WHAT IS THE ABILITY OF ALFALFA TO SUSTAIN SALINE CONDITIONS?

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ABSTRACT

Greenhouse and field experiments were conducted to evaluate released and experimental varieties of alfalfa for their tolerance to saline irrigation imposed at different growth stages. Based on the relative shoot dry matter yield (calculated as a percentage of the non-saline control) of established plants grown in the greenhouse and irrigated with dilutions of saline drainage water from the western San Joaquin Valley, we speculate that these newer "salt tolerant" varieties of alfalfa can maintain yield when irrigated with 5 dS/m water in the short term and perhaps for as long as three years, as suggested by our field results. This assumes that the plants were sown into non-saline soil and the outcome of irrigating with water of a certain salinity level will certainly vary from site to site depending on the soil texture, leaching fraction, soil chemistry and climate. With regard to the soil salinity at which at which we would expect to see yield losses in alfalfa, we speculate that under low salinity irrigation ($\leq$ 2 dS/m EC_w), alfalfa could be grown without significant yield loss in soils having salinities as high as 6.5 dS/m EC_e, assuming that water-logging, low soil moisture, or other soil conditions are not limiting yield. This soil salinity value (6.5 dS/m EC_e) is considerably higher than the threshold value for yield loss of 2.0 dS/m ECe reported by Maas and Hoffman (1986) and Maas and Grattan (1999), suggesting that many of the newer "salt tolerant" varieties are indeed more salt tolerant than those available in the 1980's when the salinity tolerance coefficients for alfalfa were developed. Our greenhouse data also suggest that concentrations of Na^+ and K^+ and the K/Na ratio in shoot tissue appears to be a useful screening tool for evaluating alfalfa germplasm for salinity tolerance. Although the root tissue showed similar patterns of ion accumulation in response to salinity, there is greater ease in sampling shoot tissue progressively over a season.

Key Words: alfalfa, CUF-101, leaching fraction, saline irrigation, salt tolerance, sodium exclusion

INTRODUCTION

Given the scarcity of irrigation water, increased frequency of drought and the salt-sensitivity of many high value crops grown in the San Joaquin Valley of California, such as grapes, almonds, citrus, lettuce and other vegetables, it is likely that alfalfa and other forages will be irrigated with more saline waters in the future. These saline water sources could include well waters, agricultural drainage waters, or wastewaters from animal production and food processing plants, or reclaimed municipal water. Utilization of saline waters for irrigation not only increases the supply of freshwater for other beneficial uses, but it can also solve some major environmental issues associated

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with the storage and management of saline wastewaters. Additionally, important alfalfa production areas such as the Imperial Valley and western San Joaquin Valley have salt-affected soils, thus salt tolerance is an increasingly important trait for alfalfa breeding and variety selection.

Alfalfa is grown on nearly one million acres in California, stretching from the Imperial Valley in the south to the Intermountain areas in the north. It is the highest acreage crop and the most widely used forage for California's large dairy industry which produces 21% of the nation's milk at a value over 5 billion dollars per year in recent years (Putnam et al., 2007. UC-ANR publication #8287). Thus, the utilization of alternative water supplies for alfalfa irrigation could free up a considerable volume of high quality water for the irrigation of more salt-sensitive crops. In addition to this expansion of the water sources deemed suitable for alfalfa irrigation, it is also likely that deficit irrigation will be employed which would likely result in increased soil salinity in alfalfa production fields. Fortunately, recent observations suggest that alfalfa can be managed under saline conditions, perhaps to a greater degree than has been previously thought (Sanden and Sheesley, 2012).

Commercial seed companies have forecasted the need for increased salt tolerance in alfalfa and have demonstrated commitment to the development of salt tolerant varieties (Miller, 2013; Reich, 2012; Reisen et al., 2013; Gardner, 2013). However, many of these genetic constructs have been primarily tested under laboratory, growth chamber or greenhouse conditions. It is to be expected that the more complex, multiple stress conditions in grower's fields represent additional challenges that necessitate field testing (Lauchli and Grattan, 2007).

Our objectives have been to conduct ongoing field and greenhouse-based studies to test crop responses of alfalfa varieties to different irrigation water salinities which will induce different levels of salt-stress in the forage. This is a work in progress, with the overall goal to develop public trials which can assist farmers and seed companies in identifying and confirming salinity tolerance in alfalfa.

