Proposition 204 Drainage Re-Use Program

Suitability Assessment of Salt Tolerant Forages and a Halophyte for Sequential Drainage Water Re-use Systems:
Plant water use (ET), Forage Quality, and Productivity

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Principal Investigator:

Dr. Sharon E. Benes, Assistant Professor
CA State University, Fresno; Dept. of Plant Science
(559) 278-2255, 278-7413 (Fax), sbenes@csufresno.edu

Co-Principal Investigators:

Dr. Peter H. Robinson, Dairy Nutrition Specialist
University of CA, Davis; Dept. of Animal Science
(530) 754-7565, phrobinson@ucdavis.edu

Dr. Girma Getachew, Postdoctoral researcher
University of CA, Davis; Dept. of Animal Science,
(530) 752 6554, ggetachew@ucdavis.edu

Dr. Stephen R. Grattan, Plant Water Relations Specialist
University of California, Dept. of Land, Air and Water Resources (LAWR)
(530) 752-4618, srgrattan@ucdavis.edu

Project Objectives:

- Evaluate promising salt tolerant forages ('*Jose*' tall wheatgrass, creeping wildrye, bermudagrass, paspalum, and '*Salado'* alfalfa) growing at Red Rock Ranch (RRR) for their water use (ET), productivity, and forage quality when irrigated with saline drainage water (DW). ***Tasks 1 and 2.***
- Evaluate productivity and quality of these same forages under uniform soil conditions (salinity, boron, SAR) and applied water volume in the greenhouse. ***Task 3.***
- Improve irrigation water monitoring to obtain field-specific measurements of applied water volume and salinity for selected forages growing at RRR. ***Task 4.***
- Investigate growing conditions suitable for salicornia and its productivity and Se accumulation under irrigation with saline DW. ***Task 5.***

II. Summary of Progress

A. Status of overall work

The contract for this research was not finalized until October 2003; however, the availability of matching funds and a graduate student to conduct part of the research as his master's thesis project, prompted us to begin in fall of 2002, shortly after receiving notification of the award. This research will include two years of data collection for all tasks and will continue through December, 2005.

Task 1: The first of two years of water use (ET) measurements was completed for all forages except '*Salado*' alfalfa which failed to grow in our lysimeters due to intensive grazing by wildlife. This year, forage ET measurements are beginning later than usual due to the need to extensively overhaul our lysimeter system over the winter. The modifications have been completed and the forages have been transplanted into the lysimeters. ET measurements will resume in June and continue through May, 2005 in order to capture a complete second year of water use measurements.

Task 2: The first year of field sampling for forage productivity, quality, and mineral composition was completed and laboratory analyses are underway. Year 2 sampling for forage productivity and quality is underway.

Task 3: The greenhouse evaluation of forages irrigated with non-saline, low salinity, and high salinity drainage water has been set up. Saline irrigations commenced in January, 2004 and most forages have had three cuttings. Monitoring of leaching fractions in the pots of each species, and adjustment of the irrigation system to maintain uniform leaching fractions, is in progress.

Task 4: A precision flow meter and in-line salinity probe linked to a datalogger have been installed in two forage stands ('*Jose*' Tall Wheatgrass and Creeping wildrye) at RRR in order to obtain field-specific measurements of the volume and salinity of the applied water. Data are currently being logged.

Task 5: Initial attempts to establish Salicornia on raised beds in a less saline area of Red Rock Ranch (RRR) than where it is currently growing were unsuccessful. New attempts at Salicornia establishment are underway.

B. Status of work conducted per task

Task 1: Forage Water use (ET)

Task = *"Measure cumulative water use (ET) under irrigation with saline drainage water using 1 m^2 "basin lysimeters" for 'Jose' Tall Wheatgrass and 'Salado' alfalfa, and 0.29 m^2 "barrel lysimeters" for bermudagrass, paspalum and creeping wildrye. The lysimeters are located at Red Rock Ranch (RRR) in Five Points.*

- *ET to be measured over two 9 month growing seasons (January-October).*
- *water use (ET) is measured in sand-filled, drainage lysimeters sunk into the ground. A closed, re-circulating, irrigation and drainage system with a metered nightly refill allows the calculation of crop water loss (ET) by a volume balance approach.*
- *To compare forage ET under saline irrigation to grass ET under nonsaline conditions, CIMIS ETo data will be obtained from nearby weather stations (Five Points or Tranquillity). Another reference ET is provided by tall fescue growing in our lysimeters, but irrigated with non-saline water, rather than drainage water.*

Progress and Data

Forage ET was measured from March 3, 2003 until Dec. 1, 2003 (ten months). Because forage and halophyte fields that are irrigated with highly saline drainage water typically contain some areas of barren soil (less than 100% cover), we adjusted our measured ET which was based on 100% cover in the lysimeters to that which would be expected for a field having 82.5% cover for measurements from the basin lysimeters and 79.5% cover for measurements from the barrel lysimeters. These estimates were obtained by measuring the cover in the lysimeter area and immediately upwind using a gridded, 1 m^2 frame containing 100 intersections. The cover estimate is done by laying the frame down throughout the entire area to be measuring and determining the percentage of intersection points below which vegetation was present. The average of all frame counts was used as the cover estimate for the field. This is a common method used by field ecologists for estimating cover in fields with natural vegetation (J. Herrick, personal communication). The method of ET adjustment described above which accounts for local conditions of high advective energy will be examined in more depth and modified if necessary.

Tall wheatgrass irrigated with saline DW (14.7 dS/m, 19.3 mg/L boron) had a cumulative ET that was equivalent to CIMIS ETo for the entire measurement period and due to its long growing season, tall wheatgrass exceeded CIMIS ETo at the end of the year, in November (Fig. 1). Cumulative ET for the tall wheatgrass for the March to November period (275 days) was 1522 mm and its average daily ET for this period was 5.53 mm/day. During the warmest months (June to August), tall wheatgrass had a daily ET of 7.45 mm/day. In comparison, CIMIS ETo for the March to November period was 1432 mm for an average of 5.21 mm/day, and during the warmest months it averaged 7.10 mm/day (Table 1). The cumulative ET of tall fescue irrigated with non-saline water was considerably lower than both tall wheatgrass irrigated with DW and CIMIS ETo. This was partly due to the fact that the fescue went dormant several weeks earlier than tall wheatgrass, and its growth was not as vigorous as it should have been.

