Integrated On-Farm Drainage Management (IFDM Phase 3):

Management factors related to the sustainability of forage production and soil quality

Final Report*

July, 2011

California State University (CSU)
Agricultural Research Initiative (ARI) Grant

Project Number: ARI/CIT/ 37593
Project Duration: January 1, 2007 – December 31, 2010

**Copy of report posted at http://ari.calstate.edu/Projects/Search.aspx*

Principal Investigator (and author of report):
Dr. Sharon Benes, Professor of Soils & Crop Nutrition
Dept. of Plant Science, California State University (CSU Fresno), sbenes@csufresno.edu

Co-Principal Investigators:
Dr. Peter H. Robinson, Dairy Nutrition Specialist
Dept. of Animal Science, University of California, Davis, PHRobinson@ucdavis.edu

Dr. Dave Goorahoo, Assistant Professor, Vegetable Crops Production and Soil Science
Soil Scientist, CSUF Center for Irrigation Technology (CIT)
Dept. of Plant Science, California State University, Fresno, dgooraho@csufresno.edu

Dr. Sergio Juchem, Dept. of Animal Science, Univ. of California, Davis (formerly)
Current: Empresa Brasileira de Pesquisa Agropecuária, Embrapa Pecuária Sul.
sdjuchem@gmail.com

Dr. Stephen R. Grattan, Plant Water Relations Specialist
Dept. of Land, Air and Water Resources (LAWR), University of California, Davis
srgrattan@ucdavis.edu

Diganta Adhikari, M.S. Research Scientist, Center for Irrigation Technology (CIT)
California State University, Fresno, diganta@csufresno.edu

Collaborators:

Dr. Catherine Grieve, USDA Salinity Lab, Riverside, CA; CGrieve@ussl.ars.usda.gov
Vashek Cervinka, California Dept. of Water Resources, vac@dcn.org

Cooperators:

John Diener, Owner/grower: Red Rock Ranch
Dr. John Maas, University of California, Davis, Emeritus Extension Veterinarian

Publications from this work

Juchem S.O., Benes S.E., Robinson P.H., Grattan S.R., Vasquez P. , Chilibroste P., Brito M. (2011). Grazing as an alternative for utilization of saline-sodic soils in San Joaquin Valley: selenium accretion and performance of beef heifers. Science of the Total Environment. *Accepted.*

Acknowledgements: we are very thankful to John Diener and his staff at Red Rock Ranch, Five Points, CA for providing the heifers, pastures and logistical support and to Dr. John Maas (Univ. of California Veterinary Medicine Extension) for performing liver and muscle biopsies. Research was co-funded by the Proposition 204 Agricultural Drainage Program (agreement #4600007357) administered by the California Department of Water Resources

---

Major Objectives:

Component 1 (Grazing Study): assess health risks for beef cattle grazing on tall wheatgrass and creeping wildrye pastures irrigated with saline drainage water that is high in selenium.

Component 2 (Soil Chemistry & Infiltration): examine changes in soil chemistry and infiltration in response to amendments (gypsum, sulfur, poultry manure) applied at very high rates to soils receiving long term irrigation with saline-sodic drainage water. Overall goal is to assess the reclamation potential of these amendments for soils highly degraded by the application of this drainage water.

Note: Due to the distinctly different nature of each study, they will be reported as separate components.

Component 1 (Grazing Study)

I. Executive Summary

Due to increasing water scarcity, saline waters previously considered unsuitable for irrigation are now considered as valuable resources to supplement fresh water supplies (Pereira et al., 2002). These saline water resources include agricultural drainage waters (Qadir & Oster, 2003).
Drainage water (DW) from the western San Joaquin Valley (SJV) is not only saline, but it is also high in sodium ("saline-sodic") and trace elements such as boron and selenium (Se) (Letey et al., 2002). Sodicity degrades soils structure (Oster, 2001) and selenium can potentially be hazardous to wildlife (Ohlendorf, 1986) and to cattle consuming forages with Se levels well above recommended levels (NRC, 2001).

Our previous research (Suyama et al., 2007a) demonstrated that forages such as 'Jose' tall wheatgrass (TWG; *Thinopyrum ponticum* var. 'Jose') and creeping wildrye (CWR; *Leymus triticoides* var. 'Rio') had acceptable biomass production and forage quality under irrigation with DW from the western SJV (EC_w= 8-12 dS/m, B= 10 to 20 mg/L, and SAR= 15 to 23). Although TWG can have high metabolizable energy under well-watered conditions (Suyama et al., 2007a,b), both of these forages are characterized by a high fiber content (NDF= 60 to 68 %, dry matter) which reduces forage quality and lowers their market value. Utilization of TWG and CWR for grazing, however, would reduce the costs of hay cutting and processing while harvesting the value of these salt-affected lands as beef.

Forages grown in saline soils from the western SJV are frequently high in Se, Mo and S and simultaneously, can have very low concentrations of Cu and Mg (Grattan et al., 2004; Suyama et al., 2007b) relative to the requirements of growing beef cattle (NRC, 2000). Because of the mineral imbalances in these forages, concerns related to toxicity, nutrient imbalance and cattle health have been raised, particularly Se toxicosis, hypomagnesemia, and Cu deficiency (Grattan et al., 2004b). Questions were also posed by local beef farmers regarding the utilization and suitability of these forages as the major source of feed for cattle. And the accumulation of selenium to as high as 10 ppm of dry matter in our field study, also raised concerns regarding the suitability of these forages as feed for ruminants. Consequently, the objective of this study was to examine animal health impacts from grazing beef cattle on selenium-enriched (> 2 ppm) forages irrigated with saline DW from the western SJV− in particular the accumulation of Se in heifer blood, liver, and muscle tissues. Body weight gains of the heifers were also determined.