METHODS & RESULTS

Greenhouse and Laboratory Testing

The objective of this research was to evaluate the salt tolerance of released and experimental varieties of alfalfa under controlled conditions and with salinity imposed at different stages in plant development: seed germination (Phase 1), emergence and early seedling growth (Phase 2) and established plant response (Phase 3). A second objective was to develop greenhouse protocols as close to the field conditions as possible. For example, rather than using solutions of NaCl, the irrigation water used for the emergence and established plant experiments was prepared from dilutions of hypersaline drainage water collected from a sump located in the San Joaquin River Improvement Project operated by Panoche Water District. Thus, the saline irrigation water had a salt composition similar to that found in salt-affected areas of the western San Joaquin Valley. Likewise, a clay loam soil collected near

Five Points, CA was used for the established plant experiment in the greenhouse (Phase 3) and was mixed with sand (60:40, soil to sand) to ensure adequate infiltration and drainage. Even after mixing, this soil maintained the cracking clay properties and tendency to form a surface crust, similar to many soils in the western San Joaquin Valley.

Phase 1 (Seed germination)

Seed germination was tested in petri dishes with saline solutions (dilutions of hypersaline drainage water) applied to the germination paper lining the dish. Under non-saline conditions (0.5 dS/m), the mean germination percentage (GP) on Day 7 for all cultivars was 97% ± 0.04% and there were no significant differences among varieties (*P*= 0.05). As the salinity (EC_w) of the incubation solution increased, the GP of most varieties decreased steadily with no threshold for germination loss (Fig. 2). At 4 dS/m, the mean GP for all cultivars was 88% ± 1% and the effect of variety on germination percentage was significant (*P = 0.05*), as it was for all the other salinity levels. At salinities of 8 dS/m or above, the effect of salinity on seed germination became much more pronounced: at 8 dS/m ECw, mean GP was 60% ± 4.38% (range of 26% to 92%) with the susceptible check (AZ88NDC) having the lowest GP and the tolerant checks (AZ 90 NDC ST and AZ GERM SALT II) having the highest GP.

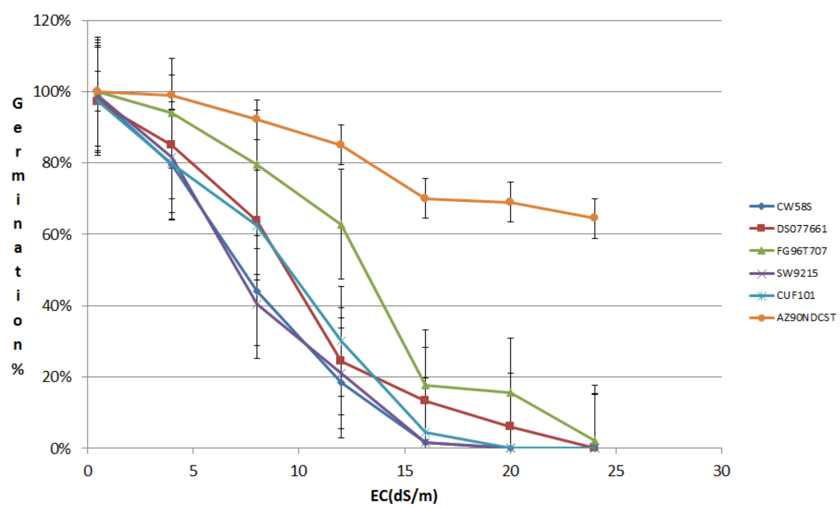


Fig. 2: Seed Germination Percentage (% relative to non-saline control) for seeds incubated in dilutions of saline drainage water from 0.5 to 20 dS/m EC_w

At 12 dS/m EC_w, the mean GP was 42% ± 5 (range of 4% to 84%) and at 16 dS/m it was 13% ± 4% (range of 0% to 70%). At the highest levels of salinity (20 and 24 dS/m ECw), average GP for nearly all varieties was less than 10%. However, the most tolerant varieties (AZ90NDCST and AZ GERM SALT II) maintained 64% and 74% germination, respectively, at 24 dS/w ECw which was significantly higher than all other cultivars: given that the mean GP for all other varieties was only 4% at this highest salinity level, it appears that there is a high degree of genetic variability in seed germination potential under saline conditions amongst these varieties.

