisheng Du[1] | Xiaomin Mao[1] | Manoj K Shukla[2]

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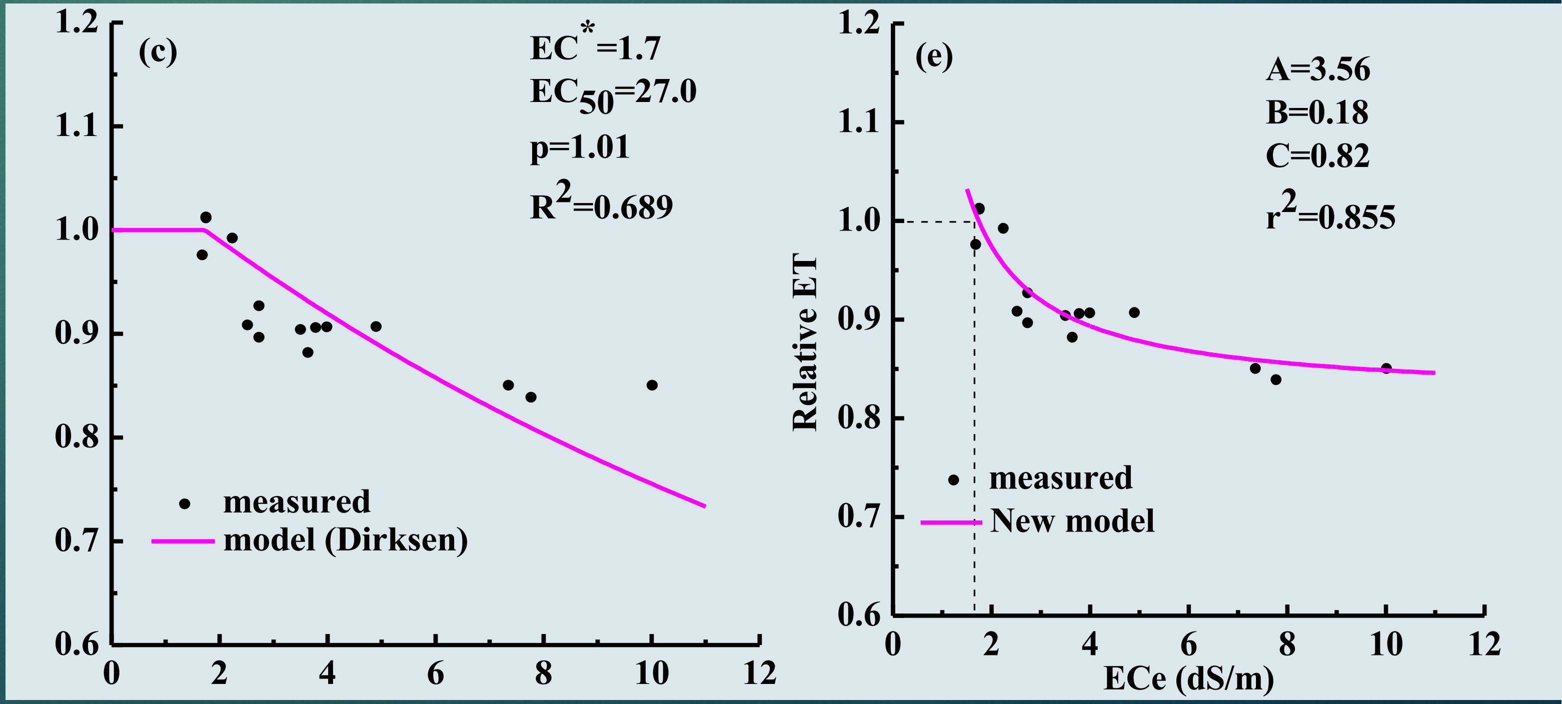
Abstract

Plant responses to salinity can be used to manage irrigation with brackish water. This study evaluated effects of brackish water irrigation on tomato (*Solanum lycopersicum* L.) plants, proposed a new model to describe plant relative evapo-



Pecan

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Irrigation with RO concentrate and brackish groundwater impacts pecan tree growth and physiology

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Leaves burn

New leaves

HortScience 48(12):1548–1555. 2013.

Drip-irrigated Pecan Seedlings Response to Irrigation Water Salinity

Sanjit K. Deb[1], Parmodh Sharma, Manoj K. Shukla, and Theodore W. Sammis
Department of Plant and Environmental Sciences, New Mexico State University, MSC 3Q, P.O. Box 30003, Las Cruces, NM 88003

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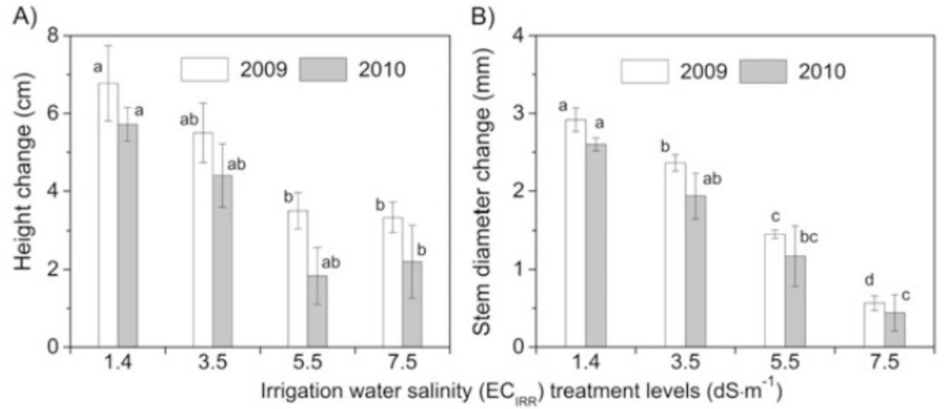

Fig. 5. Annual changes in (**A**) heights and (**B**) stem diameters of pecan (*Carya illinoinensis*) seedlings of rootstock 'Riverside' grafted with 'Western Schley' scions grown in the pot-in-pot system under the irrigation water salinity (electrical conductivity, EC_{IRR}) treatment levels of 1.4 (control), 3.5, 5.5 and 7.5 $dS \cdot m^{-1}$. Error bars are SEMs. Data for each treatment represent average differences between values measured on 2 Mar. and 5 Oct. during 2009 and 22 Mar. and 9 Oct. during 2010. For each year, mean values followed by the same letter or letters are not significantly different ($P \leq 0.05$) based on Tukey's test.