The calculated water use for alfalfa grown in Westlands Water District (www.westlandswater.org) where Red Rock Ranch is located was 1176 mm in 2003. This is considerably lower than both the ET of tall wheatgrass irrigated with DW (1522 mm) and CIMIS ETo (1432 mm). This difference may be due to several factors: (1) higher advective conditions in our lysimeter field which has a less dense vegetative cover than does a typical alfalfa field, (2) the longer growing season for tall wheatgrass as compared to alfalfa, and (3) more frequent cutting in our lysimeters. The cutting was done to keep these forages at a height similar to the surrounding vegetation, which is a requirement for ET measurement.

Problems encountered / resolution / changes

ET data were also collected for creeping wildrye, bermudagrass, and Paspalum which were grown in the barrel lysimeters that are located upwind of the basin lysimeters; but these data are still being analyzed. Because a higher rate of ET was measured for non-saline fescue grown in the barrel lysimeters, as compared to nonsaline fescue grown in the basin lysimeters, we felt that the presence of bare soil patches upwind of the barrel lysimeters may have been the cause. We are attempting to improve the vegetative cover in that upwind area, but the area is highly saline and plant establishment—even with halophytes—is difficult. We are also investigating published methods for correcting ET for local advective energy inputs, but this information is sparse due to the shortage of ET measurements under saline conditions in the field. A new FAO publication (Allen, 2003) may provide useful information for this adjustment.

ET measurements could not be conducted for '*salado'* alfalfa due to heavy grazing in these lysimeters by jackrabbits and additional disturbance by voles. Although extensive measures were taken to reduce the grazing, such as: a) re-seeding multiple times, b) use of large transplants rather than seed, c) poison bait for voles, d) wire mesh enclosures around the alfalfa lysimeters, and e) installation of an electric fence around the entire lysimeter area; we were not able to contain the grazing to a significant extent. Apparently, young rabbits were still feeding, and to a lesser extent, voles were also burrowing in the alfalfa lysimeters. Both severely compromised the alfalfa's growth. Forage quality and productivity measurements will be conducted for '*salado'* alfalfa growing in the large fields at RRR and data for this forage will also be obtained from the greenhouse experiment, but ET measurements will not be possible.

In place of '*salado'*alfalfa, we were able to plant both creeping wildrye and Paspalum in the basin lysimeters, along with the tall wheatgrass. The basin lysimeters provide the most reliable ET data because of their larger size and better vegetative cover around them as compared to the barrel lysimeters. Having these three forages that are top candidates for DW re-use systems in the same lysimeter system, should provide an excellent comparison of their ET potential. Because we have two years of ET data for non-saline fescue, we decided to move it out of the basins and into the barrel lysimeters. Bermudagrass ET will also be measured in the barrel lysimeters.

After finishing our first year of ET measurements in December 2003, the lysimeter system was overhauled. This was done because most of the lysimeters at RRR were installed in 1999 (and the last eight in 2000) and we felt it necessary to check their condition (basin liners intact and no cracks in the barrel bottoms). We also had concern that rhizomes of saltgrass which had grown into the lysimeter area from an adjacent field may have punctured the basin liners. We also wanted to examine the depth of rooting of the forages to see whether they were root-bound. With very minor exceptions the liners were intact, but some wear was evident; therefore, nearly all liners were replaced to ensure that these lysimeters would be leak-free. The basins were then re-filled with sand, drainage pumps were re-installed, and the drainage lines were blown clean using forced air. For the barrel lysimeters, there were no cracks in the bottoms, but in those containing bermudagrass, the root mass had

become very large. All of the sand and root material was removed, the drainage lines were blown clear with forced air, and they were re-filled with fresh sand. Both sets of lysimeters have been re-seeded, or re-transplanted, and they are now growing and filling out across the surface area of the lysimeter.

The lysimeter renovation delayed the start of this year's ET measurements and due to the slow establishment typical of tall wheatgrass and creeping wildrye, full cover will not be reached in the lysimeters until mid-June of this year. Consequently, we will keep the lysimeter system running through July 1st of 2005 to complete the second year of ET measurement. Forage growth and ET slows dramatically in December and January and we often we lose access to the site, so data acquisition may not be possible. However, ET data for these winter months is not critical because it is after the irrigation season. We should be able to resume ET measurements in late January or early February, 2005, which corresponds to the beginning of the spring growth flush for the cool season forages (tall wheatgrass, creeping wildrye, and nonsaline fescue). Bermudagrass and paspalum are warm season grasses and they go completely dormant during the winter season. Their growth and water use usually resumes in mid- and late-March, respectively.

***<u>Task 2:</u>* Productivity and forage quality of salt tolerant forages growing at RRR**

Task = *Measure forage quality and biomass production of DW-irrigated, forages growing in large fields at RRR. Productivity will be measured using a rotational cutting system that provides successive measures of standing biomass in the field. Forage quality will be evaluated using a rumen fluid gas test to measure metabolizable energy (ME), along with standard laboratory measurements of crude protein (CP), neutral detergent fiber (NDF), and ash. Twice a year, a subsample of the harvested material will be analyzed for inorganic ions (Se, B, S, Na, Cl, Ca, Mg, P, NO3-N).*

For the forages in common to both studies ('Jose' Tall Wheatgrass and "Salado" alfalfa), field data from RRR will be compared to those obtained from sand tank studies (Robinson et al., 2004) at the USDA Salinity Laboratory (USSL) in Riverside, CA.

