Testing Varieties for High Salinity Production Systems

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Agriculture and Natural Resources

Why is Salinity important for Alfalfa?

- Worldwide Issue: 1 billion ha, 20% of irrigated areas
- Deficit irrigation exacerbate salinity
- More precise methods increase salinity
- Alfalfa is moving to lower quality soils & water
- Use of degraded water (dairy, municipal wastewater, irrigation re-use)
- Alfalfa is higher cash/quality value than many other salt-tolerant plants

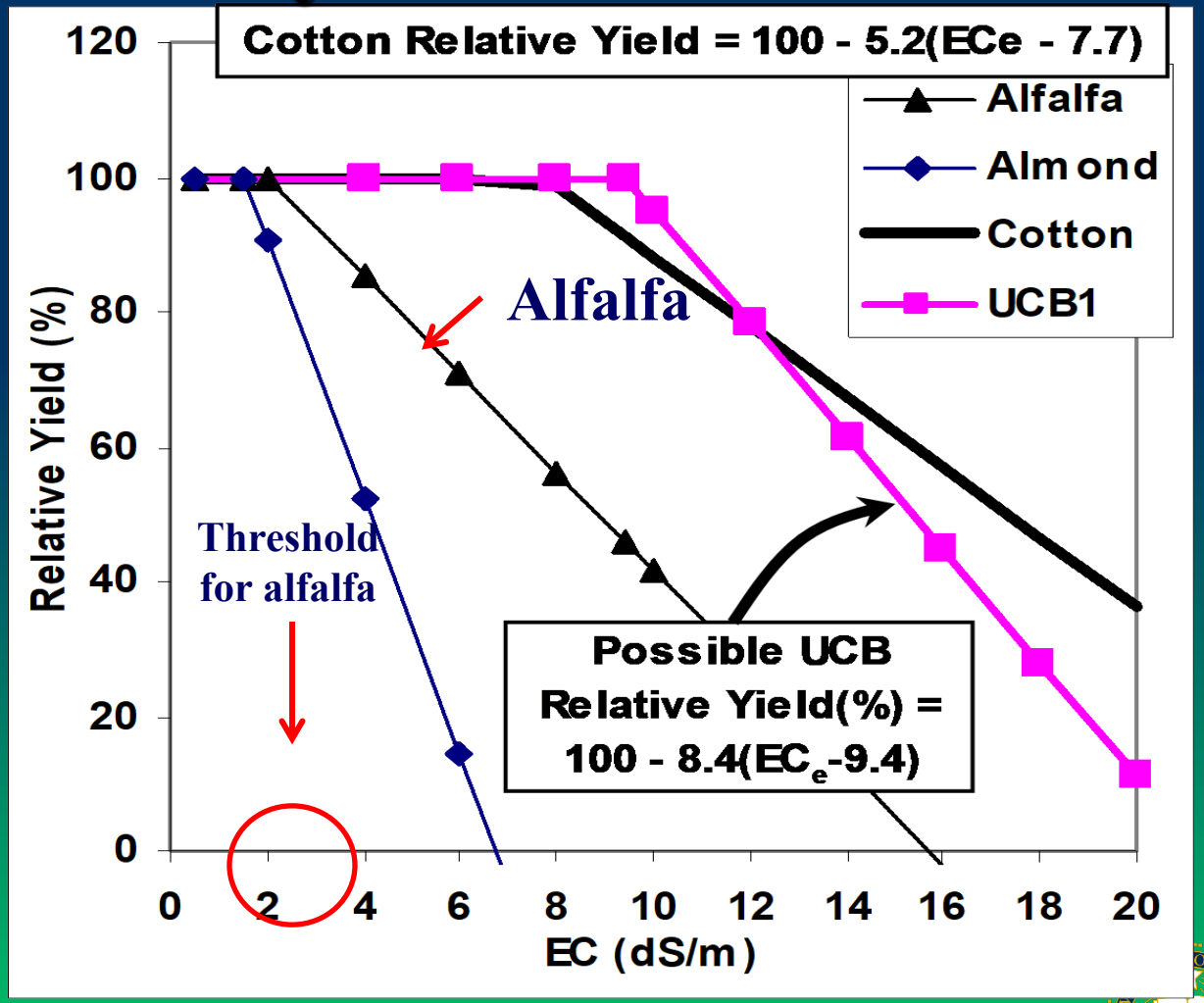
Salinity Effects tail ends of fields

Blake Sanden, Slide

January Flooding of Drip Irrigated Alfalfa Field, Buttonwillow, CA

Alfalfa, according to some literature, is only moderately salt tolerant

- the Maas-Hoffman salinity tolerance rankings list alfalfa as moderately sensitive due to a low threshold value (2 dS/m EC_e)



Which Crops are Salt Sensitive, Tolerant ? (FAO)

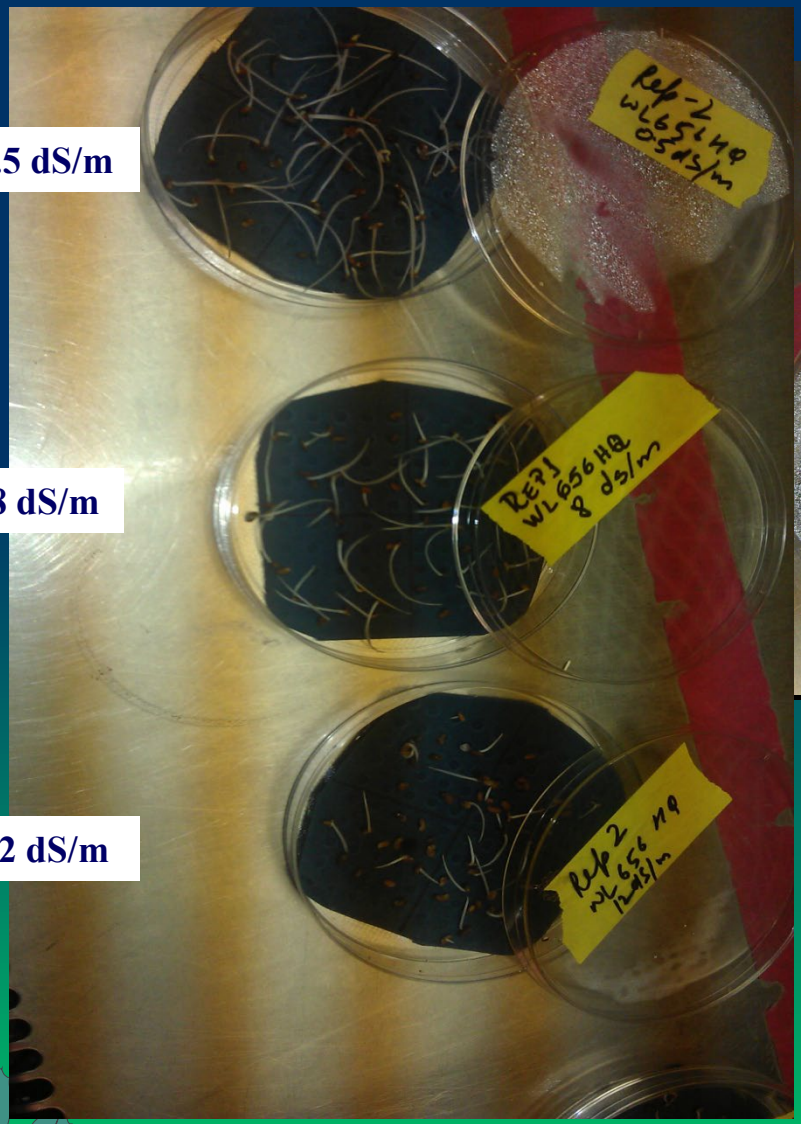
Crop	Species	Threshold (Ece)	Slope	Rating
		dS/m	% per dS/M	
Common Bean	*Phaseolus vulgaris*	1.0	19	S
Orchardgrass	*Dactylis glomerata*	1.5	6.2	MS
Corn (forage)	*Zea Mays*	1.8	7.4	MS
Alfalfa	***Medicago sativa***	**2.0**	**7.3**	**MS**
Barley (forage)	*Hordeum vulgare*	6.0	7.1	MT
Bermudagrass	*Cyndadon dactylon*	6.9	6.4	T
T. Wheatgrass	*Agropyron elongatum*	7.5	4.2	T
Rye	*Secale cereale*	11.4	10.8	T

