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 – known as evapotranspiration – 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. 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 policy surface water salinity 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 year.

The objective of this work was to gain knowledge on the current leaching fractions 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 leaching fractions ranged from 2-26 percent, with five of the seven sampling sites having a leaching fraction at or below 8 percent. Alfalfa yield declined from the first to second year of this study. We could not directly attribute the yield declines to salinity, but long-term productivity of these sites could be diminished if

salts continue to accumulate in the soil. Since winter rainfall for leaching is unpredictable, it is important to maintain good quality surface water 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 principles 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 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 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 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 plant generally dies (Davis and Frate, 2016).

In the Delta region, soil salinity can also affect the relationship between ET 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 (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) (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 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 (ECw) of 1.3 dS/m, alfalfa yield reductions are expected (Ayers and Westcot, 1985). Using these values in Equation 2, the Lr is calculated to be 15 percent. When ECet is given at 2.0 dS/m but ECw ranges from 0.5-2.0 dS/m, the Lr ranges from 5-25 percent (Figure 1). The average ECw 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 ECw is higher than 1.3 dS/m, the Lf must be higher than 15 percent.

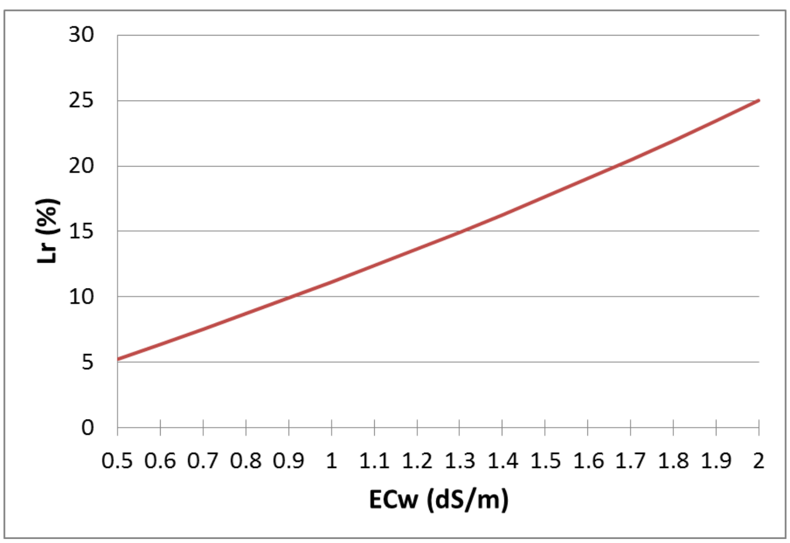

Figure 1. Alfalfa leaching requirement (Lr) as a function of the applied water salinity (ECw).

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 ECw of 1.3 dS/m. Additionally, alfalfa is often grown on soils with a low water 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 requirement 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 a higher surface water salinity objective.

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 applied water salinity that would sustain 100 percent yield potential 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 objectives 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 fractions being achieved in south Delta alfalfa soils, and update the state of knowledge on how surface water quality and rainfall affect leaching. 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 36,000 acres of the south Delta (24,580 acres of Merritt silty clay loam, 7,780 acres of Grangeville fine sandy loam, and 3,691 acres of Ryde clay loam) (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 leaching fractions.

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 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) 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.

The 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) was 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 = 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 known soil saturated paste extract salinity (ECe) to ECdw. In previous research, Lonkerd et al. (1979) did not use this relationship but instead 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). The 30-cm increment with the highest ECe 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. This is supported by Bali et al. (2001), who found that most alfalfa roots are growing in soil layers above the highest soil salinity.
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 (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 spring and fall, 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 accumulated between 90 and 120 cm because groundwater limited leaching below this depth. At Site 2 (Figure 2B), shallow, fluctuating groundwater also appeared to be influencing the soil salinity profile, albeit with a different 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 explain the different soil salinity profiles between Sites 5 and 6. 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 EC_{gw} 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.

