WHAT IS THE ABILITY OF ALFALFA TO SUSTAIN SALINE CONDITIONS?

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Water Supply– *not enough for all users*

-- especially in drought years or when environmental restrictions are greater

Thursday, January 16, 2014: bulldozed almond trees in an orchard at Sagoupse Enterprises, western Fresno County. This third generation farmer removed 160 older almond trees (~10% of the crop) to reduce his demand for irrigation during a time of drastic water shortage. — Fresno Bee Staff Photo

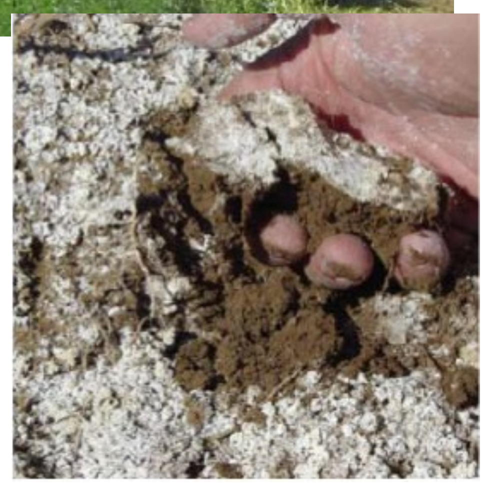
Read more here: http://www.fresnobee.com/2014/01/18/3721739/desperatemeasuresfor-valley-farmers.html#storylink=cpy

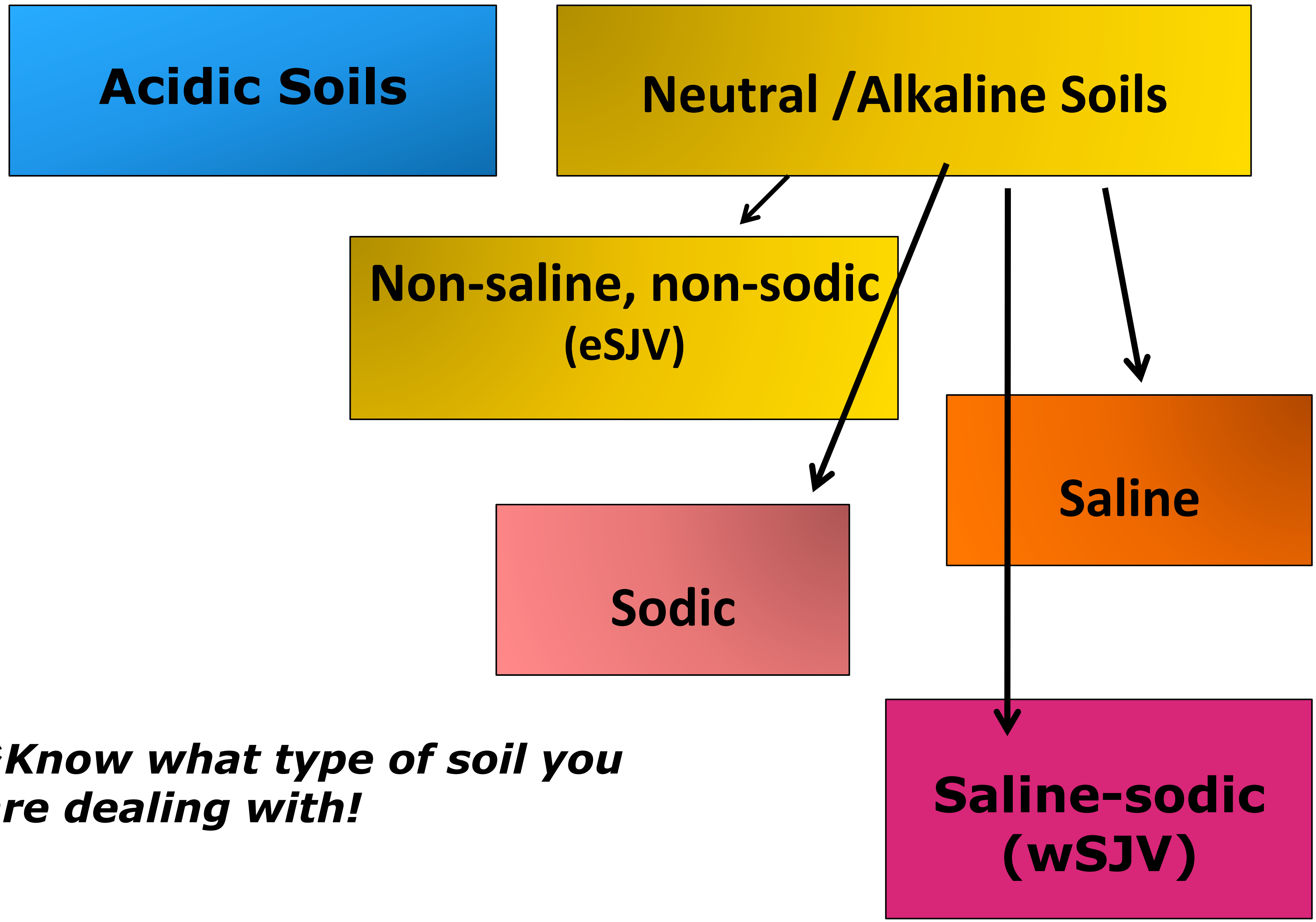
Future

- **Alfalfa grown on lower quality soils, utilizing lower quality water.**
- **Higher quality soil and irrigation water reserved for salt-sensitive, high value crops (grapes, almonds, citrus, lettuce).**
- **Deficit irrigation of alfalfa also more likely → soil salinity**
- **Commercial seed companies are developing more salt tolerant genotypes of alfalfa.**

Great interest now in salinity tolerance for alfalfa and management under saline conditions

Saline "White Alkali" is the most common type of saline soil found in North America and in most cases can be managed for alfalfa production





Know what type of soil you are dealing with!

