MANAGEMENT OF SALINITY IN ALFALFA

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ABSTRACT

Salinity affects agriculture in arid climates throughout the world, impacting crop productivity and degrading soil resources. The Sacramento-San Joaquin River Delta region of California is one such region that is impacted by salinity. The Delta is a unique agricultural region due to its soil type, climate, and irrigation and groundwater sources. Alfalfa is a widely grown Delta crop and is moderately sensitive to salinity. To prevent hay yield reductions, Delta soils should be leached of salts by applying water in excess of crop evapotranspiration. The leaching fraction is defined as the minimum fraction of the total applied water that must pass through the root zone to prevent a reduction in crop yield from excess salts. Alfalfa is irrigated with surface water in the Delta; thus, the quality of surface water affects growers' ability to leach salts. Irrigation water, groundwater, and soil salinity were monitored across seven south Delta alfalfa fields from 2013-2015. Over the course of the study period, seasonal average irrigation water salinity ranged from 0.36-1.93 dS/m, average root zone salinity ranged from 0.71-8.86 dS/m, and leaching fractions ranged from 3-26 percent across the seven sites. These data illustrate that soil salinity is reaching levels that have the potential to affect agricultural productivity and longevity, and thus, water quality is important for effective salinity management.

Key Words: alfalfa, salinity, leaching fraction, groundwater, soil, irrigation, drainage

INTRODUCTION

Salt problems occur on approximately one-third of all irrigated land in the world. In the United States, salt problems occur near the coasts and in soils of the arid west. Some soils are salty because parent materials weather to form salts; while on croplands, salts may be carried in irrigation water, added as fertilizers or other soil amendments, or be present due to a shallow saline groundwater. The salt load of a soil is typically estimated by measuring electrical conductivity (EC). Positively-charged cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) join with negatively-charged anions (Cl^-, SO_4^-, HCO_3^-) to form soluble salts ($NaCl$, $CaCl_2$, $MgCl_2$, $CaSO_4$, $CaCO_3$, and KCl). In a solution, the ions disassociate and will move toward an electrode of the opposite charge, creating a current that can be measured with an EC meter. When the solution comes from a soil saturated paste, the abbreviation used is ECe, and when the solution is water, the abbreviation is ECw. In addition to EC, soil salinity may be characterized by sodium adsorption ratio (SAR) or exchangeable sodium percentage (ESP). Both SAR and ESP characterize the sodium status of an alkaline soil. Orloff (2008) characterized ideal conditions for California alfalfa production at the time of site selection, including an ECe of 0-2 dS/m, ESP < 7, Boron at 0.5-2.0 mg/L, ECw < 1.3 dS/m, and SAR < 6.

Salt directly impairs plant growth by exerting osmotic stress that results in decreased turgor pressure in plant cells, by causing specific ion toxicities that vary by plant species, or by

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degrading soil conditions that limit plant water availability. Osmotic stress is the most common means by which salt impairs plant growth (Hanson et al., 2006). Under a low salinity condition, the concentration of solutes is higher in plant roots than in the soil-water solution. This means that water moves freely into the plant roots because there is more force, called osmotic potential, pulling the water into the plant roots than there is force holding the water to the soil particles. Under conditions of higher soil salinity, plants must transport solutes within the plant to the roots in order to keep root solutes higher than soil-water solution solutes to avoid water stress. Remobilizing solutes requires energy, and that energy, then, is not used for plant growth. Thus, some plants will not show specific salt-induced symptoms as a result of saline soil conditions; rather, they may just exhibit lower growth or generic stunting which may or may not be realized by the farmer as being salt-induced (Hanson et al., 2006).

Plant growth may also be impaired by specific ions, like sodium (Na^+), chloride (Cl^-), or boron (B), which can accumulate in plant stems and leaves. When toxic concentrations of Cl^- or B occur in plant leaves, it appears as yellowing and progresses to burning along the leaf edges. The presence of Na^+, in addition to specific toxicity, may limit plant calcium, magnesium, or potassium uptake, and therefore, result in plant nutrient deficiencies. When leaves yellow or burn, it reduces their photosynthetic capacity, thus reducing plant growth.

Relative salt tolerance ratings (i.e. sensitive, moderately sensitive, moderately tolerant, and tolerant) have been developed for various crops grown in California (Hanson et al., 2006). According to those relative ratings, alfalfa is considered a moderately sensitive crop; absolute tolerance thresholds will vary depending on climate, soil conditions, cultural practices (Ayers and Westcot, 1985), crop stage of development (Smith, 1994), and variety characteristics (Cornacchione and Suarez, 2015). Seedlings have shown delayed emergence under saline conditions (Cornacchione and Suarez, 2015). Therefore, it is important to try to strive for low salinity soil conditions at the time of planting and use the best quality water available on seedling alfalfa. Some alfalfa varieties may tolerate higher salinity based on the plant's ability to exclude Na^+ concentrations in the shoots and limit Cl^- uptake (Cornacchione and Suarez, 2015). Nevertheless, recognizing that growers need to select alfalfa varieties with dormancy, disease and insect resistance, yield, and other agronomic objectives in mind, plant breeding should not be considered a substitute for soil salinity management.