Progress and Data

Eight of the large forage stands located in Stages 2 and 3 at RRR (Fig. 2) were included in this task: two for *'Jose'* tall wheatgrass, creeping wildrye, and *'salado'* alfalfa and one each for alkali sacaton, 'Alta' tall fescue, and Puccinellia. Most of these fields had been irrigated with DW ranging from 9 to 13 dS/m (Table 2) for a minimum of three years at the time that tissue sampling began. The exceptions were creeping wildrye, field 2, which did not receive DW irrigation until just after the first tissue sampling (Table 3 data); and '*salado'* alfalfa which is growing in a field previously irrigated with DW, but is now being irrigated with fresh water at the decision of the grower. As shown in Table 3, soil salinity varies considerably amongst these fields due to their size, distances between them, the volume of DW that has been applied, and because of spatial variability that existed prior to conducting DW re-use (IFDM) on this land. Soil samples (0-12 and 12- 24 in. depths) were taken twice a year in the forage plots.

Sampling for productivity and forage quality evaluation began in October 2002. The first year of sampling and data collection has been completed and laboratory analyses are underway. The second year of sampling began in October, 2003.

Productivity

Two 5 m^2 plots were established in each of the eight forage fields. The forage was initially cut to 6 in. and then cuts were taken in 1 m^2 sub-plots in a rotational fashion when the stand reached 12 in., 18 in., and its final height prior to heading, or flowering for the alfalfa. This cycle was then repeated. The data that follow are for Year 1.

Creeping wildrye growing in soil with ECe = 12.9 dS/m produced the highest cumulative biomass (13,800 kg DM/ha/yr). '*Jose*' Tall Wheatgrass growing in a more saline field (ECe = 20 dS/m), produced only about 8,800 kg DM/ha/yr. In another tall wheatgrass field, cumulative biomass production was less than 3,500 kg DM/ha/yr. The exceptionally low productivity of this last field was probably due more to inadequate irrigation than to the high salinity in the field (ECe = 17.5 dS/m). In comparison, '*Salado*' alfalfa that has been irrigated with fresh water, produced about 16,000 kg DM/ha. The active growing period of alfalfa was from the early April to the mid-October, and most of the biomass production came from this period of time. In comparison, tall wheatgrass and creeping wildrye are cool season grasses and have a longer growing season (February to late November), but their growth slows significantly in the summer.

Organic Forage Quality

The data that follow are for samples taken from fall to the early winter of Year 1. Analyses are underway for material sampled the following spring and summer of 2003. The conclusions that follow should be considered preliminary until more data are available; in particular, data for the spring when most of these forages are at their prime.

Although tall wheatgrass had lower biomass production than creeping wildrye, it generally had higher forage quality. For organic forage quality, a higher number for ME and CP indicates better quality; whereas for NDF and ash, lower percentages are desirable. For the better of two stands of tall wheatgrass, metabolizable energy (ME) was 9.34 ±0.4 MJ/kg as compared to 8.72 ±0.3 MJ/kg for creeping wildrye. Tall wheatgrass also had lower NDF (52.2 ±0.9%) than did creeping wildrye (56.3 ±2.0%). Crude protein (CP), was nearly the same for both forages (18.5 ±0.5% and 19.4 ±1.5 %, for tall wheatgrass and creeping wildrye, respectively), and ash content was below 10% for both forages (9.6% for tall wheatgrass and 8.6% for creeping wildrye) (Fig. 3). '*Salado*' alfalfa that was fresh water-irrigated, but is growing in mildly saline soil (ECe = 4.5 dS/m), had the highest forage quality with an average ME of 9.67 MJ/kg, CP = 26.5%, NDF = 31.0%, and ash = 10.3% (Fig. 3).

Metabolizable energy is the parameter that we consider to be most indicative of organic forage quality. Unlike total dissolved nutrients (TDN) which is a calculated value used by animal producers, ME is a direct measurement of a forage's energy value. ME is measured as the amount of gas evolved during the incubation of ground forage material in rumen fluid (Menke et al. 1979, Getachew et al., 2004). Forages having ME values between 10 and 12 are considered to be of "excellent" quality, suitable for lactating animals such as dairy cows; whereas, ME values between 7 and 10 classify the forage as having "acceptable

to good" forage quality. Although ME values for both the tall wheatgrass and creeping wildrye fell into the "acceptable to good" category, the data in Fig. 3 and data taken earlier, indicate that creeping wildrye tends to have ME values from 7.0 to 8.5 which would only be considered as "acceptable". ME values between 9 and 9.5 have been measured for creeping wildrye, but only on one occasion in a young stand which had not been irrigated with saline DW for very long. On the other hand, ME values for tall wheatgrass tend to range from 8.5 to 10 which would be considered as "good" forage quality.

Alkali sacaton had the lowest organic forage quality of all the forages examined: its ME was below 7 which would be considered as poor quality. Similarly, CP was low (14.5% ±0.3%) for alkali sacaton and NDF and ash were higher than most of the other forages. *'Alta'* tall fescue had very good forage quality (ME = 9.27 ±0.11), as did Puccinellia (ME = 9.31 ±0.11 MJ/kg DM), but annual productivity was low for both of these forages (< 6,000 kg DM/ha). In the case of Puccinellia, the low productivity is due to very short growing season (December to May).

Inorganic Forage Quality (mineral composition)

Tissue samples that were analyzed for organic forage quality were also analyzed for inorganic forage quality (mineral composition). The data shown in Table 3 are for the fall to early winter sampling during Year 1. Selenium (Se) concentrations were very high in the RRR forages (4.28 to 8.65 ppm (mg/kg)). This is not surprising because the DW used to irrigate these forages has very high selenium (Se) concentrations; for example, 0.59 ppm (mg/L) for forages in Stage 2 and nearly 1 ppm (mg/L) for forages in Stage 3 (Table 2). Furthermore, at the time of sampling, many of these perennial forage stands had been irrigated with DW for at least three years. The exception was creeping wildrye, field 2, which had Se concentrations of less than 1 ppm because DW irrigation had not yet begun in this field. At the time of sampling, this forage stand was only one year old and for the purposes of stand establishment, it had been irrigated with fresh water for the entire first year after transplanting.

