OPPORTUNITIES FOR MANAGEMENT OF ALFALFA (*Medicago sativa* L.) UNDER HIGH SALINITY CONDITIONS

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ABSTRACT

Alfalfa has historically been classified as moderately sensitive to salinity with yield declines predicted at >2 dS/m ECe (electrical conductivity of the saturated soil paste extract). However, greenhouse and field studies over the past 5 years have confirmed that alfalfa can be grown with limited negative effects at much greater salinity levels. A broad collection of alfalfa varieties have shown a range of resistance at irrigation water salinities >5 dS/m EC_w in greenhouse trials, with significant variation due to variety. A three-year field study on clay loam soil using irrigation water of 5-7 dS/m EC_w indicated normal yields and excellent stand survivability. A second field study in the same soil type with irrigation water salinities of 8-10 dS/m resulting in soil salinities of 10-16 dS/m ECe (0-3 ft. depth) had yield reductions of only 9-13% when averaged across varieties, although three of the twenty-one varieties lost more than 20% yield under these highly saline-sodic soil conditions. Soil boron concentrations under the high saline (HS) irrigation reached 10 mg/kg total boron, suggesting a very high level of boron tolerance in the varieties tested. Field evaluation of variety performance was subject to greater variation due to secondary sodicity effects (poor water infiltration and crusting) than to salinity, per-se. Providing adequate irrigation water availability to the crop may be as important as salinity in impacting yields under basin irrigation with saline-sodic water. Utilization of saline waters for alfalfa irrigation will likely increase in many irrigated regions due to drought and water scarcity; however, long term impacts on soil quality and the volume of water required for leaching should be taken into consideration.

Keywords: salt tolerance, saline irrigation, alfalfa, sodium, abiotic stress

INTRODUCTION

Along with reduced irrigation water supplies, soil salinity is a major problem confronting irrigated agriculture in the western United States, particularly as we confront a warming climate. As water supplies become scarcer, there is a greater need to utilize alternative waters for irrigation: these include saline drainage or well waters, treated municipal effluent and desalinated water. Based on water quality standards published by Ayers and Westcot (1985) many of these waters were previously considered unsuitable for irrigation; however, there are many examples of the successful use of these waters for irrigation, in particular forage production (Suyama et al., 2007; Grattan et al., 2013). Over the short term, utilization of saline waters increases our irrigation

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water supplies, but consideration should also be given to long-term impacts on soil quality due to salt loading; or to the loss of soil structure and hydrologic function should these alternative waters be enriched in sodium (saline-sodic or sodic). For saline waters, leaching can reduce the build-up of salts in the root zone, but salts leached deeper in soil can negatively impact groundwater quality or surface water quality should drainage flows enter nearby water bodies. Furthermore, the need for periodic leaching increases the water requirement for successful crop production. Special attention should also be given to saline waters that are enriched in boron, as leaching fractions for boron are much higher than those for salts.

GREENHOUSE STUDY (ESTABLISHED PLANTS, 7-MONTH DURATION)

Nineteen alfalfa varieties, including new materials selected for salt tolerance, were grown in tall pots in a greenhouse to determine the relative salt tolerance of established plants to saline irrigation (0.5, 5, 10 and 15 dS/m EC_w). The cumulative relative yield (7 harvests) indicated that all varieties were fully tolerant to saline irrigation at EC_w of 5 dS/m, and differentiation of the varieties was apparent only at 10 and 15 dS/m (Figure 1). The relative yield (RY) for shoots and for root + crown dry matter decreased significantly when the EC_w was > 5 dS/m. Tolerant varieties had a RY for shoot dry matter of 48 to 58%, even at an irrigation water salinity of 15 dS/m EC_w; whereas for sensitive varieties, shoot RY was only 33% to 41% at 15 dS/m (Table 1).