Halophyte and Marginal halophytes

Hordeum vulgare
(Barley)

×Triticosecale
(Triticale)

Atriplex canescens
(Fourwing Saltbush)

Distichlis stricta
(Inland Saltgrass)

Lepidium alyssoides
(Mesa Pepperwort)

Panicum virgatum
(Switchgrass)

Alfalfa (*Medicago sativa*)

Quinoa
(*Chenopodium quinoa*)

Research in BGNDRF

Atriplex canescens and a. lentiformis

Marginal Halophytes

agronomy

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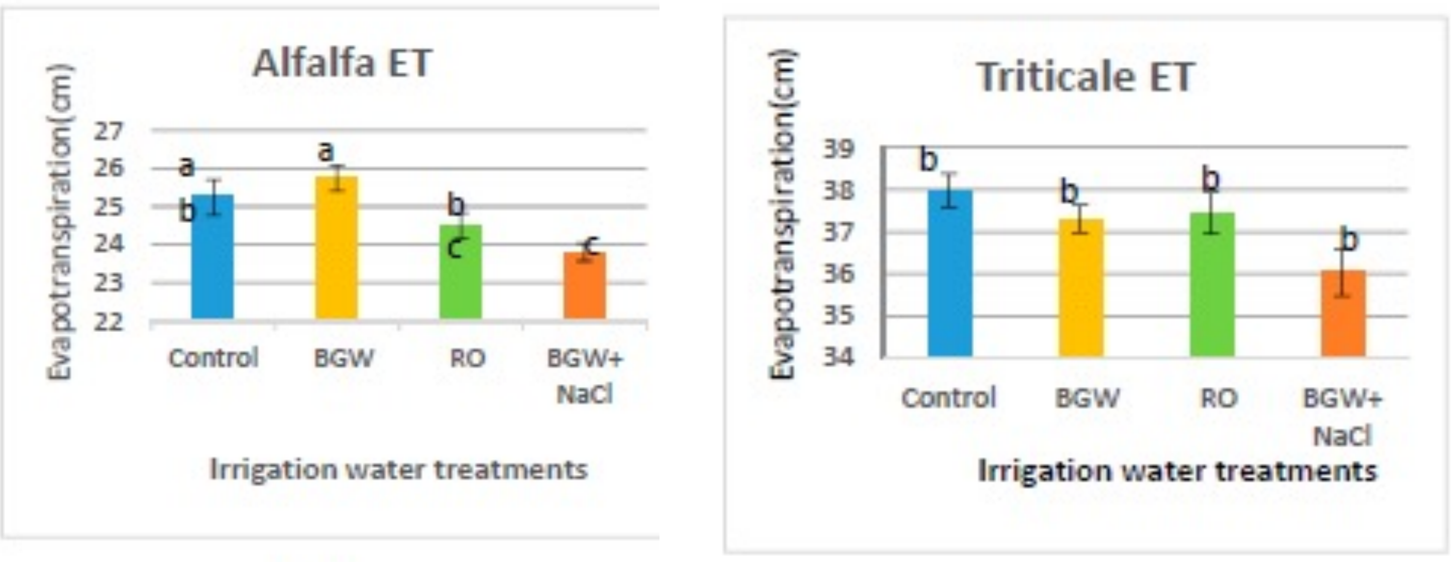
Article

Growth, Evapotranspiration, and Ion Uptake Characteristics of Alfalfa and Triticale Irrigated with Brackish Groundwater and Desalination Concentrate

V. Kankarla [1,*], M. K. Shukla [1], D. VanLeeuwen [2], B.J. Schutte [3] and G.A. Picchioni [1]



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agronomy

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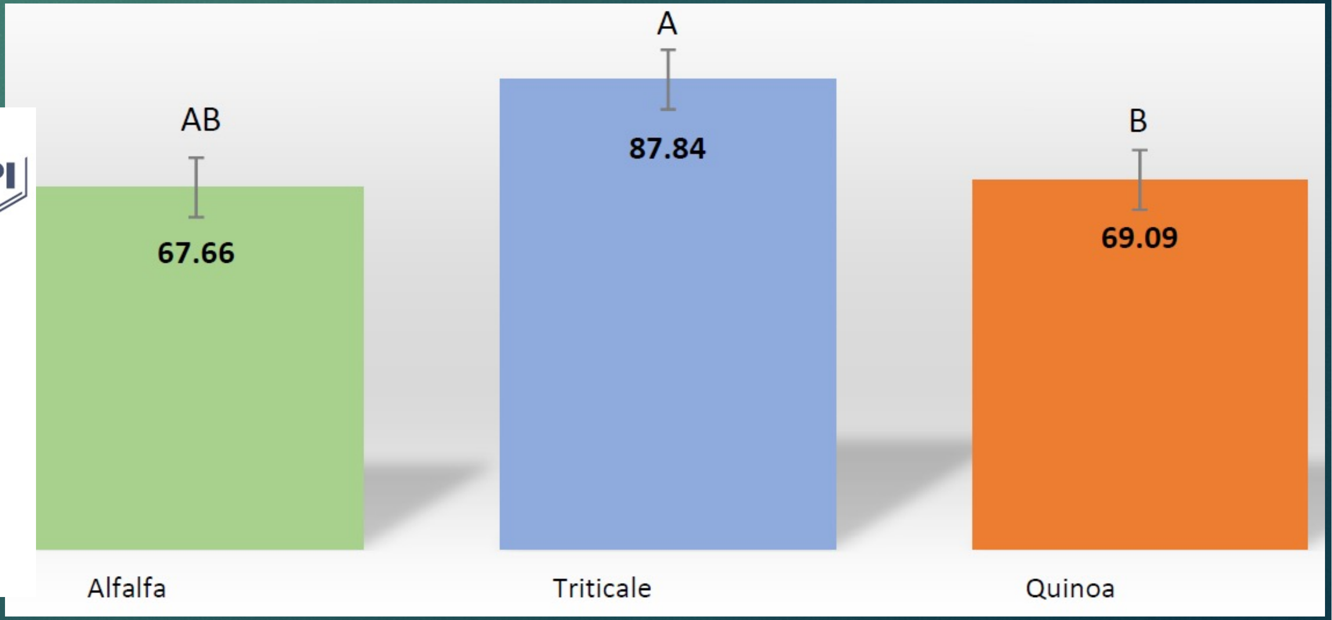
Article

Germination and Emergence Responses of Alfalfa, Triticale and Quinoa Irrigated with Brackish Groundwater and Desalination Concentrate

Vanaja Kankarla [1,*], Manoj K. Shukla [1], Geno A. Picchioni [1], Dawn VanLeeuwen [2] and Brian J. Schutte [3]



Halophytes

Total evapotranspiration readings for the six halophyte species at the conclusion of each of the two seasons for the clay soil. Different letters down a column correspond to a statistically significant difference in total irrigation, deep percolation (DP), and evapotranspiration (ET) means within a species at $\alpha = 0.05$. Measurements were not compared across species.