The Se concentrations that we measured in mature forage stands at RRR were much higher than those from a sand tank study at USSL. In that study, Se concentrations for tall wheatgrass, alkali sacaton, bermudagrass, paspalum, and other forages ranged from 0.3 to 2.2 ppm (mg/kg) (S. Grattan, personal communication), nearly always below the maximum tolerable concentration (MTC) of 2 ppm (mg/kg) for selenium in forages set by the National Research Council (Minson, 1990). The synthetic DW used in the USSL study had a Se concentration of 0.50 ppm, which is lower than that of the drainage waters applied to forages at RRR, and the duration of DW irrigation was much shorter (300 – 350 days) as compared to the three years at RRR when our sampling began.

Banuelos et al. (2003) sampled '*salado*' alfalfa and alkali sacaton growing in soil low in salts and Se that was irrigated with saline DW (6.2 dS/m) containing 0.25 ppm (mg/L) Se for two years. During this time, Se concentrations in the forages ranged from 1.3 to 2.5 ppm (mg/kg). The authors noted that *'salado'* alfalfa accumulated more Se than did alkali sacaton for both years and that Se concentrations in forages increased for both species in the second year of DW irrigation.

The much greater Se accumulation in forages at RRR that have been irrigated with high Se (0.6 to 1 ppm (mg/L)) DW for multiple years, suggests that long term irrigation with Westside DW can increase selenium concentrations above the MTC, thereby limiting their use to a mixed ration for ruminant animals. This conclusion is based on published MTC's for ruminant feeds, but it should be noted that the forages sampled in our study have been green-chopped by the grower and fed to black angus beef cattle for three years. The green chop is the sole food source except for a urea molasses lick. The cattle have shown good weight gain and have reproduced successfully (J. Diener, personal communication). A grazing project (Robinson, Benes, et al.) funded by the Proposition 204 Drainage Re-use Program in 2003-- which is not yet underway-- will include animal evaluations and may shed further light on the extent to which these high Se forages can be consumed by grazing animals.

Concentrations of other major and minor ions were generally in acceptable ranges in the RRR forages, with the exception of sulfur (S) which ranged from 0.40 to 0.57% for the forages that had received long term DW irrigation (Table 3). These sulfur levels are above the dietary limit of 0.30 % DW for ruminant animals. McBride et al. (2000) notes that dietary S above 0.3 to 0.4% DW, may be toxic to ruminants due to interactions with essential micronutrients. As noted above, more extensive monitoring of animal health after feeding these forages may be required. Furthermore, nitrate levels as well as selenium and sulfur, should be monitored in the forage. Nitrate concentrations below 1,000 ppm are considered to be safe to feed to all ruminant animals, even lactating animals (Pioneer Hi-Bred International, Inc., 1990). In spite of the very high levels of nitrate (80 – 90 ppm (mg/L) NO_3-N) in the DW at RRR, the concentrations of nitrate in the DW-irrigated forages did not exceed 180 ppm NO_3-N (Table 3). Thus far, only one set of RRR forage samples had nitrate concentrations over 1000 ppm and this was for lysimeter samples which have more frequent irrigation and higher nutrient levels.

From the nutritional standpoint, phosphorus and calcium concentrations were lower in the DW-irrigated forages than in the fresh water-irrigated alfalfa. However, these phosphorus and calcium concentrations would still be considered to be sufficient for ruminants (P. Robinson, personal communication). The difference in calcium concentration may be typical differences between grass and legume forages. More investigation of differences in ion composition between legume and grass forages will need to be explored.

Problems encountered / resolution / changes

No major problems to report.

Task 3: Greenhouse Experiment (supplement to original contract)

Task *= evaluate productivity, forage quality, and mineral composition of five of the most promising salt tolerant forages ('Jose' tall wheatgrass, creeping wildrye, 'salado' alfalfa, bermudagrass and Paspalum) under irrigation with high Se DW in the greenhouse where soil conditions and irrigation volumes can be kept more uniform than at RRR. Treatments consist of three water qualities: nonsaline (NS), low salinity (LS; 8-10 dS/m) and high salinity (HS; 18-20 dS/m)*

replicated four times. Plants are grown in 25 L pots using a 60:40 field soil: sand mix that still maintains its cracking characteristics.

Progress and Data

An automated, re-circulating irrigation system was designed and installed in the greenhouse at CSU Fresno last fall. Cracking clay soil and concentrated DW from the solar concentrator at RRR were transported to the greenhouse at CSU Fresno. A 60:40 soil: sand mix was prepared and the pots were filled. A sample of the concentrated drainage water was analyzed for major and minor elements. This information was used to determine the dilution that would be used to reach the target salinities for the LS and HS treatments and the nutrients to be added to each of the irrigation waters. In particular, thought was given to how to balance nitrogen levels between the saline treatments which have large inputs of nitrogen from the DW, and the nonsaline treatment whose source water is nearly devoid of nitrogen. Young forages seedlings were transplanted into the pots and the saline irrigation began in January. The salinity was increased incrementally each week to avoid osmotic shock to the plants and the target salinities were reached at the end of January. The tank waters are replaced each month so as to ensure that the nutrients are not depleted to a significant extent. After each mix, water samples are taken for analysis of salinity (EC), nitrate (NO_3) and other nutrients.

Forages in the greenhouse are cut when they reach a target height established for each species. This height is roughly similar to the height at which a stand might be cut in the field, but the taller forages must be slightly earlier to prevent them from shading adjacent pots. To date, all forages with the exception of Paspalum have been cut three times. After cutting, the herbage is rinsed to remove surface salts and the dry weight is taken. In order to obtain sufficient material for analysis of organic forage quality and mineral ions, material from more than one cut may be combined. Representative spring, summer, and fall samples will be submitted for analysis. The spring samples are now being collected, but they have not yet been analyzed for forage quality and ions. Biomass data are too few to report.

Measurements of the leaching fractions in the pots were taken and ranged from 10% for the alfalfa (fastest growing) to 67% for bermudagrass and paspalum which have been slower-growing, particularly during the cooler spring days. The irrigation system is being adjusted (extra emitters added to certain pots) in order to maintain similar leaching fractions for each species, rather than applying the same irrigation volume to all pots. It is important to maintain a sufficient leaching fraction (~40%) in order to keep the soil salinities similar to those of the irrigation water.