In addition to the direct effects of salinity on plants, plants may also be affected by salinity if soil conditions are degraded and water infiltration and drainage are impaired. Degraded soil conditions may exhibit white or black crusts on the soil surface or wet spots on the soil surface. The white crusting is the result of evapoconcentration of salts on the soil surface, and the black crusts form because humus is carried upward with water as water evaporates. Slick spots form because the soil particles are completely dispersed and soil structure is lost. The soil swells, and water infiltration will decrease. Poor infiltration can result in standing water on the soil surface or poor aeration in the soil pores, neither of which promotes plant health and growth.

The Sacramento-San Joaquin River Delta region – for its soil type, climate, and water sources – is a unique agricultural region of California. Diverse crops grow in the Delta region, and alfalfa was the second most widely planted crop in 2012. Border check flood irrigation using surface water is the primary method of irrigating Delta alfalfa. As a forage crop, the marketed product of alfalfa is the vegetation, or alfalfa hay. Hay yields are directly related to crop evapotranspiration (ET) (Hanson et al., 2008), but soil salinity can also affect the relationship between evapotranspiration and alfalfa yield. To prevent harmful accumulation of salts and yield impacts, the soil profile must be leached periodically with an amount of water in excess of what is used by plant ET. Leaching occurs when water is applied in excess of soil moisture depletion due to ET (Hanson et al., 2006).

The leaching fraction (Lf) is the fraction of the total applied water that passes below the root zone. This can be expressed as:

$$Lf = ECw/ECdw \qquad \text{(Equation 1)}$$

where ECw is the electrical conductivity of the applied water, and ECdw is the electrical conductivity of the drainage water at the bottom of the root zone, which is equal to 2ECe (Ayers and Westcot, 1985). The leaching requirement (Lr) is the minimum amount of the total applied water that must pass through the root zone to prevent a reduction in crop yield from excess salts. Rhoades (1974) proposed the following equation for the Lr:

$$Lr = ECw/(5ECet - ECw) \qquad \text{(Equation 2)}$$

where ECet is the average soil salinity, as measured by saturated paste extract, that a crop can tolerate. Thus, there are two factors necessary to estimate the Lr. One factor is the salt concentration of the applied water, which can vary substantially in the Delta based on time of year and location. The other factor establishing the Lr is the salt tolerance of the crop.

Excess soil salinity in the Delta varies in the short term with the depth and quality of the groundwater, quality of the surface irrigation water, and volume of effective winter rainfall. Water tables in the area are typically within 2 meters of the soil surface and may be poor quality. Additionally, alfalfa is often grown on soils with a low infiltration rate, and as a perennial crop, it has a high ET demand, generally over 48 inches annually (Hanson et al., 2008). It can be difficult to apply enough water to meet the ET and leaching requirements of alfalfa on low permeability soils. If it is not possible to apply enough water to leach salts due to poor soil permeability, proximity of groundwater, or other agronomic considerations, lower salinity irrigation water may be necessary to maintain yields. Thus, soil salinity will continue to be an issue in the Delta in the long run, especially under conditions of reduced water flows or higher surface water salinity objectives, which are currently under reconsideration by the State Water Resources Control Board. The objective of this research was to gain an understanding of the achieved leaching fraction in Delta alfalfa fields. The work provides current data to inform water quality policy and assist growers with irrigation strategies for effective salinity management.

MATERIALS AND METHODS

The study was conducted in seven commercial fields of mature alfalfa in the south Delta region. Fields were selected for their soil textural and infiltration characteristics and differing irrigation source water. In particular, the Merritt, Ryde, and Grangeville soil series were of interest. These three soil series characterize over 62,000 in San Joaquin County (NRCS, 2014). Merritt and Ryde soils have a low saturated hydraulic conductivity (Ksat), approximately 10 mm/hr in the top 124 cm and 70 cm, respectively (NRCS, 2014). The Grangeville series has a moderate Ksat of 101 mm/hr in the top 152 cm (NRCS, 2014). Having soils of different textural classes and permeabilities was of interest for understanding how soil characteristics influence the leaching fraction.

Irrigation water for these seven sites was sourced from the San Joaquin River, including Old River, Middle River, and connecting canals and sloughs. Water quality from these sources varies temporally with flows but also spatially depending on tidal and current influences.

