From: Jherrlaw@aol.com [Jherrlaw@aol.com]
Sent: Tuesday, March 31, 2015 4:28 PM
To: Riddle, Diane@Waterboards
Subject: Fwd: TUCP

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> From: Jherrlaw@aol.com
> To: DRiddle@waterrights.swrcb.ca.gov, rich.satkowski@waterboards.ca.gov
> CC: thoward@waterboards.ca.gov, dean@hpllp.com, jherrlaw@aol.com
> Sent: 3/31/2015 4:16:10 P.M. Pacific Daylight Time
> Subj: TUCP
>
> Dear Diane and Rich:
>
> I hope to have more extensive comments to the recently filed TUCP as soon as possible, but I did want to raise two issues in the short term.
>
> The first is that the Petition appears to have no treatment of how the proposed changes to the Vernalis standard will affect other legal users of water as required by the Code. Since the 0.7 EC standard was adopted to protect agricultural beneficial uses, then of course relaxing the standard will necessarily result in less protection to those users and likely damage. The Petition barley mentions such users and make no analysis of how the higher concentration of salt will affect diverters along the mainstem or downstream in the southern Delta.
>
> A common misunderstanding is that the SWRCB's Bay-Delta efforts have somehow established that agriculture can tolerate higher EC's than 1.0 without any harm. That of course was based on the Dr. Hoffman report and work which calculated leaching fractions by comparing assumed applied water quality and tile drain water quality. As I pointed out several times, the tile drainage information measures (mostly) the salinity of the poor quality ground water and not just the salts that leached out of the root zone after the application of surface water for irrigation. Hence I asserted that Dr. Hoffman' conclusions were based on a misunderstanding of the date he was using and vastly overestimated the amount of salt being leached. Since that time SDWA has funded a leaching study (attached). The study shows that in areas of the south Delta the applied water is not leaching the salts out of the root zone, but that salt is accumulating in that root zone. Thus, I believe the only information before the Board is that adequate leaching is not occurring when water qualities above 0.7 EC are being applied and thus damage is occurring. Since the TUCP ignores the issue and since the only available data indicates 0.7 EC is not protective, then relaxing the 0.7 to 1.0 EC will adversely affect legal users of water.
>
> This is not only important for Vernalis. The concentration of salts at Vernalis determines in large part the build up of salts in the south Delta channels. I recently have measured local water and found EC's

of 2.2 and 1.8. Clearly concentrations at these levels are harmful to agriculture. The more SJ River salts enter the area the more salt builds up in the channels.

Secondly, the TUCP at the very last page (?) includes a chart showing certain listed areas with 2014 and 2015 forecasts of conditions at those areas. I note the 2014 conditions indicate a forecasted SJ River flow in the summer between 500 and 1000 cfs. A quick check of the CDEC will confirm that SJ River flows last summer were for the most part well below the 500 cfs forecast. This indicates that not only is the modeling being done inaccurate, but that use of the very same modeling for 2015 forecasts is unwarranted. Again, DWR and USBR should be required to analyze the effects of the proposed changes contained in the TUCP so both you and the public can at least have some idea of the impacts of the proposed changes.

I realize the drought may eventually preclude the protections contained in D-1641. However, before such protections are weakened we should at least have an idea of the impacts which will occur. Without such impacts, there is no way to evaluate if the proposed changes are the best choice during these troubled times. JOHN

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Leaching Fractions Achieved in South Delta Soils under Alfalfa Culture
2014 Year-End Report
February 1, 2015

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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 water that passes below the root zone divided by the total applied water. 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 is 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. Anticipated outcomes of the work will be to update the state of knowledge on the achievable leaching fraction in south Delta alfalfa fields and to assist growers with irrigation strategies for effective salinity management. The work was funded by the California Institute

for Water Resources and the South Delta Water Agency. This year-end report describes the 2013 results of the project. The project is on-going, with the 2014 and 2015 results to come in a future report.