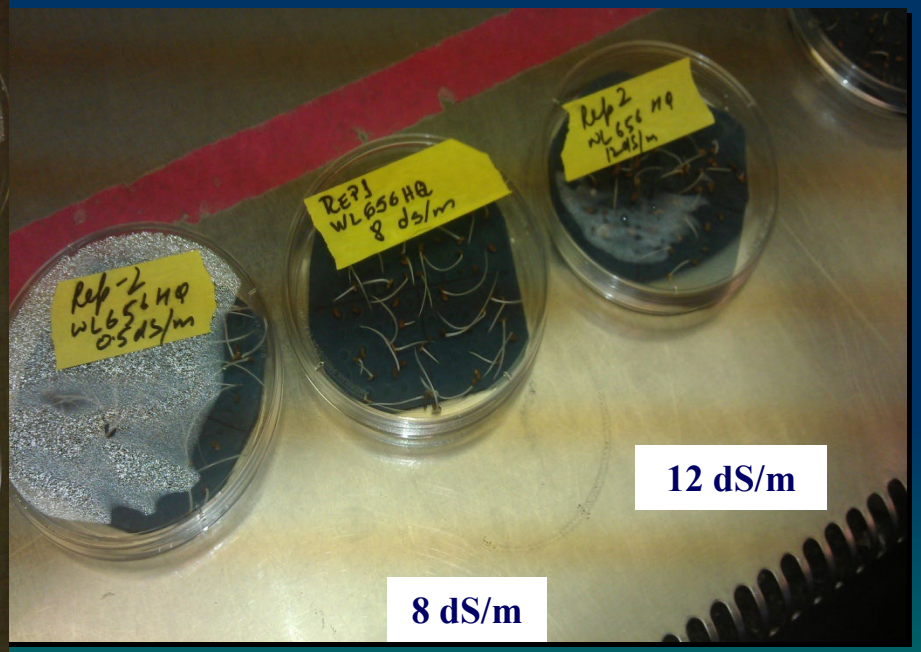
S= Sensitive, MS=Moderately Sensitive, MT=Moderately Tolerant, T=Tolerant

Alfalfa Salinity Trials
(UC Davis/Fresno State/Utah State)

- 2009-2021 - 5 grad students
- Greenhouse Studies
  - Petrie Dish germ tests
  - Tray tests w/soil (stand est.)
  - Seedling Yields (greenhouse)
- Field Trials
  - Trial 1 (3 yr. MS only flood)
  - Trial 2 (3 year Saline vs. contr. Flood)
  - Trial 3 (4 year HS vs LS buried drip)
- Breeding Screening Opportunity

Germination Test:





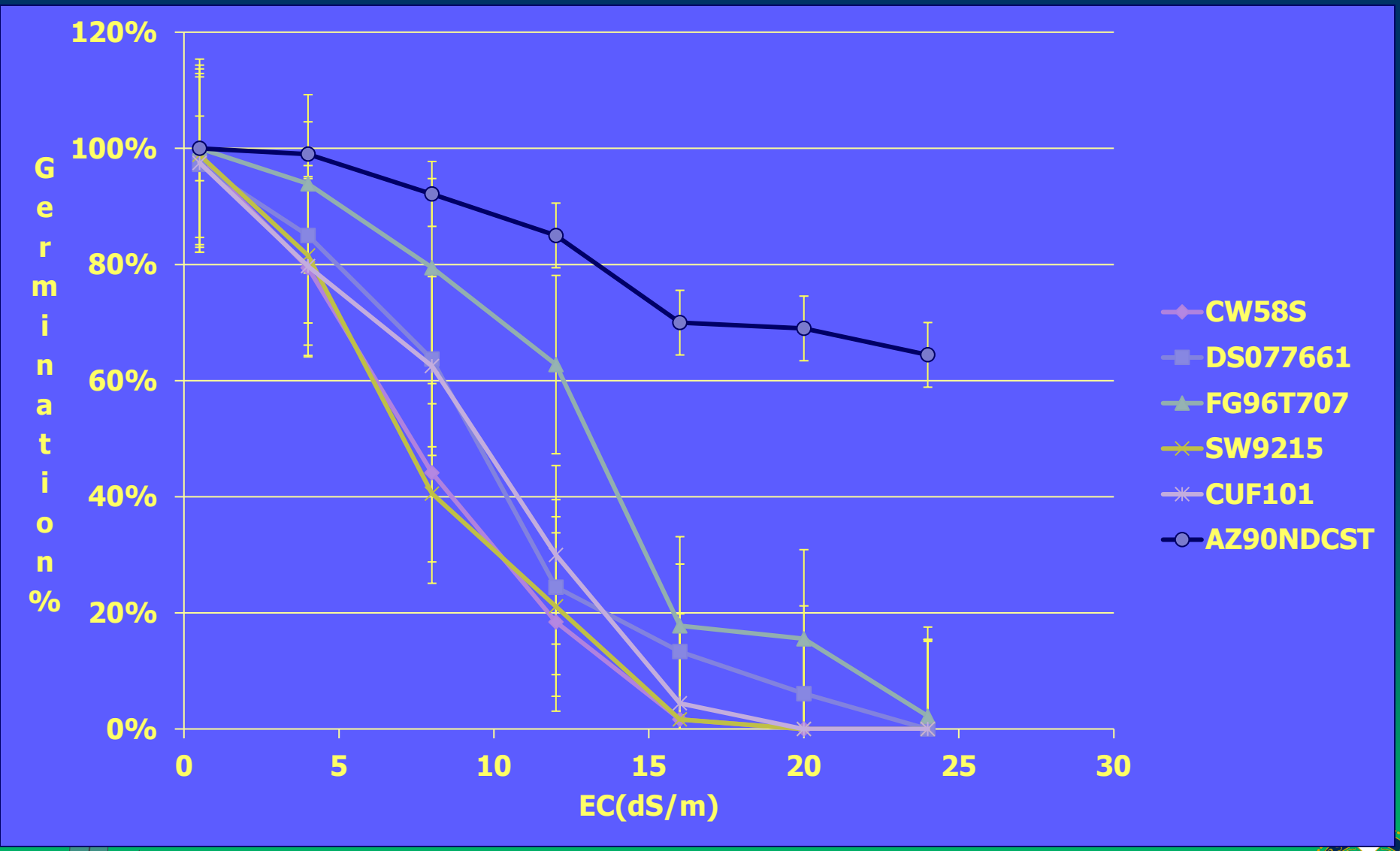
0.5 dS/m

Effect of salinity on germination of alfalfa:

Salinity (ECw)	Seed Germination%
0.5	97% [a]
4	88% [b]
8	60% [c]
12	41% [d]
16	13% [e]
20	7% [f]
24	4% [g]

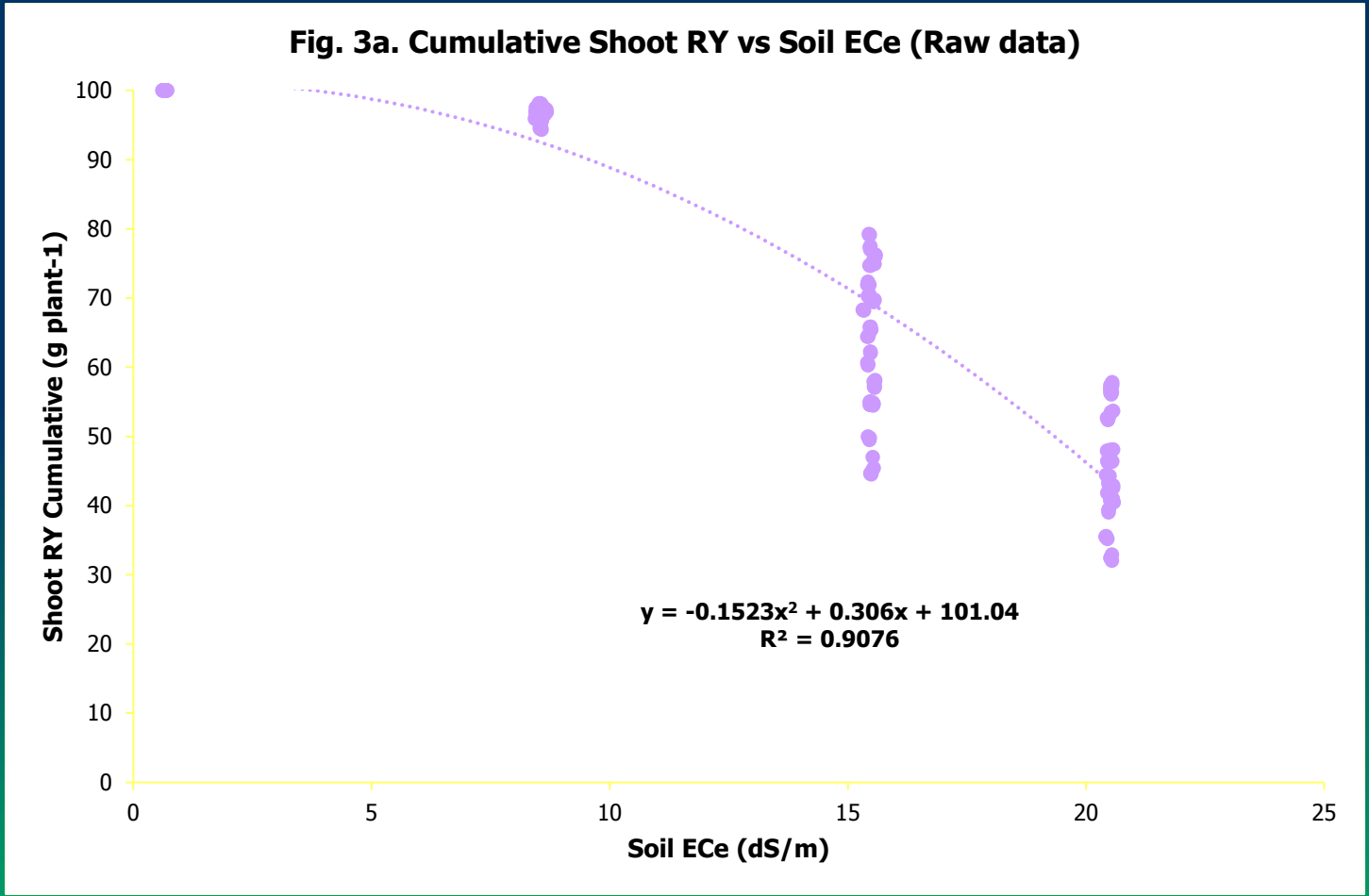
**Means within same column and same letter are not significantly different at P<0.05.*