Classification of Soils (or water)

	Salinity (ECe) (dS/m)	Sodicity (SAR)	pH	Physical Condition of Soil
Non-saline	< 4	< 13	< 8.5	Normal
"Saline"	> 4	< 13	< 8.5	Normal
"Saline-sodic"	> 4	> 13	< 8.5	Some degradation
"Sodic"	< 4	> 13	> 8.5	Poor

Proper management ⇒ proper determination of the soil condition:

Leaching to reduce salinity and amendments (gypsum, soil sulfur if free lime present) to reduce exchangeable Na+

Our approach to salt tolerance testing

- **Salt composition characteristic of the production area ($NaCl$, Na_2SO_4, ~boron)**
- **Soil system (or soil: sand mix) using a soil characteristic of the production area**
- **High transpiration conditions**
- **Long term*: field (2 years); greenhouse (6 months+)**
  - **Salinity has a cumulative effect**
  - **Alfalfa is a perennial**

Source water* for saline irrigation in our experiments (diluting hypersaline agricultural drainage water)

ECw (dS/m)	SAR	pH	Cl^{-} (meq/l)	SO_4^{2-} (meq/l)	Na^{+} (meq/l)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	B (mg/l)	NO_3-N (mg/l)	CO_3+HCO_3 meq/L
28.1	39.2	7.8	132	165	209	26.4	30.3	49	51.2	7.6

- -- saline-sodic
- -- alkaline
- -- high in boron

**Saline drainage water from Panoche Water District*– San Joaquin River Improvement Project (SJRIP)

Specific Research Objectives

<u>Overall</u>

- Determine the relative salt tolerance (germination %, emergence and established plant response) of 19 new alfalfa varieties grown under different salinity levels in the <u>greenhouse</u> and field. Included salt tolerant and salt sensitive checks developed at the University of Arizona.

- **Greenhouse: develop screening protocols closer to field conditions and identify key selection criteria**

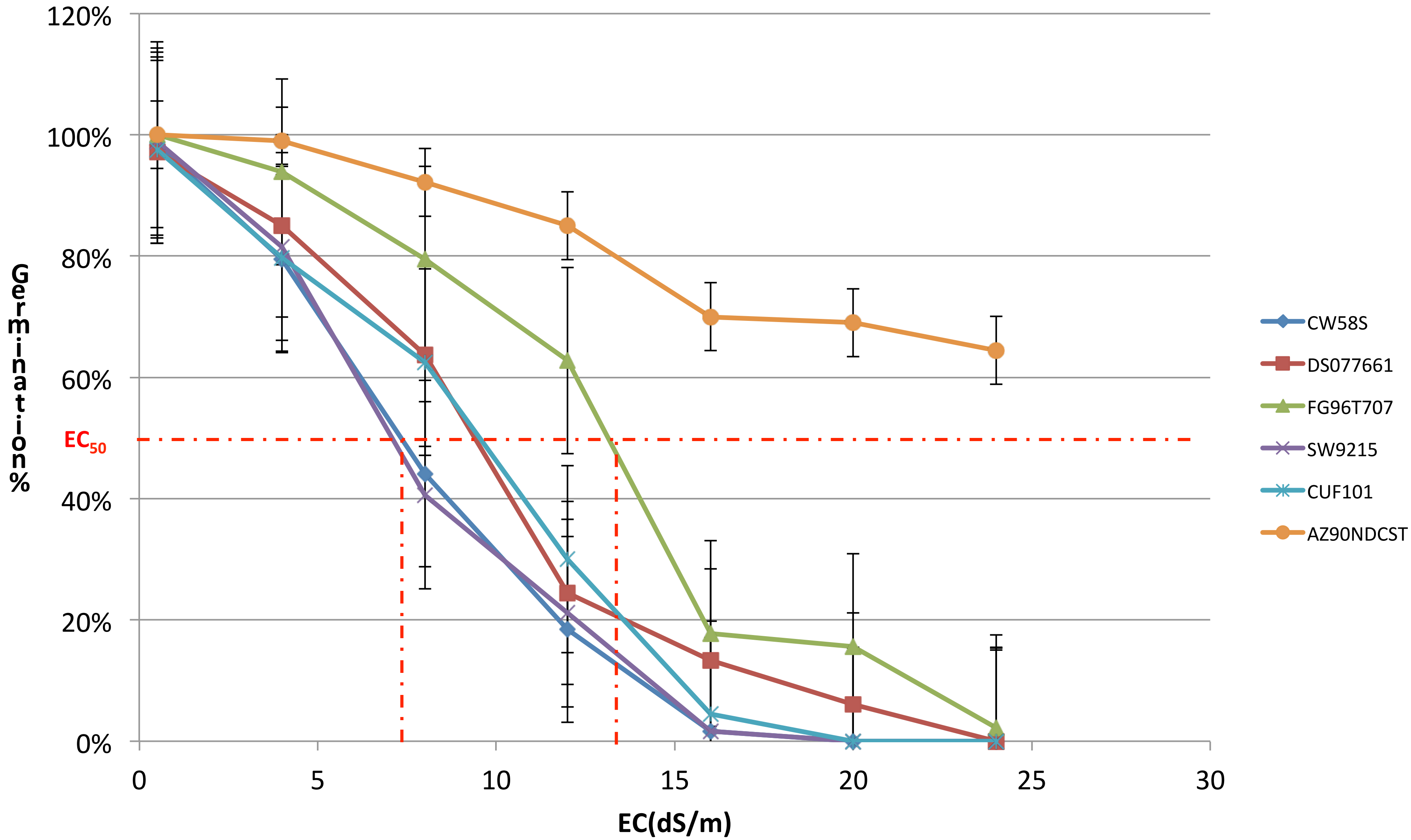
- **Investigate mechanisms of salt tolerance such as sodium exclusion from root and shoot tissue (Phase 3)**

Materials & Methods

This research consisted of 3 phases:

- **Phase1: Seed Germination Response**
- **Phase 2: Emergence & Early Seedling Growth Response**
- **Phase 3: Established Plant Response: biomass, Na, K, Cl- accumulation**
- **[Phase 4: Field Evaluation]**

Final Germination Percentage (means ± S.E.)-- *Day 7*



Phase 1- Seed Germination

Tolerance	Variety #	Variety name	EC50 Value(dS/m)
Tolerant	18	AZ90NDCST	31.4
"	17	AZGERM SALT II	28
Moderately tolerant	7	HYBRIFORCE800	13.32
"	2	SW8421S	13.06
"	9	FG96T707	12.8
"	6	AMERISTAND901SQ	11.8
"	13	CW8028	11.7
"	5	WL656HQ	10.6
"	1	SW9720	10.5
"	3	6906N	10.5
"	14	DS077661	10.2
"	4	CUF101	9.88
"	20	CUF101	9.8
"	10	CW9S	9.11
Sensitive	12	CW58S	8.77
"	15	SW9215	8.68
"	11	CW48S	8.65
"	8	DS067092	8.63
"	19	MESA SIRSA	8.07
"	16	AZ88NDC	6.76

