Leaching Fractions Achieved in South Delta Soils under Alfalfa Culture
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Executive summary:

The Sacramento-San Joaquin River Delta region is a unique agricultural region of California. While the region is named for its waterway configuration, the Delta is also unique for its fertile soils, and of the 738,000 total acres, approximately 500,000 acres of the Delta are farmed. In 2012, alfalfa was the second most widely grown crop in the Delta at approximately 72,000 acres.

Delta farming is challenged, however, by salinity, which can stress crops and reduce yields. In the Delta, applied water contains salt, and as water is evaporated and transpired, salts accumulate in the root zone. In general, plants are stressed by saline conditions because they must expend more energy to take up water, leaving less energy for plant growth. This trade-off is challenging in alfalfa production because the marketed crop is the vegetative growth, and extra energy to take up water reduces hay yields. To prevent this trade-off, the root zone must be leached to maintain salts below crop tolerance thresholds. This is accomplished by applying water in excess of that used by evapotranspiration, or the amount of water evaporated from the soil and transpired by the plant during photosynthesis. The leaching fraction is the fraction of the total applied water that passes below the root zone. The leaching requirement 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.

Two factors establish the leaching requirement: the salt concentration of the applied water and the salt sensitivity of the crop. Alfalfa is moderately sensitive to salinity and is irrigated with surface water in the Delta; thus, the quality of surface water in the Delta affects growers' ability to maintain yields. Currently, state water policy irrigation water objectives for the south Delta are set at levels meant to sustain agricultural yields, based on crop tolerances of salt-sensitive crops. Salinity levels, however, vary over space and time, and salinity objectives may be exceeded during certain times of the season.

The objective of this work was to gain knowledge on the current leaching fraction being achieved in south Delta alfalfa soils and update the state of knowledge on how surface water quality and rainfall affect the leaching fraction. Seven south Delta alfalfa fields were selected for this study, representing three soil textural and infiltration classes. All seven sites had different sources for irrigation water. Our results show that, in five of the seven sampling sites, salts accumulated in the rootzone at levels that exceeded the alfalfa crop tolerance level of 2.0 dS/m. Likewise, the leaching fraction at these five sites fell short of the 15 percent leaching requirement based on the average rootzone (2.0 dS/m) and applied water (1.3 dS/m) salinities

needed to maintain full yield potential of alfalfa. That said, alfalfa yield was maintained at average levels during the course of the study, but long-term productivity of these sites could be diminished if salts continue to accumulate. Since winter rainfall for leaching is unpredictable, it is important to maintain good surface water quality for irrigation in the south Delta.

Introduction, related research, and objectives:

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, but alfalfa is a particularly important one. According to the Agricultural Commissioners of the five-county Delta region, alfalfa was grown on approximately 72,000 acres in the Delta in 2012, making it the second most widely grown crop (Office of the Agricultural Commissioner, 2012). Approximately 46,000 of those acres were located in the San Joaquin County portion of the Delta. The south Delta – an area southwest of Stockton, CA – was reported by Hoffman (2010) to include approximately 110,000 irrigated acres in 2007. Of those acres, approximately 33,000 were planted to alfalfa.

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), or the water transpired by the crop plus the water evaporated from the soil (Hanson et al., 2008). As crop ET increases, so does alfalfa yield up to maximum ET. Nevertheless, agronomic and economic reasons constrain this relationship. A particularly important constraint is *Phytophthora* root and crown rot disease. Irrigation must be managed properly due to the susceptibility of alfalfa to *Phytophthora*. It is a common disease of alfalfa and occurs in poorly-drained soils or when the water application to meet the crop water requirement exceeds the capacity of the soil to take in the water. It can be devastating for growers because the spores are mobile in water and have the ability to infect large areas of fields. If infection stays in the roots, plant growth will be reduced, at best, and the plants may become susceptible to secondary infections. If the infection spreads to the crown of the plant – the region of the plant from which stems sprout – the plants generally die.