The grazing study was conducted for two grazing seasons (2007 and 2008) with a new group of cattle was utilized each year. In each year, twenty Angus heifers rotationally grazed the experimental pastures of TWG and CWR. The TWG pasture was entering its eighth year of irrigation with saline DW when this study began and the CWR pasture was entering its fifth year. In each year, the heifers were divided into four groups of 5 animals based on initial body weight with the objective of having groups as homogenous as possible in average body weight, yet large enough to support group grazing dynamics. Two groups of 5 heifers were then randomly selected to graze either the TWG or CWR pasture in each experiment. Within a pasture, one group of 5 heifers grazed the northern set of sub-paddocks and the other group simultaneously grazed the southern set. In 2007, the heifers were approximately 6 months old at the onset of grazing and grazed for 190 days and in 2008, the new group of heifers was approx. 8 months old and grazed

for 165 days. Several times during each season irrigation water samples were collected for chemical analysis and twice a year soils were sampled (0-45 cm = 0-18 in. depth). Forage samples were also taken frequently and analyzed for organic forage quality and mineral content. Heifer body weights and blood and liver samples were taken before and at the end of grazing (day 190) in 2007 with additional blood and body weights taken at ~45 day intervals. In 2008, muscle tissue was included and the sampling of all animal tissues and body weights was more frequent. Concentrations of Se and other minerals were measured in the blood and liver samples, whereas muscle tissue was only analyzed for Se content.

Results

In 2007, Se concentrations were similar in the TWG and CWR herbage (4.0 *versus* 3.7 ± 0.26 ppm dry matter) as was crude protein (11.3 *versus* 11.4 ± 0.8%, dry matter). However, in 2008, the concentration of Se was higher in TWG as compared to CWR forage (4.0 *versus* 2.8 ± 0.19 ppm) and crude protein was low in both forages, being 7.9 and 9.0 ± 0.6 % for TWG and CWR, respectively. The low crude protein in 2008 was presumably due to a shortage of the nitrate-rich DW and in place, tailwater which is collected from surface run-off, was used by the grower for some of the irrigations. Since the main focus of the study was selenium accumulation in the forage and soil selenium levels remained high due to previous years of irrigation with DW, this change did not affect the main focus of the study.

Selenium concentrations in the blood of the heifers increased above recommended "safe levels" (NRC, 2001) within approximately 45 days of heifers entering the TWG and CWR pastures in both years. In 2008, the increase was more rapid: within 20 days, blood Se concentration increased by 300% in TWG-grazed heifers, and by nearly 200% in CWR heifers. Concentrations of Se in the liver also increased rapidly in both years for heifers grazing TWG and CWR forage. In 2008, those grazing TWG forage accumulated more Se in the liver than did the heifers grazing CWR which was consistent with a higher level of Se in TWG forage. Muscle which was only sampled in 2008, revealed a similar trend as blood and liver, with greater Se accumulation in TWG-grazed heifers.

Conclusions

No clinical signs of Se toxicity were observed in the beef heifers in either year of grazing. TWG heifers gained more weight in 2007 than did CWR heifers (1.30 vs. 0.62 lbs./day), and these body weight gains were higher than expected. However, during 2008 the BW gains were lower overall and did not differ between heifers grazing TWG or CWR. In 2008, it could not be determined whether the low body weight gains were due to Se toxicosis, or due to the low crude protein in the forage and/or a borderline copper deficiency in the animals. However, based on results reported in the literature related to the nature of Se toxicosis, we conclude that low forage quality and Cu deficiency were more likely the causal factors for the low weight gains in 2008. Data from our two grazing seasons are consistent in demonstrating the safety of grazing beef cattle for a period of up to six months on TWG and CWR forages having elevated selenium concentrations (>2 ppm dry matter) due to irrigation with saline drainage water. This suggests that forage production using saline drainage water is a viable alternative for saline soils with limited potential for producing high value, salt-sensitive, crops.

II. Detailed Report and Major Accomplishments

Methods

Research setting and methodology: Twenty-acre pastures of TWG and CWR located in the Integrated On-Farm Drainage Management (IFDM) at Red Rock Ranch (Five Points, CA) were utilized. These pastures were previously irrigated for 4-7 years with saline drainage water. During the study period, tailwater was also applied to the pastures due to a shortage of drainage water, but soil salinity remained high (12-24 dS/m ECe) as did total Se (2-4 ppm) in soil. Two trials were run (2007 and 2008).

Twenty approximately six months-old black Angus heifers purchased from a single herd were divided into four groups balanced for body weight. Each pasture was divided into four 5-acre paddocks (i.e. A, B, C, D) which were rotationally grazed by two groups (north and south sub-paddocks) of 5 heifers. The heifers grazed from May to November (190 d) in 2007. In 2008, the heifers were approx. 9-10 months-old when entering the pastures and the grazing period was May to October (165 days).

Photos A & B (above): Creeping wildrye (CWR) in May (greener) and August (drier).

Photos C & D (above): Tall wheatgrass (TWG) pasture and heifer blood sampling

Soil and Water measurements: several times during each season, irrigation water samples were collected for chemical analysis (Table 1). The samples were kept cold (4° C) and processed for analysis within 24 hr.

Table 1. Chemical composition of the saline drainage[1] water and tailwater[2] used to irrigate the tall wheatgrass (TWG) and creeping wildrye (CWR) pastures in 2007 and 2008.

