Reuse of saline-sodic drainage water for irrigation in California: evaluation of potential forages

GRATTAN Stephen (1), **GRIEVE Catherine** (2), **POSS James** (2), **ROBINSON Peter** (3), **SUAREZ Donald** (2) **and BENES Sharon** (4)

(1) Department of LAWR, University of California, Davis, CA 95616, USA
(2) USDA-ARS Salinity Laboratory, 450 W. Big Springs rd., Riverside, CA 92507, USA
(3) Department of Animal Science, University of California, Davis, CA 95616, USA
(4) Department of Plant Science, Calif. State Univ.-Fresno, Fresno, CA 93740, USA

Abstract

Reuse of saline drainage water is a management option on the west side of California's San Joaquin Valley (SJV) that is necessary to reduce the volume of drainage water (San Joaquin Valley Drainage Implementation Program, 2000). There are a number of salt-tolerant forages that may play an important role in reducing drainage water volumes while producing a feed source for sheep and dairy cattle. Their suitableility for sequential reuse systems, however, will depend upon their production potential under saline-sodic conditions and resulting forage quality.

A controlled study using an elaborate sand-tank system was conducted at the USDA-ARS Salinity Laboratory to evaluate a number of promising forage crops including Bermuda grass, 'Salado' and 'SW9720' alfalfa, 'Duncan' and 'Polo' paspalum, 'Big' and 'Narrow leaf' trefoil, Kikuyu grass, Jose tall wheatgrass, and Alkali sacaton. Forages were irrigated frequently with synthetic drainage waters dominated by sodium sulfate with an EC of either 15 or 25 dSm^{-1}. Forages were cut periodically and biomass is presented as a function of cumulative thermal time. Shoot biomass is currently being analyzed for mineral content, trace elements, and forage quality parameters.

The forage species tested performed differently in terms of absolute biomass accumulation, biomass accumulation relative to salinity level and various forage quality parameters, which also varied from cutting to cutting.

At 25 dSm^{-1}, Kikuyu grass produced the largest amount of biomass at 5,000 growing degree-days (°C-d), followed closely by alfalfa "SW 9720', Jose tall wheat grass, bermuda grass, alfalfa 'salado' and Narrow leaf trefoil. However, Kikuyu's forage quality was among the lowest. Those forages that were of good to high quality were the two alfalfa varieties, Duncan paspalum, narrow leaf trefoil, bermuda grass, Jose tall wheat grass and polo paspalum.

Comparing species is complex, particularly when trying to rank cultivars by their combined forage production and quality potentials. Therefore the final ranking is based on both quantitative and qualitative factors. Overall, alfalfa cultivars performed best under these controlled conditions. Narrow leaf trefoil and bermuda grass fall into the next class followed closely by Jose tall wheatgrass. Under field conditions, other soil, climate and biological factors will interact to affect forages differently and this may affect the rankings based on this controlled study.

Keywords: drainage, salinity, forage-quality, selenium, sodicity, molybdenum, production

Introduction

Reuse of saline drainage water is a management option on the west side of the San Joaquin Valley (SJV) in California that is necessary for reducing the volume of drainage water requiring disposal without sacrificing the potential productivity of these lands (San Joaquin Valley Drainage Implementation Program, 2000). Several methods of utilizing saline water (i.e. sequential, cyclic and blending) have been tested experimentally or are being demonstrated under field conditions (Grattan and Oster, 2002).

High quality forages for dairy cattle, beef cattle, and sheep are in short supply in the Central Valley of California. Identifying salt-tolerant forage crops that could grow well under irrigation with saline drainage water could increase forage supplies and play a key role in drainage water management. The actual suitableility of forages in reuse systems, however, will depend upon their production potential under saline-sodic conditions and their resulting nutritional quality.