In the Delta region, soil salinity can also affect the relationship between evapotranspiration and alfalfa yield. In general, plants are stressed by saline conditions because they must expend more energy to take up water, leaving less energy for plant growth. This can cause plant stunting and reduced yields. To prevent harmful accumulation of salts, the soil profile must be leached periodically with an amount of water in excess of what is used by plant ET. Leaching occurs whenever irrigation and effective rainfall, or the amount of rainfall that is stored in the root zone and available for crops, exceed ET (Hoffman, 2010).

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

$Lf = Dd/Da = Ca/Cd = ECa/ECd$ (Equation 1)

$Lr = Dd^*/Da = Ca/Cd^* = ECa/ECd^*$ (Equation 2)

where D refers to the depth of water, C is the salt concentration, EC is the electrical conductivity, the subscripts d and a respectively designate drainage water at the bottom of the root zone and applied water as irrigation plus effective rainfall minus runoff, and * as required versus actual values (Hoffman, 2010). Many models have been proposed to relate ECd* to some value of soil salinity that is an indication of the Lr for the crop (Hoffman, 2010). For example, Rhoades (1974) proposed that ECd* could be estimated from ECd* = 5ECet – ECa, where ECet is the soil salt tolerance threshold for a particular crop and ECa is the salt concentration of the applied water. Thus, Equation 2 becomes:

$Lr = ECa/[5ECet - ECa]$ (Equation 3)

There are two factors necessary to estimate the Lr. One factor is the salt concentration of the applied water, as irrigation and effective rainfall. Salinity of irrigation water 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. Some crops are more tolerant of salinity than others; alfalfa is moderately sensitive. Beyond an average root zone soil salinity threshold (ECet) of 2.0 dS/m and an average applied water salinity threshold (ECa) of 1.3 dS/m, alfalfa yield reductions are expected (Ayers and Westcot, 1985). Using these values in Equation 3, the ECd* is calculated to be 8.7 dS/m, and the Lr is calculated to be 15 percent. When ECet is given at 2.0 dS/m but ECa ranges from 0.5-2.0 dS/m, the Lr ranges from 5-25 percent (Figure 1). The average ECa for this range of values is 1.3 dS/m, and the average Lr is 15 percent. The yield potential guidelines in Ayers and Westcot (1985) assume a 15 percent Lf. Using these guidelines to predict crop response from a given applied water salinity requires an achievable Lf of 15 percent, and when ECa is higher than 1.3 dS/m, the Lf must be higher than 15 percent.

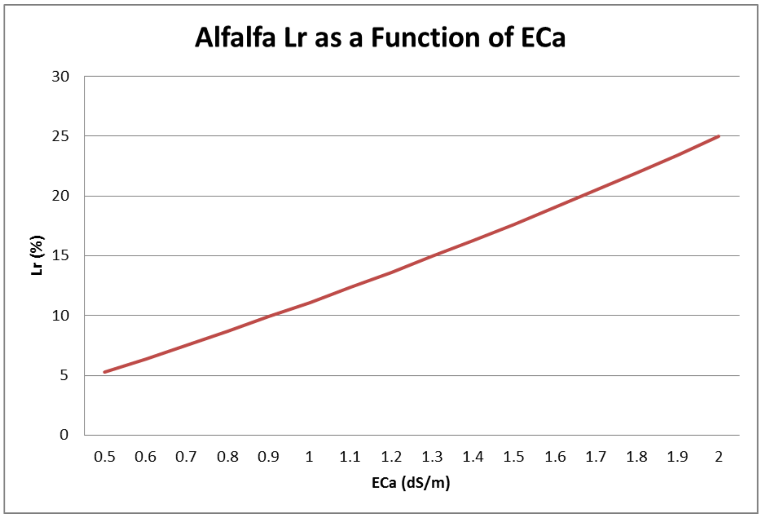

Figure 1. Alfalfa leaching requirement (Lr) as a function of the average applied water (ECa).

Excess soil salinity in the Delta is a sporadic problem in the short term – varying with the depth and quality of the groundwater, quality of the surface irrigation water, and volume of effective winter rainfall. Given the Delta's unique circumstances and constraints, a 15 percent Lf may not be possible. Water tables in the area are typically within 2 meters of the soil surface, and the groundwater quality may be near or worse than the threshold ECa of 1.3 dS/m. 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; Hoffman, 2010). 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 achieve a 15 percent Lf 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 standards.