EC_{50}

- salinity at which germination reduced to 50% of the non-saline control for that variety

Phase 2- Emergence & Early Seedling Growth

Tolerance	Variety #	Variety name	EC_w (dS/m)				
			4	8	12	16	20
Tolerant	17	AZ90NDCST	95%	49%	32%	9%	0%
"	18	AZGERM SALT II	96%	64%	31%	14%	0%
"	9	FG96T707	91%	63%	19%	3%	0%
"	2	SW8421S	91%	63%	19%	3%	0%
"	7	HYBRIFORCE800	97%	52%	17%	2%	0%
Moderately Tolerant	3	6906N	90%	47%	17%	0%	0%
"	10	CW9S	90%	63%	16%	0%	0%
"	14	DS077661	97%	56%	16%	0%	0%
"	15	SW9215	83%	45%	15%	0%	0%
"	13	CW8028	86%	38%	13%	0%	0%
"	5	WL656HQ	88%	50%	11%	0%	0%
"	11	CW48S	91%	51%	10%	0%	0%
"	1	SW9720	81%	49%	10%	0%	0%
"	12	CW58S	94%	39%	8%	0%	0%
"	6	AMERISTAND901SQ	91%	43%	7%	0%	0%
Sensitive	20	CUF101(a)	88%	38%	7%	0%	0%
"	4	CUF101(b)	88%	38%	7%	0%	0%
"	8	DS067092	79%	46%	6%	0%	0%
"	19	MESA SIRSA	66%	36%	6%	0%	0%
"	16	AZ88NDC	71%	27%	5%	0%	0%

Relative shoot dry weight (g/40 seedlings).

Day 30, saline irrigation from seeding to emergence

*Phase 3 (established plants)

- **19 varieties**
- **4 salinity levels (0.5, 5, 10 and 15 dS/m EC_w)**
- Experimental design: **split plot with salinity as the main plot and varieties as the sub plot**
- 3 replications
- Greenhouse: using tree pots (60:40 soil to sand mix)
- Plants were cut after every 4 weeks (~based on the flowering of the control)
- 7 cuts (7 month experiment)

Experimental Design

Rep 1	Rep 2	Rep 3
NS (20 pots)	**HS** (20 pots)	**LS** (20 pots)
MS (20 pots)	**LS** (20 pots)	**HS** (20 pots)
LS (20 pots)	**NS** (20 pots)	**MS** (20 pots)
HS (20 pots)	**MS** (20 pots)	**NS** (20 pots)

0.5 dS/m = Non-saline (NS)

5 dS/m = Low Saline (LS)

10 dS/m = Moderately Saline (MS)

15 dS/m = High saline (HS)

4 salinity levels x 20 varieties x 3 reps

.= 240 pots

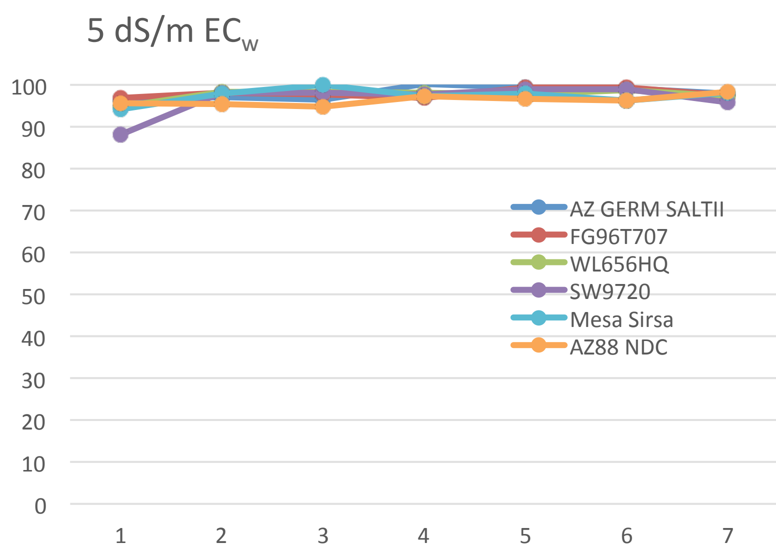
SPLIT PLOT DESIGN

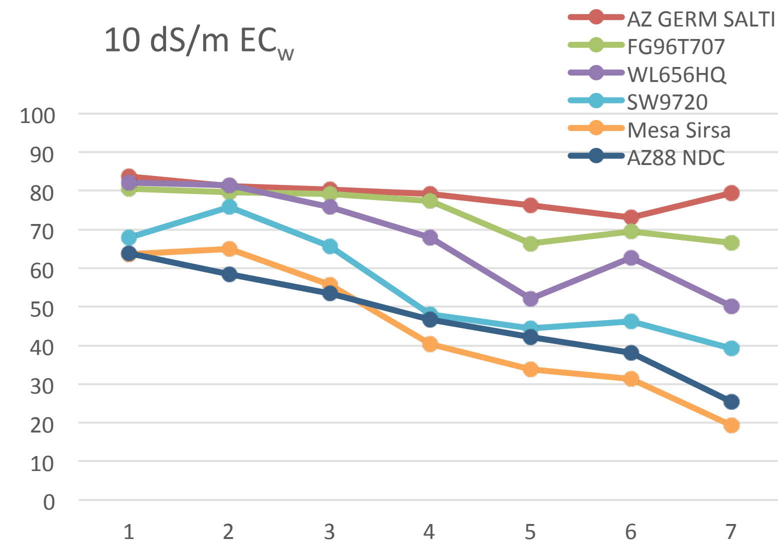
Main plot factor (salinity),

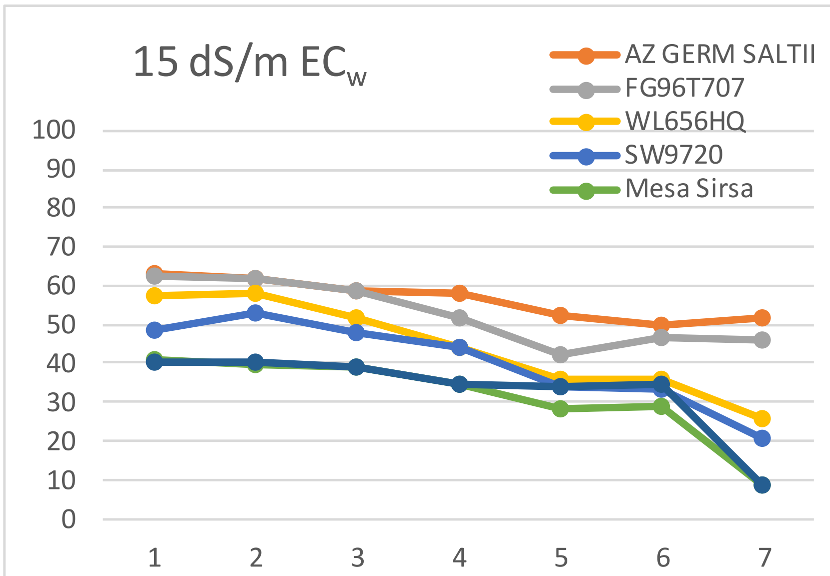
Sub-plot factor (variety)