Soil and groundwater sampling. Modified procedures of Lonkerd et al. (1979) were followed for sampling. Spring soil samples were collected after most seasonal rainfall had ceased and before irrigations commenced, in March and April of 2013, 2014, and 2015. Before sampling, holes were augured, and the soil was visually assessed for its representation of the Merritt, Ryde, or Grangeville classifications. Once visually confirmed as representative soil, samples were collected from one border check per field. Each check was divided into "top," "middle," and "bottom" sections, where the top of the field was where irrigation water entered, and the bottom was where irrigation water drained. These three sections were distinguished because it was suspected that irrigation management and/or soil variability would result in leaching differences from the top to the bottom of the check.

Three replicate holes were augered (4.5-cm diameter) from each of the top, middle, and bottom sections. The holes were augured in 30-cm increments to a depth of 150-cm. The three replicate-depths from the top, middle, and bottom sections were composited into one bulk sample; thus, there were 15 bulk samples collected from each field. Bulk samples were oven-dried at 38 degrees C and ground to pass through a 2-mm sieve.

At the same time that bulk soil samples were taken, soil moisture samples were also collected using a volumetric sampler (60-cm^3). These samples were collected from the center 7 cm of each 30-cm depth increment. After extracting the soil, it was sealed in a metal can to prevent moisture loss. The soil was weighed before and after oven-drying at 105 degrees C for 24 hours, and the soil moisture content (as a percent of the soil volume) was calculated.

Groundwater samples were collected by auguring until water was visually or audibly reached. The water was allowed to equilibrate in the hole before measuring the depth to groundwater and collecting a sample (200-mL). Samples were taken from the top, middle, and bottom sections. Water was stored in a cooler (37 degrees C) until analyzed.

These procedures for soil and groundwater sampling were again followed in October 2013 and 2014, after irrigations ceased for the season.

Irrigation water sampling. Water samples (200-mL) were collected when irrigation water was applied during the 2013 and 2014 irrigation seasons. Water was collected at the top of the field from the source pipe or ditch. Water samples were vacuum-filtered for clarity and stored in a cooler (37 degrees C) until analyzed. Growers' irrigation frequency varied among the sites; water was collected from each site 5-8 times throughout the irrigation seasons (April-October).

Precipitation. We used California Irrigation Management Information System (CIMIS) data, averaged between the Manteca and Tracy locations for the 2014-2015 precipitation season, as the water applied as rainfall. Data from these two locations were averaged because the seven field sites were located near these stations.

Soil and water analysis. Soil salinity was determined by measuring the electrical conductivity (EC) and chloride (Cl) ion concentration of the saturated paste extract, where higher EC and Cl indicate higher levels of dissolved salts in the soil. To conduct these procedures, a saturated paste extract was made by saturating a soil sample with deionized water until all pores were filled but before water pooled on the surface (Rhoades, 1996). When saturation was achieved, the liquid and dissolved salts were extracted from the sample under partial vacuum. The EC of the saturated paste extracts (ECe), and of the irrigation (ECw) and groundwater (ECgw), were measured in the laboratory of UC Cooperative Extension in San Joaquin County using a conductivity meter (YSI 3200 Conductivity Instrument). Chloride in the saturated paste extracts (Cle), and of the irrigation water (Clw) and groundwater (Clgw) were measured at the UC Davis Analytical Laboratory by flow injection analysis colorimetry (http://anlab.ucdavis.edu/analyses/soil/227).

Alfalfa yield sampling. Yield samples from each field were collected from the first, a middle, and the last cutting during the 2013 and 2014 growing seasons to investigate salinity effects on yield. Three 0.25-m^2 quadrat samples were taken from each of the top, middle, and bottom sections of the field. Plants were cut approximately 5-cm above the ground level, bagged, and weighed for fresh weight. Plants were then dried in an oven at 60 degrees C for 48 hours and weighed for dry weight. Average annual yield was calculated by averaging all quadrat samples, across all field sections and cuttings, scaling to yield per acre, then multiplying by the total number of cuttings, as reported by the grower.

Calculations and analysis. The aforementioned equation Lf = ECw/ECdw was used for the leaching fraction calculation, where, as previously described, ECdw is the electrical conductivity of soil water draining below the root zone, and ECw is the electrical conductivity of the applied water (Ayers and Westcot, 1985). We used the equation ECdw = 2ECe (Ayers and Westcot, 1985) to relate ECe to ECdw. The 30-cm increment with the highest ECe and Cle in the fall was considered the bottom of the root zone for the Lf calculations and represented the salt concentration of deep percolation water from the bottom of the root zone. The achieved Lf were calculated as both Lf = ECw/2ECe and Lf = Clw/2Cle. Data for the top, middle, and bottom sections were averaged to one Lf per site.