Although some studies have been conducted that address forage quality in salt-stressed land (e.g Atiz-ur-Rehman *et al.*, 1999), a considerable amount of additional research in this area is needed (San Joaquin Valley Drainage Implementation Program, 2000). Currently, field studies and field demonstrations are underway to test the feasibility of a few salt-tolerant forages and forage cropping strategies (S. Benes and S. Kaffka, personal communication; Oster *et al.*, 1999) for irrigation with saline-sodic water.

Naturally occurring trace elements in soils in the SJV and in the underlying shallow-groundwater adds a new dimension to the management of saline drainage waters (van Schilfgaarde, 1990). Selenium (Se) and molybdenum (Mo) are trace elements of particular interest. They occur in relatively high concentrations (i.e. <1.0 to 5,000 $\mu g\ L^{-1}$ for Mo and <1.0 to 3,800 $\mu g\ L^{-1}$ for Se) at many locations in the geochemically mobile and biologically available forms (i.e. selenate and molybdate) (Deverel *et al.*, 1984). Due to the presence of these trace elements, there are potential toxicological concerns regarding livestock whose diet relies almost entirely on forages grown with drainage water that contains appreciable levels of these elements.

An interdisciplinary research project was developed involving scientists from the University of California, USDA-ARS, and California State University -Fresno. The team members have expertise in soils and irrigation management, plant physiology, salinity, plant nutrition, and ruminant nutrition. The overall objective of this study was to evaluate a number of promising forage crops in terms of their production potential and nutritive quality when irrigated with saline-sodic drainage water, containing selenate and molybdate.

Materials and Methods

The experiment was conducted in greenhouse sand-tanks at the USDA-ARS, George E. Brown, Jr. Salinity Laboratory located on the UC Riverside campus. The sand tank system creates a uniform and controlled rootzone such that actual production potentials among forages can be compared. There are 30 large tanks (1.2 m x 0.6 m x 0.5 m deep) filled with washed sand that has an average bulk density of 1.4 $Mg\ m^{-3}$.

Each tank was irrigated with a complete nutrient solution salinized to either 15 or 25 dSm^{-1}. The salt solutions were prepared to simulate the composition of typical drainage water in the San Joaquin Valley and from predictions based on appropriate simulations using UNSACHEM (Suarez and Simunek, 1997). These waters are dominated by sodium and sulfate. Tanks were irrigated three times daily each for a 15- min duration. These irrigations allows the sand to become completely saturated, after which the solutions drained to 765 L reservoirs below the sand tanks for reuse in the next irrigation. Therefore the salinity of the irrigation water was similar to that of the sand water. The irrigation waters were analyzed by inductively coupled plasma optical emission spectrometry (ICPOES) to confirm that target ion concentrations were maintained. Chloride in the solutions was determined by coulometric-amperometric titration.

Water lost by evapotranspiration was replenished automatically to maintain constant volumes and osmotic potentials in the irrigation waters using a pulse output water meter coupled to an electronic water level detector installed in each reservoir. A Class I agrometerological station was situated immediately adjacent to the experimental site. Micrometeorological data, including sand and air temperature, pan evaporation, photosynthetically active radiation (PAR), relative humidity, and wind velocity were recorded.

Ten forages were grown in sand tanks at two salinity levels (15 or 25 dSm^{-1}) and each treatment was replicated three times. The forage species chosen for this study were: alfalfa (*Medicago sativa*) cvs. 'Salado' and 'SW 9720', narrow leaf trefoil (*Lotus glaber*), big trefoil (*L. ulginosus*), kikuyu grass (*Pennisetum clandestinum*) cv. Whittet, alkali sacaton (*Sporobolus airoides*), paspalum (*Paspalum vaginatum*) cvs. 'Polo' and 'Duncan', tall wheatgrass (*Agropyron elongatum*) cv. 'Jose', and bermuda grass (*Cynodon dactylon*) cv. 'Tifton'. Forages were planted in July and August 2000 with the exception of Bermuda grass which was planted in January, 2001. Salinization began 4 to 6 wk after planting except for the Paspalum varieties which were salinized 20 wk after planting. Bermuda was planted directly in salinized tanks. In each tank, two different forages were planted in a 0.6 x 0.6 m area, separated by a plastic partition extending ~20 cm below and 10 cm above the surface of the sand. With the exception of bermuda grass, all species were well-establelished in the tanks by irrigation with complete nutrient solution (EC_W) prior to application of salinity.