Plants in the Greenhouse (Phase 3)

Relative Yield (%) of Shoots vs. Time (cut)







Relative Yield* (%) for Shoots– *sum of cuts 1 to 7 (cumulative)*

*as percentage of non-saline (0.5 dS/m) treatment

Tolerance *	Var. #	Variety name	EC_w(dS/m) 5	10	15
T	18	AZGERM SALT II	98.0	79.2	**57.0**
"	17	AZ90NDCST	98.0	77.3	**57.6**
"	7	HYBRIFORCE800	95.5	76.2	**56.3**
"	9	FG96T707	97.9	74.7	**53.6**
"	2	SW8421S	97.6	70.3	**52.6**
MT	8	DS067092	95.6	75.2	**48.0**
"	13	CW8028	95.8	72.1	**47.8**
"	5	WL656HQ	97.5	69.6	**46.4**
"	3	6906N	97.2	68.3	**46.4**
MS	15	SW9215	96.9	64.5	**43.2**
"	12	CW58S	96.2	65.7	**42.7**
"	20	CUF101(a)	94.7	54.9	**44.3**
"	4	CUF101(b)	94.6	54.7	**43.9**
	11	CW48S	96.2	62.2	**40.8**
"	1	SW9720	96.2	57.2	**41.9**
S	14	DS077661	97.2	60.5	**39.3**
"	6	AMERISTAND901SQ	97.0	57.9	**40.8**
"	10	CW9S	97.0	44.6	**40.6**
"	16	AZ88NDC	96.1	49.8	**35.4**
"	19	MESA SIRSA	98.3	45.8	**32.5**

Best
- **Hybriforce 800**
- **FG96T707**
- **SW8421S**

Next best
- **DS067092**
- **CW8028**
- **WL656**
- **6096N**

**based on performance at 15 dS/ ECw)*

Absolute Yield* (g/pot) for Shoots– *sum of cuts 1 to 7 (cumulative)*

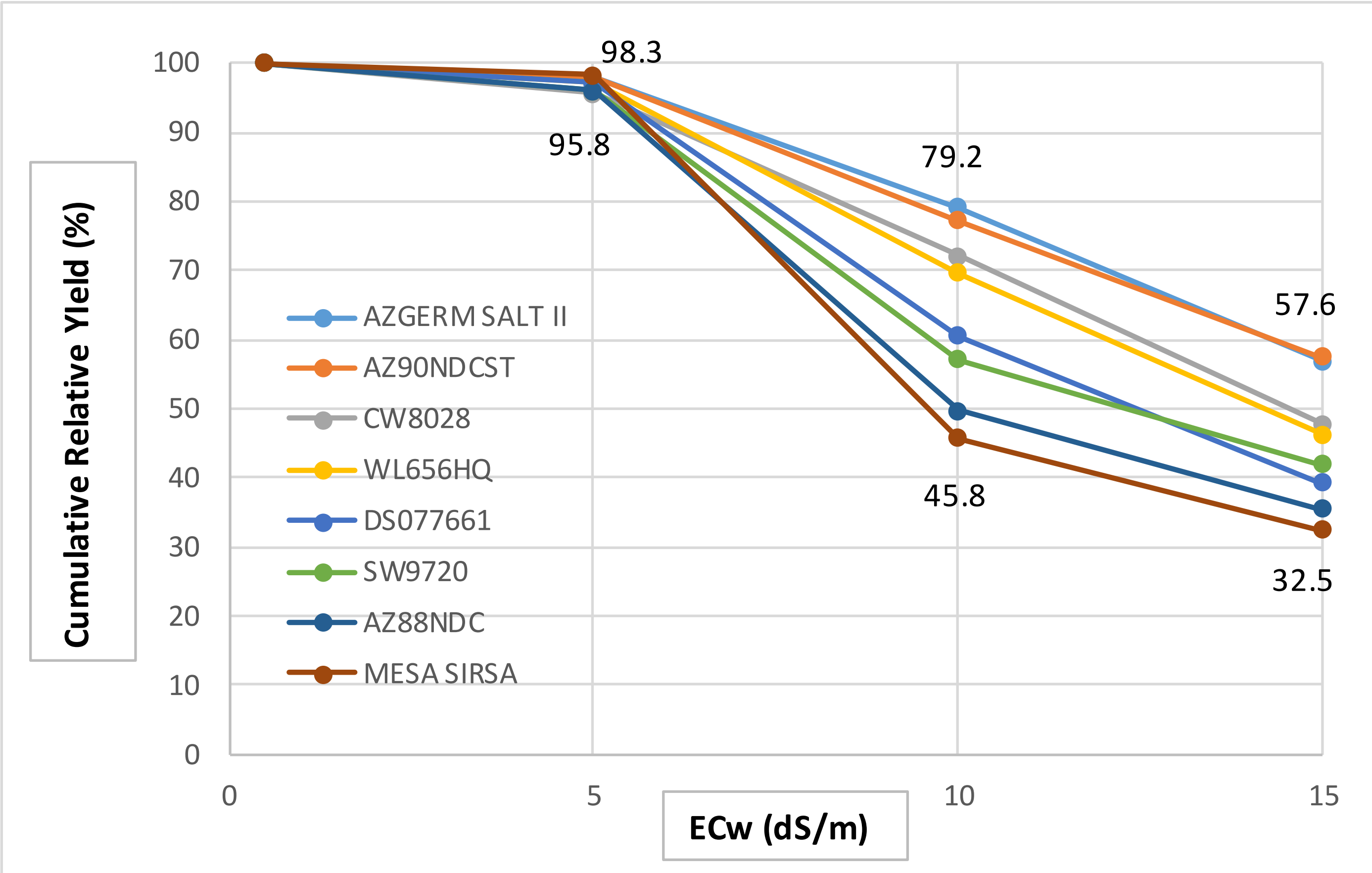
*as percentage of non-saline (0.5 dS/m) treatment