The California State Water Resources Control Board (SWRCB) adopts water quality objectives for the protection of various beneficial uses in the Bay-Delta, including agricultural uses. An agricultural objective was first developed by the SWRCB in the 1978 Water Quality Control Plan, which was not formally adopted until the 1995 Water Quality Control Plan and not implemented until the 2000 Water Rights Decision D-1641. The objective was determined using knowledge of the soil types, irrigation practices, and salinity standards of predominant crops in the area (Ayers and Westcot, 1985). In particular, the objective was based on the salt sensitivity of beans and alfalfa, and the maximum salinity of applied water that would sustain 100 percent yields for these crops. Since beans were the most salt sensitive summer crop, the objective for the months of April through August was set at 0.7 mmhos/cm (equivalent to dS/m), and the objective for the months of September through March was set at 1.0 mmhos/cm based on the sensitivity of seedling alfalfa. When the SWRCB adopted the 2006 Water Quality Control Plan, no changes were made to the original 1995 Plan objective because there was a lack of scientific information to justify a change (Hoffman, 2010).

The objective of this work was to gain knowledge on the current leaching fraction being achieved in south Delta alfalfa soils and update the state of knowledge on how surface water quality and rainfall affect the leaching fraction. The knowledge gained from this study provides current data to inform water policy that sets south Delta salinity objectives, and it will assist growers with irrigation strategies for effective salinity management.

Methods:

The study was conducted in seven commercial fields of mature alfalfa in the south Delta region. South Delta alfalfa 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). Within the south Delta, Merritt silty clay loam encompasses 24,580 acres, Grangeville fine sandy loam encompasses 7,780 acres, and Ryde clay loam encompasses 3,691 acres

(Hoffman, 2010). 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). While the Grangeville and Ryde series are not as widespread in the south Delta as the Merritt series, 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 is 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 is where irrigation water enters, and the bottom is where irrigation water drains. 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) each from 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 between 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 (Sparks et al., 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, then multiplying by the total number of cuttings, as reported by the grower.

Calculations and analysis. The equation Lf = ECa/ECd was used for the leaching fraction calculation, where, as previously described, ECd is the electrical conductivity of soil water draining below the root zone, and ECa is the electrical conductivity of the applied water (Ayers and Westcot, 1985). We used the equation ECd = 2ECe (Ayers and Westcot, 1985) to relate known soil saturated paste extract salinity (ECe) to ECd. The 30-cm increment with the highest ECe and Cle in the fall was considered the bottom of the root zone for the Lf calculation and represents the salt concentration of deep percolation water from the bottom of the root zone.

Instead of using ECd = 2ECe, Lonkerd et al. (1979) multiplied by a ratio of FC/SP, where FC is the field capacity of the soil and SP is the saturation percentage. This ratio makes the assumption that soil water content below the root zone is at field capacity. We did not make this assumption given the presence of a fluctuating water table and because soil moisture calculations demonstrated that not all soils were at field capacity when collected (data not shown). We also used ECw in place of ECa in the equation because rainfall data was not collected during the previous winter (2012-2013).

The achieved Lf was calculated as both Lf = ECw/2ECe and Lf = Clw/2Cle, where ECw and Clw are the average irrigation water salinity over the season, and 2ECe and 2Cle are the salinity of the soil water near field capacity (Ayers and Westcot, 1985). 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 had a seasonal average ECw exceeding 0.7 dS/m, the irrigation season salinity objective set by the California State Water 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 by depth is illustrated in Figure 2. The soil salinity profiles at Site 1 (Figure 2A) and Site 6 (Figure 2B) exhibit a similar trend of increasing until a certain depth and then decreasing below that depth. At Site 1, soil salinity reached its highest at the depth increment between 90 and 120 cm at every sampling except that during Spring 2015. 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 a shallow groundwater table is limiting the leaching below this depth. At Site 6, the soil reached their highest salinities in the 60 to 90 cm depth-increment during the spring seasons, but by the fall, the maximum salinities were in the 90 to 120 cm depth-increment. Thus, it would appear that some leaching is occurring during the season at this site to lower the salts in the profile but not completely eliminate them from the profile. Groundwater does not appear to be playing as large a role in the soil salinity profile because it is generally lower and less salty than layers of soil with the highest level of salinity.