Varieties Differ in Germination: *Day 7*



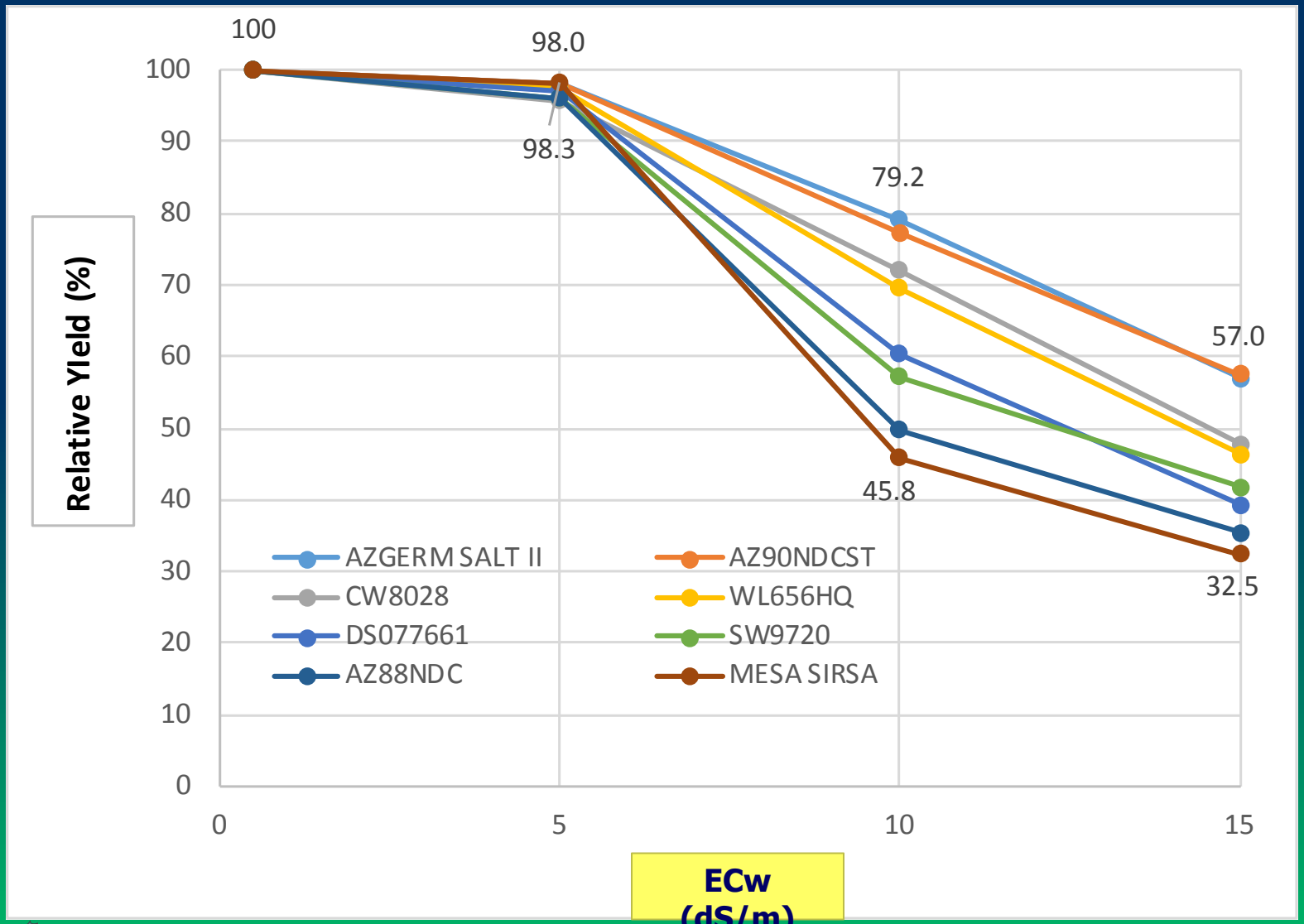
Greenhouse Yield Response

Greenhouse Studies

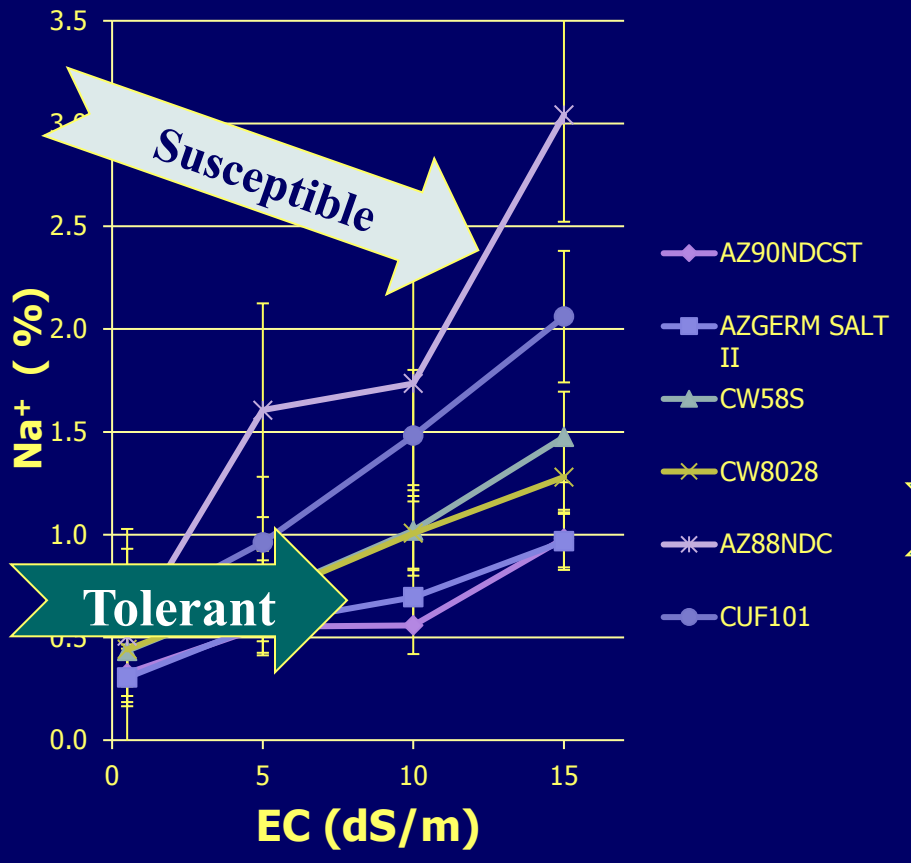


Sharon Benes, Fresno State Univ.