Tolerance	Var. #	Variety name	EC_w(dS/m)			
			0.5	5	10	15
T	18	AZGERM SALT II	36.5	35.8	**28.9**	**20.8**
"	17	AZ90NDCST	36.8	36.0	**28.4**	**21.2**
"	9	FG96T707	34.7	34.0	**25.9**	**18.6**
"	7	HYBRIFORCE800	31.2	29.8	**23.8**	**17.6**
"	2	SW8421S	30.0	29.3	**21.1**	**15.8**
MT	5	WL656HQ	29.2	28.5	**20.4**	**13.6**
"	1	SW9720	29.7	28.5	**17.0**	**12.4**
	11	CW48S	28.8	27.7	**17.9**	**11.8**
"	14	DS077661	29.2	28.4	**17.7**	**11.5**
"	12	CW58S	26.7	25.7	**17.6**	**11.4**
"	15	SW9215	26.7	25.8	**17.2**	**11.5**
"	6	AMERISTAND901SQ	29.2	28.3	**16.9**	**11.9**
MS	8	DS067092	22.9	21.9	**17.2**	**11.0**
"	3	6906N	23.4	22.8	**16.0**	**10.9**
S	13	CW8028	21.5	20.6	**15.5**	**10.3**
"	10	CW9S	26.7	25.9	**11.9**	**10.8**
"	20	CUF101(a)	21.8	20.7	**12.0**	**9.7**
"	4	CUF101(b)	21.9	20.7	**12.0**	**9.6**
"	16	AZ88NDC	26.0	25.5	**11.9**	**8.4**
"	19	MESA SIRSA	26.0	25.5	**11.9**	**8.4**

Same 3 top-performing varieties

Next group: 3 of 4 shifted

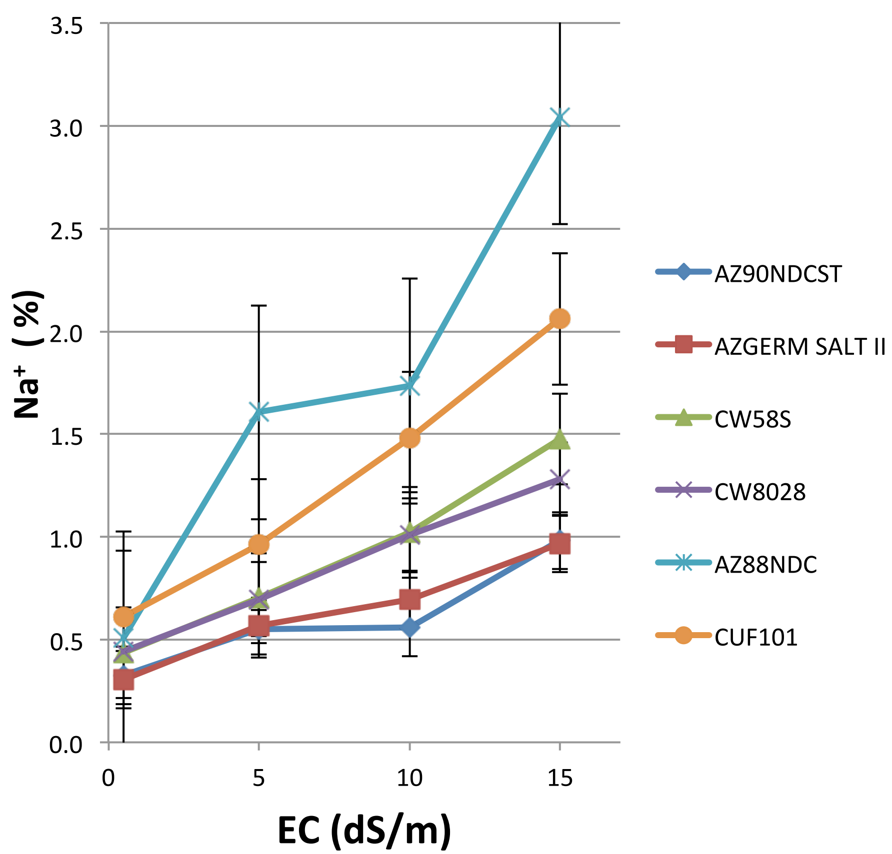
Shoot RY vs. EC_w



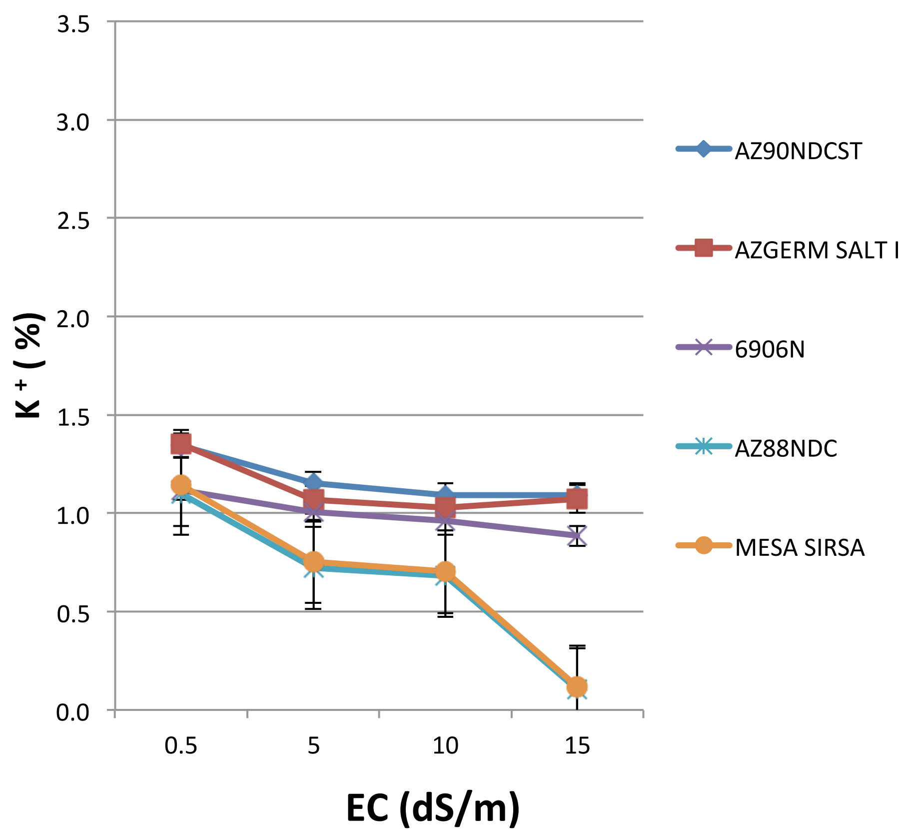
Var. #	18	17	13	5	14	1	16	19
Salinity	**ZGERM SALT**	**AZ90NDCST**	**CW8028**	**WL656HQ**	**DS077661**	**SW9720**	**AZ88NDC**	**MESA SIRSA**
0.5	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
5	98.0	98.0	95.8	97.5	97.2	96.2	96.1	98.3
10	79.2	77.3	72.1	69.6	60.5	57.2	49.8	45.8
15	57.0	57.6	47.8	46.4	39.3	41.9	35.4	32.5