Forage		n	EC (dS/m)	pH	SAR	B (ppm)	NO3-N (ppm)	Se (ppb)	Mo (ppb)	Cl^- (meq/l)	SO_4^{2-} (meq/l)	Na^+ (meq/l)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)
TWG	Drainage	2	6.9	7.5	11.9	9.30	131	98	33	22.4	51.8	48.6	25.7	7.47
	Tailwater	5	1.8	7.7	8.2	2.34	0.58	11	28	6.78	11.0	13.5	4.36	1.13
CWR	Drainage	4	7.7	7.5	13.5	12.0	131	144	30	25.9	60.4	55.9	25.7	8.47
	Tailwater	6	2.0	7.5	7.9	2.33	1.2	12	28	7.22	12.0	13.9	5.33	1.30

[1]*drainage water= applied water that infiltrated the soil and collected in a subsurface drainage system*
[2]*tailwater= applied water that ran across the soil surface (or otherwise ran off the field) without infiltrating into the soil*

Soil samples (0-18 in. (= 0- 45 cm) depth) were taken twice each year (August and November in 2007 and April and November in 2008). For each pasture, a composite sample consisting of four soil cores from each of the eight sub-paddocks was taken. Salinity, pH, SAR, B, Cl-, SO_4^{2-}, Na^+, CA^{2+}, Mg^{2+} were measured on saturated paste extracts. Total Se and Mo were measured on digested soils.

Table 2. Soil salinity (ECe), sodium adsorption ratio (SAR) and ion composition for the 0-45 cm (0-18 in.) soil depth in tall wheatgrass (TWG) and creeping wildrye (CWR) pastures grazed by beef heifers in 2007 and 2008. N= 16.

	Grazing Season	ECe (dS/m)	pH	SAR	B (mg/L)	Cl^- (meq/l)	Total Se (mg/L)	Total Mo (mg/L)	Cl^- (meq/l)	SO_4^{2-} (meq/l)	Na^+ (meq/l)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)
TWG	2007	22.2	8.3	50.9	31.6	2.2	2.98	1.31	84.5	213	240	24.9	18.9
	2008	14.5	8.3	34.4	24.8	0.1	3.99	.	40.0	151.3	148.3	24.0	13.0
CWR	2007	15.5	8.3	36.0	25.4	1.6	1.86	0.94	52.8	145.5	161.2	27.2	12.7
	2008	13.1	8.3	30.7	21.8	0.1	2.24	.	30.8	139.5	131.5	23.9	12.1

Forage Measurements: during the rotational grazing, forage was sampled prior to and after the cattle entered a sub-paddock. In 2007, a 'frame' method was utilized in which a 0.5 m^2 square was thrown in four locations to create four forage samples per sub-paddock. The forage was cut and weighed fresh, and then dried at 55 °C in a forced air oven for dry weight determination. Due to the extremely heterogeneous nature of these pastures and concerns with the accuracy of the 'frame' method, the method was changed. In 2008, each sub-paddock was systematically walked through before grazing and visually scored (0 to 3 scale) for vegetative cover every 10 m on a two-dimensional 10 m grid, by two scorers, which yielded 70 to 90 individual scores per sub-paddock. Once the scores were determined, the 0.5 m^2 frame was used twice in each score area (1, 2 and 3) to generate six forage samples per sub-paddock for each measurement period. These samples were weighed fresh and then dried. A regression equation plotting forage dry weight per m^2 by score was constructed and the intercept of the regression line was forced through zero. Utilizing these regressions, total dry weight of forage per sub-paddock prior to grazing was calculated. Even with the more rigorous method used in 2008 reliable estimates of standing biomass were not achieved for these pastures. Hence, estimation of forage dry matter intake by the heifers was not possible. These samples did, however, serve for mineral composition and organic forage quality measurements.

Animal body weight measurement and tissue sampling: In 2007, body weights and blood and liver samples were taken before and at the end of grazing (day 190) with additional blood and body weights taken at ~45 day intervals (135, 150 and 190 d of grazing). In 2008, muscle tissue was included and the sampling of all tissues and body weights was more frequent. Concentrations of numerous minerals in whole blood or serum, and in liver tissue were determined in 2007 whereas in 2008, analyses were largely restricted to Se.

Statistical Analysis: Data sampled over time were analysed as repeated measures with the experimental unit (heifers) nested within subplots utilizing the MIXED procedure from SAS software.

Depletion study: After the 2nd year of grazing (2008), blood, liver, and muscle sampling was continued to determine the speed of Se depletion once heifers were removed from high Se pastures. Results are not reported here as this study was funded by another agency.

Results and Discussion

Organic forage quality: TWG had higher forage quality than CWR in 2007 as shown by its higher metabolizable energy (ME) and lower fiber (NDF and ADF) (Table 3). However in 2008, forage quality was low for both forages, in particular the ME (6.66 and 6.05 MJ/kg DM for TWG and CWR, respectively), as compared to our earlier study (9.3 and 8.2 MJ/kg DM) (Suyama et al., 2007a) when hay was cut from the same pastures. In the earlier study, saline drainage water was abundant and the pastures were well-irrigated; whereas during this grazing study both irrigation and drainage waters were in short supply and the pastures were minimally irrigated which likely reduced the energy value of the forage. Generally an ME $\geq$7.0 MJ/kg DM is required to be acceptable as feeds for beef cattle, sheep, and some classes of dairy cattle (NRC, 2001). Crude protein (CP) was exceptionally low for both forages in 2008 (less than 10% dry matter at the beginning of grazing) and it decreased ($P < 0.01$) in TWG pastures to as low as 6.4 % towards the end of grazing (data not shown). This was likely due to less irrigation with the nitrate-rich DW and greater use of tailwater for pasture irrigation. Because these pastures were part of a DW re-use system (IFDM), the grower did not fertilize these pastures.

Table 3. Organic chemical composition of tall wheatgrass (TWG) and creeping wildrye (CWR) forage during the grazing seasons of 2007 and 2008.