Harvest scheduling depended on growth patterns of the forages in question. For example, alfalfa cultivars were sampled at first flowering; alkali sacaton, kikuyu, tall wheatgrass, on plant height; the trefoils, paspalums, and bermudagrass on biomass production. At each harvest, herbage was cut 5 to 10 cm above the surface of the sand. Shoot material was weighed, washed in deionized water and dried in a forced-air oven at 70°C for 72 h, reweighed, and ground in a Wiley mill to pass a 60-mesh screen. Statistical analyses were performed by analysis of variance with mean comparisons at the 95% level based on Tukey's studentized range test.

Dry-ground forage material were analyzed for a number of inorganic constituents including Ca, Mg, Na, K, P, N, Cl, S, B, Se and Mo. Total S, total P, Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} were determined on nitric-perchloric acid digests of the tissues by ICPOES. Chloride was determined on nitric-acetic acid extracts by coulometric-amperometric titration. For tissue Se analysis, the method described by Briggs and Crock (1986) was followed. Data from these assays are not yet available so no discussion of these elements are included in this paper.

In vitro gas production was carried out using 30 mL of buffered rumen fluid according to the *in vitro* gas method of Menke *et al*. (1979). Approximately 200 mg of dry-ground shoot tissue was incubated in water bath at 39°C and gas production at 24 h was recorded and corrected for blank incubation (i.e buffered rumen fluid with no sample). Organic matter (OM) was determined according to Association of Official Analytical Chemists (AOAC, 1990). *In vitro* true degradability (IVTD), neutral detergent fiber (NDF), and *in vitro* neutral detergent fiber degradability (dNDF) were determined by incubating the samples in multi-layer polyethylene polyester cloth bags (F57 filter bag; ANKOM, NY) as described by Robinson *et al*. (1999).

Forage quality determinations were statistically analyzed as a factorial experiment with salinity, forage, cut and the forage by harvest interaction as factors in the model. In a number of forage nutritive value descriptors, the cut by forage interaction was statistically significant (i.e., $P<0.05$). Therefore forages were statistically analyzed within cuts and data presented represent all forages that were cut once and three times.

Results and Discussion

Biomass accumulation

Biomass accumulation in relation to thermal time (°C-d) represents potential accumulation under field conditions if the average rootzone salinity of the soil water is either 15 or 25 dSm^{-1} (Figure 1). However under field conditions, there may be additional stresses that could affect plant growth such as anoxia, increased soil strength or pathogenic pressures such as phytophthora.

Given the limitations of comparing species that have different optimal preferences for temperature and different planting dates, we ranked the forage production potential based on cumulative production (kg ha^{-1} dw) at 5000 growing degree-days after planting. At 15 dSm^{-1}, alfalfa SW 9720 > salado alfalfa = kikuyu > JTWG = Bermuda > Duncan paspalum = AS = NL trefoil > Polo paspalum > big trefoil. At 25 dSm^{-1}, the ranking differs slightly: Kikuyu > SW 9720 > JTWG = Bermuda = salado alfalfa = NL trefoil > AS > Duncan paspalum > Polo paspalum > big trefoil.

An important feature of the figures is the relative difference in the slopes (i.e. cumulative biomass as a function of thermal time) between the 15 and 25 dSm^{-1} treatments. Larger differences in slopes, or smaller ratios of slope at 25 / slope at 15 dSm^{-1}, indicates greater sensitivity of crop to salinity. In this study, with the exception of Big trefoil that died at 25 dSm^{-1} shortly after salinization, both alfalfa cultivars are among the most salt-sensitive along with, perhaps, Duncan paspalum. Other forages show considerably more tolerance to this synthetic drainage water, suggesting that the performance rankings would differ from those determined here should the salinity increase further. Therefore the alfalfa cultivars grew vigorously and accumulated the most biomass despite showing less overall tolerance to salinity.