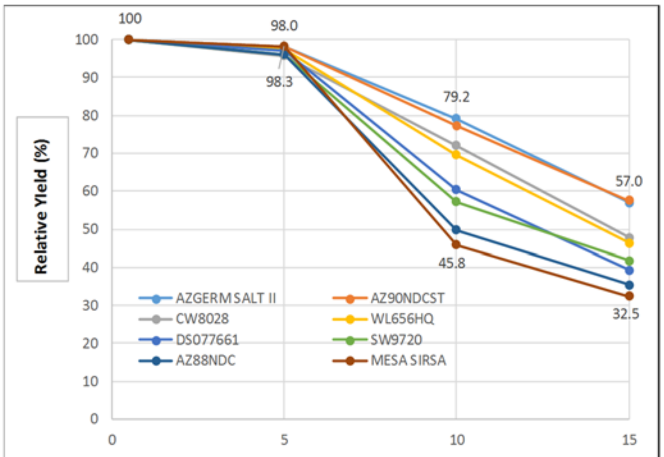

Fig 1. Relative shoot biomass for eight alfalfa varieties exhibiting a range of salt tolerance in a greenhouse experiment. Shoot biomass is based on the cumulative yield for seven cuts over the seven-month experiment. Values are means with n=3

On an absolute basis (cumulative yield for seven cuts), a consistent pattern was observed whereby the varieties which yielded the highest under nonsaline irrigation also yielded the highest at all levels of saline irrigation; e.g. varieties CUF101, AZNDCST, AZGERMSALTII, FG96T707 and Hybriforce 800 were the top five yielding regardless of salinity level (data not shown). Notable was the high biomass production (absolute basis) of CUF101 under saline irrigation, a variety grown in the San Joaquin Valley for many years that was not bred for salt tolerance per se. On a relative basis, CUF101 was ranked as moderately sensitive (Table 1) with large yield reductions for the 10 and 15 dS/m ECw treatments (as compared non-saline conditions); however, it still yielded higher than most other varieties at these salinity levels. The other top-yielding varieties under saline irrigation were materials that were selected for salt tolerance.

Table 1. Relative shoot biomass (% of non-saline control[†]) of nineteen greenhouse-grown alfalfa varieties irrigated with different levels of salinity (0.5, 5, 10, 15 dS m^{-1} EC_w). Tolerance levels (left column) is based primarily on yields at 10 dS m^{-1} EC_w.

Tolerance*	Var.#	Variety name	Relative Yield (%)		
			------------- EC_w (dS/m) -------------		
			5	10	15
T	18	AZGERM SALT II	98	79.2	57
"	17	AZ90NDCST	98	77.3	57.6
"	7	HYBRIFORCE800	95.5	76.2	56.3
"	9	FG96T707	97.9	74.7	53.6
"	8	DS067092	95.6	75.2	48
"	2	SW8421S	97.6	70.3	52.6
MT	13	CW8028	95.8	72.1	47.8
"	5	WL656HQ	97.5	69.6	46.4
"	3	6906N	97.2	68.3	46.4
"	12	CW58S	96.2	65.7	42.7
"	15	SW9215	96.9	64.5	43.2
MS	11	CW48S	96.2	62.2	40.8
"	14	DS077661	97.2	60.5	39.3
"	1	SW9720	96.2	57.2	41.9
"	6	AMERISTAND901S	97	57.9	40.8
"	20	CUF101(a)	94.7	54.9	44.3
"	4	CUF101(b)	94.6	54.7	43.9
S	10	CW9S	97	44.6	40.6
"	16	AZ88NDC	96.1	49.8	35.4
"	19	MESA SIRSA	98.3	45.8	32.5

† calculated from cumulative biomass for seven cuts taken during the seven-month experiment.
††AZ = Arizona, FG= Forage Genetics, CW = CalWest (now Alforex), WL=W-L Alfalfa, SW= S&W Seed.