RESULTS AND DISCUSSION

Irrigation and groundwater salinity. Over the 2013 and 2014 irrigation seasons, average ECw ranged from 0.36-1.93 dS/m across the seven sites, and average Clw ranged from 1.42-9.14 meq/L (Table 1). These averages include applied water as rainfall that fell either after spring soil sampling or before fall soil sampling, as applicable for each site. In both years, three out of seven sites (Sites 2, 5, and 6) had a seasonal average ECw exceeding 0.7 dS/m, the irrigation season salinity objective set by the California State Water Resources Control Board.

Groundwater depth and salinity varied from spring to fall in both years (Table 2). Average groundwater depth, ECgw, and Clgw represent the average across top, middle, and bottom field sections at a site. Average groundwater depth ranged from 102-232 cm across the two years and seven sites. Average ECgw ranged from 2.3-14.3 dS/m across the two years and seven sites, and average Clgw ranged from 7.6-108.7 meq/L.

Table 1. Irrigation water salinity as electrical conductivity (ECw) and chloride ion concentration (Clw) at seven south Delta alfalfa sites from April to October in 2013 and 2014.

		2013				2014			
		ECw (dS/m)		**Clw (meq/L)**		**ECw (dS/m)**		**Clw (meq/L)**	
Site	**Water Source**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**
1	San Joaquin River	0.2-0.7	0.58	0.7-3.9	2.76	0.2-0.7	0.54	0.4-3.6	2.22
2	Old River	0.5-1.0	0.74	1.6-4.6	3.12	0.7-1.2	0.88	1.1-5.0	3.55
3	San Joaquin River	0.2-0.7	0.57	0.6-3.0	2.16	0.1-0.6	0.40	0.3-2.3	1.46
4	Middle River	0.3-0.8	0.47	1.2-3.6	2.02	0.5-0.7	0.57	2.0-3.2	2.73
5	Paradise Cut	0.3-2.8	1.78	5.4-13.5	8.02	1.6-3.1	1.93	7.2-19.1	9.14
6	Grant Line Canal	0.6-1.1	0.85	2.5-4.7	3.81	0.6-1.1	0.87	2.6-5.6	3.99
7	North Canal	0.3-0.4	0.36	1.1-2.0	1.42	0.4-0.6	0.49	1.8-3.0	2.32

Table 2. Average groundwater depth (Dep), electrical conductivity (ECgw), and chloride ion concentration (Clgw) across seven south Delta alfalfa sites in fall and spring, 2013 and 2014.

	Spring 2013			**Fall 2013**			**Spring 2014**			**Fall 2014**		
Site	**Dep (cm)**	**ECgw (dS/m)**	**Clgw (meq/L)**	**Dep (cm)**	**ECgw (dS/m)**	**Clgw (meq/L)**	**Dep (cm)**	**ECgw (dS/m)**	**Clgw (meq/L)**	**Dep (cm)**	**ECgw (dS/m)**	**Clgw (meq/L)**
1	117	10.7	77.5	148	7.8	49.5	117	11.0	76.4	183	7.0	45.0
2	177	9.6	72.3	153	10.6	76.5	132	12.2	92.3	117	14.3	108.7
3	198	3.7	19.2	208	2.3	7.6	232	3.0	13.2	200	2.7	11.2
4	197	5.7	36.1	192	6.2	52.2	218	5.1	33.4	212	5.7	37.9
5	168	5.2	29.9	177	4.8	25.3	157	6.0	33.5	177	4.4	23.4
6	155	3.6	18.7	182	3.0	14.5	162	2.8	13.9	163	3.6	18.3
7	185	3.0	12.1	102	3.5	12.6	135	2.7	11.1	155	3.6	15.6

Soil salinity. Soil salinity is illustrated by depth (Figure 2) and depicted as average root zone salinity (Tables 3 and 4). At Site 1 (Figure 2A), soil salinity reached its highest at the 90-120 cm-depth increment at every sampling except the Spring 2015 sampling. This was also the depth of groundwater in the spring of each year. Thus, it would appear that salts are accumulating between 90 and 120 cm because groundwater was limiting leaching below this depth. At Site 2 (Figure 2B), shallow, fluctuating groundwater also appeared to be influencing the soil salinity profile, albeit with a less distinctive pattern than at Site 1.