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, at best, plant growth will be reduced and the plants become susceptible to secondary infections. If the infection spreads to the crown of the plant – or 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 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. The minimum leaching fraction (Lf), or fraction of water that passes through the root zone divided by total applied water, that a crop can endure without yield reduction is the Lr. These can be expressed as:

$Lr = Dd^*/Da = Ca/Cd^* = ECa/ECd^*$ (Equation 1)

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

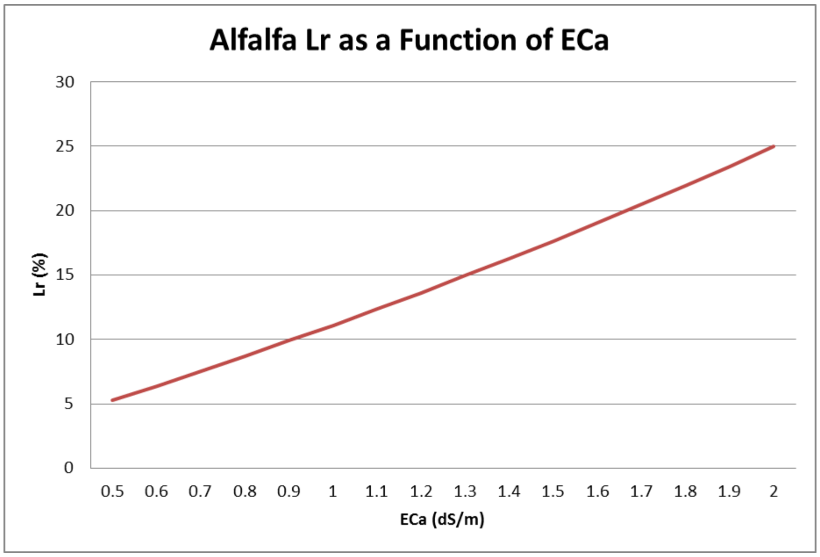

Figure 1. Alfalfa leaching requirement (Lr) as a function of the average applied water (ECa).

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 is 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 will provide 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 is being conducted in seven commercial fields of mature alfalfa in the southern Sacramento-San Joaquin River 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 rainfall ceased and before irrigations commenced, in March and April of 2013. 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, after irrigations ceased for the season.

Irrigation water sampling. Water samples (200-mL) were collected when irrigation water was applied. 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 season (April-October).

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 (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 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 be dried in an oven at 60 degrees-C for 48 hours and weighed for dry weight. Average yield was determined by averaging all quadrat samples, across all field sections and cuttings, then multiplying by the total number of cuttings.

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 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. This represents the concentration of deep percolation 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).

Three Lf calculations were made for each site, representing the top, middle, and bottom sections of the border check. The achieved Lf was calculated as 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.

Preliminary results and discussion:

Irrigation and groundwater salinity. In 2013, average ECw ranged from 0.37-1.79 dS/m across the seven sites, and average Clw ranged from 1.43-8.05 meq/L (Table 1). Three out of seven sites had an average ECw exceeding 0.7 dS/m, the irrigation season salinity objective set by the California State Water Board.

Groundwater varied in depth and salinity from spring to fall and across top, middle, and bottom field sections (Table 2). Average groundwater depth, ECgw, and Clgw represent the average across field sections at a site. Average spring groundwater depth ranged from 117-198 cm, and average fall groundwater depth ranged from 102-208 cm across the seven sites. Average spring ECgw ranged from 2.97-10.72 dS/m, and average fall ECgw ranged from 2.29-10.56 dS/m across the seven sites. Average spring Clgw ranged from 12.10-77.52 meq/L, and average fall Clgw ranged from 7.62-76.49 meq/L across the seven sites.

Table 1. April-October 2013 average irrigation water salinity as electrical conductivity (ECw) and chloride ion concentration (Clw) at seven south Delta alfalfa sites.

		ECw (dS/m)		**Clw (meq/L)**	
Site	**Water Source**	**Range**	**Average**	**Range**	**Average**
1	San Joaquin River	0.2-0.7	0.6	0.7-3.9	2.8
2	Old River	0.5-1.0	0.8	1.6-4.6	3.1
3	San Joaquin River	0.2-0.7	0.6	0.6-3.0	2.2
4	Middle River	0.3-0.8	0.5	1.2-3.6	2.0
5	Paradise Cut	0.3-2.8	1.8	5.4-13.5	8.1
6	Grant Line Canal	0.6-1.1	0.9	2.5-4.7	3.8
7	North Canal	0.3-0.4	0.4	1.1-2.0	1.4

Table 2. Spring and Fall 2013 groundwater depth, electrical conductivity (ECgw), and chloride ion concentration (Clgw) across seven south Delta alfalfa sites.