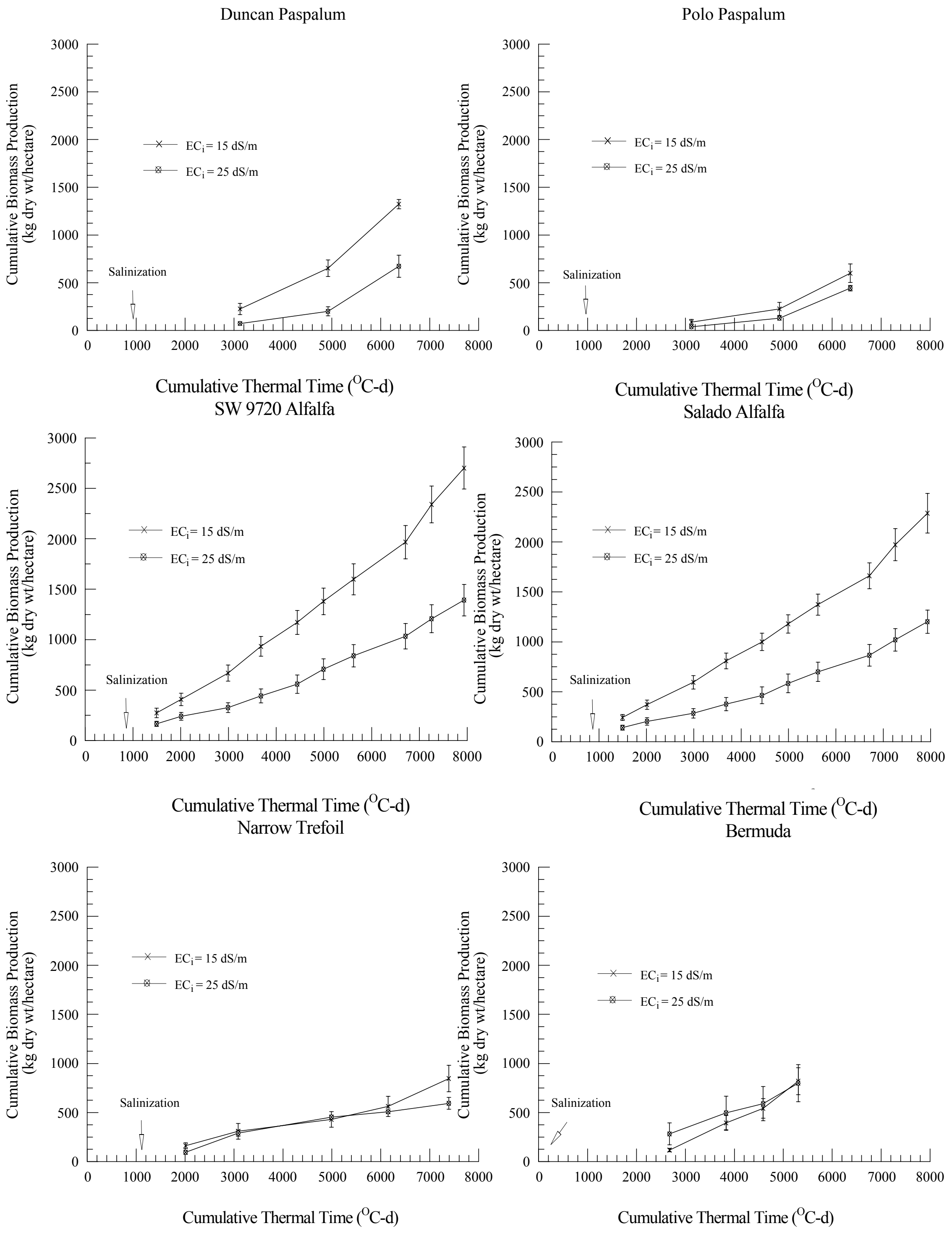

Figure 1 Cumulative forage biomass as a function of thermal time.