Sampling†			CP†††	ME†††	aNDF†††	ADF†††	Ash
Forage	date	N††	%	MJ/kg DM	%	%	%
TWG	2007	16	11.4	7.61	60.0	34.0	10.2
TWG	2008	66	7.9	6.66	64.2	.	8.5
CWR	2007	14	11.4	6.65	67.5	37.1	6.9
CWR	2008	36	9.0	6.05	68.3	.	7.4

†early sampling was May 8 to July 11th as cattle rotated through paddocks and late sampling was July 11 through October
††N = number of samples
†††CP = crude protein, ME = metabolizable energy, NDF = neutral detergent fiber, ADF = acid detergent fiber; all on a dry weight basis

Forage minerals: concentrations of Na and Cl were high in the forage, especially for TWG (1.51 and 1.91%, respectively) (Table 4) which was growing in the more saline pasture. In 2008,

forage concentrations of Ca and Mg were below the mineral requirements recommended for ruminants (0.3% for Ca) (McDowell and Valle, 2000) and (0.1- 0.2% for Mg) (NRC, 2001).

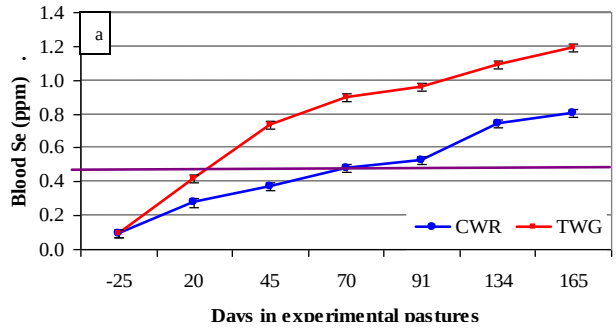
In 2007, Se concentrations were similar in the TWG and CWR herbage (4.0 *versus* 3.7 ± 0.26 ppm). In 2008, Se levels in the herbage of TWG forage were again 4.0 ppm and they were consistently higher ($P < 0.05$) than in the CWR forage (2.82 ppm). However, Se concentrations in the CWR herbage did increase ($P < 0.05$) from the beginning to the end of grazing season (2.4 to 3.2 ± 0.21 ppm dry weight).

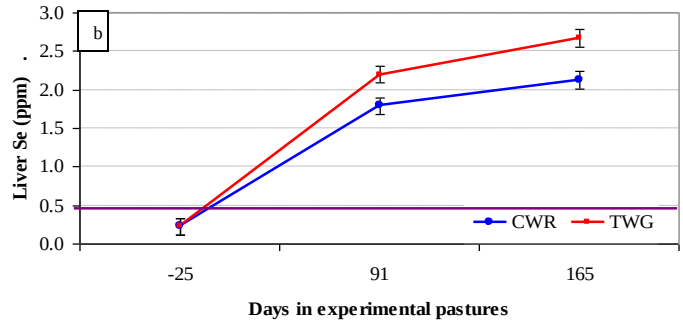
Table 4. Mineral composition of tall wheatgrass (TWG) and creeping wildrye (CWR) forage during the grazing seasons of 2007 and 2008.

Sampling†			N	NO_3-N	Ca	P	K	Mg	Na	Cl	S	B	Se	Mo	Cu
Forage	date	N††	%	ppm	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm
TWG	2007	16	1.52	182	0.31	0.15	1.30	0.15	1.51	1.91	0.50	480	4.05	3.56	5.5
TWG	2008	66	1.00	143	0.22	0.11	1.10	0.10	.	.	0.29	558	3.97		4.1
CWR	2007	14	1.49	81	0.31	0.12	1.74	0.11	2.48	9.64	0.24	185	3.68	1.15	6.8
CWR	2008	36	1.45	247	0.23	0.12	2.14	0.09	.	.	0.24	337	2.82		6.7

†early sampling was May 8 to July 11th as cattle rotated through paddocks and late sampling was July 11 through October.
††N = number of samples. All data on a dry weight basis.

Animal tissue minerals: in both years, Se concentrations in the blood, liver, and muscle rose rapidly when the heifers began grazing these Se-enriched forages. **Blood Se** increased above recommended "safe levels" (NRC, 2001) within approx. 45 days of heifers entering the TWG and CWR pastures in both years (data not shown for 2007). In 2008, the increase was more rapid: within 20 days, blood Se concentration increased by 300% in TWG-grazed heifers, and by nearly 200% in CWR heifers (Fig. 1a). **Liver Se** also increased rapidly and continuously in response to grazing the DW-irrigated pastures. In heifers grazing TWG forage which had the higher Se content, liver Se increased 7-fold from 0.3 to 2.7 ppm (wet liver basis) and for those grazing CWR forage, liver Se increased 6.7-fold from 0.3 to 2.1 ppm (Fig. 1b). **Muscle** was sampled in 2008 only and revealed a similar trend as blood and liver with greater Se accumulation in TWG-grazed heifers (Fig. 1c).





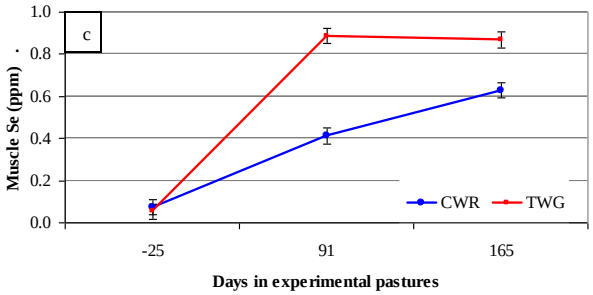


Fig. 1a,b,c. Selenium accumulation in the blood, liver, and muscle of beef heifers during the 2008 grazing season (n= 10). Purple lines show recommended "safe" levels for blood and liver tissue.

The nutritional requirements of Cu for heifers can be variable, *e.g.* 4 to 15 ppm of forage dry matter, because of interactions with other minerals such as Mo, Mg and S (NRC, 2000). Mo levels lower than 2 ppm forage dry matter and sulfur lower than 2500 ppm should not interfere with Cu absorption (NRC, 2000). Cu concentrations in our forages were consistently marginal during both experiments, and were particularly low at the end of the 2008 grazing season for TWG which exposed this group of heifers to Cu deficiency, but not those grazing CWR. In 2007, supplementation of Cu through a slow releasing bolus appeared to alleviate Cu depletion during the grazing period given that CWR and TWG heifers finished the grazing season with similar ($P = 0.61$) Cu levels in serum (0.66 *versus* 0.69 ± 0.036 ppm).