		Spring			Fall		
Site	Field Section	Depth of Groundwater (cm)	ECgw (dS/m)	Clgw (meq/L)	Depth of Groundwater (cm)	ECgw (dS/m)	Clgw (meq/L)
1	Top	110	11.1	78.6	155	9.0	59.5
	Middle	115	11.1	85.5	150	7.2	48.1
	Bottom	125	9.9	68.5	140	7.1	41.0
	Average	117	10.7	77.5	148	7.8	49.5
2	Top	170	7.6	55.9	160	11.1	73.0
	Middle	175	14.7	119.9	150	14.1	112.4
	Bottom	185	6.4	41.2	150	6.5	44.1
	Average	177	9.6	72.3	153	10.6	76.5
3	Top	210	2.6	12.1	245	2.6	10.2
	Middle	195	6.7	37.6	190	2.6	7.5
	Bottom	190	1.8	7.8	190	1.7	5.1
	Average	198	3.7	19.2	208	2.3	7.6
4	Top	215	3.4	19.5	210	5.2	38.5
	Middle	200	8.1	62.2	200	7.6	54.6
	Bottom	175	5.5	26.6	165	5.8	63.5
	Average	197	5.7	36.1	192	6.2	52.2
5	Top	190	4.0	19.1	185	4.1	19.7
	Middle	170	5.0	33.1	175	5.0	27.7
	Bottom	145	6.8	37.4	170	5.3	28.4
	Average	168	5.2	29.9	177	4.8	25.3
6	Top	170	1.4	5.4	195	1.3	5.1
	Middle	160	3.8	18.5	185	3.3	15.8
	Bottom	135	5.7	32.2	165	4.3	22.7
	Average	155	3.6	18.7	182	3.0	14.5
7	Top	190	1.4	5.1	95	2.8	9.9
	Middle	185	3.5	13.8	100	4.2	18.6
	Bottom	180	4.1	17.3	110	3.4	9.3
	Average	185	3.0	12.1	102	3.5	12.6

Soil salinity. Soil salinity by depth is represented in Figures 1-14. Points on the graphs are shown in the middle of the 30-cm increment, but the salinity values represent the bulked soil salinity for the entire 30-cm increment. These figures illustrate how the salinity profiles differ among the top, middle, and bottom field sections and from spring to fall seasons. These differences may be the result of local irrigation and soil management or varying soil characteristics down the check. Changes in irrigation management may allow growers to better manage salinity when differences down the border checks exist, but changes in irrigation management is not guaranteed to solve the problem. For example, some growers may be managing their irrigation water well but still struggle with salinity because the salinity build-up is due to soil textural differences. Soil texture is an inherent soil condition that cannot be changed by management. While all of the sites had the same soil classification from one end of the check to the other, occasionally, there were visual differences between sections, particularly with the presence or absence of sand lenses or clay layers, and differing depths of these layers.

At Site 1, soil salinity was higher in the middle section of the field compared to the top and bottom sections, especially in the fall (Figure 2). This may be explained by the top section having longer opportunity time for leaching since the irrigation water enters at this end of the field and it remains wetted while water moves down the check. The bottom of the check also exhibits lower ECe than the middle section, and this may be explained by water ponding at the bottom of the field due to soil characteristics or slightly upward field sloping at the end of the check. Each line illustrates that ECe was highest between 60 and 120 cm and that salts were accumulating between these depths. Average ECe increased over the course of the irrigation season for all but the lowest depth (Figure 3). The ECgw was higher in the spring than in the fall and may have been diluted by the irrigation water that was applied during the season. The decrease in ECe below 120 cm appears to relate to the presence of groundwater.

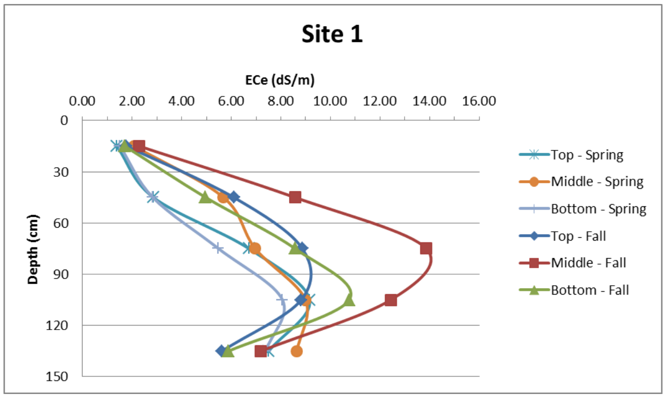

Figure 2. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth at Site 1 in the 2013 spring and fall seasons.