Merritt silty clay loam is the soil series that characterizes Sites 1-4 and is a low permeability soil. At Sites 1, 2, and 4 (Figures 2A, 2B, and 2D, respectively), the maximum salinity in the profile ranged from about 8-14 dS/m, depending on sampling date. The maximum salinity was sometimes as shallow as the 60-90 cm-depth increment. Similarly, in the Imperial Valley where alfalfa is grown on low permeability soils, Bali et al. (2001) found that most root growth was in the top 90 cm when soil salinity reached its maximum (12 dS/m) between 90 and 120 cm. Thus, the base of the root zone is where salinity reaches its maximum in the profile. In the same study, Bali et al. (2001) also found that the alfalfa crop coefficient used to calculate crop water use was smaller in the saline conditions of the Imperial Valley compared to other regions in the southwestern states. Since crop ET is correlated with alfalfa yields, this suggests that yields may have been higher under lower salinity conditions. This has implications for these Delta sites where low permeability soils and shallow groundwater also appear to be impairing leaching.

Sites 5 and 6 (Figures 2E and 2F, respectively) are both characterized by the soil series Granville fine sandy loam, which has higher permeability than the Merritt series. Average root zone salinity at Site 5 was low relative to Sites 1, 2, 4, and 6. It increased from Spring 2013 to Fall 2014 but then decreased in Spring 2015, reflecting higher winter rainfall in 2014-15 compared to 2013-14 (approximately 22 cm and 15 cm, respectively). The salinity profile of Site 6 resembled that of Site 1 more than it did Site 5. Two possible explanations may elucidate the different soil salinity profiles between these sites. First, while Site 5 had the highest applied water salinity of all seven sites, it also had the highest leaching fractions (Table 5). Because of the sandy loam texture and higher permeability, the grower was able to apply more water to the field without agronomic consequences, thus leaching salts deeper into the profile. The higher ECgw of Site 5 may be reflective of salts leaching through the soil profile and accumulating in the groundwater. Second, the soil salinity profiles of the top, middle, and bottom sections of Site 6 (data not shown) illustrated that the top section of the field had a salinity profile similar to that of Site 5, but the middle and bottom sections had much higher salinity. More leaching was occurring on the top section of the field compared to the middle and bottom sections. Because Site 6 is also a sandy loam, the grower may be able to manage soil salinity better by affording a longer opportunity time for irrigation water to infiltrate the middle and bottom sections without agronomic consequences. This type of management may not be wise on low permeability soils if longer opportunity time results in standing water and anaerobic conditions on the middle and bottom sections.

The salinity profiles at Sites 3 and 7 were the lowest of all seven sites (Figures 2C and 2G, respectively). At Site 3, the sampling profile never reached an ECe of 2.0 dS/m at any sampling date. At Site 7, the salinity was generally low but increased by Fall 2014. Application of low salinity water may explain the low soil salinity down these profiles; however, these fields were also observed to be the weediest fields of the seven sites and were disked in because of low productivity at the end of Fall 2014. (Hence, there is no data for Spring 2015.) Site 3 had high leaching fractions, and Site 7 had moderately high leaching fractions, relative to Sites 1, 2, 4, and 6. The amount of applied water at these sites may have leached salts with the consequence of anaerobic conditions on these low permeability soils, reducing stand quality with weed infestation.