Problems encountered / resolution / changes

No major problems to report.

<u>Task 4: Water monitoring</u>

Task = *improve water monitoring at RRR. A flow meter with an EC probe and datalogger will be installed in two forage fields so as to obtain field-specific measurements of the salinity and volume of irrigation water applied during each growing season.*

Progress and Data

A flow meter, salinity probe, and datalogger were installed in two forage fields (creeping wildrye and tall wheatgrass) in Stage 3 (formerly "Area C") at RRR (Fig. 2). Problems related to proper wiring and data acquisition were encountered initially and again when the datalogger cables were disconnected in order to bury them in a trench to avoid tractor damage. Data for the 2004 irrigation season (volume and EC of applied water) are now being acquired, but have not yet been analyzed. Similar water monitoring equipment has also been installed by Jim Ayars' research group (USDA-WMRL) in Stage 2 ("formerly Area B"). If available, this would provide irrigation water data for the 40-acre 'Jose' tall wheatgrass field and the 20-acre creeping wildrye field. Up until this time, irrigation flows have been monitored from sumps at RRR, but the volume and salinity of the water applied to individual forage fields in Stages 2 and 3 have not been monitored. This information is critical to compare forage production and ion accumulation amongst the forage stands at RRR which are not replicated and have considerable differences in soil salinity and boron.

Task 5: Halophyte evaluation (Salicornia)

Task =*Determine the biomass production, seed yield and selenium accumulation for Salicornia grown in the IFDM at the Red Rock Ranch.*

- *Biomass will be measured from five subplots mid-season (July) and at the end of the season (late October/ early November) during two growing seasons (2004 and 2005). The vegetative material will be analyzed for Se content.*
- *For fall samples, the seed spikes will be separated out, broken up, and then fed through a seed cleaning machine and/or sieves to remove the chaff prior to weighing.*

Salicornia samples for biomass determination and Se accumulation were taken from the halophyte block (Stage 4, Fig. 2) in 2003, but these data have not been processed yet. Harvests for seed determination will begin in the fall of 2004. It is difficult to determine salicornia seed yield due to the non-uniform maturation of the seeds-- seeds from lower portion of the seed spike often shatter and fall to the ground before those at the terminal end of the spike are mature. It may therefore be necessary to devise a means of collecting the fallen seeds along with harvested plant material. This will be attempted in the fall of 2004.

Because the salicornia growing in Stage 4 at RRR is not a vigorous stand, we attempted to establish it on raised beds in an open check in Stage 3 where the soil salinity and sodicity are lower, and the physical soil conditions are not as poor as in Stage 4. Sodium that is present in the DW tends to disperse the clays in soil which in turn, leads to poor infiltration and permeability to water—hence soil aeration is poor. The raised beds were to help improve drainage and soil aeration. Two seedings were attempted in C13 and both were unsuccessful for several reasons: 1) the working of the soil to prepare raised beds created a hard surface crust, 2) both the salicornia seed and straw that was laid over it to keep the seed on the bed blew off, and 3) competition from Atriplex seedlings that grew from seed that blew in. Even though the beds were weeded, very little salicornia emerged.

From these efforts, it became apparent that the major impediment to salicornia establishment is a tough surface crust. Salicornia will germinate under highly saline conditions, but it does not emerge well under physical resistance. The only reliable seed source for salicornia at the moment is Saline Seed, Inc., in Ensenada, Mexico. This company has generously supplied us with 5-10 kg of seed every fall which is the amount needed to seed large areas (1 to a few acres). The salicornia grows very well in Ensenada, but the soils there are coarse- to medium-textured and they do not form hard surface crusts. The original *SOS-10* accession which grew very well in the Mendota Agroforestry project is no longer available. It is becoming apparent that we will probably need to collect salicornia seed again from a location near San Diego where we collected in 1998. This accession grew well in our lysimeters in 1999 and 2000, but no seed remains. If a new accession can be obtained, the USDA Plant Materials Center in Lockeford, CA will store the seed and try to multiply it. These difficulties with salicornia establishment represent a major limitation to its use in DW re-use (IFDM systems). Many Westside soils are fine-textured and long term irrigation with saline-sodic (high SAR) will disperse clays and lead to crusting. Given that salicornia is an annual which must reseed itself each year, it may be difficult to maintain the stand even if supplemental seeding is done.

III. Upcoming Activities

Task 1 (ET): As described in section II, we have completed renovations of the lysimeter system at RRR and have transplanted new forage material into the lysimeters. Cover is about 50% in most of the lysimeters. We hope to have sufficient cover to begin logging ET data by mid-June. ET data collections will continue through July 1, 2005. We will also be comparing ETo data from a new CIMIS station at RRR to that from nearby stations (Five Points and Tranquillity) to help us to assess the influence of bare soil patches on our ET measurements. Information on the "oasis effect" on ET from R. Allen (1998) and consultation with Rick Snyder (UC Davis) should also be helpful in this regard.

Task 2 (Forage productivity and quality): Year 2 sampling for forage productivity, quality, and mineral nutrient composition is underway in the large field plantings at RRR. Beef cattle have been introduced to one of the creeping wildrye fields in our study, but secure enclosures have been built to protect our plots in this field.

Task 3 (Greenhouse Experiment): The irrigation system in the greenhouse is being adjusted to achieve similar leaching fractions for all five of the forages species included in the experiment. Soil samples will be collected periodically from extra pots that contain forages in order to determine whether the soil salinities are staying close to the irrigation water salinity. The forages will be cut as they reach their target cutting heights and composited samples will be analyzed for forage quality and ions. The tank waters will be changed at the beginning of each month. A second transport of solar concentrator water from RRR to CSUF will be done in early June.

Task 4 (Water Monitoring): Data on irrigation volume and salinity (EC) for the creeping wildrye and tall wheatgrass fields in Area C (Stage 3) will be downloaded from the datalogger on a two to three week-basis. The frequency and format of this data collection

may need to be adjusted. We will be consulting with Jim Ayars' team to acquire similar data from their dataloggers located in the larger stands of tall wheatgrass and creeping wildrye in Area B (Stage 2).