For most varieties, Na^+ and Cl^- concentrations in shoots (and roots + crowns) steadily increased (and K^+ decreased) as the irrigation water salinity increased; e.g. shoot Na^+ was 1.7 to 2.8 times greater than the non-saline control at 10 dS/m EC_w and 3.0 to 4.8 times greater at 15 dS/m ECw, with the more sensitive varieties (based on shoot RY) having the greatest increases. Differences in sodium accumulation amongst the varieties were greatest at the 7th (last cut) in which case, the most sensitive varieties accumulated 2 to 3% sodium (= 870 – 1305 mmol/kg) in the shoot tissue at the highest salinity level. The most tolerant varieties had smaller increases in Na^+ and Cl^- (and less reduction in K^+) in shoot tissue. Toxic ion exclusion and K^+ discrimination (over Na^+) may be important traits contributing to salinity tolerance in these alfalfa varieties.

FIELD TRIAL 1 (2009–2012; BASIN IRRIGATION, 5.5–6.5 dS/m EC_w)

This trial was conducted in a clay loam soil at the University of California Westside Research and Extension Center (WSREC) in western Fresno County, California, testing the yield response of a broad range of alfalfa varieties to irrigation waters of 5.5-6.5 dS/m EC_w which resulted in soil salinities of ~9.0 dS/m EC_e by the end of the trial. In this trial, yields were in the normal range for this site (e.g. 12.3 ton/acre average) over the 3 years of saline irrigation (see http://alfalfa.ucdavis.edu/+producing/variety/data/2012/09WSFS10-12.htm for data). In fact, in this trial, varieties gained in their yield potential from year 1 to year 3, with yields increasing from 9.81 to 14.7 t/acre, in spite of an increase in salinity over the period of the trial. This trial was conducted only with saline water (no non-saline controls) with 6 replications and the varieties were significantly different over 3 years, ranging from an average low of 11.1 to a high of 13.3 t/a.

FIELD TRIAL 2 (2015-2017; BASIN IRRIGATION, 8-10 dS/m EC_w)

In this trial, the alfalfa was planted into pre-salinized, clay loam soil (~4 to 5 dS/m EC_e) and the 24 varieties were challenged with higher salinity water (8-10 dS/m ECw) which resulted in soil salinities of 9.7 – 15.1 dS/m ECe (0-5 ft. depth) in the high salinity (HS) basin during the second and third year. The low salinity (LS) basin received water averaging 1.24 dS/m and soil salinities were 3.8 – 4.4 dS/m ECe (0-5 ft. depth) during this period. Only a 9-13% yield decline was observed over three years of HS irrigation (Table 2), as compared to the 50-60 percent yield losses predicted by the Maas Hoffman yield loss coefficients.

Table 2. Alfalfa variety performance in a three-year field trial, Five Points, CA

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 provided valuable information on the overall salt tolerance of alfalfa, but we were unable to rank the varieties for salt tolerance due to the lack of uniform salinity (Fig. 2) and soil moisture within the basins. In spite of the replicated plots (4) for each variety and the use of 1 m borders, a significant border effect was observed. Adjustments were made to improve the distribution uniformity of the irrigation water and to increase the depth of water penetration, but care had to be taken to avoid water-logging given alfalfa's sensitivity to poorly-aerated soils and irrigation had to cease 10 - 12 days before harvesting. It was expected that the saline-sodic water used for irrigation in the HS basin would lead to clay dispersion and reduced infiltration, but at times infiltration was slow in the LS basin as well, due to the expanding clay loam soil that swells upon wetting. Small differences in elevation also created spatial variability in water infiltration. A third field trial at WSREC was established in spring 2017, utilizing subsurface irrigation in combination with surface irrigation (sprinkler systems) to resolve some of these uniformity problems.