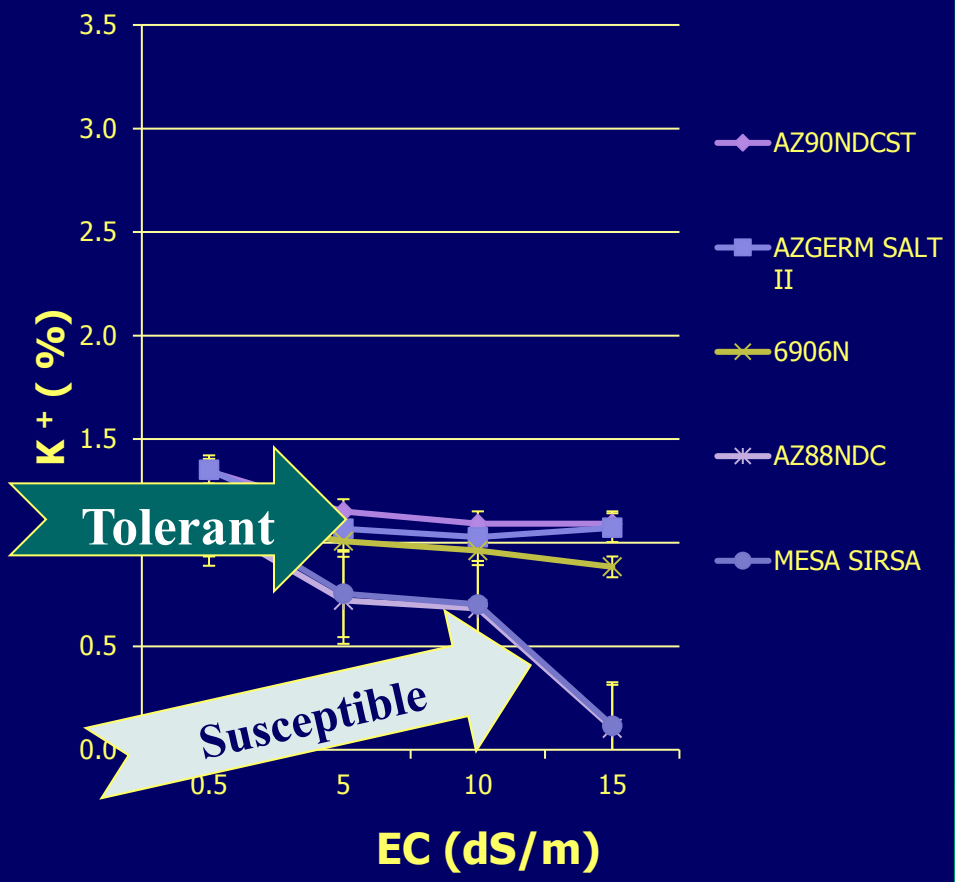
Shoots-- Relative Yield (RY- %)*– *Cumulative for 7 harvests*



Na (%) accumulated in alfalfa shoots--



K (%) accumulated in alfalfa shoots-



Field Evaluations- UC Westside Field Station, 3- 4-yr. trials (shallow saline well)

- Trial 1: Basin irrigation. Irrig. water 5.5 to 7.0 dS/m Ec_w 24 alfalfa varieties No NS control. 5 years
- Trial 2: Basin irrigation. Irrig. water 7 - 10 dS/m (HS) EC_w 21 alfalfa varieties, replicated field trial in two basins (HS and LS). 3 years
- Trial 3: Subsurface drip irrigation (SDI). Irrig. water 7 - 10 dS/m (HS) 4 years
  - SDI to deliver water more directly to the plant; avoid excess wetting & drying of soil
  - 35 varieties replicated in eight blocks (four HS and four LS)

Saline Irrigation Trials in the field

- Salt composition representative of western SJV (3:1 ratio of Na:Ca on a meq basis)
- Achieve uniformity in water and salt application & distribution in the field
- Clay Loam Soil Types

Salinity has complex effects on plants in the field:

Osmotic Effect (inability to take in water)

Toxic Ion Effect (specific toxic effects, e.g. Boron)

Soil Effects (soil structure, infiltration)

Normal growth vs. growth under saline conditions

Trial 1.Field Salinity Yield Trials

2010-12 YIELDS. WSREC ALFALFA SALINITY TRIAL. TRIAL PLANTED 10/27/09

	FD	2010 Yield	2011 Yield	2012 Yield	Average		% of CUF 10
		Dry t/a					%
Released Varieties							
WL 656HQ	9	9.7 (12)	13.9 (1)	16.3 (3)	13.3 (2)	A B	106.9
Hybriforce 800	8	10.7 (2)	13.3 (5)	15.2 (7)	13.1 (4)	A B C	105.2
Ameristand 901STQ	9	9.6 (17)	13.4 (4)	15.5 (5)	12.8 (6)	A B C D E	103.1
Magna 995	9	9.7 (13)	12.8 (9)	15.5 (6)	12.7 (7)	A B C D E F	101.8
CUF101	9	10.1 (7)	12.4 (11)	14.9 (10)	12.4 (10)	A B C D E F G H	100.0
Medina	8.5	10.9 (1)	11.7 (19)	14.5 (14)	12.3 (11)	B C D E F G H	99.2
CW 95	9	10.0 (8)	12.0 (15)	14.4 (15)	12.2 (12)	C D E F G H I	97.8
CW 485	8	10.3 (5)	11.9 (16)	13.9 (16)	12.0 (13)	D E F G H I	96.8
UC 452		10.0 (9)	12.5 (10)	13.5 (19)	12.0 (14)	E F G H I	96.5
Highline	9	10.1 (6)	12.3 (12)	13.4 (21)	11.9 (15)	E F G H I	95.7
Integra 8900	9	9.1 (23)	11.8 (18)	14.8 (12)	11.9 (16)	E F G H I	95.5
AmeriStand 803	8	9.2 (22)	11.6 (21)	14.8 (11)	11.9 (17)	E F G H I	95.3
SW9803	9	8.8 (24)	12.1 (13)	14.6 (13)	11.8 (18)	F G H I	95.0
CW 585	8	9.8 (11)	12.1 (14)	13.5 (20)	11.8 (19)	F G H I	94.8
BAR 9242	8.5	9.2 (21)	11.7 (20)	13.8 (18)	11.6 (22)	H I	92.9
GrandSlam	8	9.6 (16)	10.9 (24)	13.2 (23)	11.3 (23)	I	90.4
CW 8028	8	9.9 (10)	11.9 (17)	11.8 (24)	11.2 (24)	I	89.9
Experimental Varieties							
FG 96T706	9	9.4 (20)	13.3 (7)	17.1 (1)	13.3 (1)	A	107.2
FG 94T02	9	10.4 (3)	13.7 (2)	15.7 (4)	13.3 (3)	A B	106.6
FG 96T707	9	9.7 (15)	12.8 (8)	16.5 (2)	13.0 (5)	A B C D	104.6
DS593	9	9.7 (14)	12.9 (7)	15.1 (8)	12.6 (8)	A B C D E F G	100.9
SW9812	9	9.4 (19)	13.1 (6)	15.1 (9)	12.5 (9)		
DS077661	8	10.4 (4)	11.5 (22)	13.3 (22)	11.7 (20)		
DS067092	8	9.5 (18)	11.4 (23)	13.8 (17)	11.6 (21)		
MEAN		9.80	12.38	14.59	12.26		
CV		10.2	11.9	10.5	8.2		
LSD (0.1)		0.99	1.46	1.51	0.99		

Trial seeded at 25 lb/acre viable seed at WSREC, Five Points, CA.
Entries followed by the same letter are not significantly different at the 10% probability level according to Fisher's (protected) LSD.
FD = Fall Dormancy reported by seed companies.

Ave. Yields 27.5 Mg/ha – 3 yr

EC Water: 5.5

ECs 4 yrs: 8.9

T=21.9°C	EC (dS/m)
1	8.64
7	9.56
13	8.71
19	9.62
25	8.10
31	8.84
Avg.	8.91

3 years field data cuts/year – normal yields

Alfalfa after full summer, no watering, EC 8-9, SJV

Five-year old alfalfa variety trial after two years of season-long drought conditions 2013 and 2014 (Western Fresno County, CA).

Photo taken Nov. 2014 after a single irrigation

Trial 2- Basin Irrigation

- UC Westside Research and Extension Center, Five Points, CA
  - Clay loam soil– *Cerini Series*
- 21 alfalfa varieties bred for salt tolerance

-experimental or recently released

- CUF-101 public control (well-known, grown in CA for many years)

#	Variety Name	Marketer
1	CUF101	Public Control
2	9R100	Eureka
3	FG R814W257S	FGI
4	FG R814W258S	FGI
5	FG R914W259S	FGI
6	AZ-90NDC-ST	Salt Tolerant Control
7	AZ-88NDC	Non Tolerant Control
8	AmeriStand 915TS RR	America's Alfalfa
9	AmeriStand 901TS	America's Alfalfa
10	Desert Sun 8.10RR	Croplan
11	Sun Quest	Croplan
12	Saltana	S&W Seed
13	SW 8421-S	S&W Seed
14	SW 9813	S&W Seed
15	SW9106	S&W Seed
16	SW9215	S&W Seed
17	SW9812	S&W Seed
18	SW 9215-RRS	S&W Seed
19	SW 8421-RRS	S&W Seed
20	CW050085	Alforex Seeds
21	CW058071 (Impalo)	Alforex Seeds

Resulting Soil Salinity (Trial 2)

		ECe (dS/m)					
		Soil depth (cm)					
Basin	Time	0-30	30-60	60-90	90-120	120-150	Avg. 0-150
LS	May 2015	4.2	4.7	3.7	.	.	.
	Oct. 2015	2.3	3.6	4.5	.	.	.
	May 2016	2.6	4.6	4.5	4.1	3.4	3.8
	Oct. 2016	3.1	6.6	4.3	4.4	3.9	4.4
	Nov. 2017	2.1	4.2	3.4	3.4	4.1	3.4
HS	May 2015	7.3	5.6	4.7	.		.
	Oct. 2015	13.0	11.1	10.4	.	.	.
	May 2016	12.7	10.0	9.1	8.9	8.0	9.7
	Oct. 2016	19.8	16.0	13.8	13.8	12.1	15.1
	Nov. 2017	18.6	14.9	14.4	14.7	13.0	15.1