EC50 values (irrigation water salinity (ECw) at which seed germination is reduced to 50% of the non-saline control germination) were used to rank the varieties for salt tolerance at the germination stage. Other than the salt tolerant (AZ) checks which are not commercially available, Hyrbriforce800, SW8421S and FG96T707 had the highest EC50's, indicating that these varieties were the most tolerant at the germination stage.

Table 1: EC50 values (ECw at which germination was reduced to 50% of the non-saline control germination) for seeds incubated in dilutions of saline drainage water from 0.5 to 20 dS/m EC_w

Tolerance	Variety #	Variety name	EC_{50} Value (dS/m)
Tolerant	18	AZ90NDCST	31.4
"	17	AZGERM SALT II	28
Moderately tolerant	7	HYBRIFORCE800	13.3
"	2	SW8421S	13.1
"	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

Phase 2 (Emergence and Seedling Growth)

Seeds were sown into plug trays containing a 60:40% sand to soil mix and the saline solutions were applied with step-wise increases in salinity over a 3-day period. Seedling biomass was recorded 30 days after sowing and was calculated relative to the non-saline treatment (0.5 dS/m) for that variety. Salinities above 8 dS/m (EC_w) substantially reduced the emergence and growth of the alfalfa seedlings: with the exception of the two salt tolerant checks (AZ90NDCST and AZGERM SALT II), relative shoot dry weight was less than 20% of the non-saline treatment when the plants germinated and emerged under irrigation at 12 dS/m EC_w (Table 2). These data support results of other studies which show that the seedling phase is typically more salt-sensitive than is the germination phase.

Table 2: Relative shoot dry weight (g/40 seedlings) of alfalfa seedlings irrigated with saline drainage water (0.5 to 20 dS/m) for 30 days from seeding through emergence in a greenhouse experiment.

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%

Phase 3

For Phase 3 (established plants), seedlings were grown under non-saline conditions, transplanted into tree pots (10 x 10 x 36 cm, 2.33 L volume) filled with a 50:50 clay loam: sand mix and grown for four more weeks after which they were cut to the crown and saline treatments began. For nearly all varieties, the relative dry matter yield for shoots (Table 3) and for roots + crowns (data not shown) decreased significantly when the EC_w was > 5 dS/m.

Table 3: Cumulative shoot relative yield (% of non-saline (0.5 dS/m) control) for established plants irrigated with saline water (0.5 to 15 dS/m) in a greenhouse experiment. Cumulative data (sum of cuts 1 to 7) were used.

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
"	14	DS077661	97.2	60.5	39.3
"	6	AMERISTAND901SQ	97.0	57.9	40.8
S	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

Based on cumulative shoot relative yield at both 10 and 15 dS/m EC_w and excluding the Arizona materials which are not destined for release, three varieties were ranked as the most salt tolerant amongst those tested and another four varieties were considered to be the next most tolerant based on the established plant (Phase 3) response.

Most Tolerant	Moderately Tolerant
Hybriforce 800	DS067092*
FG96T707	CW8028
SW8421S	WL656HQ
	6906N

**not ranked high for seed germination or emergence/early seedling growth under saline irrigation*

When irrigated with 15 dS/m irrigation water, the most tolerant varieties had cumulative shoot relative yields of 52 to 57% and the moderately tolerant group had shoot relative yields of 46 to 48%; whereas the most salt-sensitive varieties had shoot relative yields of 40% or less. Interestingly, the most tolerant varieties based on established plant response (Hybriforce 800, FG96T707 and SW8421S) were also the top-ranked varieties when salinity was imposed at the germination stage (Phase 1) and at the emergence/ early seedling growth stage (Phase 2).

The variety DS067092 had a cumulative shoot relative yield close to that of the most tolerant varieties at 15 dS/m EC_w and even surpassed two of these varieties under irrigation with 10 dS/m irrigation water, but it ranked poorly with regard to seed germination and emergence/ early seedling growth under saline irrigation. However, the other three varieties ranked as moderately tolerant based on established plant response (CW8028, WL656HQ and 6906N) ranked relatively high with regard to seed germination and emergence/ early seedling growth under saline irrigation.