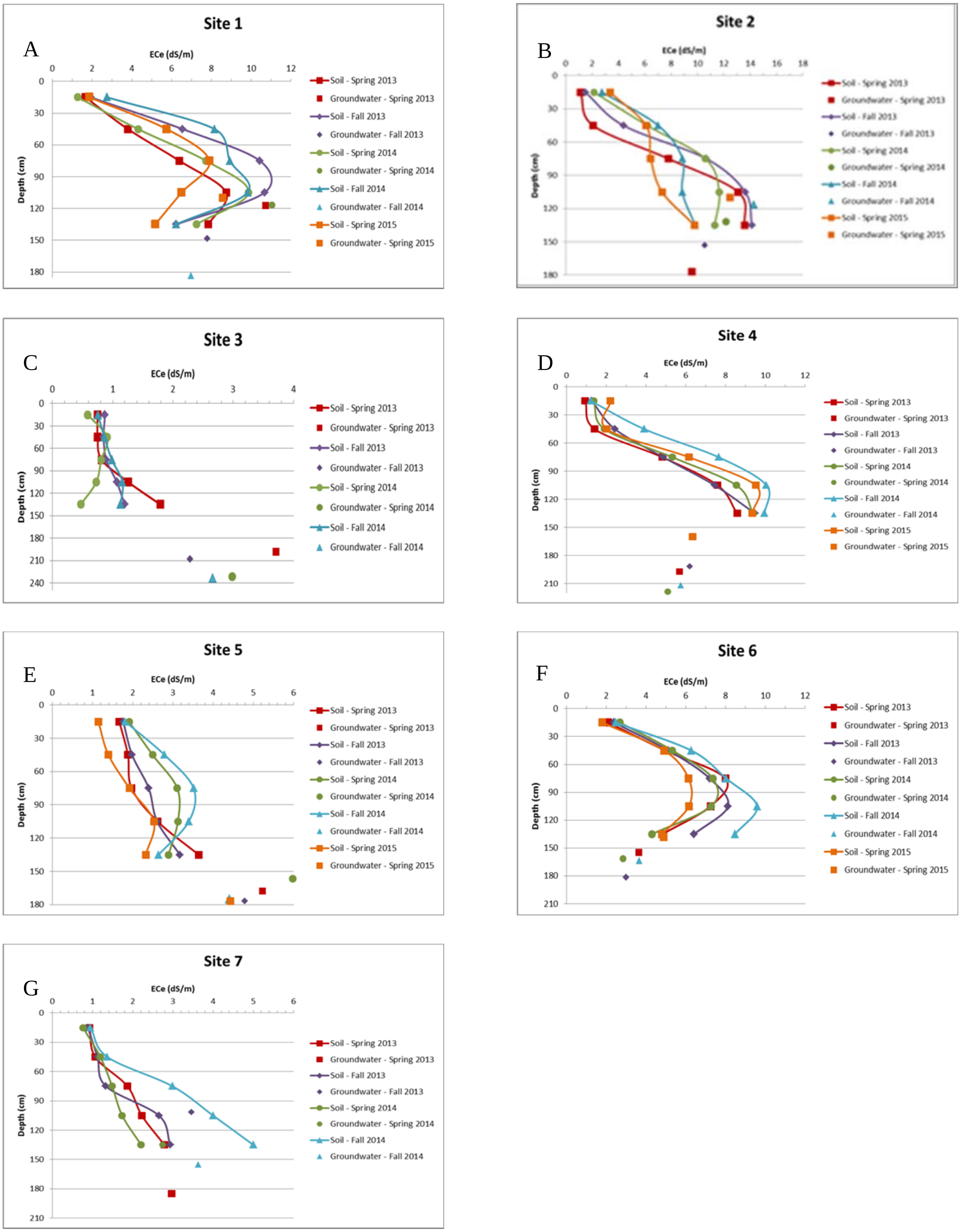

Figure 2. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity. Curves are the average ECe values across top, middle, and bottom sections of the field (average of nine samples).

Table 3. Average root zone salinity (ECe, dS/m) for seven south Delta alfalfa sites across 2013-2015.

	Average Root Zone ECe (dS/m)				
Site	**Spring 2013**	**Fall 2013**	**Spring 2014**	**Fall 2014**	**Spring 2015**
1	4.35	6.77	5.79	7.41	5.28
2	7.53	8.86	8.07	7.18	6.60
3	1.07	0.98	0.71	0.96	No data
4	4.67	5.10	4.69	5.96	5.15
5	2.27	2.40	2.77	3.13	1.90
6	5.57	5.70	5.56	6.89	4.77
7	1.72	1.75	1.48	2.51	No data

Table 4. Average root zone salinity (Cle, meq/L) for seven south Delta alfalfa sites across 2013-2015.

	Average Root Zone Cle (meq/L)				
Site	**Spring 2013**	**Fall 2013**	**Spring 2014**	**Fall 2014**	**Spring 2015**
1	29.5	47.8	39.7	45.8	33.0
2	55.1	70.9	63.0	43.5	42.2
3	4.4	3.7	3.2	3.6	No data
4	24.0	32.8	33.4	37.8	34.6
5	11.3	12.6	13.8	15.4	9.0
6	26.2	34.2	33.9	40.2	24.6
7	4.5	6.5	5.4	7.7	No data

With the possible exception of salt-tolerant varieties (Cornacchione and Suarez, 2015), the average root zone salinity for maintaining 100 percent yield potential is an ECe of 2.0 dS/m (Ayers and Westcot, 1985), or Cle of 20 meq/L (Tanji, 1990). Average root zone salinity of five of the seven sites exceeded the ECe thresholds in all five of the samplings across the three years (Table 3). Four sites exceeded the Cle thresholds across the three years (Table 4). The difference was that Site 5 had average ECe values that were slightly above the threshold but Cle values that were slightly below the threshold. Some of the study sites likely accumulated salts because shallow groundwater impeded salts from leaching out of the root zone, or low permeability soil impaired leaching. Only Sites 3 and 7 had average root zone salinity consistently below the ECe and Cle thresholds.

Overall, four out of seven sites had an ECe that met or exceeded 6 dS/m at the 90 cm depth on all sampling dates. This illustrates that salinity may build up in soil layers just below the depth which is typically sampled for soil nutrient and salinity status, approximately the top 60 cm (Meyer et al., 2008). Thus over time, growers may not be aware of the degree to which soil salinity is increasing in their fields.