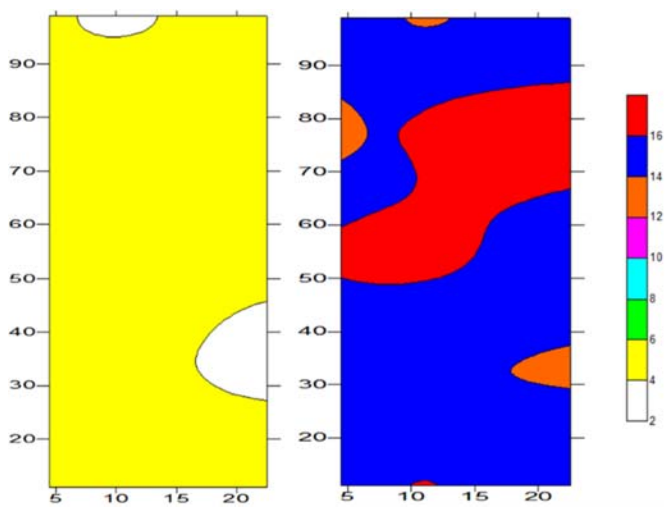

Fig. 2. Soil salinity contour map (ECe, dS/m, 0-5 ft. depth) for October 2016 (end of 2nd year) of saline irrigation. LS basin (left) and HS basin (right), each 35 x 200 ft. Variation in soil salinity and soil moisture interfered with alfalfa variety comparisons under saline irrigation.

FIELD TRIAL 3 (2017-2020; SUBSURFACE DRIP IRRIGATION, 8-10 dS/m EC_w)

A third variety trial at WSREC established in spring 2017 in non-salinized soil utilizes subsurface drip irrigation (SDI) to apply the saline water (8-10 dS/m EC_w), along with occasional sprinkling for salt leaching. The primary intent is to deliver water more frequently (daily) and directly to the root zone and to avoid the wide variation in soil moisture that accompanies basin irrigation (soils excessively wet and poor aeration post-irrigation followed by extensive drying prior to harvest). The drip lines were buried 30 in. apart and approx. 12 in. deep in the clay loam soil. Thirty-four varieties, including AZ-90NDC-ST and AZ-88NDC as salt tolerant and salt-sensitive controls, respectively, and CUF101 as the public control were planted in 3 x 15 ft. plots replicated four times in a split plot design (Fig. 3). Low saline control plots receive water of 1–1.5 dS/m EC_w. Acid is injected into both the LS and HS irrigation systems to keep the water pH below 7.0.