No clinical signs of Se toxicity were observed in the beef heifers in either year of grazing. TWG heifers gained more weight in 2007 than did CWR heifers (1.30 vs. 0.62 ±.09 lbs./d (= 0.59 vs. 0.27 ± 0.040 kg/d); $P<0.01$), and these body weight gains were higher than expected. However in 2008, the body weight gains were lower overall (0.60 *vs.* 0.79 lb./day (= 0.27 *vs.* 0.36 kg/d), respectively) and did not differ between heifers grazing TWG or CWR. In 2008, it could not be determined whether the low body weight gains were due to Se toxicosis, the low crude protein in the forage, or a borderline copper deficiency in the animals. Lawlar et al. (1994) reported liver Se concentrations of 9.9 to 10.8 ppm (dry weight basis) in beef steers whose diets were supplemented with high Se feeds (*i.e.*, hay or wheat grain), or sodium selenate, for 126 d. Accounting for differences between their data reported on a dry weight basis and our liver data on a wet weight basis, the liver Se concentrations in the Lawlar study were approximately twice that observed in our study and these authors also reported no clinical signs of Se toxicity. Furthermore, dry matter intake and body weight gains were not affected by the high Se intake in their beef steers.

We therefore conclude that it is unlikely that exposing non-pregnant, non-breeding cattle to these high Se forages (up to 4 ppm, dry weight) for a grazing season of 6 to 7 months would result in death due to Se intoxication. In fact, in most cases, potential micro-mineral imbalances in forages grown in soils irrigated with saline drainage waters from the western SJV are likely to be a more relevant concern for animal health and performance than is their high Se content.

Component 2 (Reclamation Potential of Soil Amendments)

I. Executive Summary

The application of saline-sodic drainage water (DW) from the western San Joaquin Valley (SJV) degrades soil structure due to high levels of sodium (Na) in the water. Over time, infiltration and hydraulic conductivity (the flow of water through soil) are affected (Oster, 2001; Qadir & Oster, 2004). To keep this system of forage and animal production sustainable, periodic soil reclamation may be required. The second component of this study assessed the impact of irrigation with DW on soil quality and the potential to mitigate this soil degradation with the use of soil amendments.

We examined the effect of three amendments (gypsum, sulfur, and poultry manure) on soil pH, salinity, sodicity, and hydraulic conductivity in soils of two re-use areas (Stages 3 and 4) of the Integrated On-Farm Drainage Management (IFDM) system operating at Red Rock Ranch (Jacobsen and Basinal, 2004). The effect of salinity of the infiltrating water on hydraulic conductivity was also examined. A split-plot design with amendment as the main plot factor and infiltration water salinity (0.5, 6, and 12 dS/m) as the subplot factor was used. The replication level was three.

Due to the highly degraded soil conditions in Stages 3 and 4 of the IFDM, the amendments were intentionally applied at very high agronomic rates. These rates were gypsum and poultry manure applied at 10 ton/acre two times a year (total = 20 tons/acre/year) and soil sulfur applied at 2 ton/acre twice a year (total = 4 tons/acre/year). A non-amended control was also included. The amendments were applied to 1 m^2 plots in Stage 1 (freshwater-irrigated) and Stages 3 and 4 representing the 2nd and 3rd reuse of the DW. Due to unexpected plowing of the soil by the landowner, measurements in Stage 1 were discontinued midway through the experiment.

Hydraulic conductivity (K_{unsat}) was measured at three soil tensions (0.5, 2, and 6 cm) using "mini-disk" tension infiltrometers (Decagon Devices®). The different tensions represent the different strengths by which water is held to soil particles, with 0.5 cm being closest to saturation, i.e., water moves faster at this tension (macro-pore flow is achieved), and 6 cm being the slowest (micro-pore flow is achieved). K_{unsat} measurements were conducted in the fall and late spring of each year, beginning in Fall 2006. Immediately after K_{unsat} measurements were completed, soil samples were taken for chemical analysis and then the amendments were applied. Thus, the K_{unsat} and soil chemistry results from spring 2007, fall 2007, and spring 2008 reflect the outcome of the 1st, 2nd, and 3rd amendment applications, respectively.

Results

Soil chemistry: soils in Stages 3 and 4 of the IFDM had been irrigated with saline DW for seven and nine years, respectively, when measurements began in fall 2006. At this time, Stage 4 soils had salinities of >24 dS/m ECe, sodium adsorption ratio (SAR) >60 and soil pH $\geq$ 8.0. Stage 3 soils had salinities > 11 dS/m ECe, SAR >25 and pH $\geq$ 8.0.

The amendments had a significant effect on soil pH and SAR in the 0-5 cm (0-2 in.) depth (P < 0.05) in spring 2008 (after three amendment applications). In both Stage 3 and 4 soils, the

amendments significantly decreased soil pH and SAR in the 0-5 cm depth ($P < 0.05$), but not for the 0-30 cm (= 0-12 in.) soil depth, in most cases. The lowering of pH in the gypsum-amended plots was not expected, as unlike sulfur and poultry manure, this amendment usually does not have an acidifying effect in soils. Soil salinity (ECe) was not significantly increased by the amendments, in spite of the high application rates.

Soil hydraulic conductivity: salinity (EC) of the infiltrating water had no effect on the hydraulic conductivity at any measurement date thus data for 0.5, 6, and 12 dS/m infiltrating waters were averaged. Generally, saline waters infiltrate better than purer waters, but in these soils it is likely that SAR, rather than EC, was the critical factor influencing infiltration and K_{unsat} (Suarez et al., 2006).