Leaching fraction. The Lf of the water percolating from the bottom of the root zone was calculated for both EC (Table 5) and Cl (data not shown), and the data were highly correlated ($R^2 = 0.96$). Only two sites (Sites 3 and 5) had a Lf that exceeded 15 percent, which is the Lf assumed in crop tolerance tables that predict alfalfa yield declines at ECe and ECw values greater than 2.0 dS/m and 1.3 dS/m, respectively (Ayers and Westcot, 1985). Site 7 had moderate leaching compared to Sites 1, 2, 4, and 6, which all had inadequate leaching, as illustrated by a Lf lower than the Lr.

While it has previously been explained how different management may have improved leaching at Site 6, results from leaching studies in the Imperial Valley suggest that management cannot always improve leaching on low permeability soils with shallow groundwater. In a location where a shallow, saline aquifer was the source of soil salinity, Grismer and Bali (1996) continuously ran shallow well pumps for three years, discharging into surface drainage canals, in an effort to lower the groundwater level and reduce soil salinity. Under typical cropping and irrigation practices, groundwater level was lowered but soil salinity did not significantly change. Ponding water on the site for one month, however, did result in decreased soil salinity. In a separate study, Grismer and Bali (1998) found that existing and augmented subsurface drainage systems were no more effective at managing salinity than deep ripping clay soils for better water penetration. Because alfalfa is a perennial crop that typically grows for four or more years in the Delta, and low dormancy varieties are also typical for the Delta, the management practices that lowered soil salinity in these studies – ponding and deep ripping – are only possible when rotating out of alfalfa. Thus, maintaining high quality surface irrigation water is important for maintaining Delta alfalfa production.

Table 5. Root zone depth (RZ Dep), soil salinity at the base of the root zone (ECe), leaching fraction (Lf), and leaching requirement (Lr) at seven south Delta alfalfa sites in Fall 2013 and 2014, averaged across top, middle, and bottom field sections.

	2013				**2014**			
Site	**RZ Dep (cm)**	**ECe (dS/m)**	**Lf (%)**	**Lr (%)**	**RZ Dep (cm)**	**ECe (dS/m)**	**Lf (%)**	**Lr (%)**
1	100	11.2	3	6	120	9.8	3	6
2	150	14.1	3	8	130	9.8	5	10
3	140	1.4	21	6	140	1.2	18	4
4	150	9.5	3	5	120	10.7	2	6
5	130	3.6	25	22	130	4.1	26	24
6	120	8.1	6	9	130	9.8	5	10
7	140	3.1	7	4	150	3.8	8	5

Yield. Alfalfa yield is presented in Table 6. In California, alfalfa yields reach 8-10 tons/acre/year on average (Orloff, 2008). Average yield at all seven sites reached or exceeded this range in 2013, but four sites did not reach this average range in 2014. The ECe threshold for maintaining

100 percent yield potential is 2.0 dS/m (Ayers and Westcot, 1985). While previous work has illustrated linear decreases in yield as average root zone salinity increases (Bower et al., 1969; Shalhevet and Bernstein, 1968), in this study, alfalfa yield was not correlated with average root zone salinity, suggesting that other factors, like pest pressure, stand quality or economic factors were more influential on yield during these growing seasons.

Table 6. Alfalfa yield averaged across cuttings and field sections at seven Delta sites in 2013 and 2014.

		2013			**2014**	
Site	**Number of Cuttings**	**Annual Yield (tons/acre)**	**Annual Yield (Mg/ha)**	**Number of Cuttings**	**Annual Yield (tons/acre)**	**Annual Yield (Mg/ha)**
1	6	8.2	18.7	6	5.6	12.7
2	6	11.9	27.1	6	9.3	21.2
3	6	8.3	18.9	7	4.4	10.0
4	6	8.1	18.4	6	5.4	12.3
5	5	9.8	22.3	5	9.2	20.9
6	6	10.4	23.7	6	8.2	18.7
7	6	8.4	19.1	6	7.8	17.7

While a 15 percent Lf is a general rule of thumb in agricultural systems, given the Delta's unique circumstances and constraints, a 15 percent Lf may not always be possible. Soil permeability may be low, water tables are typically around 2 meters from the soil surface, and groundwater quality may be near the salinity thresholds for maintaining crop yield potential. Additionally, as a perennial crop, alfalfa has a high annual ET demand. It can be difficult to apply enough water to meet the ET and Lr to maintain yields, particularly on low permeability soils like those in the south Delta.