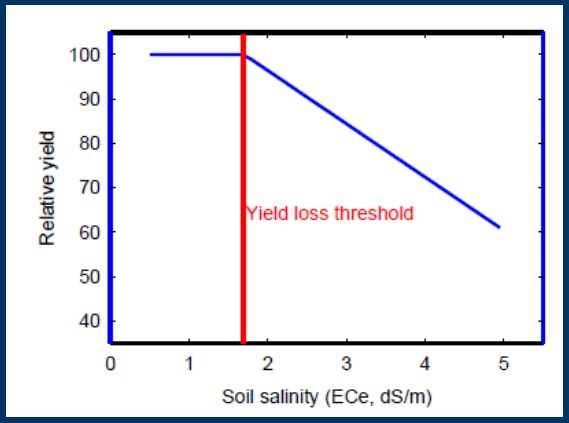
Yield Results (Trial 2)

**but three varieties had > 20% yield loss*

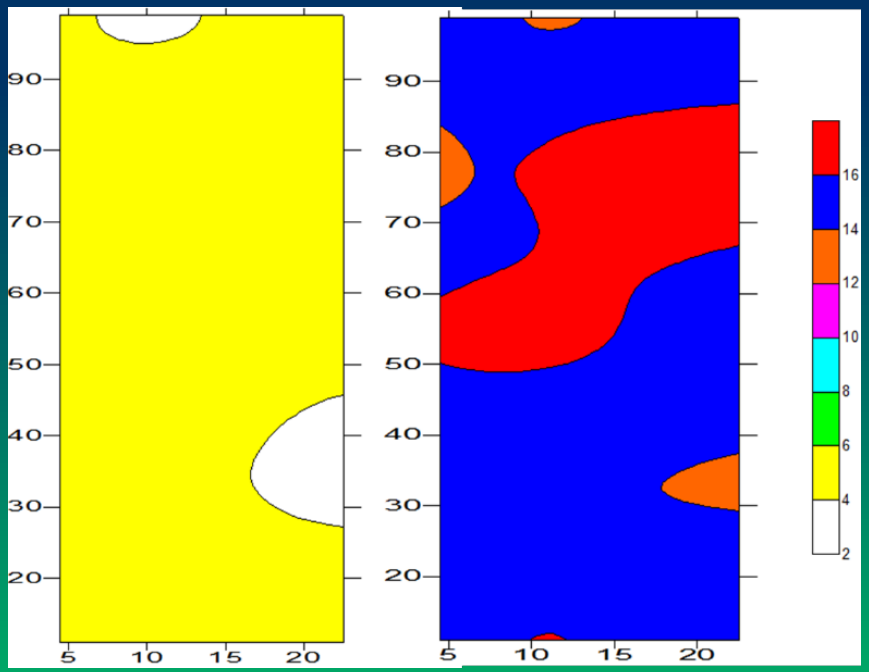
Variety	Yield (t/A)									
	2015		2016		2017		3-year Avg.		Cum. Yield	
	LS	HS	LS	HS	LS	HS	LS	HS	LS	HS
SW9812	6.5	7.4	8.4	10.9	9.4	12.0	8.1	10.1	24.3	30.3
SW 9813	7.9	7.2	9.3	10.2	9.3	12.8	8.8	10.1	26.5	30.2
FG R914W259S	8.3	7.6	10.0	9.4	10.5	10.6	9.6	9.2	28.8	27.6
AmeriStand 915TS RR	7.6	7.0	8.7	9.3	9.0	10.7	8.4	9.0	25.3	27.0
SW 8421- RRS	7.8	7.3	10.4	8.5	12.1	10.2	10.1	8.7	30.3	26.0
Saltana	7.4	6.8	9.7	8.7	11.5	10.4	9.5	8.7	28.5	26.0
AmeriStand 901TS	7.3	6.3	9.7	8.7	11.5	10.4	9.5	8.5	28.6	25.4
FG R814W257S	7.7	6.4	8.8	9.6	9.3	9.1	8.6	8.4	25.8	25.1
CUF101	7.8	7.0	9.9	9.0	10.6	8.8	9.5	8.3	28.4	24.8
9R100	7.8	7.0	9.7	8.2	10.4	9.4	9.3	8.2	27.9	24.6
SW9215	6.9	6.9	8.0	8.1	10.9	9.4	8.6	8.1	25.8	24.4
Sun Quest	7.4	6.6	9.8	7.6	12.4	9.9	9.9	8.0	29.6	24.1
AZ- 90NDC-ST	7.9	6.1	9.9	8.4	10.6	9.4	9.5	8.0	28.4	24.0
CW050085	7.8	6.3	9.9	8.0	10.4	9.3	9.4	7.9	28.1	23.6
FG R814W258S	7.0	6.5	9.3	8.3	11.1	8.5	9.1	7.8	27.4	23.3
AZ-88NDC	7.4	6.3	9.3	7.8	9.5	8.5	8.7	7.5	26.2	22.5
SW 9215-RRS *	7.6	6.2	10.3	7.4	10.6	8.4	9.5	7.3	28.4	22.0
CW058071	8.0	6.2	9.0	7.4	9.5	8.3	8.8	7.3	26.5	21.9
Desert Sun 8.10RR *	7.5	6.4	8.6	7.4	9.8	8.0	8.6	7.3	25.9	21.8
SW 9106 *	8.3	5.9	11.2	7.4	12.6	7.9	10.7	7.1	32.1	21.2
SW 8421-S	7.7	6.1	9.1	6.4	9.3	8.1	8.7	6.8	26.0	20.5
Average	*7.6*	*6.7*	*9.5*	*8.4*	*10.5*	*9.5*	*9.19*	*8.20*	*27.6*	*24.6*
CV (%)	*10.9*	*23.5*	*19.6*	*28.2*	*31.0*	*30.3*	*21.8*	*25.8*	*27.1*	*30.7*
LSD (P = 0.05)	*1.2*	*2.2*	*2.6*	*3.4*	*4.6*	*4.1*	*0.3*	*0.3*	*2.0*	*2.0*
Yield loss due to salinity	*13.0%*		*11%*		*9%*		*11%*		*11%*	

Trial 2 Results (basin irrigation)

- Soil salinities (9.7 – 15.8 dS/m ECe; 0 – 5 ft. depth), 2nd and 3rd year of trial
  - far above the established yield loss estimate (2.0 dS/m)



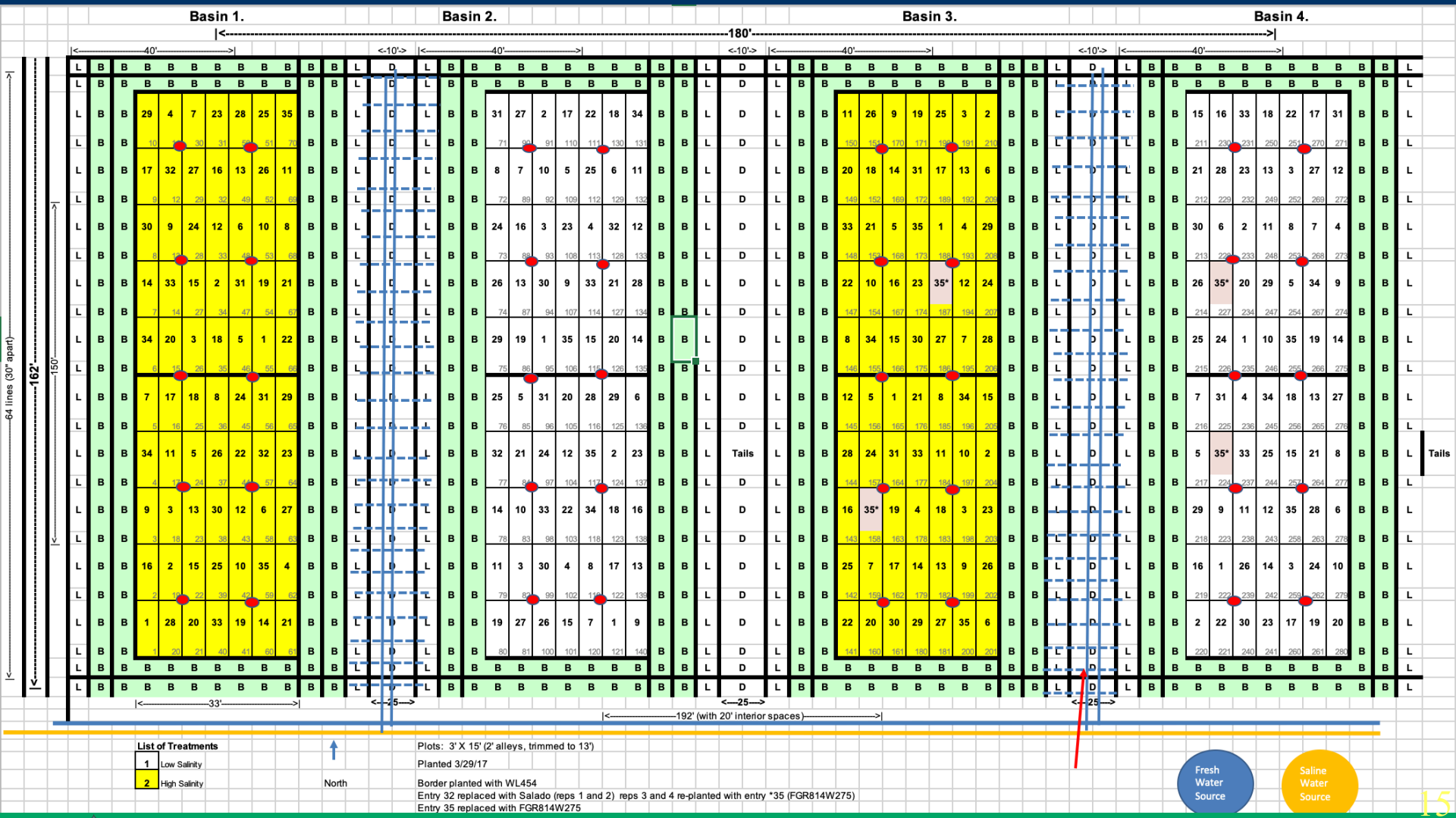
- Unable to rank varieties for salt tolerance due to the lack of uniform salinity and soil moisture within the basins.
- Greater variation due to secondary effects of sodicity (poor water infiltration and crusting) than to salinity, per-se