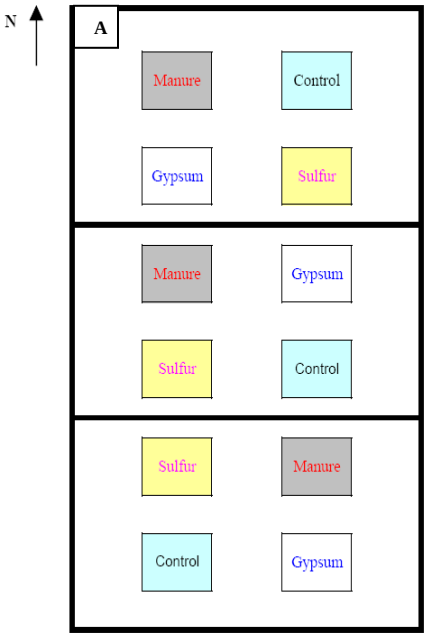
In both Stage 3 and 4 soils, hydraulic conductivity (K_{unsat}) was significantly higher ($P \leq 0.05$) at all three soil tensions in the amended soils as compare to non-amended. Sulfur- amended plots generally had the highest K_{unsat}, numerically-speaking, followed by the gypsum-amended plots, but in most cases differences amongst the amended plots were not statistically significant. Averaging across the three soil tensions at which measurements were taken and for Stage 4 soils which were the most highly degraded, K_{unsat} was 4.0 times higher in sulfur-amended plots, 3.8 times higher in gypsum-amended plots, and 3.3 times higher in poultry-amended plots as compared to the non-amended control plots. These data were from fall 2008, after three applications of the amendments. The improvement in hydraulic conductivity at the 6 cm tension achieved by all three amendments is particularly noteworthy as this is the slowest flow (through micropores) which would likely be the limiting factor for water to enter soil and not pond on the surface.

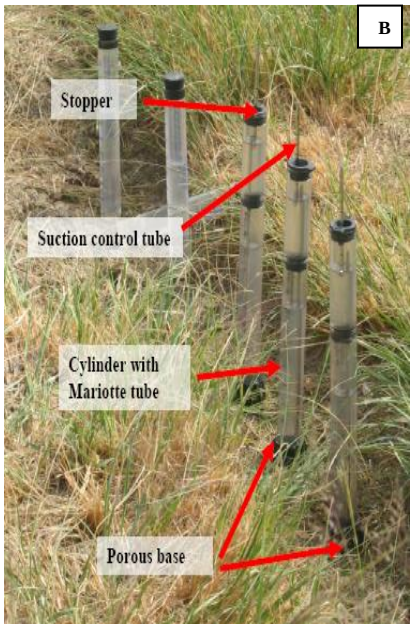
In summary, the three amendments used in this study significantly influenced the physical (unsaturated hydraulic conductivity) and chemical (pH and SAR) properties of soils in the IFDM at Red Rock Ranch. These findings also suggest that in addition to the inorganic forms more typically used (sulfur and gypsum), an organic source such as manure can be successfully used for the reclamation of soils degraded by irrigation with saline-sodic drainage water. The very high amendment application rates used in this study may not be economically feasible, but lower rates could likely be used when irrigating with less saline DW, or if reclamation practices were initiated at the onset of irrigation with this saline DW.

II. Detailed Study and Major Accomplishments

A split-plot experiment with treatments replicated three times was utilized.

- The main plot factor (amendment) consisted of gypsum or poultry manure at 10 tons/acre, or sulfur at 2 tons/acre, applied twice yearly to 1 m^2 plots. A plot receiving no amendment was used as a control.
- The sub-plot factor was salinity of the infiltrating water (0.5, 6, and 12 dS/m). The 0.5 dS/m water was typical of canal water used for irrigation and 6 and 12 dS/m represent low and high DW salinities. (Photo A).
- Minidisk Infiltrometers (Decagon Devices®) (Photo B) were used to measure cumulative infiltration. Cumulative infiltration vs. time curves were fitted and unsaturated hydraulic conductivity (*k*) was then calculated using the approach of Zhang (1997).