Task 5 (Salicornia evaluation) Samples will be taken for biomass determination in July and late October. A system will be developed to more efficiently harvest salicornia seed in the field. After securing permission, we will collect salicornia seed from an estuary in southern California in order to obtain a new accession that may be better suited to soils with hard surface crusts such as those found on the Westside San Joaquin Valley.

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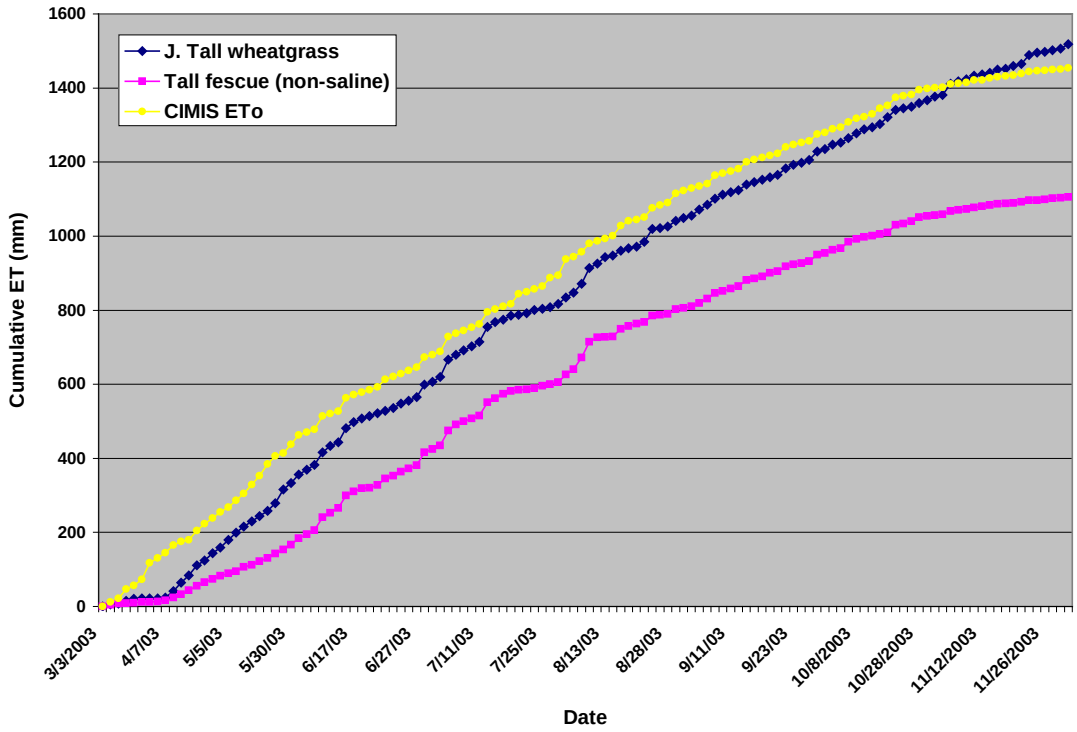
<u>Fig. 1</u>: Cumulative, adjusted* ET of *'Jose'* Tall wheatgrass irrigated with DW and tall fescue irrigated with fresh water, as compared to CIMIS reference ET (ETo).



<u>Table 1</u>. Adjusted* water use (ET) of 'Jose' Tall Wheatgrass grown in drainage lysimeters and irrigated with saline drainage water (average $EC_{i.w.}$ 14.7 dS/m and boron = 19.3 mg/L) at RRR, as compared to tall fescue irrigated with freshwater ($EC_{i.w.}$ = 1.8 dS/m) and CIMIS reference ETo. 2003 data.

Forage	Cumulative (Mar. - Nov.) (mm)	Daily Mar. – Nov. (mm / day)	Daily June - August (mm / day)
***'Jose'* Tall Wheatgrass**	**1521**	**5.53**	**7.45**
Tall fescue (non-saline)	**1106**	**4.02**	**6.72**
CIMIS (Tranquility)**	**1432**	**5.21**	**7.10**

**ET adjusted using the average cover in the area around and just upwind of the lysimeters*
***California Irrigation Management Information System's micrometerological estimate of the ET of a well-watered, cool season grass, under nonsaline conditions.*

Fig. 2. Red Rock Ranch (RRR) sequential drainage water re-use system. Fresh water is applied to Stage 1 (quarter sections A11, A10, A9) where agronomic crops are grown, including salt-sensitive vegetables. Saline drainage collected from Stage 1 is applied to Stage 2 (salt tolerant forages). Drainage from Stage 2 is applied to Stage 3 (forages). Drainage from Stage 3 is then applied to Stage 4 (halophytes) and the final effluent is evaporated in a terminal solar concentrator. Project areaa = 640 acres (260 ha).