Soil salinity contour maps (ECe, dS/m, 0-150 cm depth),

October 2016 (end of 2nd year) of saline irrigation.

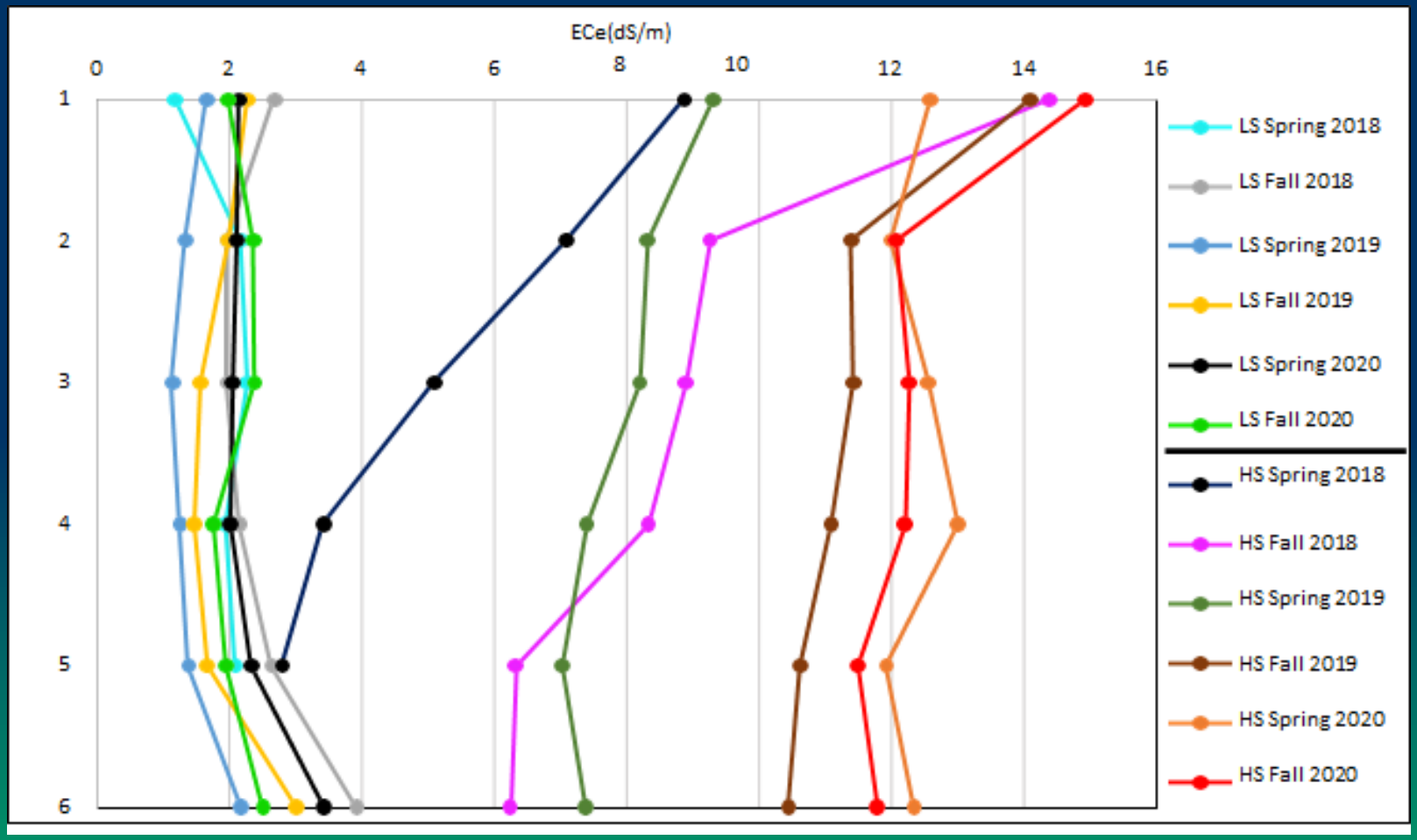
Trial 3


Basin 1.
Basin 2.
Basin 3.
Basin 4.
180'
40'
10'
25
33'
192' (with 20' interior spaces)
162'
150'
64 lines (30" apart)
Tails
List of Treatments
1 Low Salinity
2 High Salinity
North
Plots: 3' X 15' (2' alleys, trimmed to 13')
Planted 3/29/17
Border planted with WL454
Entry 32 replaced with Salado (reps 1 and 2) reps 3 and 4 re-planted with entry *35 (FGR814W275)
Entry 35 replaced with FGR814W275
Fresh Water Source
Saline Water Source

Trial 3 (subsurface drip irrigation)

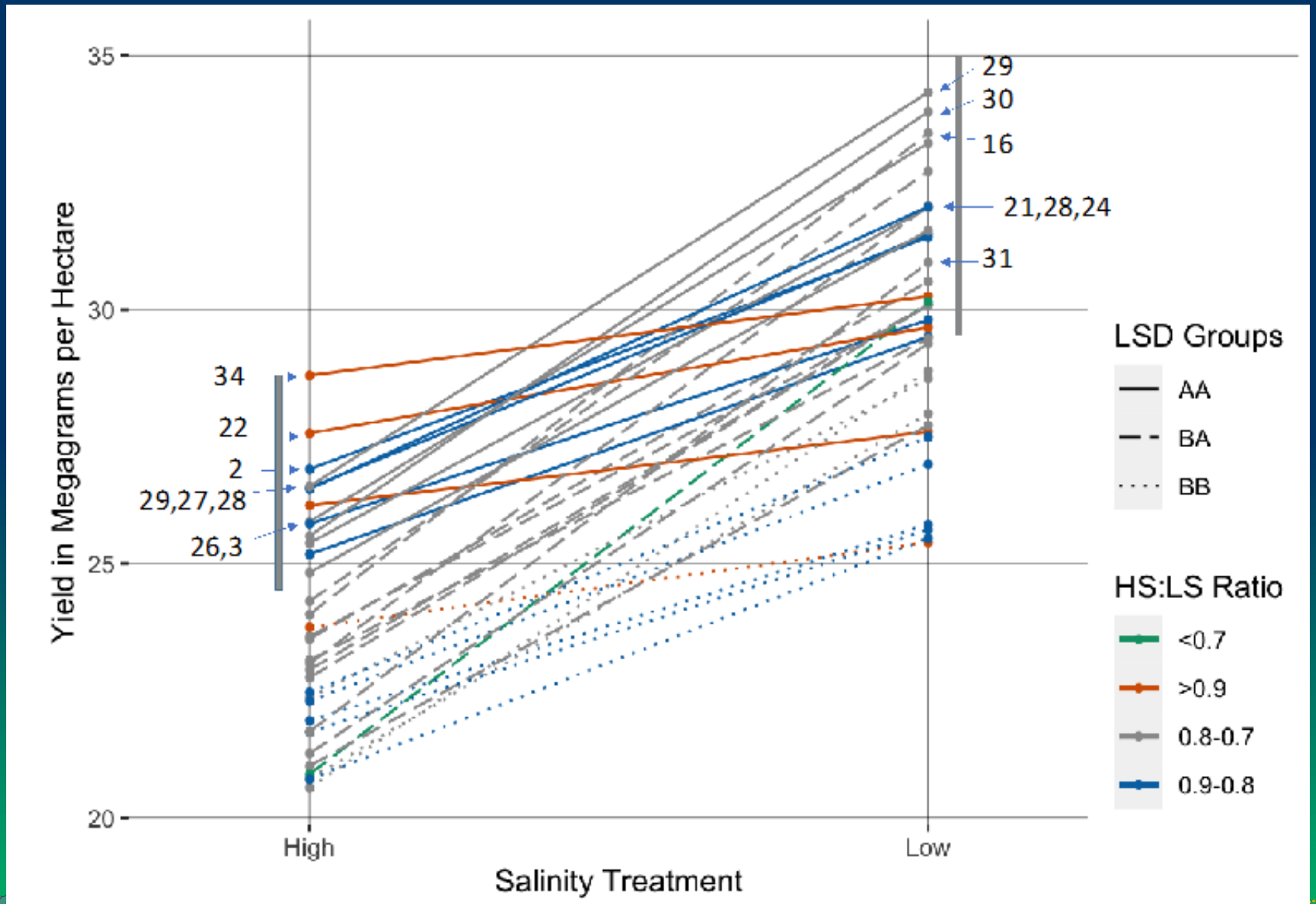
- 3.5 year alfalfa variety trial. 35 varieties
- (HS) 7- 11 dS/m - low saline
- (LS) 0.3- 1.2 dS/m ECw