		Clay 1			Clay 2		
Species	Treatment	IR (cm) ± SE	DP (cm) ± SE	ET (cm) ± SE	IR (cm) ± SE	DP (cm) ± SE	ET (cm) ± SE
A. canescens	EC 0.9	80.90 ± 0.00 a	36.04 ± 1.85 a	44.86 ± 1.85 a	84.94 ± 0.00 a	46.32 ± 1.21 a	38.62 ± 1.21 a
	EC 4.1	80.90 ± 0.00 a	39.31 ± 1.03 a	41.59 ± 1.03 a	84.94 ± 0.00 a	46.23 ± 0.62 a	38.71 ± 0.62 a
	EC 8.0	80.90 ± 0.00 a	36.67 ± 1.35 a	44.23 ± 1.35 a	84.94 ± 0.00 a	43.12 ± 1.59 a	41.82 ± 1.59 a
H. vulgare	EC 0.9	80.90 ± 0.00 a	29.15 ± 0.46 a	51.75 ± 0.46 a	84.94 ± 0.00 a	29.09 ± 3.71 b	55.85 ± 3.71 a
	EC 4.1	80.90 ± 0.00 a	26.06 ± 1.71 a	54.84 ± 1.71 a	84.94 ± 0.00 a	37.25 ± 2.71 ab	47.69 ± 2.71 ab
	EC 8.0	80.90 ± 0.00 a	29.78 ± 1.47 a	51.12 ± 1.47 a	84.94 ± 0.00 a	38.19 ± 0.83 a	46.75 ± 0.83 b
L. alyssoides	EC 0.9	80.90 ± 0.00 a	35.41 ± 2.13 a	45.49 ± 2.13 a	84.94 ± 0.00 a	41.09 ± 0.88 a	43.85 ± 0.88 a
	EC 4.1	80.90 ± 0.00 a	35.96 ± 1.98 a	44.94 ± 1.98 a	84.94 ± 0.00 a	41.53 ± 1.14 a	43.41 ± 1.14 a
	EC 8.0	80.90 ± 0.00 a	37.04 ± 0.68 a	43.86 ± 0.68 a	84.94 ± 0.00 a	38.22 ± 2.79 a	46.72 ± 2.79 a
D. stricta	EC 0.9	80.90 ± 0.00 a	38.64 ± 1.24 a	42.26 ± 1.24 a	84.94 ± 0.00 a	46.73 ± 2.56 a	38.21 ± 2.56 a
	EC 4.1	80.90 ± 0.00 a	38.71 ± 2.77 a	42.19 ± 2.77 a	84.94 ± 0.00 a	51.45 ± 1.63 a	33.49 ± 1.63 a
	EC 8.0	80.90 ± 0.00 a	38.49 ± 0.99 a	42.41 ± 0.99 a	84.94 ± 0.00 a	51.17 ± 1.84 a	33.77 ± 1.84 a
P. virgatum	EC 0.9	80.90 ± 0.00 a	42.11 ± 1.46 a	38.79 ± 1.46 a	84.94 ± 0.00 a	50.93 ± 0.52 b	34.01 ± 0.52 a
	EC 4.1	80.90 ± 0.00 a	41.27 ± 2.05 a	39.63 ± 2.05 a	84.94 ± 0.00 a	54.48 ± 0.37 a	30.46 ± 0.37 b
	EC 8.0	80.90 ± 0.00 a	43.77 ± 0.77 a	37.13 ± 0.77 a	84.94 ± 0.00 a	54.84 ± 1.32 a	30.10 ± 1.32 b
×*Triticosecale*	EC 0.9	80.90 ± 0.00 a	31.81 ± 0.66 a	49.09 ± 0.66 b	84.94 ± 0.00 a	19.34 ± 2.04 b	65.60 ± 2.04 a
	EC 4.1	80.90 ± 0.00 a	25.45 ± 1.16 b	55.45 ± 1.16 a	84.94 ± 0.00 a	21.93 ± 1.84 b	63.01 ± 1.84 a
	EC 8.0	80.90 ± 0.00 a	26.70 ± 1.13 b	54.20 ± 1.13 a	84.94 ± 0.00 a	29.97 ± 0.70 a	54.97 ± 0.70 b

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Evapotranspiration changes with irrigation using saline groundwater and RO concentrate

Alison M. Flores [a, *], Manoj K. Shukla [a], David Daniel [b], April L. Ulery [a], Brian J. Schutte [c], Geno A. Picchioni [a], Sam Fernald [d]

Agricultural Water Management 195 (2018) 142–153

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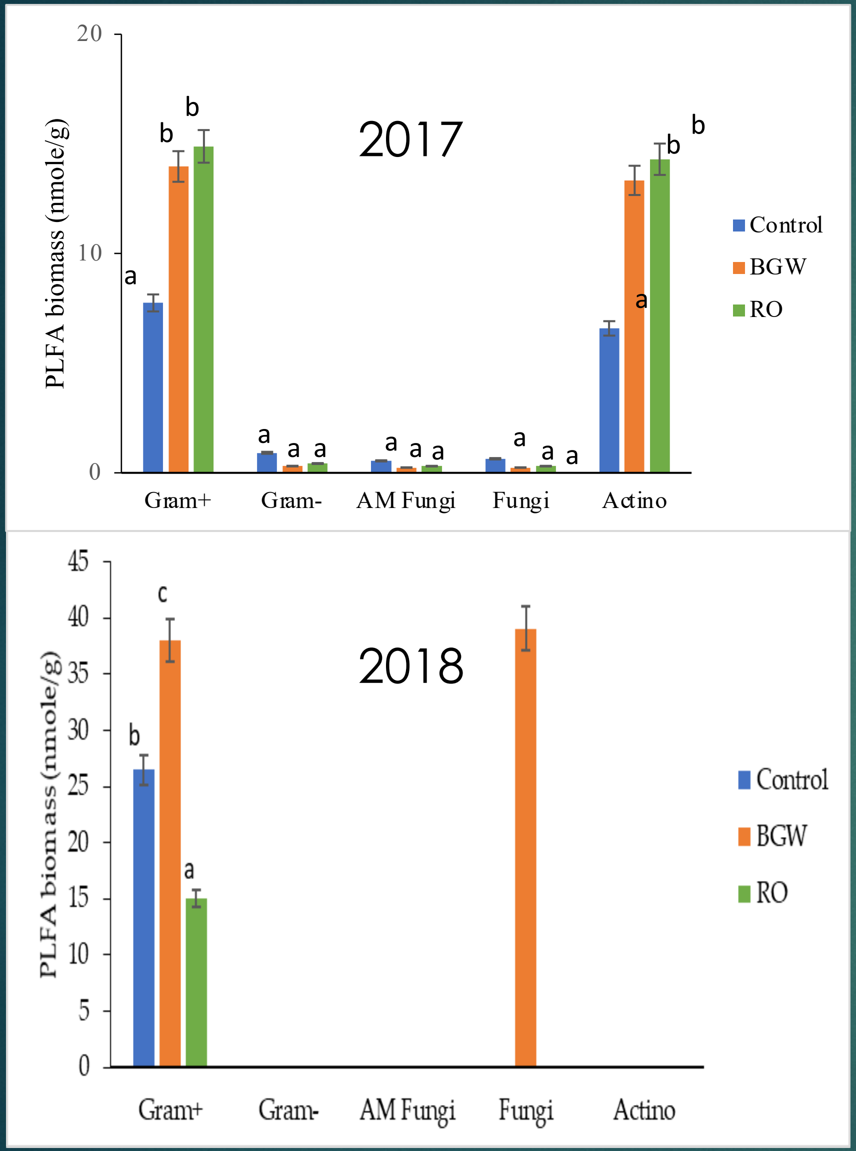
Research Paper