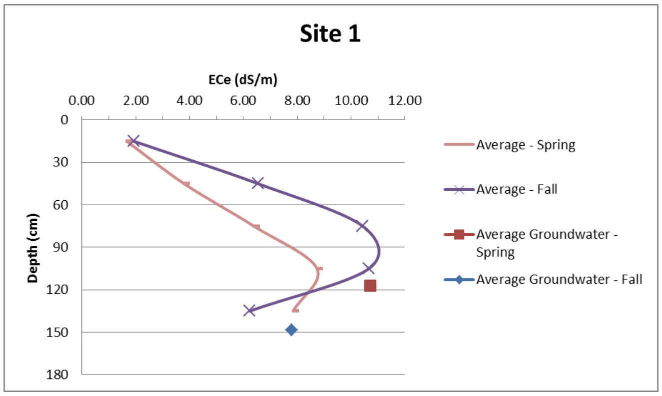

Figure 3. Average soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity at Site 1 in spring and fall 2013.

At Site 2, the ECe showed interesting trends among the field sections. The top section had a decrease in salinity over the irrigation season, but the middle and bottom sections increased in salinity over the season (Figure 4). The grower could possibly improve salinity management with longer run times that keep the water on the middle and bottom sections for longer time. This strategy is not guaranteed to improve the salinity profile in these sections, however, because the Ksat of this soil is low, and the water may not infiltrate well. If the water does not infiltrate well, it will pond on the surface and potentially expose the alfalfa to water-borne diseases, like Phytophthora. The average curves illustrate that salinity increased from the spring to the fall (Figure 5). The ECe appears to have reached the highest value between 120 and 150 cm, but deeper soil sampling would have provided a better picture.

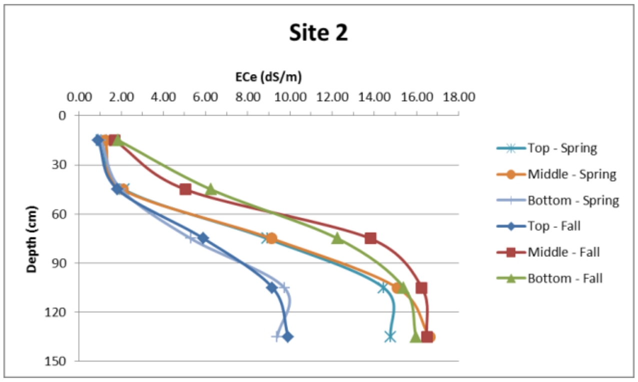

Figure 4. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth at Site 2 in the 2013 spring and fall seasons.

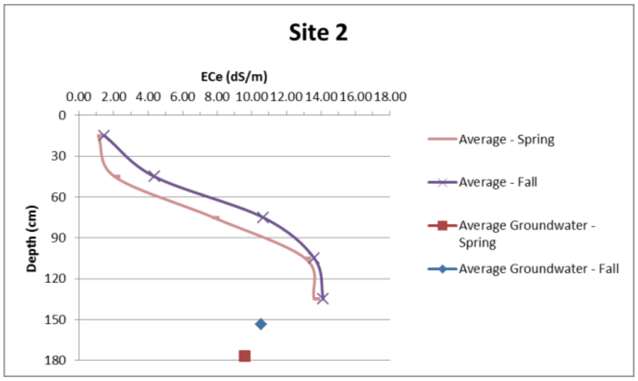

Figure 5. Average soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity at Site 2 in spring and fall 2013.

The salinity profile at Site 3 was the lowest, on average, of all the seven sites (Figure 6). There were some fluctuations in salinity down the profile among the field sections, but the averages illustrate only a slight increase in salinity from spring to fall in the top 90 cm of the profile (Figure 7). The average ECe at each depth was generally much lower than the alfalfa soil salinity threshold for maintaining 100 percent yields, 2.0 dS/m (Ayers and Westcot, 1985). Irrigating with good quality water allowed for leaching within the season from the 90-150 cm depth. Groundwater was much lower than the soil sampling profile in both the spring and the fall, and the ECgw is higher than the ECe and ECw.