For most varieties, Na^+ and Cl^- concentrations in shoots (Table 4) and in roots + crowns (data not shown) steadily increased (and K+ decreased) as the irrigation water salinity increased. However, the most tolerant varieties exhibited much less of an increase in Na^+ and Cl^- (and decrease in K^+) in the shoot tissue, and in root + crown tissue, indicating that toxic ion exclusion and K^+ discrimination (over Na^+) are key tolerance mechanisms in these alfalfa varieties. Toxic ion exclusion at the organ level therefore appears to be much more significant for alfalfa, as compared to the compartmentalization of toxic ions in vacuoles, a salinity tolerance mechanism more commonly reported for halophytic plants. Hence along with monitoring shoot dry matter yield, the monitoring of Na^+, K^+ and K/Na ratio in shoot tissue appears to be a useful screening tool for evaluating alfalfa germplasm for salinity tolerance. Although the root tissue showed similar patterns of ion accumulation in response to salinity, there is greater ease in sampling shoot tissue progressively over a season.

Table 4: Shoot Na^+ and K^+ concentrations (% DM) and K/Na ratio for alfalfa irrigated with saline water (0.5, 5, 10 or 15 dS/m EC_w) from January 2013 to June 2013 in a greenhouse experiment. Data are the averages for Cuts 1 to 7.

red= top ranked and blue = next best ranked based on shoot DM yield

	Var.	ST			Na+ (%)				K+ (%)				K/Na	
Variety Name	**#**	**ranking***	**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)

Field trial (2010 – 2014)

This trial was conducted at the University of California's Westside Research & Extension Center (WSREC) and evaluated the salinity tolerance of 24 new, or recently introduced, alfalfa varieties from ten seed companies and the UC breeding program. Eight of these 24 varieties were also tested in the greenhouse experiment. Yield and forage quality were measured for three full growing seasons (2010 to 2012) with a final harvest in June 2014. The trial was irrigated with water from the most saline well at WSREC which averaged close to 5 dS/m EC_w from 2010 to 2012, but was higher (~7 dS/m) prior to the final harvest. Soil salinities in fall 2011 were not significantly higher than the irrigation water salinity, averaging 5.01 and 5.85 dS/m ECe for the 0-12 and 12-24 ft. depth, respectively. However, after the final harvest (June 2014) the soil salinity was higher, averaging 8.91 dS/m ECe for the 0-12 in. soil depth.

The high yields obtained, e.g. average of 12.4 tons per acre in 2011 and 14.7 dry tons/acre in 2012 (Table 5), suggest that irrigation with 5 dS/m water did not impose a high enough level of salt stress to reduce yield to a large extent or to effectively separate the newer, purportedly more salt tolerant varieties. Table 1 shows the harvest results from 2010 to 2012. Based on the average yield for these three seasons, the released varieties WL656HQ, SW9215, Ameristand 901STQ and Hybriforce 800 and the experimental varieties FG96T706 and FG94T02, had the highest numerical yields (107 to 108% of the "public control, CUF-101) but their yields were not statistically higher than CUF-101; nor were they significantly higher than the next four released varieties (Magna 995, CW95, SW9803, CW485), or the top four experimental varieties (FG96T707, SW9812, DS 593, UC452) which, respectively, had 99-102% and 101-104% of the yield of CUF-101. Thus the salinity stress imposed by irrigation with the 5 dS/m water (the most saline available at the station) was not great enough to challenge these new, more salt tolerant varieties. A new field trial has been established at WSREC and was pre-irrigated four times with 7 dS/m water (the shallow well is now delivering more saline water) and with a new reservoir that allows us to add salts to the irrigation water, we hope to see greater differences in salt tolerance amongst the varieties that will be tested in the new trial.

Table 5: Yields (fresh weight of shoots) from former alfalfa salinity trial (2010-2014) with comparison to the public control (CUF-101).