CONCLUSIONS

The Sacramento-San Joaquin River Delta region is a unique agricultural region of California that is challenged by salinity. Leaching is the primary means of managing salinity and must be practiced when there is the potential for salinity to impact yield. In 2013-2015, seven alfalfa fields in the Sacramento-San Joaquin River Delta region were monitored for irrigation water, groundwater, and soil salinity. Results illustrate the inherent low permeability of certain Delta soils, the build-up of salts in the soil to levels that have the potential to affect crop yields, and a low achieved Lf. The Delta's unique growing conditions, including low permeability soils and shallow groundwater, coupled with unpredictable winter rainfall, put constraints on growers' ability to manage salts by leaching and achieve a Lf that meets the Lr to sustain crop yields. While salinity and yield were not statistically correlated in this study, salinity at these sites is increasing down the soil profile to unsuitable levels, which could challenge alfalfa yield in the future, preclude the growing of other salt-sensitive crops, or reduce agricultural longevity of these fields. Thus, salinity – a pervasive issue in the Delta – will continue to impact Delta agriculture, especially under conditions of higher surface water salinity.

REFERENCES

Ayers, R. S. and D. W. Westcot. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 Rev. 1. FAO, United Nations, Rome. 174 p.

Bali, K. M., M. E. Grismer, and R. L. Snyder, 2001. Alfalfa water use pinpointed in saline, shallow water tables of Imperial Valley. California Agriculture. 55(4): 38-43.

Bower, C. A., G. Ogata, and J. M. Tucker. 1969. Rootzone salt profiles and alfalfa growth as influenced by irrigation water salinity and leaching fraction. Agronomy Journal. 61: 783-785.

Cornacchione, M.V. and D.L. Suarez, 2015. Emergence, forage production, and ion relations of alfalfa in response to saline waters. Crop Science. 55: 444-457.

Grismer, M. E. and K. M. Bali, 1996. Continuous ponding and shallow aquifer pumping leaches salts in clay soils. California Agriculture. 51(3): 34-37.

Grismer, M. E. and K. M. Bali, 1998. Subsurface drainage systems have little impact on water tables, salinity of clay soils. California Agriculture. 52(5): 18-22.

Hanson, B. R., K. M. Bali, and B. L. Sanden. 2008. Irrigating alfalfa in arid regions. In: C. G. Summers and D. H. Putnam (eds.). Irrigated Alfalfa Management for Mediterranean and Desert Zones. The Regents of the University of California Agriculture and Natural Resources. Oakland, CA. p. 89-111.

Hanson, B., S.R. Grattan, and A. Fulton, 2006. Agricultural Salinity and Drainage. Publication 3375. University of California Agriculture and Natural Resources. Oakland, CA.

Lonkerd, W. E., C. F. Ehlig, and T. J. Donovan. 1979. Salinity profiles and leaching fractions for slowly permeable irrigated field soils. Soil Sci. Soc. Am. J., 43: 287-289.

Meyer, R. D., D. B. Marcum, S. B. Orloff, J. L. Schmierer. 2008. Alfalfa fertilization strategies. In: C. G. Summers and D. H. Putnam (eds.). Irrigated Alfalfa Management for Mediterranean and Desert Zones. The Regents of the University of California Agriculture and Natural Resources. Oakland, CA.

Natural Resources Conservation Service (NRCS), United States Department of Agriculture. Accessed August 2017. Soil Survey Geographic (SSURGO) Database for San Joaquin County, California. Accessed via SoilWeb Apps: http://casoilresource.lawr.ucdavis.edu/drupal/node/902.

Orloff, S. B. 2008. Choosing appropriate sites for alfalfa production. In: C. G. Summers and D. H. Putnam (eds.). Irrigated Alfalfa Management for Mediterranean and Desert Zones. The Regents of the University of California Agriculture and Natural Resources. Oakland, CA. p. 19-29.

Rhoades, J. D. 1974. Drainage for salinity control. In: J. van Schilfgaarde (ed.), Drainage for Agriculture. Agronomy Monograph No. 12. SSSA, Madison, WI. p. 433-461.

Rhoades, J.D. 1996. Salinity: Electrical conductivity and total dissolved solids. In: Sparks, D. L., A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston, and M. E.
Sumner (ed.). 1996. Methods of soil analysis, part 3, chemical methods. Soil Science Society of America, Inc. and American Society of Agronomy, Inc. Madison, WI.

Shalhavet, J. and L. Bernstein. 1968. Effects of vertically heterogeneous soil salinity on plant growth and water uptake. Soil Science. 106: 85-93.

Smith, S. E. 1994. Salinity and the production of alfalfa (*Medicago sativa* L.). In: M. Pessarakli (ed.). Handbook of Plant and Crop Stress. Marcel Dekker. New York. p. 431-448.

Tanji, K.K. 1990. (ed). Agricultural salinity assessment and management. ASCE manuals and reports on engineering practice No. 71. Am. Soc. Civil Eng., New York, NY.