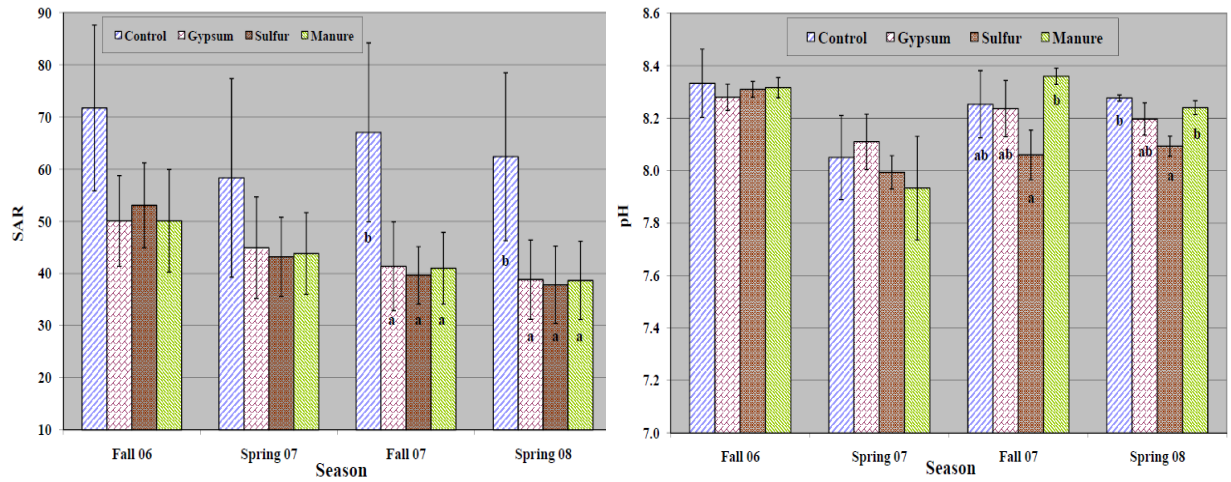


- Infiltration measurements began in fall 2006 (Round 1) and continued twice yearly through spring 08 (Round 4). Round 1 measurements were taken prior to application of the amendments and the remaining infiltration measurements were taken approximately six months after applying the amendments.
- Starting in fall 2007, gravimetric soil moisture was measured in each plot to examine the variation and potential influence of initial soil moisture on the infiltration measured.
- Infiltration was measured at tensions of 0.5, 2, and 6 cm representing flow through large, medium, and small soil pores, respectively.
- To achieve normal distribution and apply conventional statistics, K_{unsat} data were converted to a negative log scale prior to statistical analysis, but for data presentation they were converted back to a non-logarithmic scale (cm/hr.) for ease of understanding.
- Soil samples were collected immediately after the infiltration measurements at depths of 0-5 cm (0-2 in.) and 0-30 cm (0-12 in.) and analyzed for EC, SAR & pH.

Results

The SAR of the top 0-5 cm of soil was significantly lower in the amended soils after two and three applications of gypsum, sulfur, or poultry manure at very high rates to the highly dispersed Stage 4 soils (3rd re-use of DW) (Fig. 1).

Sulfur was the only amendment which after 3 applications resulted in a significantly lower soil pH at the 0-5 cm and 0-30 cm (data not shown) soil depths. This difference, however, was numerically very small (< 0.2 pH unit) (Fig. 2).



Figs. 1 and 2: SAR and pH (0-5 cm depth) for Stage 4 soils after three rounds of amendment application

Unsaturated hydraulic conductivity (K_{unsat}) was significantly increased at all three soil tensions (0.5, 2 & 6 cm) after three applications of the amendments (Table 1). The increase at the 6 cm tension is most noteworthy as it reflects the water held most tightly in soil which moves the slowest and contributes to water-logging. Ponding of water on the soil surface must be avoided in IFDM due to the potential for wildlife exposure to selenium.

Table 1: Hydraulic conductivity (Kunsat in cm/hr) for amended and non-amended soils in Stages 3&4, representing the second and re-use of the DW, respectively. Data are averages for infiltrating waters of 0.5, 6, and 12 dS/m EC_w. Fall 06 measurements were taken prior to commencing amendment application and spring 08 were after the third application of amendments.

	Stage-3			Stage-4	
	Fall 06	Spring 08		Fall 06	Spring 08
	0.5cm			**0.5cm**	
Control	1.68	2.07 a	Control	3.00	2.41 a
Gypsum	1.83	6.84 b	Gypsum	2.58	9.56 b
Sulfur	2.56	6.75 b	Sulfur	4.27	9.37 b
Manure	2.01	6.49 b	Manure	2.31	8.39 b
	2 cm			**2 cm**	
Control	0.78	0.98 a	Control	1.16	1.21 a
Gypsum	0.78	2.62 b	Gypsum	1.01	3.53 bc
Sulfur	0.76	2.64 b	Sulfur	1.08	4.58 c
Manure	0.68	2.39 b	Manure	0.64	3.22 b
	6 cm			**6 cm**	
Control	0.17	0.34 a	Control	0.20	0.28 a
Gypsum	0.16	1.01 b	Gypsum	0.21	1.64 b
Sulfur	0.20	0.99 b	Sulfur	0.22	1.81 b
Manure	0.15	1.01 b	Manure	0.16	1.38 b

Overall, data indicated that when applied twice a year at very high rates (2 T/A, sulfur and 10 T/A for gypsum and poultry manure), all three amendments can effectively reclaim soils highly degraded by long term application of saline-sodic drainage water. Although gypsum and sulfur are traditionally considered more effective in reducing SAR and improving water flow through soil, under unsaturated conditions (K_{unsat}) poultry manure also significantly improved these soil properties. Future research is needed to determine if lower (and more economical) application rates could be used.

Overall Conclusions: There were two distinct components to this project, both important aspects related to the implementation of Integrated On-Farm Drainage Management (IFDM). At the time of writing the proposal, both salinity and poor drainage (due to elevated groundwater levels) were significant problems for agriculture in the western San Joaquin Valley. Now in 2011, after three years of drought and irrigation water scarcity in this area, elevated groundwater levels are less of a problem. Problems with adequate irrigation water supplies remain, however; thus saline drainage water can now be viewed as an alternative water source which if used properly, could augment irrigation water supplies in this area. We view forage production using saline water as a viable alternative due to the large local demand for animal feed, the relatively low maintenance required for perennial forage production, and the high degree of salt tolerance– especially in tall wheatgrass. Furthermore, the fibrous root system of these forages helps to maintain water flow through the soil, and the nearly complete grass cover reduces capillary flow of water and salt accumulation at the soil surface. These factors are critical for the long term sustainability of irrigation with saline-sodic drainage water in the western San Joaquin Valley.

It is not likely, however, that it would be cost-effective to reclaim pastures or other agronomic fields irrigated for multiple years with saline-sodic DW from the western San Joaquin Valley due to the high rates of soil sulfur or gypsum required. Although substantial improvement in soil physical properties could be achieved with these amendments when applied at very high rates, it would be difficult to return the soil to its original condition.