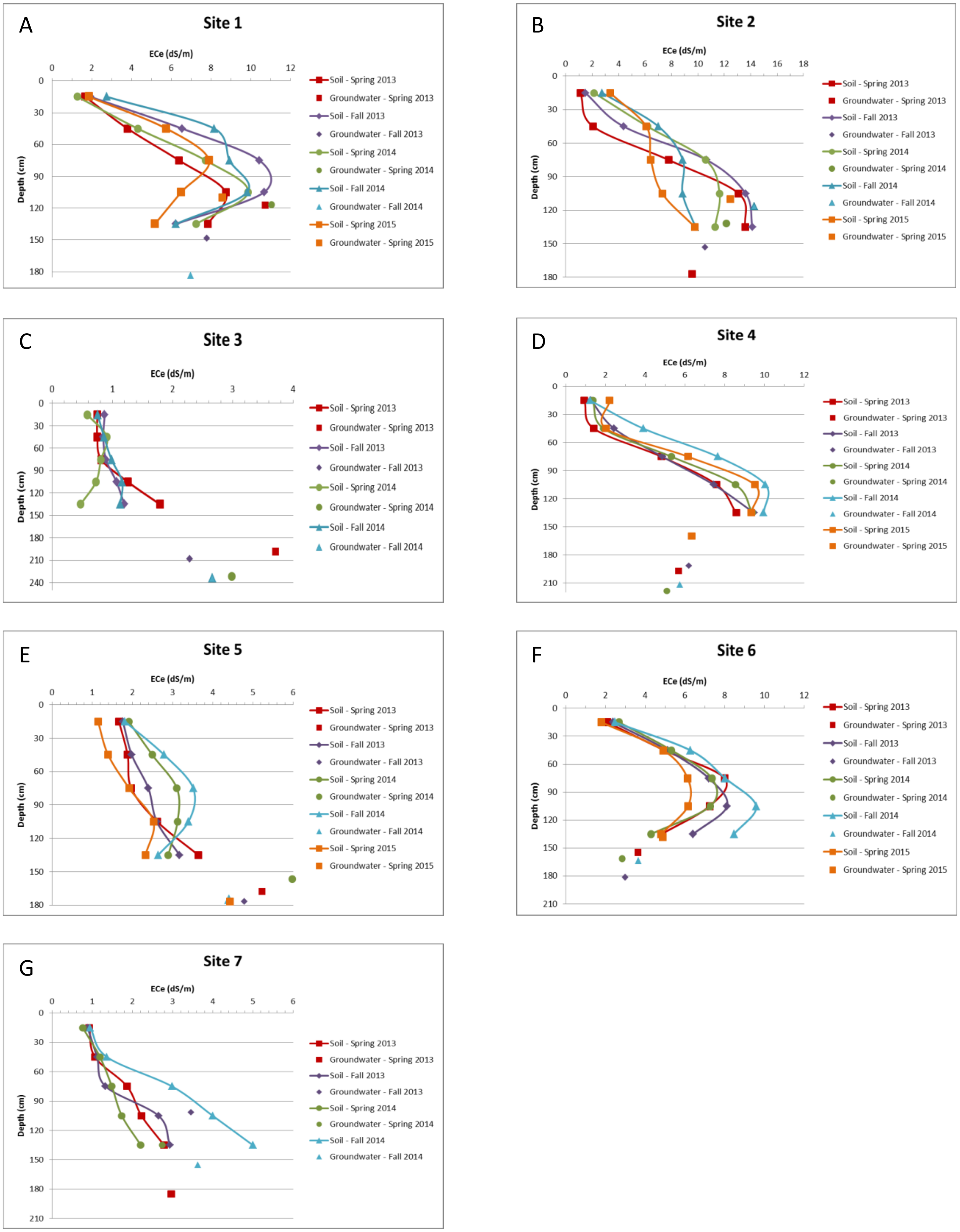

Figure 2. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity. Curves are the average ECe values across top, middle, and bottom sections of the field (average of nine samples).

Table 3. Average root zone salinity down the soil profile (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 down the soil profile (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 and Cl (Table 5), 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. 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.

While management could have improved leaching at Site 6, as previously described, 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, 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 (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.

	2013					**2014**				
Site	**RZ Dep**	**ECe**	**Cle**	**Lf**		**RZ Dep**	**ECe**	**Cle**	**Lf**	
	(cm)	**(dS/m)**	**(meq/L)**	**EC (%)**	**Cl (%)**	**(cm)**	**(dS/m)**	**(meq/L)**	**EC (%)**	**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

Yield. Alfalfa yield is presented in Table 6. Across 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, and all sites showed a decrease in yield. While previous work has illustrated linear decreases in yield as average root zone salinity increases (Bower et al., 1969; Shalhevet and Bernstein, 1968), alfalfa yield was not correlated with average root zone salinity in this study. Because this project was not a replicated experiment with imposed treatments, but rather involved surveying current conditions, other sources of variability that affect yield – like pest pressure or stand quality, among others – could not be statistically controlled. Thus, a statistical relationship between salinity and yield was not evident.

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

Summary:

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 compromise alfalfa yields 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.

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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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.

Davis, R. M. and C. A. Frate, 2006. Alfalfa – Phytophthora root and crown rot. UC IPM. http://ipm.ucdavis.edu/PMG/r1101011.html. Viewed December 2016.

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.

Hoffman, G. J. 2010. Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta. Final Report for the California Environmental Protection Agency, State Water Resources Control Board, Division of Water Rights. January 5, 2010.

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.

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.

Natural Resources Conservation Service (NRCS), United States Department of Agriculture. Accessed 2014. Soil Survey Geographic (SSURGO) Database for San Joaquin County, California. Accessed via SoilWeb: http://casoilresource.lawr.ucdavis.edu/drupal/node/902.

Office of the Agricultural Commissioner – San Joaquin, Sacramento, Yolo, Solano, and Contra Costa counties. 2012. Pesticide use reports.

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.

Platts, B. E. and M. E. Grismer. 2014. Chloride levels increase after 13 years of recycled water use in the Salinas Valley. California Agriculture. 68 (3): 68-74.

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.

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

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.

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.

US Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook No. 60. USDA US Government Printing Office, Washington, DC.

Weber, E., S. R. Grattan, B. R. Hanson, G. A. Vivaldi, R. D. Meyer, T. L Prichard, and L. J. Schwankl. 2014. Recycled water causes no salinity or toxicity issues in Napa vineyards. California Agriculture. 68 (3): 59-67.