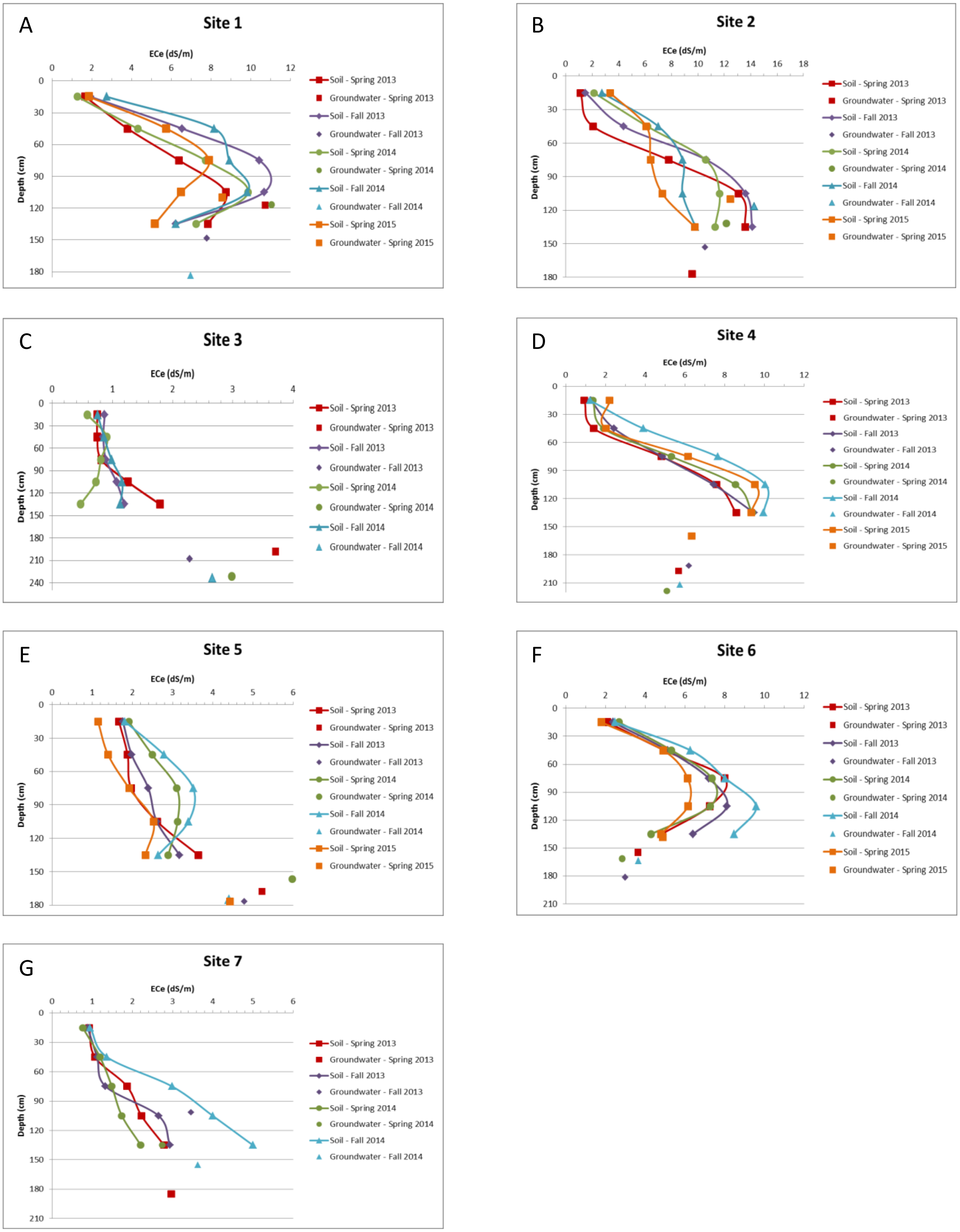

Figure 2. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity. Curves are the average ECe values across top, middle, and bottom sections of the field (average of nine samples).