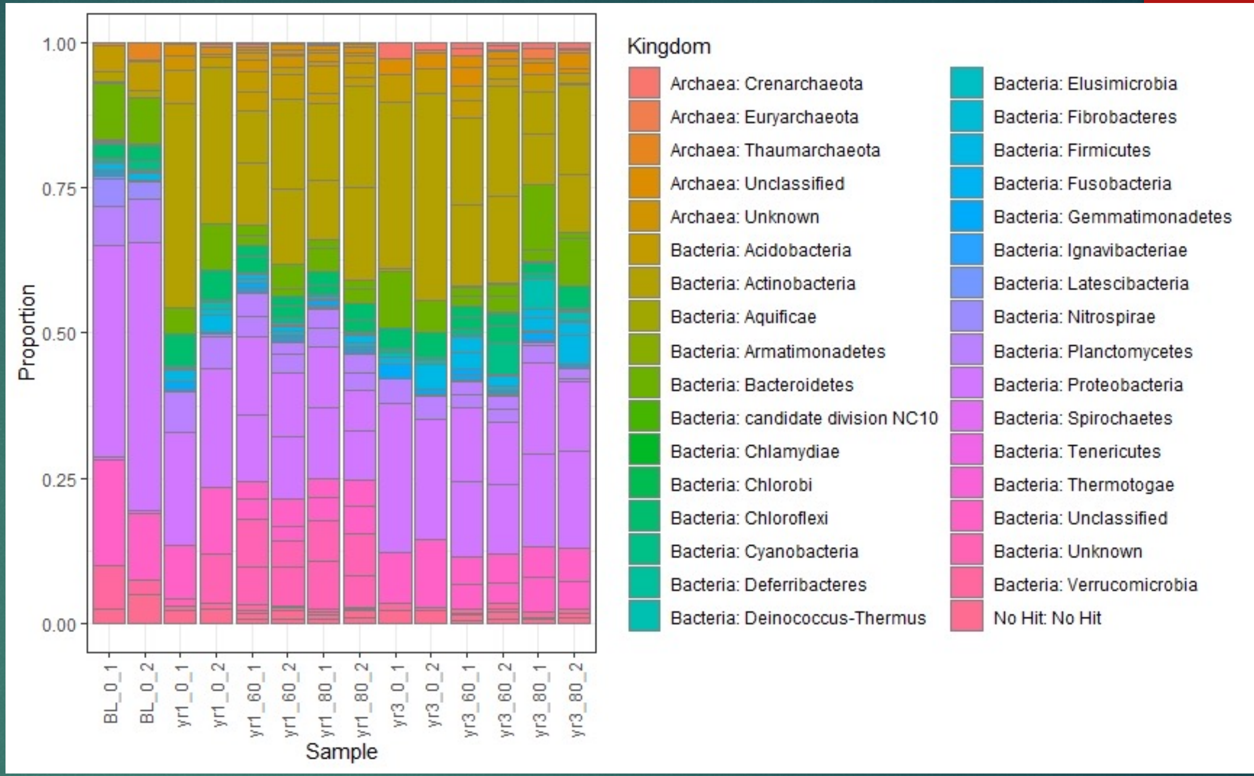
Irrigation with brackish water changes evapotranspiration, growth and ion uptake of halophytes

Omer Faruk Ozturk [a], Manoj K. Shukla [b, *], Blair Stringam [b], Geno A. Picchioni [b], Charlotte Gard [c]

Soil Microbiological Properties



Phospholipids fatty acids (PLFA) biomass of gram+ bacteria, gram- bacteria, AM fungi, fungi, and actinomycetes (nmol/g)

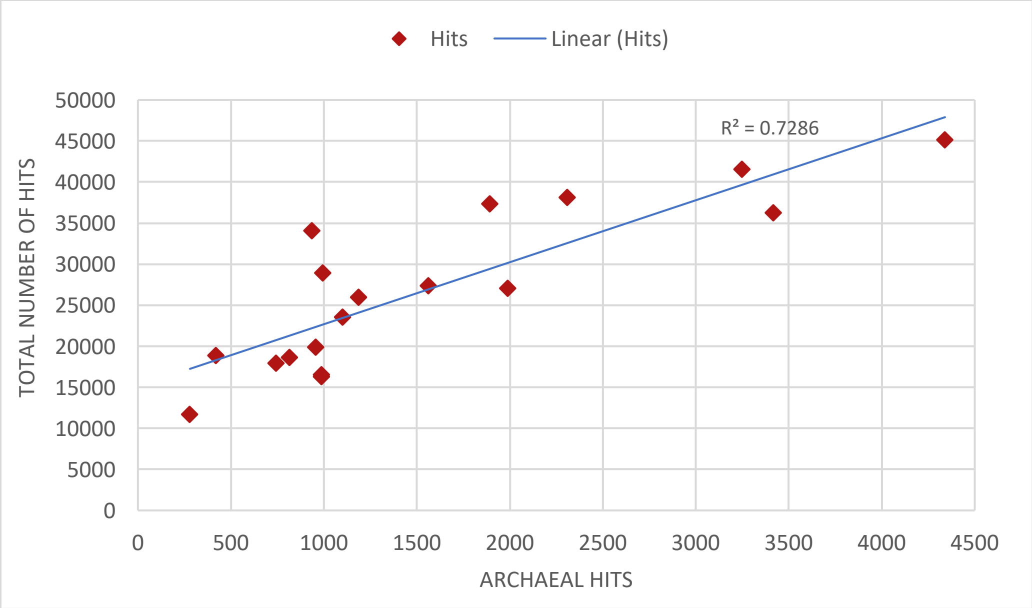


Bacteria and archaea species distribution from samples at various years (BL= Baseline, yr1 = end of year 1 and yr3= end of year 3), irrigation levels (0= control or no irrigation, 60= 60% ET_0 and 80 = 80% ET_0) and depth (1 = 0-25cm and 2= 25-50cm). Both initially decreased from baseline but then increased (16S rRNA showed similar pattern)

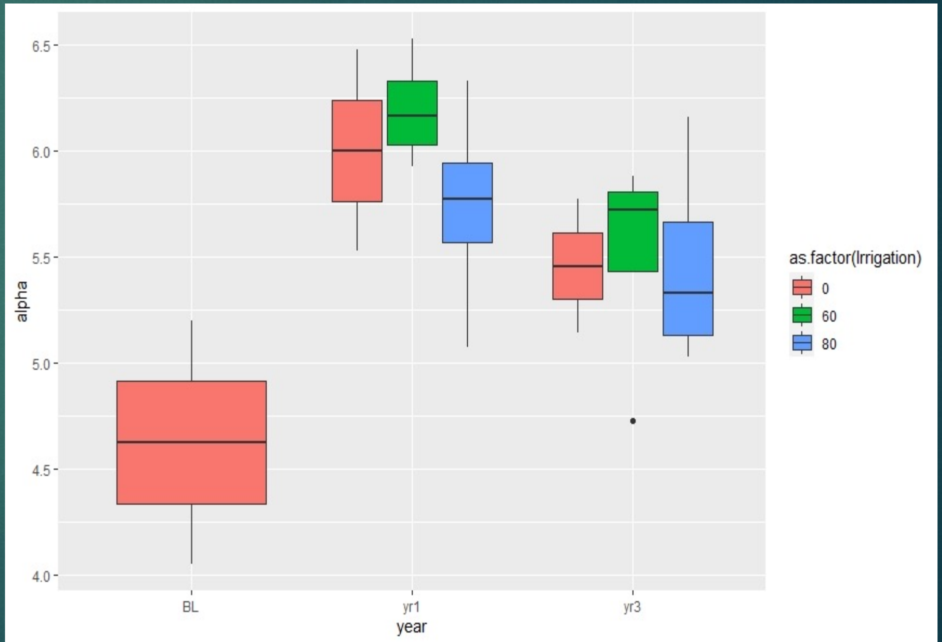
PERMANOVA: geometric partition of variation across multivariate data cloud