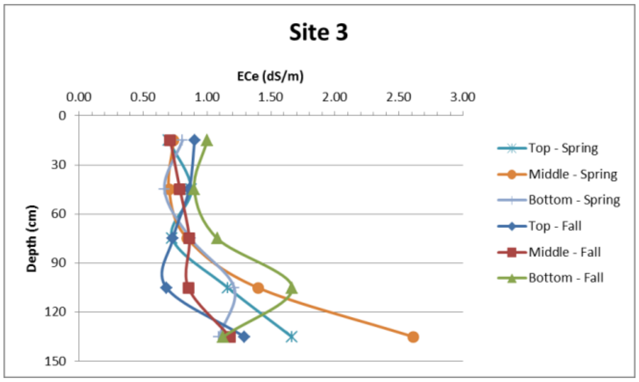

Figure 6. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth at Site 3 in the 2013 spring and fall seasons.

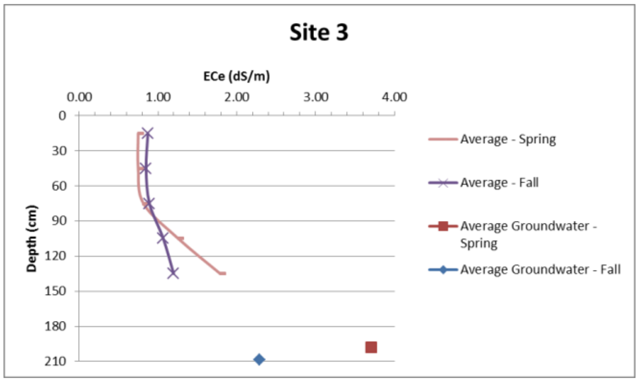

Figure 7. Average soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity at Site 3 in spring and fall 2013.

At Site 4, the salinity profile increased with depth, and there were differences in salinity among field sections (Figure 8). At the bottom of the profile, the top section both in spring and fall had the highest salinity. This may suggest that irrigation water is getting shut-off too soon, and the top is not receiving adequate water to leach the profile, or that a clay layer is preventing leaching. The average salinity curves illustrate that spring salinity was high, and it generally did not change with irrigating (Figure 9).The spring average ECe appears to be leveling off below

150 cm, and given the depth and salinity of the groundwater, the average curves may possibly follow similar patterns as those for Sites 1 and 6, with salinity decreasing deeper in the profile – closer to the groundwater.

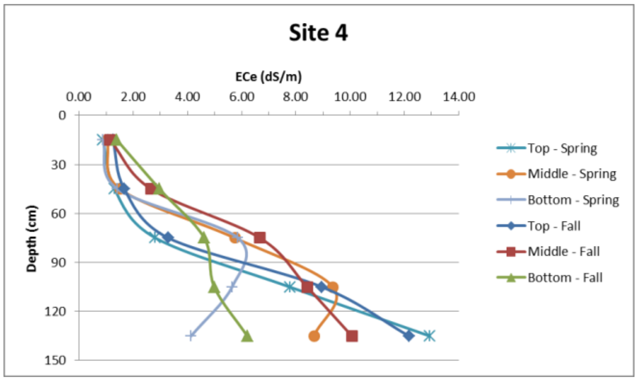

Figure 8. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth at Site 4 in the 2013 spring and fall seasons.

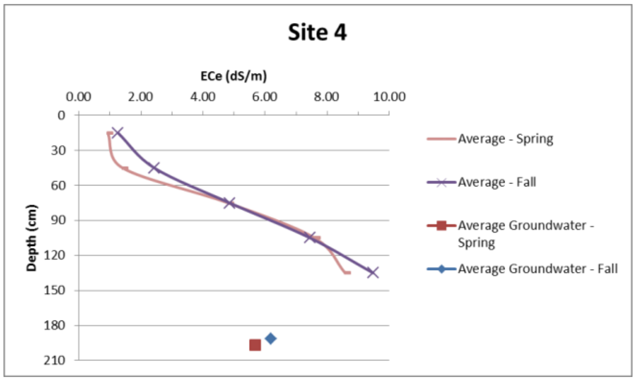

Figure 9. Average soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity at Site 4 in spring and fall 2013.