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

	FD	2010 Yield		2011 Yield		2012 Yield		Average			% of CUF 101
				Dry t/a							%
Released Varieties											
WL 656HQ*	9	9.7	(13)	13.9	(1)	16.3	(4)	13.3	(1)	A	107.8
SW 9215*	9	9.6	(15)	13.8	(2)	16.4	(3)	13.3	(2)	A	107.4
*Ameristand 901STQ	9	10.7	(4)	13.4	(5)	15.5	(6)	13.2	(4)	A	107.1
Hybriforce 800*	8	11.0	(2)	13.3	(6)	15.2	(8)	13.2	(5)	A	106.9
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	99.48
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	99.03
Medina	8.5	9.8	(11)	11.7	(20)	14.5	(15)	12.0	(16)	B C D E F	97.05
Highline	9	10.2	(6)	12.3	(13)	13.4	(22)	12.0	(17)	B C D E F	96.93
Integra 8900	9	9.2	(20)	11.8	(19)	14.8	(13)	11.9	(18)	B C D E F	96.66
AmeriStand 803	8	8.9	(25)	11.6	(22)	14.8	(12)	11.8	(19)	B C D E F	95.39
CW 585	8	9.4	(18)	12.1	(15)	13.5	(21)	11.7	(20)	C D E F	94.45
BAR 9242	8.5	9.3	(19)	11.7	(21)	13.8	(19)	11.6	(21)	C D E F	93.76
CW 8028*	8	10.1	(8)	11.9	(18)	11.8	(25)	11.3	(24)	E F	91.34
GrandSlam	8	9.1	(24)	10.9	(25)	13.2	(24)	11.1	(25)	F	89.61
Experimental Varieties											
FG 96T706	9	9.1	(23)	13.5	(4)	17.1	(1)	13.2	(3)	A	107.3
FG 94T02	9	10.2	(7)	13.7	(3)	15.7	(5)	13.2	(6)	A	106.8
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	101.6
UC 452	9	11.4	(1)	12.5	(11)	13.5	(20)	12.5	(11)	A B C D	101.1
DS067092	8	9.5	(17)	11.4	(24)	13.8	(18)	11.6	(22)	C D E F	93.69
DS077661*	8	9.2	(22)	11.5	(23)	13.3	(23)	11.3	(23)	D E F	91.78
MEAN		9.82		12.44		**14.66**		12.31			
CV		17.1		11.6		10.2		9.5			
LSD (0.1)		NS		1.43		1.48		1.15			

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.
* = varieties also included in the greenhouse experiment

The first trial was scheduled to end in Fall 2013 at the time that the new trial was being planted. However, with a more salinized profile (due to deficit irrigation in 2013 followed by a dry winter which provided no leaching), it was decided to irrigate this field early in spring 2014 and take an additional harvest. These data are not yet available, but it is possible that greater yield separation between the varieties will be obtained for this harvest.

More interestingly, this field was not irrigated for five months (April 22- Sept. 19th) in 2014. Nevertheless, it fared very well (Photo 1) and thus it was decided to re-water the field to see how the varieties would respond to the combination of water and salt stress. The recovery was truly amazing: photo 1 shows the stand a little more than a week after re-irrigating. Yield was not measured again, but the rapid re-growth of the stand suggests that these newer "salt tolerant" varieties have a considerable level of drought tolerance bred into them as well.

Photo 1: alfalfa salt tolerance trial (2010-2014), re-watered after five months without irrigation. Photo taken Oct. 1, 2014, slightly more than one week after watering.