Soil Salinity by depth in low salinity (LS) and high salinity (HS)-irrigated basins



Data points represent sampling at ten locations in each of two basins per treatment
HS had ~uniform salinity below 30 cm indicating some degree of leaching..

	2017 Season Yield (ton/A)		2018 Season Yield (ton/A)		2019 Season Yield (ton/A)		2020 Season Yield (ton/A)		Cumulative Average (t/A)	
Variety	**Low Salinity**	**High Salinity**	**Low Salinity**	**High Salinity**	**Low Salinity**	**High Salinity**	**Low Salinity**	**High Salinity**	**Low Salinity**	**High Salinity**
UC Salton	5.2	5.2	12.0	12.2	15.0	13.4	13.8	13.2	46.0	**44.0**
SW9573	5.5	5.1	12.0	11.3	14.4	13.3	15.0	13.0	47.0	**42.7**
SW9106M	4.7	5.5	12.9	10.4	15.2	13.2	16.4	11.3	49.2	**40.4**
AZ-88NDC	6.0	4.7	13.7	10.9	14.4	13.0	14.6	11.6	48.6	**40.4**
9R100	5.5	5.0	14.6	11.1	16.0	12.5	16.3	11.4	52.4	**40.0**
Integra 8810S	4.9	4.6	12.9	11.3	15.6	12.3	16.0	11.6	49.5	**39.8**
UC Impalo	4.5	4.9	12.7	9.9	15.4	12.3	15.2	12.5	47.8	**39.6**
PGI 908-S	5.4	5.0	14.3	9.8	15.9	13.0	17.1	11.6	52.7	**39.3**
SW8421RRS	5.0	5.5	13.5	11.3	16.2	11.7	17.3	10.7	52.0	**39.2**
CUF101	4.9	4.6	12.9	10.4	13.7	12.6	13.1	11.6	44.6	**39.2**
H0916ST223	4.5	4.9	10.8	10.5	13.8	12.8	12.3	10.8	41.4	**38.9**
SW9577	5.2	5.0	13.7	10.2	14.8	12.4	14.3	10.3	48.1	**38.0**
C0916ST232	5.3	4.8	12.9	10.7	13.4	11.8	13.9	9.9	45.5	**37.1**
SW9215RRS	4.8	5.2	13.3	10.1	15.8	11.5	15.9	10.0	49.8	**36.8**
R814W258S	4.8	4.7	11.8	9.1	15.0	11.9	16.1	10.9	47.8	**36.6**
SW8476	4.5	4.8	13.1	9.1	15.4	11.5	16.7	11.3	49.8	**36.6**
H0715ST209	4.5	5.0	10.2	10.4	12.5	10.8	14.5	9.5	41.7	**35.7**
AZ-90NDC-ST	4.8	4.4	12.5	9.3	14.8	11.6	15.5	10.1	47.6	**35.5**
R914W259S	4.2	4.5	11.5	9.0	15.4	11.3	15.6	10.1	46.6	**34.9**
R814W257S	5.2	4.6	13.7	9.4	16.1	12.0	16.4	8.7	51.5	**34.7**
SW8409	4.9	5.0	11.7	9.0	13.8	11.0	15.2	9.6	45.7	**34.5**
H0916ST218	4.9	4.9	12.1	9.4	14.2	11.2	13.5	9.0	44.6	**34.5**
SW8412	4.9	3.7	12.3	8.4	13.3	10.0	14.4	11.8	45.0	**33.9**
H0716ST227	4.2	4.4	10.6	9.0	12.4	10.5	12.9	9.6	40.1	**33.5**
FGR814W275	3.5	3.6	10.5	9.2	14.0	10.9	13.0	9.8	41.1	**33.5**
H0916ST216	4.5	3.7	11.5	8.5	12.6	11.4	12.9	9.7	41.4	**33.3**
SW9576	4.9	4.6	11.5	9.5	11.4	9.9	12.3	8.9	40.1	**32.8**
H0915ST214	4.3	4.0	11.3	8.9	15.5	11.5	16.1	8.3	47.2	**32.8**
AFX149092	4.7	4.0	13.5	8.3	14.1	11.1	14.7	8.7	47.0	**32.1**
H0915ST212	4.8	3.9	11.1	8.4	13.8	10.1	14.2	9.6	43.9	**32.1**
H0815ST210	4.7	4.0	11.8	8.4	14.3	10.5	15.7	8.7	46.5	**31.8**
H0916ST217	4.0	4.2	10.4	8.6	12.4	9.9	12.3	8.7	39.0	**31.4**
H0716ST222	4.9	4.3	12.9	7.9	14.0	10.7	12.0	8.1	43.8	**31.0**
H0715ST211	5.0	4.0	11.5	8.6	13.2	10.2	14.0	7.7	43.7	**30.5**
Average	4.8	**4.6**	12.3	**9.6**	14.4	**11.5**	**14.7**	**10.2**	**46.1**	**36.1**
Yield loss	**4%**		**22%**		**20%**		**31%**		**22%**	
Treatment Mean	4.7		11.0		13.0		13.0		41.1	
CV%	16.3		16.5		12.8		20.5		10.0	
LSD (p=0.05)	0.2		1.8		1.6		0.6		1.0	


35
30
25
20
Yield in Megagrams per Hectare
High
Low
Salinity Treatment
29
30
16
21,28,24
31
34
22
2
29,27,28
26,3
LSD Groups
AA
BA
BB
HS:LS Ratio
<0.7
>0.9
0.8-0.7
0.9-0.8

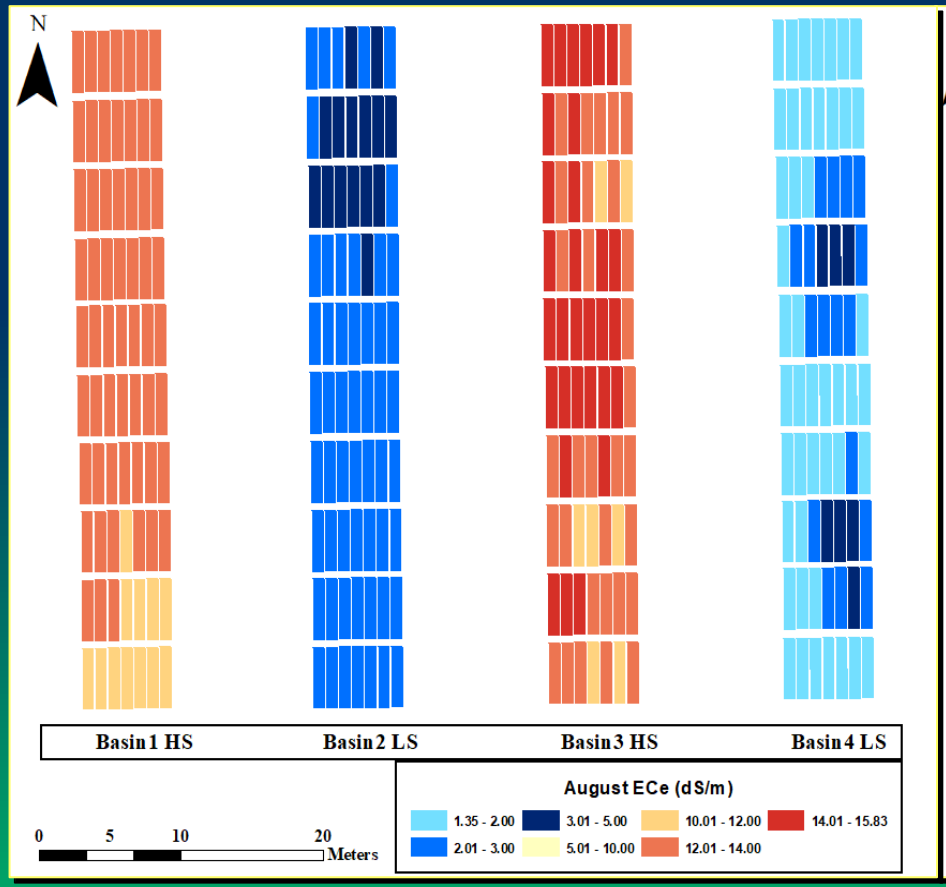
Na^+/K^+ Ratio (last 3 harvests of 2020)