The salinity profiles of Site 2 (Figure 2B) and Site 4 (Figure 2D) show similar trends of salinity increasing with depth, indicating that soil characteristics and groundwater are not limiting the downward movement of salts in the profile depth that was sampled. While salts may be moving down the profile, the salinities are still higher than what would generally be recommended for alfalfa (Ayers and Westcot, 1985) at depths where alfalfa roots are still likely to be present.

The salinity profiles at Sites 3 and 7 were the lowest of all seven sites (Figures 2C and 2G, respectively). These soils were not sampled in Spring 2015 because the alfalfa was removed and the soil was tilled after the Fall 2014 sampling. 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. Good quality water, deep groundwater, and no restricting soil layers could explain the generally low salinity at these sites.

Site 5 (Figure 2E) had relatively low salinity down the profile compared to other sites, despite Site 5 having the worst quality irrigation water (Table 1). Salinity progressively increased from Spring 2013 to Fall 2014 but generally decreased down the profile by Spring 2015. Soil characteristics likely explain the lower soil salinity relative to other sites. Site 5 is classified as a fine sandy loam (Table 3), which is more permeable than other soils in this study and would be easier to leach. The higher ECgw may be reflective of salts leaching through the soil profile and accumulating in the groundwater.

Leaching fraction. The Lf of the water percolating from the bottom of the root zone is presented in Table 3. The Lf calculations were made using both EC and Cl data, and the data were highly correlated ($R^2 = 0.96$). Hoffman (2010) states, “The common assumption is that with time, a transient system will converge into a steady-state case and provide justification for steady-state analyses if crop, weather, and irrigation management remain unchanged over long periods of time. This assumption is true primarily at the bottom of the root zone.” One could argue that alfalfa is a model crop for these assumptions given that it is a perennial crop that growers are likely to manage similarly for at least four years.

Only two sites (Sites 3 and 5) had a Lf that exceeded 15 percent (Table 3), which is the Lf assumed in the Ayers and Westcot (1985) 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. At Site 3, low salinity applied water (Table 1) resulted in low ECe down the soil profile and a corresponding average Lf of 21 and 18 percent, for 2013 and 2014, respectively. While Site 5 had the poorest quality applied water among the seven sites (Table 1), ECe was relatively low and the corresponding average Lf was 25 and 26 percent, for 2013 and 2014, respectively. The grower was managing salinity by applying enough water to leach the salts. The fine sandy loam texture at Site 5 likely explains the grower’s ability to do so, as water would infiltrate well into this coarser-textured soil. At Site 6, the leaching fraction was 6 and 5 percent, for 2013 and 2014, respectively. Given that Site 6 has the same soil classification as Site 5, this grower may be able to increase the Lf by lengthening the irrigation run time and applying more water. The grower could try experimenting with this practice but would need to monitor closely whether the longer run time results in standing water at the bottom of the field. If standing water were to occur, the practice of longer run times is not a solution for this salinity problem. Site 7 had relatively low ECe at the bottom of the profile, yet had Lfs below 15 percent. This is an example of where good quality irrigation water resulted in a low soil salinity profile; the soil profile is not being loaded with salts by the irrigation water. With a clay loam textural classification, it may not be possible to apply excess water for leaching at this site without the consequence of ponding water. Thus, good quality water is imperative for maintaining soil quality.

Sites 1, 2, and 4 all show inadequate leaching, resulting in high soil salinity at the base of the root zone (Table 3). Higher salinity irrigation water would negatively impact these growers' ability to farm these fields, especially with salt-sensitive crops.

Table 3. Root zone depth (RZ Dep), soil salinity (ECe, Cle), and leaching fraction (Lf) at the base of the root zone at seven south Delta alfalfa sites in Fall 2013 and 2014, averaged across top, middle, and bottom field sections. Sites 1-4 are represented by the soil series Merritt silty clay loam; sites 5-6 are represented by Grangeville fine sandy loam; and site 7 is represented by Ryde clay loam.