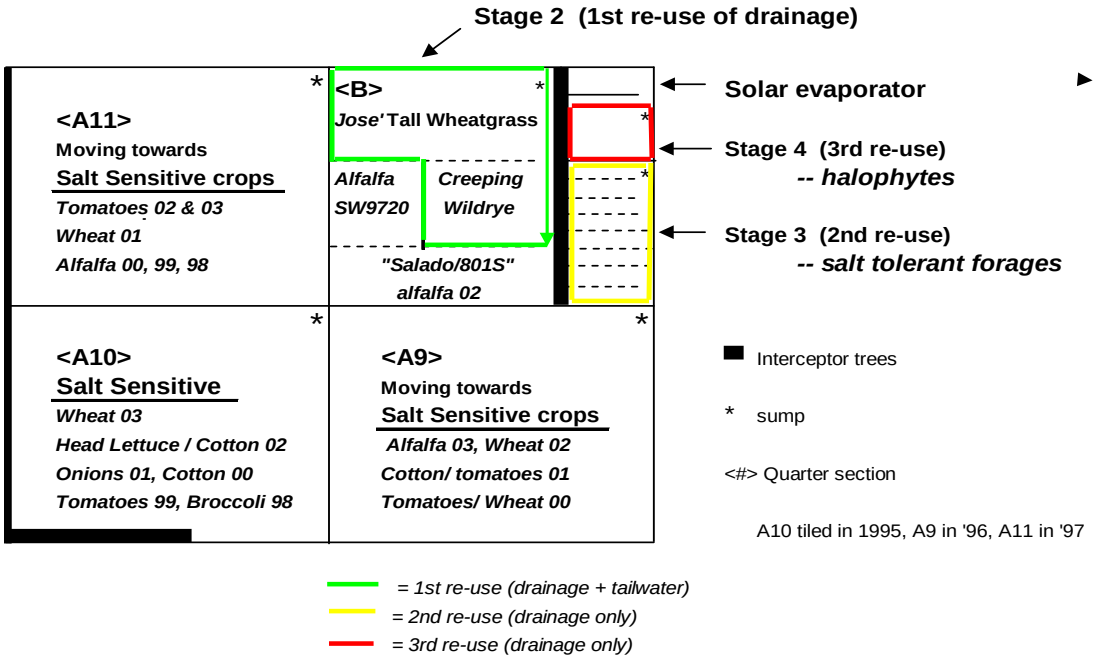


Table 2. Composition of drainage waters used to irrigate salt tolerant forages at Red Rock Ranch. Andrew's Ag data are shown for comparison.

Location & Year	Plants irrigated	EC (dS/m)	SAR	Boron (ppm) (mg/L)	Selenium (ppm) (mg/L)	Molybdenum (ppb) (ug/L)	Sodium (meq/L)	Calcium (meq/L)	Magnesium (meq/L)	Chloride (meq/L)	Sulfate (meq/L)	NO3-N (ppm) (mg/L)	pH
Red Rock Ranch													
	Forages‡												
(7/09/02)	(1st re-use)	10.5	15	19	**0.59**	< 50	77	35	15	37	.	88	8.2
(Avg. 00 to 03)	(Stage 2)	9.26	.	.	.	.	.	.	.	.	.	.	.
(5/22/03)	**Forages‡**	13.7	27	24	**0.98**	< 50	122	27	14	62	102	85	7.2
(1/29/03)	(2nd re-use)	13.0	42	23	**0.99**	.	134	27	13	57	101	83	7.8
(Avg. 00 to 03)	(Stage 3)	11.8	.	.	.	.	.	.	.	.	.	.	.
Andrews Ag (1/02/03)	**Halophytes** (2nd re-use) (Stage 2)	10.6	27	14	**0.26**	.	126	21	25	25	142	83	8.3

†*Water from Sump A at Red Rock Ranch*

††*Water from Sump B at Red Rock Ranch*

Fig. 3. Forage Dry Matter Production from Sept. 2002 to 2003.