Site 5 had relatively low salinity compared to other sites, this despite the fact that Site 5 had the worst quality irrigation water on average. The salinity profiles varied among field sections (Figure 10), but the average curves illustrate that salinity only slightly increased in the top 90 cm from spring to fall (Figure 11). Soil characteristics likely explain the lack of salt accumulation over the course of the season. 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.

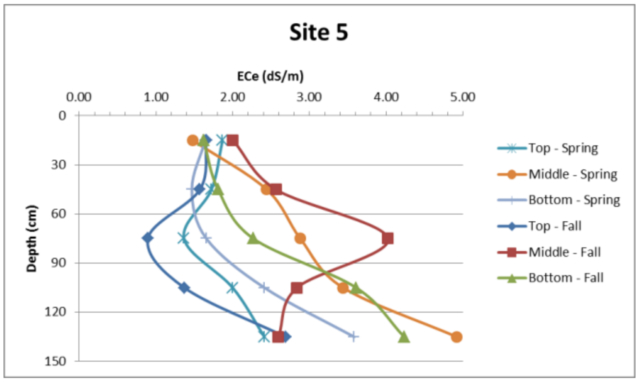

Figure 10. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth at Site 5 in the 2013 spring and fall seasons.

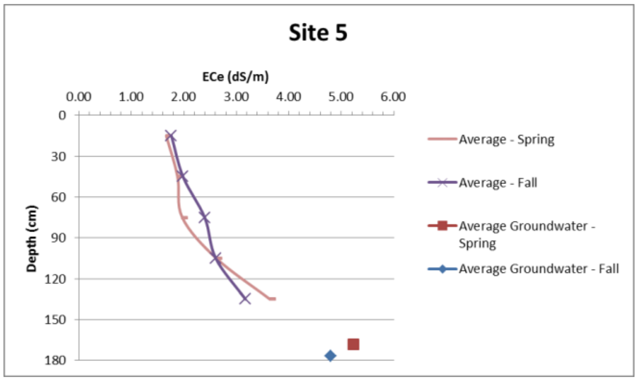

Figure 11. Average soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity at Site 5 in spring and fall 2013.

At Site 6, the top section of the field had much lower salinity in both the spring and the fall (Figure 12). Irrigation management, like a longer opportunity time on the middle and bottom sections of the field, may help to lower the salinity at this site. Since the soil of Site 6 is a fine sandy loam (Table 3), water would likely infiltrate well even with longer run times – a management practice that may not be suitable for clayier soils like Sites 1-4 and 7. The average curves illustrate relatively stable salinity from spring to fall, with the highest salinity between 60-120 cm (Figure 13). The salinity profile improves below 120 cm, as it approaches the groundwater.

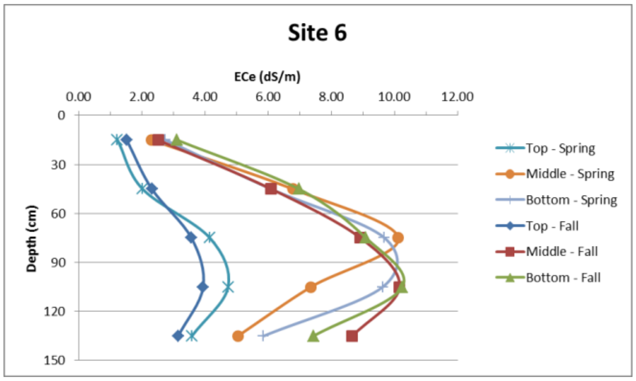

Figure 12. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth at Site 6 in the 2013 spring and fall seasons.

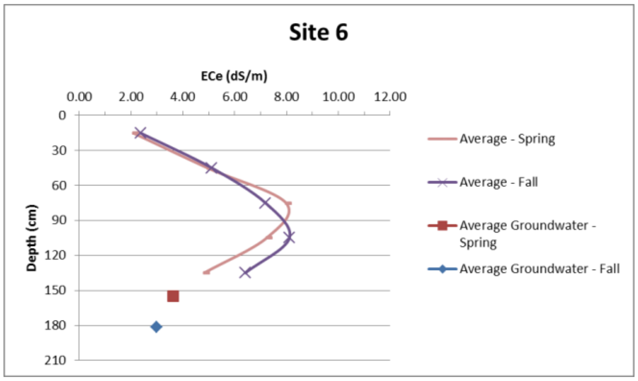

Figure 13. Average soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity at Site 6 in spring and fall 2013.