CONCLUSIONS

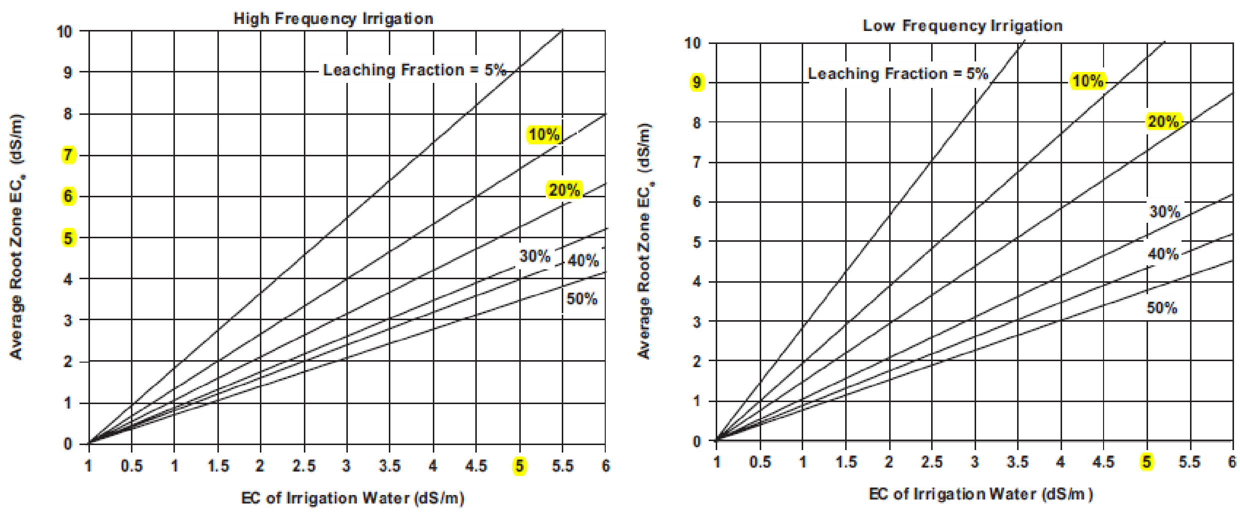
The question of greatest interest to the producer is at what irrigation water and at what soil salinity do we expect to see substantial yield losses in alfalfa? With regard to irrigation water salinity, assuming that one is starting with a relatively non-saline soil (< 2.5 dS/m ECe), we can speculate from our greenhouse results and those in the field, that alfalfa can be irrigated in the short term (up to 3 growing seasons) with 5 dS/m EC water and not suffer major yield losses, especially if the more salt tolerant varieties identified in our research were utilized. It should be pointed out, however, that the outcome of irrigating with water of a certain salinity level will vary from site to site depending on the soil texture, leaching fraction, soil chemistry and climate. For example, soils that are fine-textured (clays and clay loams), saline-sodic (high SAR or ESP), and irrigated with a low leaching fraction ($\leq$ 15%) in hot dry areas (high reference ET) typically have greater increases in soil salinity for a given irrigation water salinity as compared to coarser-textured, low SAR soils having good infiltration and drainage that are effectively leached such that there is much less increase in soil salinity over the irrigation water salinity. It should also be pointed out that the UC Westside Research and Extension Center where this research was conducted has excellent soils for growing alfalfa and that on lower quality soils, the crop may not fare as well under saline irrigation.

With regard to the soil salinity at which at which we would expect to see yield losses in alfalfa, we speculate that under low salinity irrigation ($\leq$ 2 dS/m EC_w), alfalfa could be grown without significant yield loss in soils having an EC_e as high as 6.5 dS/m. This value was determined based on the fact that in the greenhouse (plants grown in a 60:40 soil: sand mix), little yield loss was observed with 5 dS/m irrigation water. The final soil salinities resulting from this irrigation were 1.3 to 1.9 times higher than the irrigation water salinity (Table 6). With the assumption that soil salinity increased throughout the irrigation period, we selected the low end of this range (1.3) as a conversion factor to calculate the soil salinity that could be tolerated by alfalfa when grown in medium- to fine-textured soils with slow infiltration and drainage characteristics. This value of 6.5 dS/m ECe is considerably higher than the threshold value for yield loss of 2.0 dS/m ECe reported by Maas and Hoffman (1986) and Maas and Grattan (1999), suggesting that many of the "salt tolerant" varieties currently available, or soon to be released, are indeed more salt tolerant than those available in the 1980's when these salinity tolerance coefficients were developed.

Irrigation EC_w (dS/m)	Rep	Soil EC_e*	Ratio 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

Table 6: Soil salinities (ECe) after the final harvest and the ratio of soil salinity (ECe) to irrigation water salinity (ECw) for established plants irrigated with saline drainage water (0.5 to 15 dS/m ECw) in the greenhouse.

When irrigating with saline water, it is difficult to predict the resulting soil salinity that will be obtained unless the leaching fraction can be measured, but practically speaking, this is difficult to do. Should an estimate of leaching fraction be obtained, Figs. 4a and 4b can be utilized to calculate the predicted soil salinity for a given irrigation water salinity under low vs. high frequency irrigation. In our greenhouse experiment with established plants and high frequency (daily) irrigation, the final soil salinity was 9.27 dS/m for the 5 dS/m ECw treatment which suggests that the average leaching fraction in the experiment was less than 5%. Interestingly, the final soil salinity for the field trial (irrigation water ~5 dS/m from 2010 to 2012 and ~7 dS/m at the end of the trial) was 8.91 dS/m. Low frequency, basin irrigation was used which according to Fig. 4b. would suggest that the leaching fraction in this experiment was nearly 20%.



Figs. 4a,b. Assessing the maintenance leaching fraction under high (left) and low (right) frequency irrigation. Source: Hanson et al. (2006), extracted from Rhoades, 1982).

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