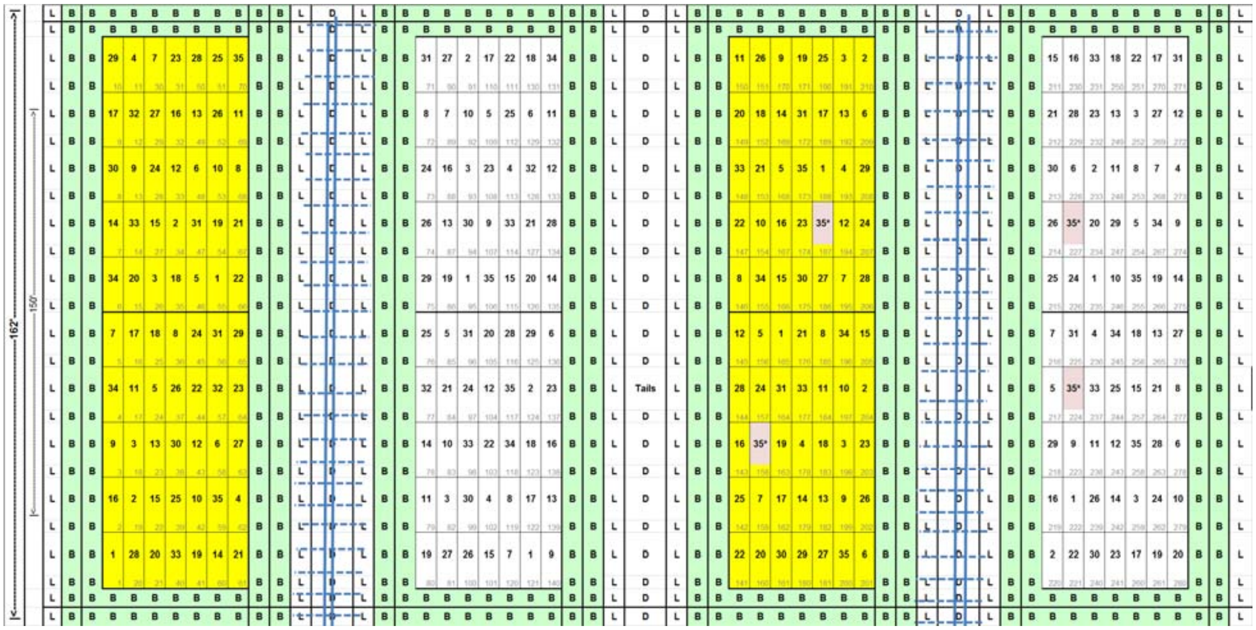

Fig. 3. Plot map showing the four basins (yellow = HS, white = LS irrigation) for the Trial 3 using SDI.

Cumulative hay yields (7 cuts) for the first full year of saline irrigation (2018), averaged 9.60 ton/acre across all varieties for the high salinity (HS) irrigated alfalfa as compared to 12.3 tons/acre under low salinity (LS) irrigation. This represents a much higher yield loss (21.8%) as compared to the average yield loss of 11% observed in Trial 2 over three years of basin irrigation at similar salinity levels. The delivery of saline water directly to the root zone of the alfalfa by the SDI could be an explanation, but yield outcomes cannot be determined from one year of data. Soil salinity data for early in the first full growing season (May 2018) reveal that the salinity was highest in the top foot (8.87 dS/m EC_e) and decreased with depth.

PRELIMINARY CONCLUSIONS

Results from our two basin-irrigated variety trials indicate that alfalfa is much more salt tolerant than previously thought, similar to the conclusions of Cornacchione and Suarez (2015). These results suggest that irrigation waters of higher salinity (5 – 8 dS/m EC_w) which result in soil salinities of 10 dS/m ECe or higher can be used for basin-irrigated alfalfa grown on deep fertile soils, with potential yield losses ranging from negligible to 20% over three years, depending on the variety. In spite of modest yield losses under saline conditions, these are still economically viable yield levels for alfalfa grown under relatively high levels of salinity. Furthermore, the HS irrigation waters used in our study averaged 7.0 ppm (mg/L) of boron. Most water quality standards (e.g. Ayers and Wescot, 1985) consider irrigation waters with boron > 2.0 ppm (mg/L) to have a severe restriction and they should only be used to irrigate boron tolerant crops. The high yields observed under our HS irrigation confirm that alfalfa is quite boron tolerant, similar to the results of Maas and Grattan (1999). Furthermore, the deep-rooted characteristics of alfalfa may enable utilization of deeper subsurface moisture, even at moderate to high salinity levels.

Although most alfalfa is still surface-irrigated, subsurface drip-irrigation (SDI) is showing promising results to irrigate alfalfa more quickly and uniformly and to avoid long periods of low soil moisture when the field is dried down for harvesting (Putnam et al., 2017). Based on the very limited results from our SDI trial, we can say that the yield response under saline irrigation may be different in this system and thus we cannot extend our saline irrigation recommendations for basin-irrigated systems to SDI, as of yet. Two more years of yield data from our SDI trial should allow us to draw some preliminary conclusions. It will also be more challenging to maintain an SDI system when saline waters are utilized due to the tendency for salts to clog the emitters.