Abbreviations

ADF- acid detergent fiber
CWR = creeping wildrye
CP = crude protein
DM = dry matter
DW = drainage water
EC_e- electrical conductivity of soil paste extract (measure of salinity)
K_{unsat}- unsaturated hydraulic conductivity (meausure of rate at which water flows through soil)
ME- metabolizable energy
NDF = neutral detergent fiber
SAR- sodium adsorption ratio (measure of sodicity)
Se = selenium
TWG = tall wheatgrass

III. Impact Statements (grazing and soil reclamation studies)

1. Young Angus heifers (6-9 months of age) were grazed for 6 to 7 months on high selenium forages (2-4 ppm) and no clinical signs of selenium toxicity were observed in either trial (2007 or 2008). Data from both years demonstrate that in spite of having Se concentrations in blood, liver, and muscle well above recommended levels, young beef heifers can be safely grazed for one year on Se-enriched '*Jose'* tall wheatgrass or creeping wildrye forage. This suggests that saline drainage water from the western San Joaquin Valley can be a valuable water resource for forage and beef cattle production. Se effects on heifer reproduction were not determined, but could limit these operations to one-year feeder cattle only.

2. In a depletion study, conducted immediately after the grazing period— but not funded by this grant— it was found that at 81 days of post-grazing feeding, Se concentrations were reduced by 77% in liver, 49% in blood, but only 31% in muscle. The slow depletion of Se from muscle tissue would be desirable for the production of selenium-enriched beef, a potential value-added product due to the antioxidant properties of Se in the human system.

3. When abundant (wet years), saline drainage water can be a valuable water resource for the production of salt tolerant forages in either a cut-and-carry (hay) system or in a grazing system using pastures of tall wheatgrass or creeping wildrye. In wet years, this would allow for the operation of subsurface drainage systems for water table control (to lower perched water tables). In dry years, use of this saline water for forage production would reduce the demand on freshwater supplies needed for the production of salt-sensitive crops such as fruits, nuts, and vegetables.

4. Results of this study led to a study currently underway in which high Se forages will be fed to dairy cattle (confined feeding operation) to determine whether an organic source of selenium such as that from drainage-water irrigated tall wheatgrass has sufficient bioavailability to substitute for sodium selenate, the supplement currently used by producers in Se-deficient areas such as the eastern San Joaquin Valley. This could potentially decrease the import of Se into the SJV in the form of animal supplements and bring the valley back into balance with regard to Se import and export.

5. Results of the soil reclamation study demonstrated that when applied twice a year at very high rates (2 T/A, sulfur and 10 T/A for gypsum and poultry manure), all three amendments can effectively reclaim soils highly degraded by long term application of saline-sodic drainage water. Although gypsum and sulfur are traditionally considered more effective in reducing SAR and improving water flow through the soil under unsaturated conditions (K_{unsat}), poultry manure also significantly improved these soil properties. Future research is needed to determine if lower (and more economical) application rates could be used.

6. This grant supported two graduate students on assistantship and one undergraduate student working hourly in the project. It formed the thesis research of both graduate

students. One of the graduate students, Vijay Chaganti, is continuing this line of research in a doctoral program at the University of California, Riverside.

7. Industry support consisted of the two groups of twenty beef heifers (one group in 2007 and another group in 2008) purchased by the grower, John Diener.

IV. Literature Cited

Grattan SR, Grieve CM, Poss JA, Robinson PH, Suarez DL, Benes SE (2004). Evaluation of salt tolerant forages for sequential re-use systems. III. Implications for ruminant mineral nutrition. Agric Water Manage 70:137–50.

Jacobsen T, Basinal L (2004). A Landowner's Manual: Managing Agricultural Irrigation Drainage Water. A guide for developing Integrated On-Farm Drainage Management systems. Grant 319H. CA State Water Resources Control Board. Hudson Orth Comm. http://cit.cati.csufresno.edu/DrainageManual/

Lawler TL, Taylor JB, Finley JW, Caton JS (2004). Effect of supranutritional and organically bound selenium on performance, carcass characteristics, and selenium distribution in finishing beef steers. J Anim Sci 82:1488-93.

Letey J, Williams CF, Alemi M (2002). Salinity, drainage and selenium problems in the Western San Joaquin Valley of California. Irrigation and Drainage Systems 16: 253-259.

McDowell LR, Valle G (2000). Major minerals in forages. In: Givens, D.I., Owens, E., Axford, R.F.E., Omed, H.M. (Eds.), Forage Evaluation in Ruminant Nutrition, CABI Publishing, Oxon, UK, pp. 373-397.

National Research Council (NRC) (2000). Nutrient Requirements of Beef Cattle (7th ed. revised). National Academy Press, Washington, DC.

National Research Council (NRC) (2001). Nutrient Requirements of Dairy Cattle (7th ed). National Academy Press, Washington, DC.

Ohlendorf HM, Hoffman DJ, Saiki MK, Aldrich TW (1986). Embryonic mortality and abnormalities of aquatic birds: Apparent impacts of selenium from irrigation drain water. Sci Total Environ 52:49-63.

Oster JD, Shainberg I (2001). Soil responses to sodicity and salinity: challenges and opportunities. Aus. J. of Soil Res. 39:1219–1224.

Pereira LS, Oweis T, Zairi A (2002). Irrigation Management under Water Scarcity. Agric Water Manage 57: 175-206.

Qadir M., Oster JD (2004). Crop Management Strategies for Saline-sodic Soils and Waters aimed at Environmentally Responsible Agriculture. Sci of the Total Environ. 19 pp.

Suarez DL, Woods JD, Lesch SM (2006). Effect of SAR on water infiltration under a sequential rain-irrigation management system. Ag Water Management 86: 150-164.

Suyama H, Benes SE, Robinson PH, Getachew G, Grattan SR, Grieve CM (2007a). Productivity and quality of forages under long-term irrigation with saline-sodic drainage water on the Westside San Joaquin Valley. Anim Feed Sci Technol 135:329–45.

Suyama H, Benes SE, Robinson PH, Grattan SR, Grieve CM, Getachew G (2007b). Forage yield and quality under irrigation with saline-sodic drainage water: Greenhouse evaluation. Agric Water Manage 88:159–72.

Zhang R (1997). "Determination of soil sorptivity and hydraulic conductivity from the disk infiltrometer". Soil Sci. Soc. Am. J. 61: 1024-1030.