Ion Accumulation in Shoots

Na (%) accumulated in alfalfa shoots--



K (%) accumulated in alfalfa shoots-



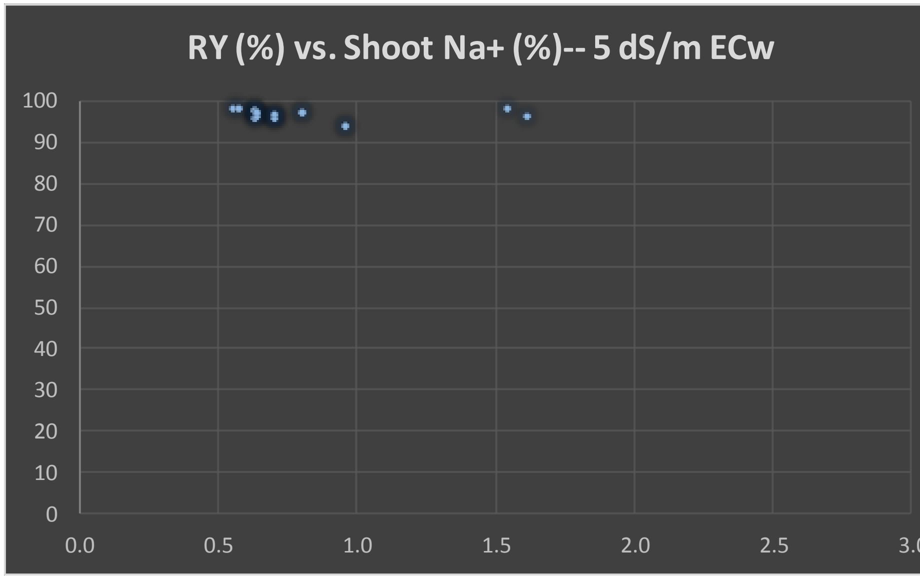
Shoot Na^+ & K^+ (% dry matter) and K/Na ratio– avgs. *Cuts 1 to 7*

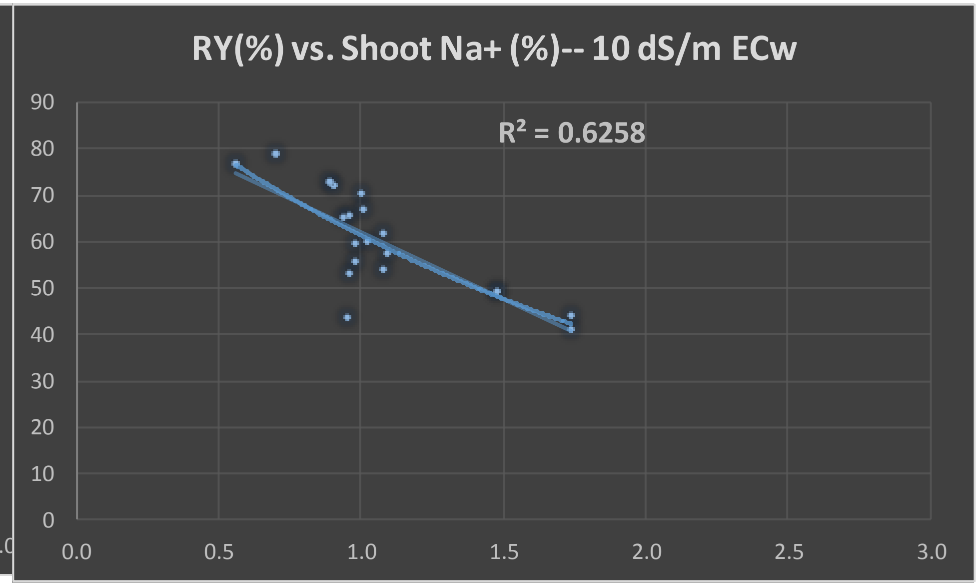
Red= top performers (shoot DM yield)
Blue = 2nd best performers (shoot DM yield)