Good quality irrigation water was likely the reason behind low salinity in the profile of Site 7. All field sections, with the exception of the top section in the spring, had salinity lower than the 2.0 dS/m threshold down to 90 cm (Figure 14). The ECe of the bottom section increased from spring to fall below 90 cm, and this affected the average salinity curve. While salinity did not change much between the spring and fall in the top 60 cm of soil, the presence of shallow groundwater table likely influenced the ECe below 90 cm (Figure 15).

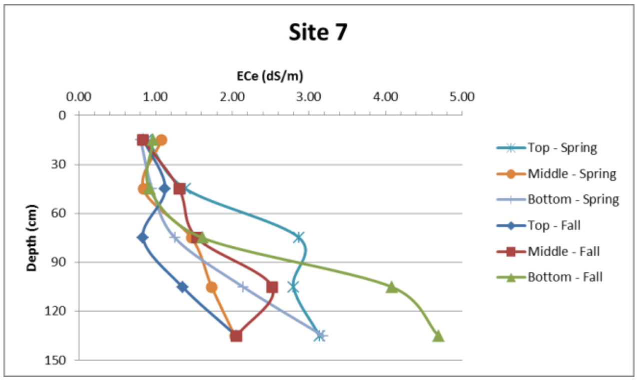

Figure 14. Soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth at Site 7 in the 2013 spring and fall seasons.

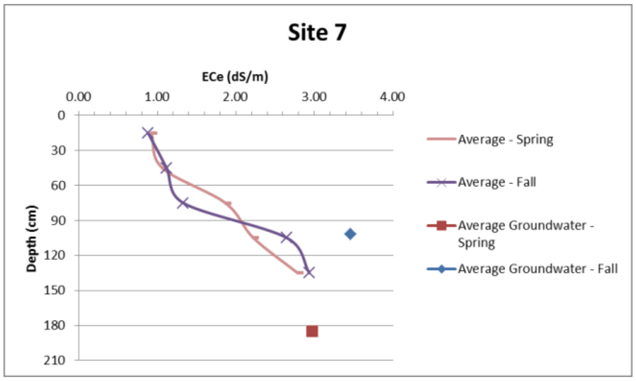

Figure 15. Average soil salinity as electrical conductivity of the soil saturated paste (ECe) by depth, and groundwater depth and salinity at Site 7 in spring and fall 2013.

Leaching fraction. The Lf of the water percolating from the bottom of the root zone was calculated for the three field positions at each of the seven sites, and then it was averaged for those three field positions (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. In the case of Site 3, low salinity water resulted in low ECe down the soil profile and a corresponding average Lf of 21 percent. While Site 5 had the poorest quality water among the seven sites, ECe was relatively low and the corresponding average Lf was 25 percent. The grower was managing salinity by applying enough water to leach the salts. The fine sandy loam texture 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 higher in the top section of the field compared to the middle and bottom sections, averaging 6 percent, using the ECe calculation. This mirrors the curves in Figure 11. Given that Site 6 has the same soil classification as Site 5, this grower may be able to increase the Lf – particularly in the middle and bottom sections – 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 is resulting 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 results in a low salinity soil profile; the soil profile is not being loaded with salts by the irrigation water. The average Lf across field sections was 7 percent. 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 down the profile and low average Lfs, 3 percent at each site using the ECe calculation (Table 3). It is difficult to theorize a solution to this problem when there could be practical limitations to implementing theory. One could theorize that applying more water could solve the problem of low leaching and salt accumulation. After all, Site 3 – having the same soil classification as Sites 1, 2, and 4 – appears to be doing that successfully. This may be a practice worth experimenting with at Sites 1, 2, and 4, recognizing that it is not a solution if the extra water does not infiltrate well. In that event, higher salinity irrigation water would negatively impact these growers' ability to farm these fields, especially with salt-sensitive crops.

Table 3. Fall 2013 soil salinity and leaching fractions at the base of the root zone for each field section, and averaged across field sections, at seven south Delta alfalfa sites.