Kingdom	Phylum	Median %	Mean %	Baseline	EOY 1	EOY 3
Archaea	Crenarchaeota	1.79	1.51	No	Yes	Yes
Archaea	Euryarchaeota	0.06	0.30	Yes	Yes	Yes
Archaea	Thaumarchaeota	0.00	0.31	Yes	No	Yes
Archaea	Unclassified	2.57	2.40	Yes	Yes	Yes
Bacteria	Acidobacteria	0.60	2.23	Yes	Yes	Yes
Bacteria	Actinobacteria	28.09	24.93	Yes	Yes	Yes
Bacteria	Aquificae	0.01	0.09	Yes	Yes	Yes
Bacteria	Armatimonadetes	0.02	0.03	No	No	Yes
Bacteria	Bacteroidetes	4.83	6.56	Yes	Yes	Yes
Bacteria	Chlamydiae	0.01	0.04	Yes	No	Yes
Bacteria	Chlorobi	0.01	0.03	Yes	No	Yes
Bacteria	Chloroflexi	4.83	4.75	Yes	Yes	Yes
Bacteria	Cyanobacteria	0.37	1.00	Yes	Yes	Yes
Bacteria	Deferribacteres	0.00	0.01	Yes	No	Yes
Bacteria	Deinococcus-Thermus	0.17	1.02	No	Yes	Yes
Bacteria	Elusimicrobia	0.05	0.06	Yes	No	Yes
Bacteria	Fibrobacteres	0.00	0.15	Yes	Yes	No
Bacteria	Firmicules	1.83	2.81	Yes	Yes	Yes
Bacteria	Fusobacteria	0.00	0.02	Yes	No	Yes
Bacteria	Gemmatimondetes	1.11	1.25	Yes	Yes	Yes
Bacteria	Ignavibacteriae	0.11	0.11	Yes	No	No
Bacteria	Latescibacteria	0.21	0.21	Yes	No	No
Bacteria	Nitrospirae	0.25	0.55	Yes	Yes	Yes
Bacteria	Planctomycetes	5.71	5.35	Yes	Yes	Yes
Bacteria	Proteobacteria	25.03	26.02	Yes	Yes	Yes
Bacteria	Spirochetes	0.00	0.05	Yes	Yes	Yes
Bacteria	Tenencutes	0.00	0.01	No	No	Yes
Bacteria	Thermotogae	0.01	0.01	Yes	No	No
Bacteria	Verrucomicrobia	1.11	1.42	Yes	Yes	Yes
Bacteria	Unclassified	9.45	9.57	Yes	Yes	Yes
Bacteria	Unknown	14.80	13.74	No	Yes	No
Bacteria	Candidate NC10	0.14	0.14	Yes	No	No
No Hit	No Hit	1.84	1.98	Yes	Yes	Yes

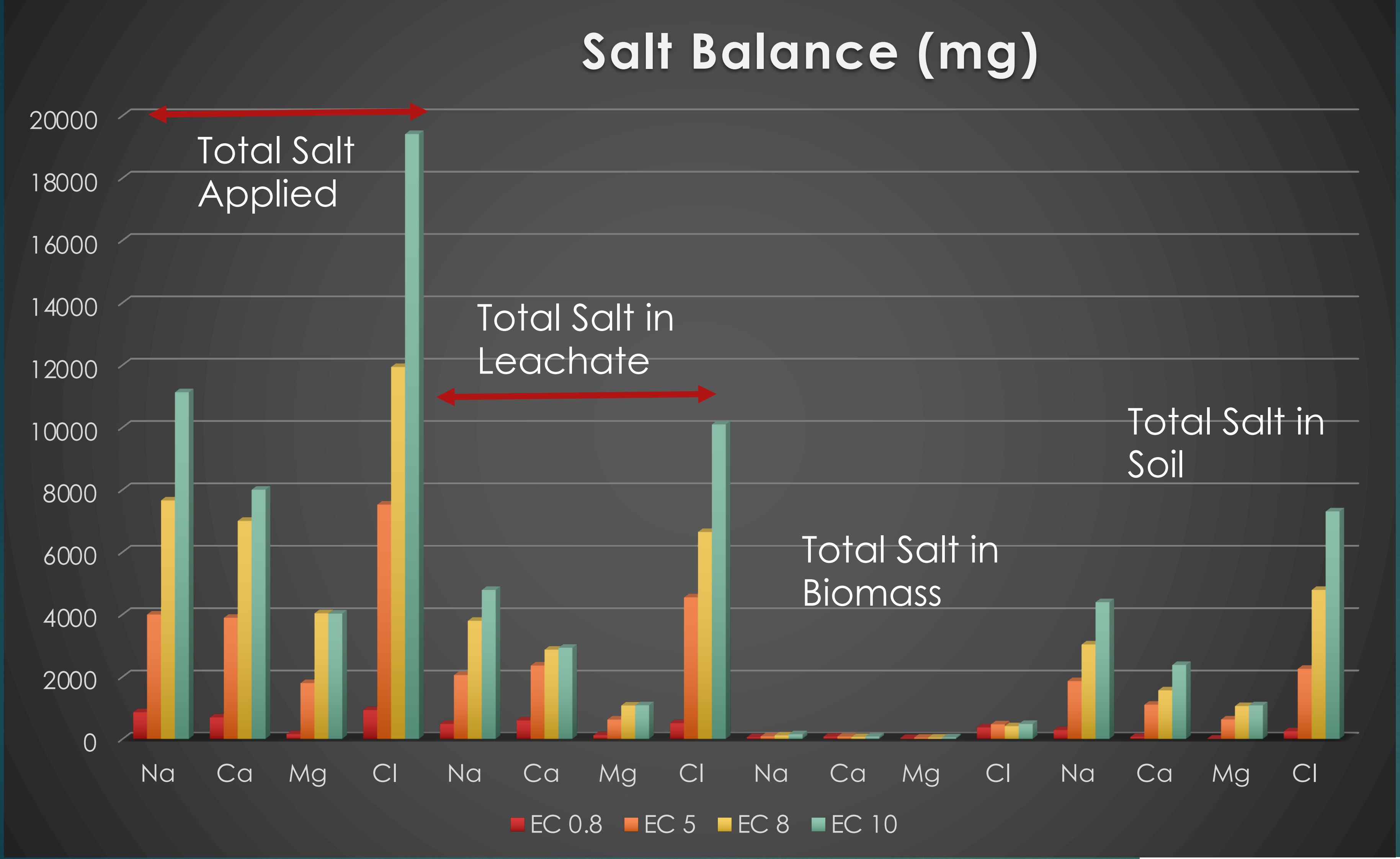
Phylum presence in baseline, end of year 1 and end of year 3 for Archaea and Bacteria kingdoms