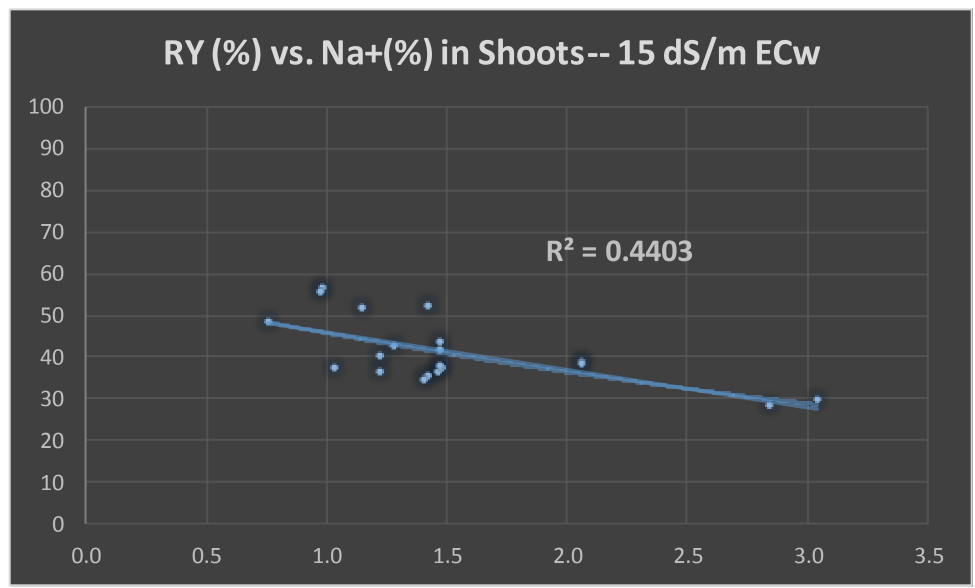
Variety Name	Var. #	ST ranking*	Na+ (%)				K+ (%)				K/Na			
			0.5	5	10	15	0.5	5	10	15	0.5	5	10	15
SW8421S	2	T	0.32	0.63	0.96	0.76	1.11	1.05	0.93	0.95	3.45	1.67	1.05	0.83
AZ90NDCST	17	"	0.33	0.55	0.56	0.98	1.35	1.15	1.09	1.09	4.14	2.07	1.94	1.11
AZGERM SALT II	18	"	0.30	0.57	0.70	0.97	1.35	1.07	1.03	1.07	4.37	2.04	1.49	1.11
SW9720	1	MT	0.37	0.70	0.96	1.03	1.11	1.09	1.01	0.83	2.96	1.56	1.06	0.81
FG96T707	9	T	0.31	0.63	0.89	1.15	1.17	1.15	1.02	0.95	3.78	1.84	1.14	0.83
6906N	3	MT	0.47	0.80	1.08	1.22	1.11	1.00	0.96	0.88	2.46	1.26	0.89	0.72
AMERISTAND901SQ	6	S	0.47	0.80	1.08	1.22	1.17	1.09	1.06	0.81	2.98	1.57	1.11	0.64
CW8028	13	MT	0.44	0.70	1.01	1.28	1.15	1.09	0.95	0.83	2.57	1.57	1.08	0.64
DS077661	14	S	0.42	0.64	0.98	1.40	1.21	1.10	1.02	0.76	2.86	1.71	1.04	0.55
HYBRIFORCE800	7	T	0.38	0.63	0.90	1.42	1.20	1.10	1.02	0.85	3.14	1.70	1.21	0.59
CW9S	10	S	0.42	0.64	0.95	1.42	1.21	1.10	0.95	0.68	2.86	1.71	1.01	0.49
CW48S	11	MS	0.40	0.64	1.09	1.46	1.22	1.09	1.05	0.69	2.96	1.69	0.96	0.48
WL656HQ	5	MT	0.40	0.63	0.94	1.47	1.15	1.09	1.02	0.76	2.90	1.73	1.11	0.52
DS067092	8	"	0.44	0.70	1.00	1.47	1.17	1.08	0.94	0.82	2.68	1.54	0.95	0.52
SW9215	15	MS	0.47	0.70	0.98	1.47	1.12	1.15	1.06	0.75	2.69	1.63	1.09	0.52
CW58S	12	"	0.44	0.70	1.02	1.48	1.20	1.11	1.02	0.75	2.76	1.70	1.01	0.51
CUF101	20	MS	0.61	0.96	1.48	2.06	1.07	0.89	0.70	0.05	1.76	0.93	0.47	0.28
CUF101	4	"	0.61	0.96	1.48	2.06	1.07	0.89	0.70	0.05	1.76	0.89	0.46	0.28
AZ88NDC	16	S	0.51	1.61	1.74	3.04	1.09	0.72	0.68	0.10	2.14	0.47	0.39	0.04
MESA SIRSA	19	S	0.55	1.54	1.74	2.84	1.14	0.75	0.70	0.11	1.97	0.49	0.40	0.04

*Tolerance ranking based on shoot relative yield (T= Tolerant, MT= Moderately Tolerant, MS = moderately sensitive, S= Sensitive)

Relative Yield (%) vs. Shoot Na^+(%)– *Average Cuts 1 to 7*







Conclusions- Established plant response (GH)

- Of the commercial varieties, **Hybriforce 800, FG96T707, SW8421S** were the top varieties based on relative shoot DM yield at 15 dS/m EC_w. For the most part, they
  - maintained lower Na^+ (and Cl-) and higher K^+ in the shoots (and roots)
  - higher root + crown dry matter production

- **DS067092, CW8028, WL656HQ and 6906N** were the next best varieties based on shoot DM yield and correspondingly, Na exclusion and K discrimination

- **Top performing varieties had consistent performance throughout the season (6 months, 7 cuts)**

- Considerable genetic variation existed in the materials tested.

		2010 Yield		2011 Yield		2012 Yield		Average								% of CUF 101
	FD	Dry t/a														%
Released Varieties																
WL 656HQ*	9	9.7	(13)	13.9	(1)	16.3	(4)	13.3	(1)	A						108
SW 9215*	9	9.6	(15)	13.8	(2)	16.4	(3)	13.3	(2)	A						107
*Ameristand 901STQ	9	10.7	(4)	13.4	(5)	15.5	(6)	13.2	(4)	A						107
Hybriforce 800*	8	11.0	(2)	13.3	(6)	15.2	(8)	13.2	(5)	A						107
Magna 995	9	9.5	(16)	12.8	(10)	15.5	(7)	12.6	(9)	A	B	C				102
CUF101*	9	9.7	(12)	12.4	(12)	14.9	(11)	12.3	(12)	A	B	C	D	E		100
CW 95	9	10.4	(5)	12.0	(16)	14.4	(16)	12.3	(13)	A	B	C	D	E		99.5
SW9803	9	10.0	(9)	12.1	(14)	14.6	(14)	12.2	(14)	A	B	C	D	E		99.1
CW 485	8	10.8	(3)	11.9	(17)	13.9	(17)	12.2	(15)	A	B	C	D	E		99
Medina	8.5	9.8	(11)	11.7	(20)	14.5	(15)	12.0	(16)		B	C	D	E	F	97
Highline	9	10.2	(6)	12.3	(13)	13.4	(22)	12.0	(17)		B	C	D	E	F	96.9
Integra 8900	9	9.2	(20)	11.8	(19)	14.8	(13)	11.9	(18)		B	C	D	E	F	96.7
AmeriStand 803	8	8.9	(25)	11.6	(22)	14.8	(12)	11.8	(19)		B	C	D	E	F	95.4
CW 585	8	9.4	(18)	12.1	(15)	13.5	(21)	11.7	(20)			C	D	E	F	94.5
BAR 9242	8.5	9.3	(19)	11.7	(21)	13.8	(19)	11.6	(21)			C	D	E	F	93.8
CW 8028*	8	10.1	(8)	11.9	(18)	11.8	(25)	11.3	(24)					E	F	91.3
GrandSlam	8	9.1	(24)	10.9	(25)	13.2	(24)	11.1	(25)						F	89.6
Experimental Varieties																
FG 96T706	9	9.1	(23)	13.5	(4)	17.1	(1)	13.2	(3)	A						107
FG 94T02	9	10.2	(7)	13.7	(3)	15.7	(5)	13.2	(6)	A						107
FG 96T707*	9	9.2	(21)	12.8	(9)	16.5	(2)	12.8	(7)	A	B					104
SW9812	9	9.9	(10)	13.1	(7)	15.1	(10)	12.7	(8)	A	B	C				103
DS593	9	9.6	(14)	12.9	(8)	15.1	(9)	12.5	(10)	A	B	C				102
UC 452	9	11.4	(1)	12.5	(11)	13.5	(20)	12.5	(11)	A	B	C	D			101
DS067092	8	9.5	(17)	11.4	(24)	13.8	(18)	11.6	(22)			C	D	E	F	93.7
DS077661*	8	9.2	(22)	11.5	(23)	13.3	(23)	11.3	(23)				D	E	F	91.8
MEAN		9.82		12.44		$\boxed{14.66}$		12.31								
CV		17.1		11.6		10.2		9.5								
LSD (0.1)		NS		1.43		1.48		1.15								