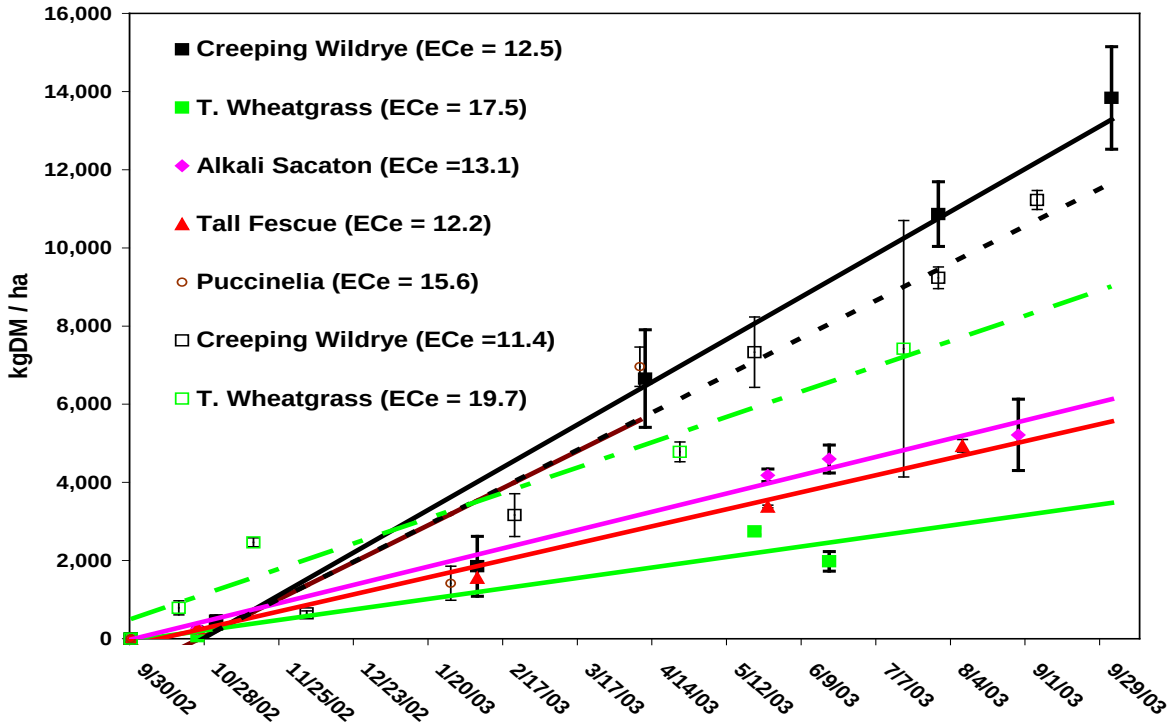
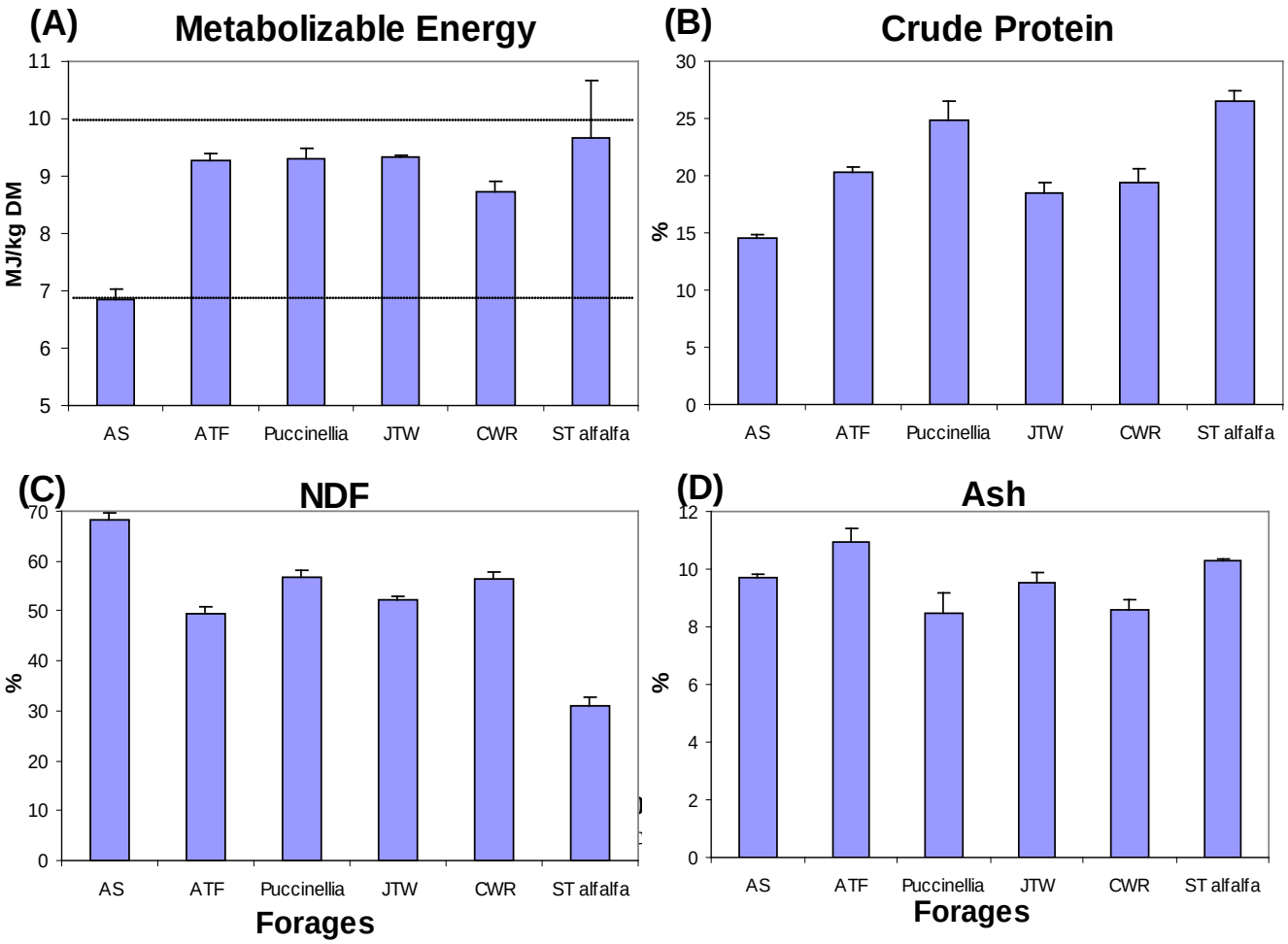


Table 3. Ion composition of forages sampled from Oct. 2002 to Jan. 2003. Most forages were in their fourth year of irrigation with saline drainage water (9-13 dS/m): except for creeping wildrye, field 1 which had one year of DW irrigation, and salt tolerant alfalfa which was fresh water-irrigated.

Forage	Soil Salinity (ECe)	Na (%)	Cl %	S %	B ppm (mg/kg)	Se ppm (mg/kg)	NO_3-N ppm (mg/kg)	Ca %	Mg %	P %
T. wheatgrass	19.7	1.35	1.26	0.47	718	6.27	67.5	0.30	0.17	0.12
" " , field 2	17.5	1.03	1.05	0.51	680	8.67	125	0.34	0.20	0.22
Puccinellia	15.6	0.68	1.36	0.40	60	4.98	175	0.34	0.14	0.24
'*Alta*' Tall fescue	12.2	1.25	1.19	0.57	790	6.05	128	0.41	0.20	0.18
Creeping wildrye	12.5	0.42	0.80	0.49	333	8.65	72.5	0.43	0.16	0.14
" " , field 2	11.4	0.10	1.26	0.25	50	0.78	180	0.41	0.12	0.22
Alkali sacaton	13.1	0.32	1.09	0.54	315	4.28	75.0	0.72	0.25	0.12
ST alfalfa	3.7	0.52	1.00	0.40	115	0.84	27.5	1.66	0.24	0.25
" "	5.1	0.59	1.01	0.38	125	0.97	22.5	1.61	0.23	0.28

<u>Fig. 3</u> Organic forage quality for forages grown in large fields at RRR, Oct. 2002 to Jan., 2003. The forages were DW-irrigated, except for ST alfalfa which was freshwater-irrigated. Dashed lines on the metabolizable energy graph are to indicate that acceptable values must fall in the 7 to 10 range. Forage designations are: AS (alkali sacaton), ATF (‘*Alta*’ Tall fescue), JTW (‘*Jose*’ tall wheatgrass), CWR (creeping wildrye) and ST alfalfa (salt tolerant alfalfa). Data from two fields of each of JTW, CWR, and ST alfalfa have been averaged.



<u>Photo 1</u>. Creeping wildrye plug transplanted into saline soil in Stage 2 at RRR. ECe = ~ 12 dS/m ECe.

<u>Photo 2</u>. Field plot of salt tolerant alfalfa at RRR. Within plots, forages are rotationally cut in 1 m^2 sub-plots until heading (grasses) or flowering (alfalfa).

<u>Photo 3</u>. Forages growing in a field soil and sand mix in a greenhouse study at CSUF. Pots are irrigated by a drip system, and drainage water is re-circulated back to the source tank.