		Field	**Base of Root Zone**	**ECe**	**Cle**	**Leaching Fraction**	
Site	**Soil Series**	**Section**	**Depth (cm)**	**(dS/m)**	**(meq/L)**	**EC (%)**	**Cl (%)**
1	Merritt Silty Clay Loam	Top	90	8.9	64.9	3	2
		Middle	90	13.9	111.4	2	1
		Bottom	120	10.8	78.2	3	2
		Average	100	11.2	84.8	3	2
2	Merritt Silty Clay Loam	Top	150	9.9	68.5	4	2
		Middle	150	16.5	145.8	2	1
		Bottom	150	16.0	128.4	2	1
		Average	150	14.1	114.2	3	1
3	Merritt Silty Clay Loam	Top	150	1.3	4.9	22	22
		Middle	150	1.2	3.4	24	32
		Bottom	120	1.7	6.8	17	16
		Average	140	1.4	5.0	21	23
4	Merritt Silty Clay Loam	Top	150	12.2	88.9	2	1
		Middle	150	10.1	78.2	2	1
		Bottom	150	6.2	28.4	4	4
		Average	150	9.5	65.1	3	2
5	Grangeville Fine Sandy Loam	Top	150	2.7	15.3	33	26
		Middle	90	4.0	22.4	22	18
		Bottom	150	4.2	24.2	21	17
		Average	130	3.6	20.6	25	20
6	Grangeville Fine Sandy Loam	Top	120	3.9	19.1	11	10
		Middle	120	10.2	64.6	4	3
		Bottom	120	10.3	75.5	4	3
		Average	120	8.1	53.0	6	5
7	Ryde Clay Loam	Top	150	2.1	9.1	9	8
		Middle	120	2.5	12.9	7	6
		Bottom	150	4.7	13.1	4	6
		Average	140	3.1	11.7	7	7

Yield. Alfalfa yield in 2013 is presented in Table 4. Average yield varied little down the border check at each of the seven sites, but it decreased from the first cutting of the season to the last (data not shown). In California, alfalfa yields generally reach 8-10 tons/acre/year (Orloff, 2008). Average yield at all seven sites reached or exceeded this range.

Table 4. Average alfalfa yield at seven Delta sites in 2013.

Site	Number of Cuttings	Average Annual Yield (tons/acre)	Average Annual Yield (Mg/ha)
1	6	8.2	18.7
2	6	11.9	27.1
3	6	8.3	18.9
4	6	8.1	18.4
5	5	9.8	22.3
6	6	10.4	23.7
7	6	8.4	19.1

The Ayers and Westcot (1985) ECw threshold for maintaining 100 percent yield potential is 1.3 dS/m. Site 5 had an average ECw that exceeded that threshold, but that site had a high Lf and yielded well. Alfalfa yield was not correlated with Lf across the seven sites, suggesting that other factors, like pest pressure or stand quality, were more influential on yield during this growing season. Another consideration is that hay was in demand in 2013, and some growers may have traded quality for quantity. For example, growers may have lengthened their cutting cycles to attain higher yields that may have been lower in quality. Quality parameters were not measured in this study, but observations made at the time of yield sampling described many fields as well into flowering. Higher quality hay is generally cut before the alfalfa starts to flower.

Table 5. Fall 2013 average root zone salinity as EC and Cl achieved for seven south Delta alfalfa sites.

Site	Avg Root Zone ECe (dS/m)	Avg Root Zone Cle (meq/L)
1	6.8	47.8
2	8.9	70.9
3	1.0	3.7
4	5.1	32.8
5	2.4	12.6
6	5.7	34.2
7	1.8	6.5

The Ayers and Westcot (1985) average root zone ECe for maintaining 100 percent yield potential is 2.0 dS/m. Average root zone salinity as both ECe and Cle were calculated for each site (Table 5), where ECe and Cle were highly correlated (R^2 = 0.97). The fall average ECe of five of the seven sites met or exceeded this threshold. Only Sites 3 and 7 had an average root zone ECe lower than 2.0 dS/m.

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 could be limiting root growth, particularly at Sites 1, 2, 4, and 6. With time, limitations to root growth could impact yield.

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, 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 high infiltration rate. 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 growing season. Despite the lack of correlation, 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, the achieved leaching fraction for the seven sites will be compared to the leaching fraction models presented in Hoffman (2010) in order to ground-truth these models with actual data. These models use ECw data and an assumed Lf to understand the salinity profile of the soil. Our results will use ECw and ECe data to determine the achieved Lf. In addition to soil and irrigation water salinity, rainfall from the 2013-14 winter season will be incorporated into the 2014 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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