Extremophile Archaeal bacteria



Alpha diversity of soil samples at different irrigation rates, with 0= control (no irrigation), 60= 60% ET_0 and 80 = 80% ET_0



- Halophytes not removing enough salts
- Able to block it without changing ET or growth
- Soil salinization is occurring even with BGW
- Higher leaching fractions will be needed to control soil salinization

Ion balance for Mg^{2+}, Na^{+}, Ca^{2+}, and Cl^{-} ions in the irrigation water, BGW (EC 5), RO1 (EC 8) and RO2 (EC 10)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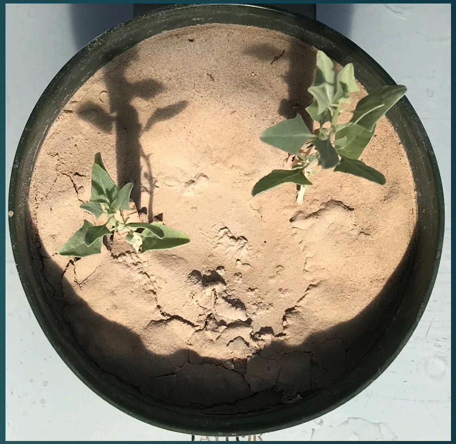
Research Paper

Irrigation with brackish water changes evapotranspiration, growth and ion uptake of halophytes

Omer Faruk Ozturk[a], Manoj K. Shukla[b,*], Blair Stringam[b], Geno A. Picchioni[b], Charlotte Gard[c]

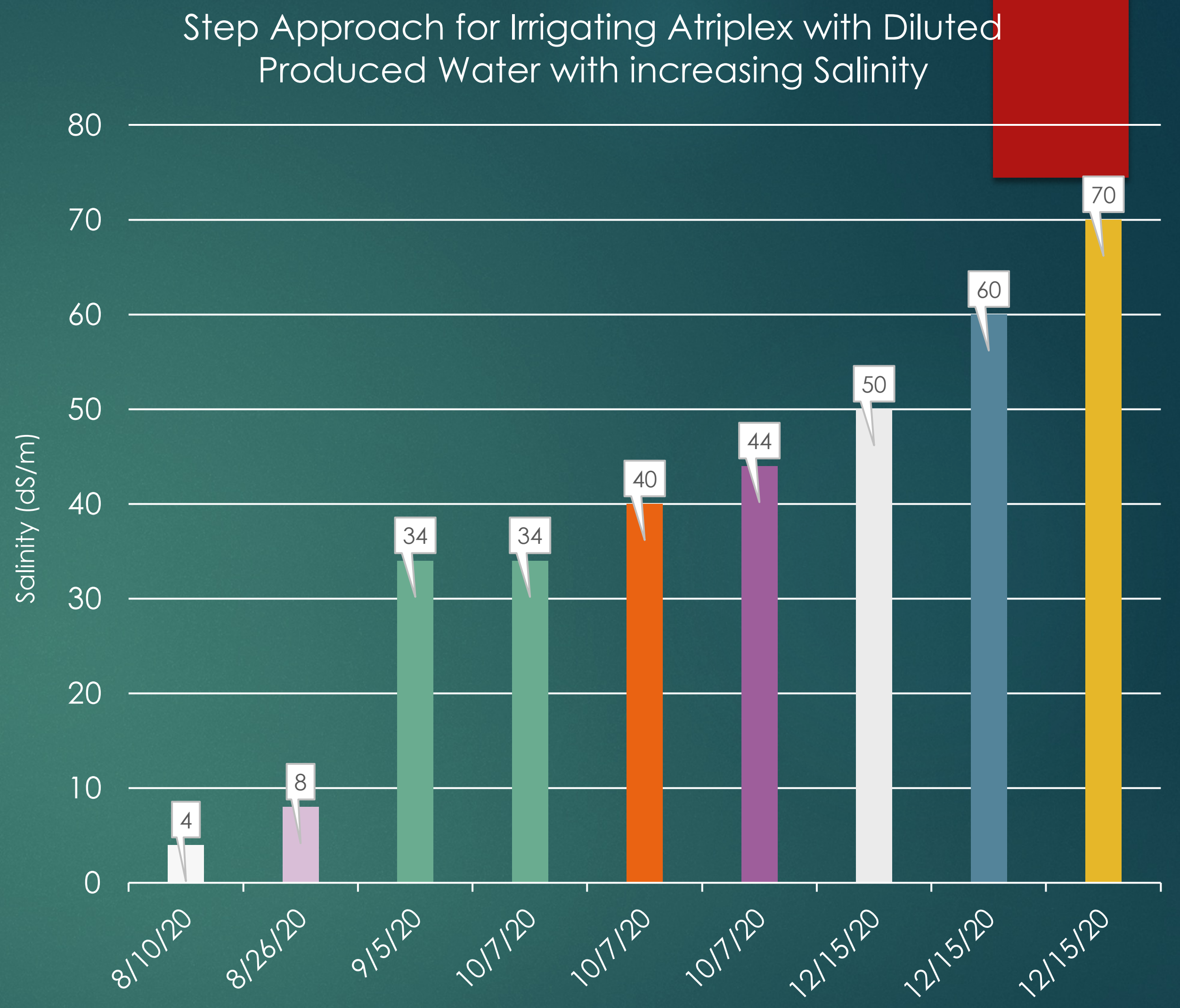
Halophytes irrigated with produced waters of salinity of