	2013					**2014**				
Site	**RZ Dep (cm)**	**ECe (dS/m)**	**Cle (meq/L)**	**Lf EC (%)**	**Lf Cl (%)**	**RZ Dep (cm)**	**ECe (dS/m)**	**Cle (meq/L)**	**Lf EC (%)**	**Lf Cl (%)**
1	100	11.2	84.8	3	2	120	9.8	60.2	3	2
2	150	14.1	114.2	3	1	130	9.8	58.0	5	3
3	140	1.4	5.0	21	23	140	1.2	4.9	18	19
4	150	9.5	65.1	3	2	120	10.7	66.2	2	2
5	130	3.6	20.6	25	20	130	4.1	20.7	26	25
6	120	8.1	53.0	6	5	130	9.8	57.0	5	4
7	140	3.1	11.7	7	7	150	3.8	10.5	8	14

<u>Yield.</u> Alfalfa yield is presented in Table 4. In California, alfalfa yields reach 8-10 tons/acre/year (Orloff, 2008) on average. Average yield at all seven sites reached or exceeded this range in 2013, but four sites did not reach this average range in 2014.

Table 4. 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

The Ayers and Westcot (1985) ECe threshold for maintaining 100 percent yield potential is 2.0 dS/m. 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. For example, hay prices were high during the study years, and some growers may have lengthened their cutting cycles to attain higher yields that may have been lower in quality.

Table 5. 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 6. 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

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). The average root zone salinity as both ECe and Cle were calculated for each site (Table 5 and Table 6, respectively) across five samplings in three years. Five of the seven sites exceeded the ECe thresholds in all five of the samplings across the three years; whereas, four sites exceeded the Cle thresholds. 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. Only Sites 3 and 7 had average root zone salinity consistently below the ECe and Cle thresholds.

Rooting depth was not measured as part of this study, but alfalfa roots have the potential to grow 180-360 cm deep under ideal rooting conditions (Orloff, 2008). At a minimum, a site should provide 90 cm of rooting depth for alfalfa production (Orloff, 2008). All seven sites in this study had at least the minimum rooting depth based on the depth of the water table, but the average root zone salinity has the potential to stress the crop and reduce yields, particularly at Sites 1, 2, 4, and 6.

Summary:

This study provides current data for understanding the Lf being achieved in alfalfa fields of the south Delta, a region that would be further challenged by salinity under conditions of reduced rainfall, reduced water flows, or a higher surface water salinity standard. In 2013 and 2014, three out of seven south Delta alfalfa sites had an average ECw exceeding 0.7 dS/m, the irrigation season salinity objective set by the CA State Water Board. Groundwater salinity appeared to influence the soil salinity profile at several sites, particularly at Sites 1 and 6, where soil salinity decreased at the groundwater depth to reflect the groundwater salinity. Soil salinity increased with depth and generally increased from the spring to the fall season. Only two sites had a Lf at the base of the root zone that was greater than 15 percent. At some sites, there may be the potential to decrease salinity with irrigation management. This is most evident at Site 6, where the top of the profile is being leached fairly well, but the middle and bottom sections are not. Lengthening the run-time so that water sits longer on the middle and bottom sections could be a management option, particularly because this soil has a higher infiltration rate relative to the other sites. Any changes to irrigation should be monitored, however, because if different practices result in standing water on the field, then Phytophthora root and crown rot may result. For other growers, soil characteristics that reduce infiltration may preclude their ability to change irrigation practices. Alfalfa yield at these sites met or exceeded the average yield for California alfalfa and was not correlated with Lf, suggesting that other factors like pest pressure, stand quality, or market forces may have been more influential on yield during the 2013 and 2014 growing seasons. Despite the lack of correlation between salinity and yield, 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.

In future reporting, rainfall from the 2014-15 winter season will be incorporated into the analysis. Recent studies have emphasized the importance of rainfall for leaching (Platts and Grismer, 2014; Weber et al., 2014), suggesting that irrigation water during the season cannot substitute for low winter rainfall. Low winter rainfall results in inadequate leaching unless other measures are taken, such as replenishing the soil profile with irrigation water after harvest in the fall (Weber et al., 2014) or irrigating before a storm in order to leverage the rainfall and optimize winter leaching. Such measures may be necessary to sustain soil longevity and agricultural productivity in the Delta where the achieved Lf is low, particularly in low rainfall years.

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