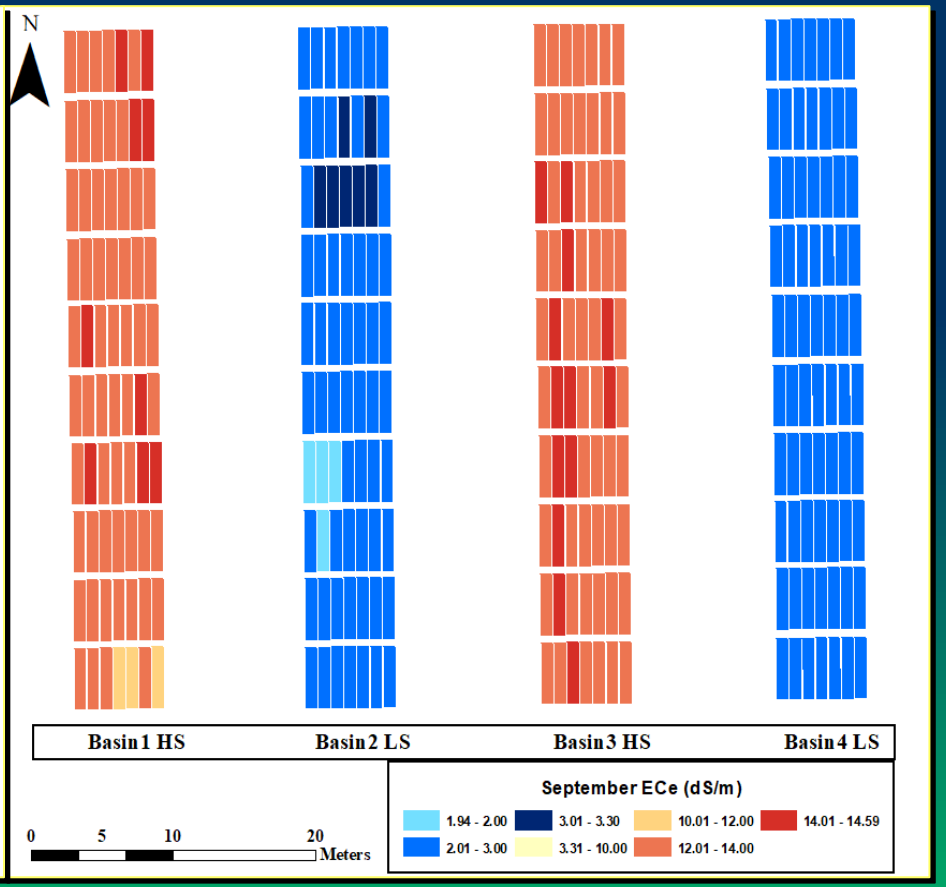
- Shoot Na^+/K^+ ratio has been used as an indicator of salinity tolerance
- The Pearson correlation (shoot Na^+/K^+ and dry matter yield) indicated that alfalfa shoot Na^+/K^+ ratio was negatively correlated with DM yield for the last three harvests of 2020.

DMY (ton/acre)	Na^+/K^+		
	August	September	October
August	-0.23*		
September		-0.63*	
October			-0.73*

*indicates significance at P< 0.05

Spatial map: soil salinity (ECe) in experimental basins. August & Sept. 2020 (year 3). Blue = low salinity. Orange and red = highly saline soils.





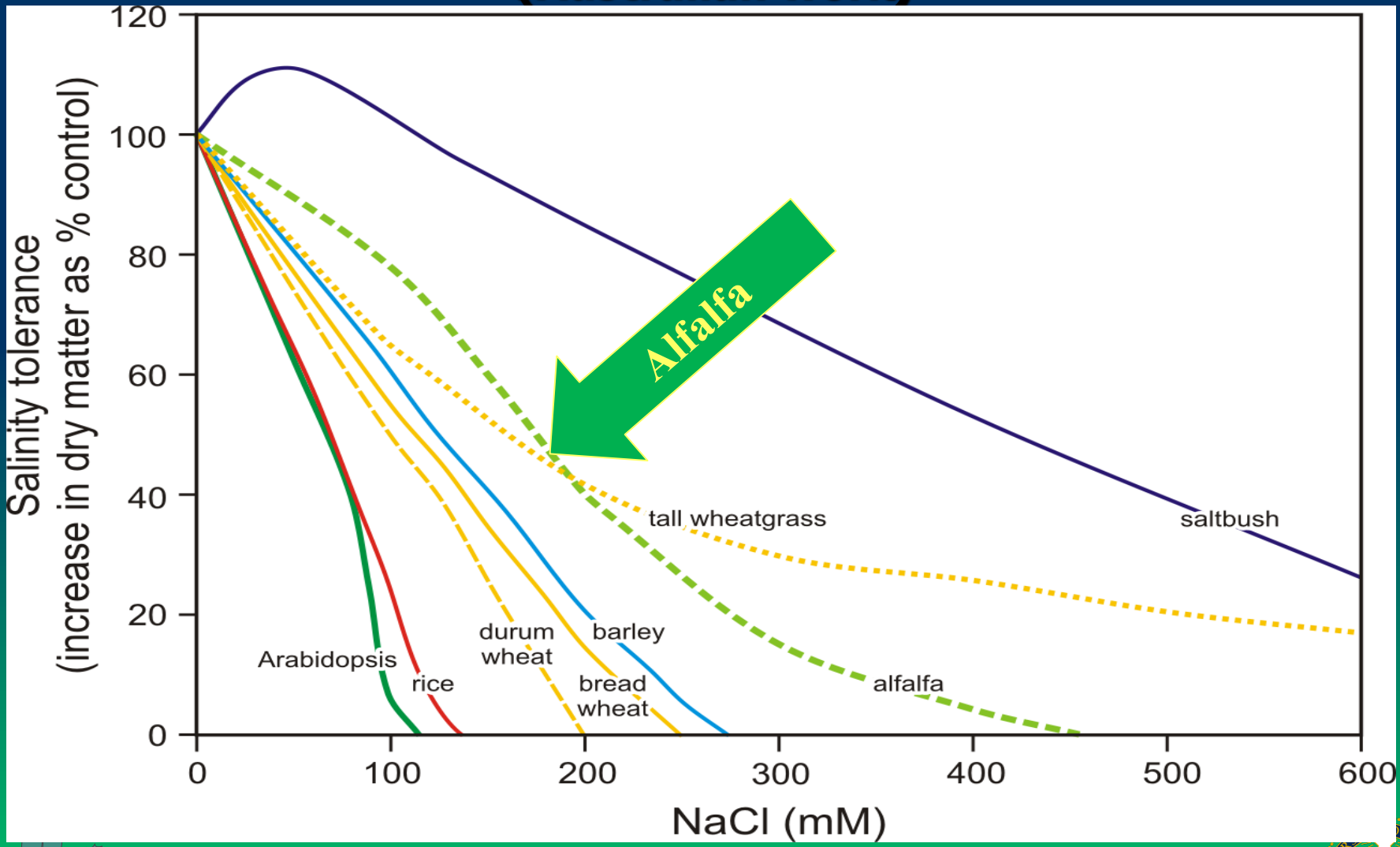
Field Studies: Overall Conclusions

- Established alfalfa is very tolerant of High Saline Conditions (ECs 6.5 or greater)
- Yield losses, but still economically viable at higher EC levels up to ECs 9-16 dS/m
- Boron tolerance (vs. other crops)
- Few significant salinity x variety interactions in field (High variability), but salinity tolerance was detected.
- 'Relative Yield' is a limited metric (absolute yield)
- Na+/K+ indicators?
- Soil effects may be more important than salinity per se. (esp. with sodicity)
  - Infiltration, water supply to roots, crusting drainage

Problems with Salinity:

- Osmotic resistance
- Ion toxicity
- Standing Water (Sodic)
- Lack of Infiltration
- Compaction/Crusts
- Salinity? Or Salinity-soil effects?
- Traits: anoxia tolerance? Root vigor?

Salinity tolerance
(Australian work)



Munns & Tester, Ann Rev Plant Biol, 2008

Thank You