Atriplex Conescense



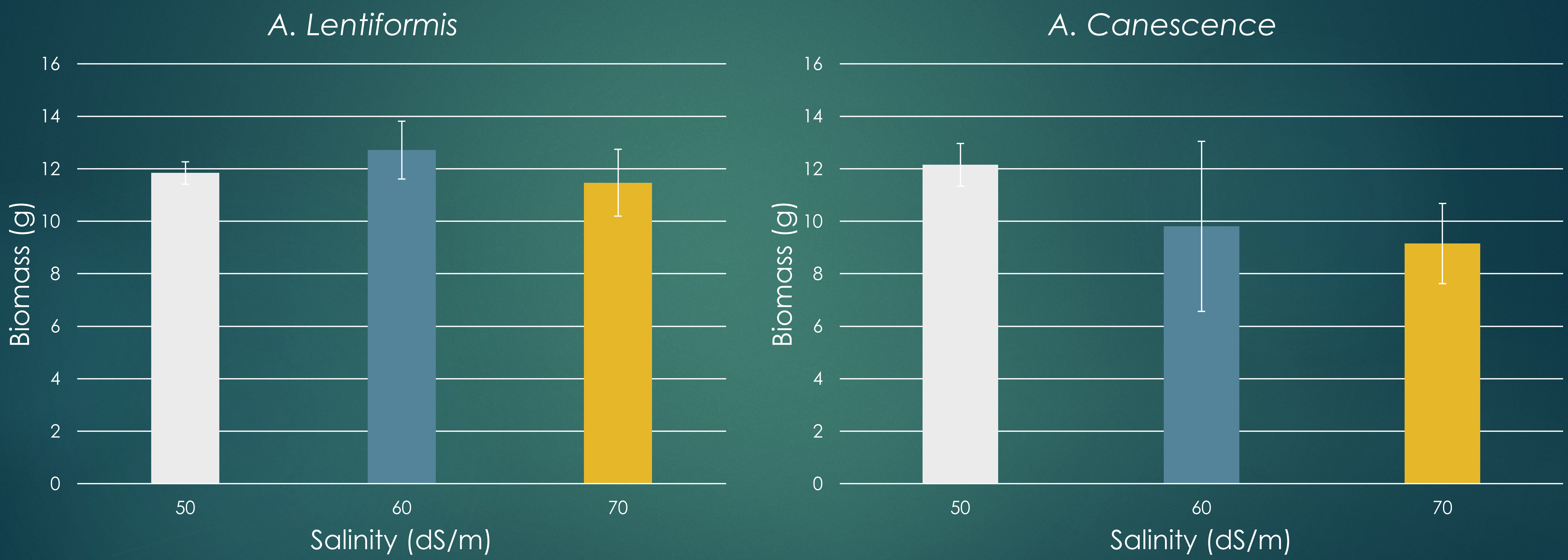
Atriplex Lentiformis

- To ensure the plants did not receive shock, they were initially (first two) watered with Brackish groundwater.
- Then starting on September 5th, 2020, all the plants were irrigated with produced water, supplied by **NGL Water Solutions Permian, LLC**, with an electrical conductivity of **34dS/m**.
- On October 13th, 2020, all three treatments **(34dS/m, 40dS/m, and 44dS/m)** had been initiated and were in effect for 8 weeks. After that period, the plants were then watered at **50dS/m, 60dS/m, and 70dS/m** beginning on December 15th, 2020.
- At each irrigation, the volume of the leachate (deep percolation, DP) was collected and later used to calculate the volumetric leaching fraction (LF) and evapotranspiration (ET).



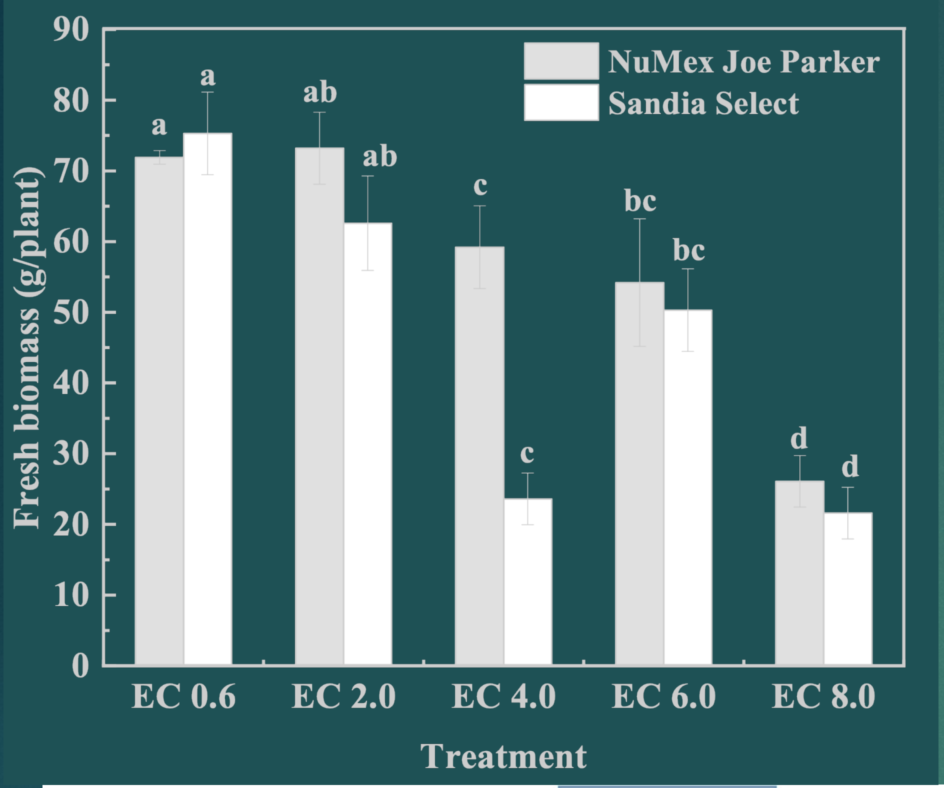
- A dilution process was used to make all the irrigation treatments.
- All species were watered at a regular interval, on the 7th day of the previous irrigation (4 irrigations per month).

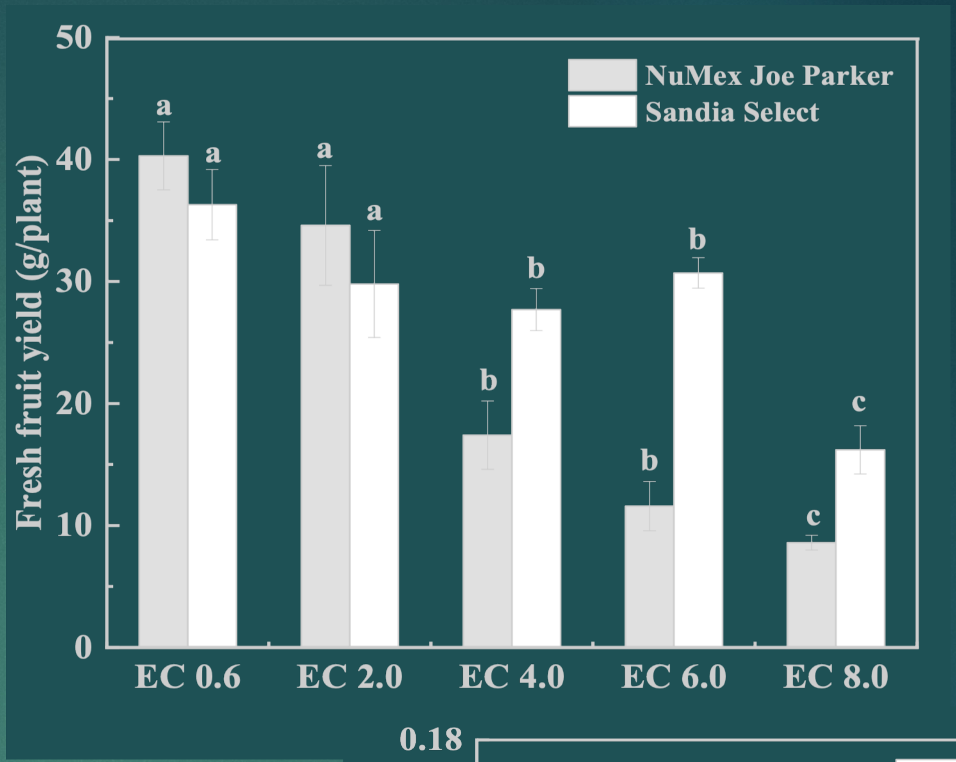
Average Biomass of Both *Atriplex* Species Collected at End of Experiment