CONSIDERATIONS FOR THE USE OF SALINE IRRIGATION IN ALFALFA PRODUCTION

The long term impact of saline irrigation on soil quality should be considered, including the volume of irrigation water required to return the soil salinity to levels suitable for most other crops– ideally below 5.0 dS/m ECe. Therefore, less saline irrigation should be utilized when future rotations would include more salt-sensitive crops. Soil texture and infiltration characteristics largely determine the extent to which salts can be leached from saline-irrigated fields and some soils are not easily leached due to their saline-sodic condition or subsurface impediments. Careful water management during stand establishment, prevention of crusting, and agronomic practices to promote water infiltration and prevent ponding will be particularly important to the successful production of alfalfa under saline-sodic conditions. When waters are affected by sodicity (high sodium with respect to calcium), the tendency for sodium to disperse clay particles and break down the soil structure poses significant challenges. Typically, soil amendments such as gypsum are needed to supply calcium and reduce exchangeable sodium, or soil sulfur can be used to reduce soil pH and solubilize native calcium in the soil. Use of these amendments is essential, but it also increases production costs. Likewise, when saline waters are also high in boron, attention should be given to boron accumulation in the soil given that boron is not easily leached from soil.

When irrigating with saline water, it is difficult to estimate the resulting soil salinity. This will depend on the volume and frequency of water application and the leaching fraction which is a function of the infiltration characteristics of the soil as influenced by soil texture, structure, EC/SAR ratio, pH and other soil chemical properties (Suarez et al. 2006). Most yield loss thresholds are based on soil salinity, thus it is desirable to estimate the resulting soil salinity. A factor of 1.5 is often used ($EC_e = EC_w \times 1.5$), but this is for low frequency irrigation and assumes a 15-20% leaching fraction applied at every irrigation (maintenance leaching) which for the most part, is no longer feasible due to scarce irrigation water supplies and concerns for leaching nitrate below the root zone. Occasional reclamation leaching is a more likely scenario but it implies that the soil salinity will increase until it reaches an undesirable level after which leaching will be employed. With high frequency irrigation such as SDI, however, the soil salinity may not increase as much above the irrigation water salinity, except perhaps in the surface layer. Less water may be required for leaching, but to effectively leach salts in an SDI system, sprinklers may be required. Thus, the irrigation system is key and the ability of the system to maintain adequate and uniform soil moisture will determine the true outcome under saline as well as non-saline conditions.

REFERENCES

Ayers, R.S., Westcot, D.W. 1985. Water quality for agriculture. FAO. Irrigation and Drainage Paper 29 Rev. 1, Food and Agriculture Organization of the United Nations, Rome, Italy. 174 pp

Cornacchione, M. and Suarez, D.L. 2015. Emergence, Forage Production and Ion Relations of Alfalfa in Response to Saline Waters. Crop Sci 55: 444-457

Grattan, S.R., Oster, J.D., S.R. Kaffka. 2013. Chapter 10: Drainage Water Reuse: Concepts, Practices and Potential Crops. In: A.C. Chang and D. Brawer Silva (eds.), Salinity and Drainage in San Joaquin Valley, California: Science, Technology, and Policy, Global Issues in Water Policy 5, DOI 10.1007/978-94-007-6851-2_10, © Springer Science+Business Media Dordrecht 2013

Maas, E.V., Grattan S.R. 1999. Crop yields as affected by salinity. p. 55–108. In: R.W. Skaggs and J. van Schilfgaarde (Eds.). Agricultural drainage. Agron. Monogr. 38. ASA, CSSA, and SSSA, Madison, WI.

Putnam, D.H., Montazar, A., Zaccaria, D. Kisekka, I., Bali, K. 2017. Agronomic Practices for Subsurface Drip Irrigation in Alfalfa. In: Proceedings, 2017 Western Alfalfa and Forage Symposium, Reno, NV, Nov 28-30. UC Cooperative Extension (http://alfalfa.ucdavis.edu)

Suarez, D.L., Lesch, Wood, J.D., Lesch, S.R. 2006. Effect of SAR on water infiltration under a sequential rain–irrigation management system. Agric. Water Manage. 86: 150-164.

Suyama H., Benes S.E., Robinson P.H., Getachew G., Grattan S.R., Grieve C.M. 2007. Biomass yield and nutritional quality of forage species under long-term irrigation with saline-sodic drainage water: field evaluation. Anim. Feed Sci. Technol. 135:329-345. http://www.sciencedirect.com/science