Field trial

UC Westside Research & Ext. Center

Irrigation water ~ 5 dS/m

High yield for most varieties. 2012 average: 14.6 tons/acre!

Overall Conclusions

- **Production at EC_w's of 5.0 dS/m insufficient pressure to reduce performance, but large yield loss between 5 and 10 dS/m EC_w**
  - **Maas-Hoffman Yield Loss threshold of 2.0 dS/m EC_e appears to be too low**

Table 3. Salt tolerance of herbaceous crops — Grasses and forage crops.

Crop	*Threshold*	*Salinity (A)*	*Slope (B)*
Alfalfa	$\boxed{2.0}$	$\boxed{7.3}$	$\boxed{\text{MS}}$
Alkali grass, nuttall			T
Alkali sacaton			T
Barley (forage)	6.0	7.1	MT
Bentgrass			MS
Bermuda grass	6.9	6.4	T
Bluestem, Angleton			MS
Brome, mountain			MT
Brome, smooth			MS
Buffelgrass			MS
Burnet			MS
Canary grass, reed			MT
Clover alsike	1.5	12.0	MS
Clover, Berseem	1.5	5.7	MS
Clover, Hubam			MT
Clover, ladino	1.5	12.0	MS
Clover, red	1.5	12.0	MS
Clover, strawberry	1.5	12.0	MS
Clover, sweet			MT
Clover, white Dutch			MS
Corn, forage	1.8	7.4	MS
Cowpea (forage)	2.5	11.0	MS

**S = sensitive; MS = moderately sensitive; MT = moderately tolerant, T = tolerant*

What might be a new soil salinity threshold for newer ST alfalfa varieties?

<u>Final</u> soil salinities- established plant experiment in greenhouse

Irrigation			Ratio
EC_w (dS/m)	Rep	Soil EC_e*	EC_e/EC_w
0.5	1	0.66	1.3
5	1	9.27	1.9
10	1	15.5	1.6
15	1	20.0	1.3

Irrigation with 5 dS/m water had little impact on shoot dry matter yield in field and greenhouse.

GH: ratio of <u>final</u> soil salinity to irrigation water salinity ranged from 1.3 to 1.9.

Taking a conservative approach, we speculate that these ST alfalfa varieties could have a yield loss threshold of

5 dS/ ECw x 1.3 = 6.5 dS/m ECe

-- or at least considerably higher than current MH threshold (2.0 dS/m ECe)

Overall Conclusions cont'd

- **Shoot Na^+ & K/Na are good predictors of salt tolerance in alfalfa, but do not tell entire story**
  - relatively good correlation (0.625) with shoot relative yield, but for a given Na^+ concentration in shoots, RY could be quite different, suggesting that **tolerance to the osmotic stress is also key** to salt tolerance in alfalfa.

Future Work

- **Standardize Phase 2 and 3 protocols** to allow seed companies to test under conditions using
  - mixed salt solutions
  - soil (or soil: sand mix), rather than greenhouse potting mix
- **New field trial in the ground– salinized soil at planting and irrigation water will be higher in salinity (8-10 dS/m)**
- **Examine effects of salinity on N_2 fixation and the N fertilizer requirement of alfalfa**

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- Dan Karsten (S&W Seed)
- Dan Gardner (Dairyland /Alforex). *Now at S&W seeds*
- Don Miller and John Reich (Cal West / Alforex)
- John Lyons (Novozymes)

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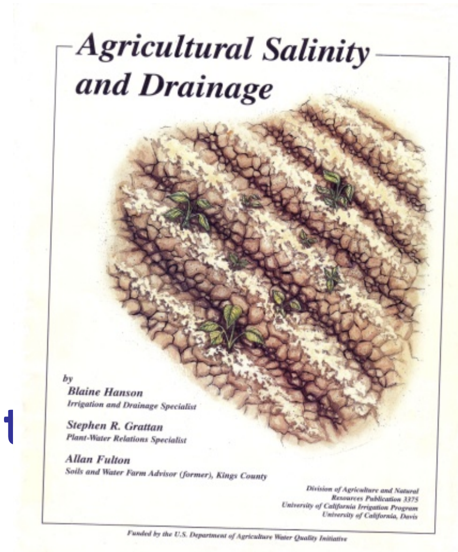

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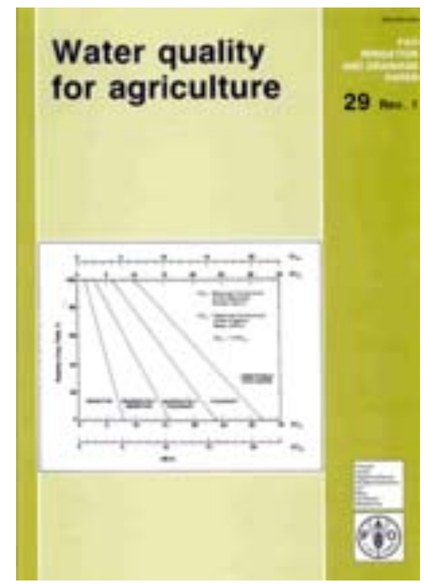

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