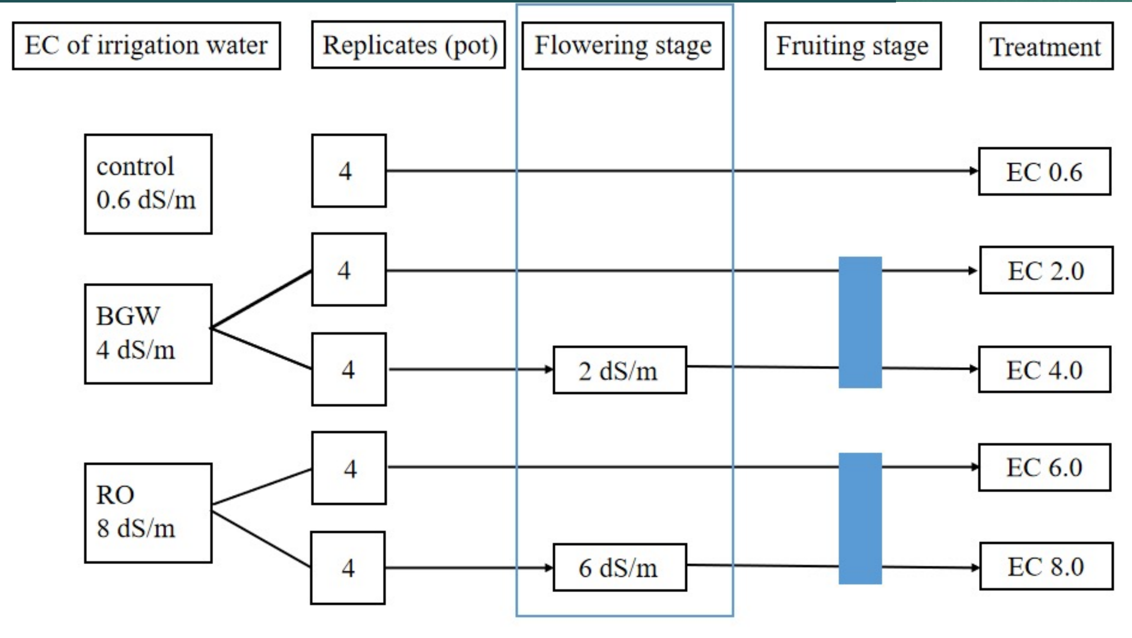


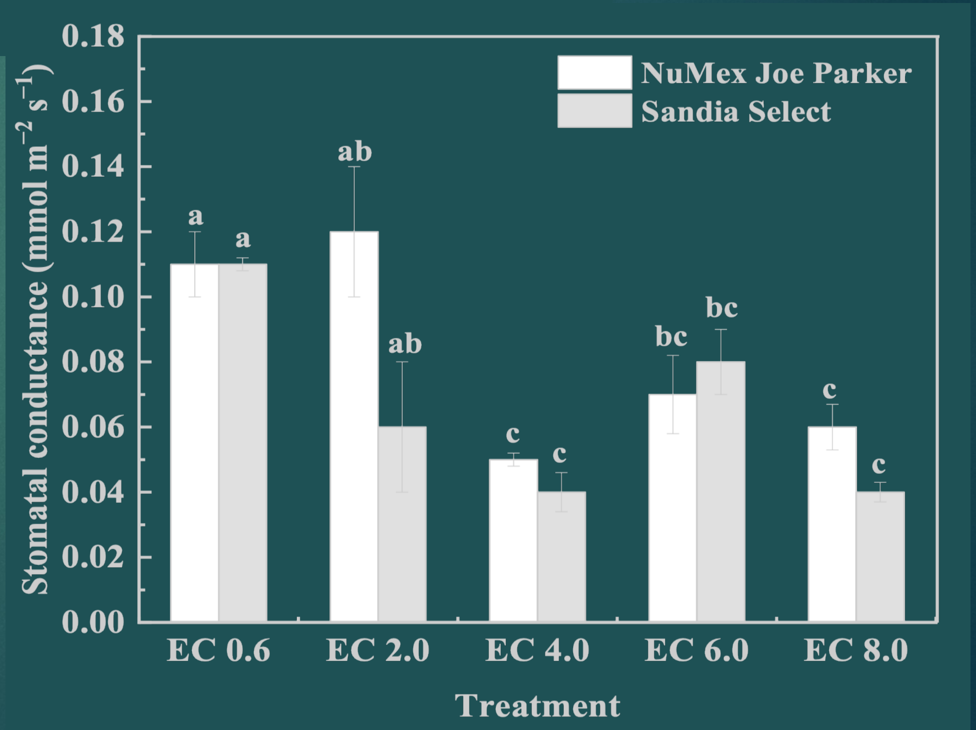
Percent Sodium and Chloride in Plants will have important implications for forage quality

- Soil microbial habitats should change as reverse osmosis concentrate is added over an extended period of time to the soil.
- As ion accumulation increases in the soil substrate, microbes will adapt to the environment, showing a greater abundance of extremophile bacteria accumulating over three years.
- Results from this study could potentially be used to determine further research in metabolic processes of extremophilic bacteria, perhaps isolating proteins which help rhizosphere plants survive in abiotic stressful environments.
- This information will also allow researchers to determine the salinity limit of organisms that are adapted to saline soil environments.


NuMex Joe Parker
Sandia Select
Fresh biomass (g/plant)
0
10
20
30
40
50
60
70
80
90
EC 0.6
EC 2.0
EC 4.0
EC 6.0
EC 8.0
Treatment


NuMex Joe Parker
Sandia Select
Fresh fruit yield (g/plant)
0
10
20
30
40
50
EC 0.6
EC 2.0
EC 4.0
EC 6.0
EC 8.0


EC of irrigation water
Replicates (pot)
Flowering stage
Fruiting stage
Treatment
control
0.6 dS/m
BGW
4 dS/m
RO
8 dS/m
4
4
4
4
4
2 dS/m
6 dS/m
EC 0.6
EC 2.0
EC 4.0
EC 6.0
EC 8.0


NuMex Joe Parker
Sandia Select
Stomatal conductance (mmol m^{-2} s^{-1})
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
EC 0.6
EC 2.0
EC 4.0
EC 6.0
EC 8.0
Treatment

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- NGL Water Solutions Permian, LLC
- NMSU Agricultural Experiment Station
- NIFA

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