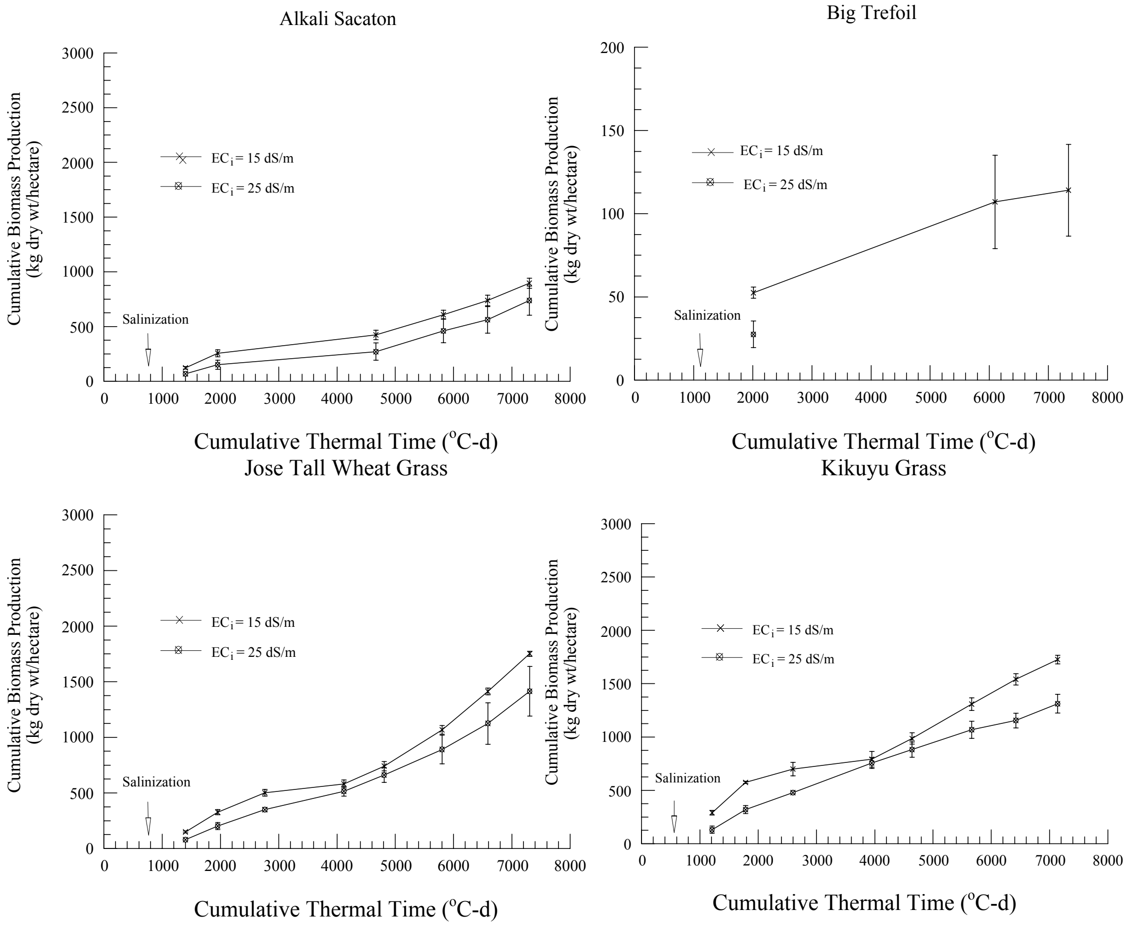

Figure 1 (Continued) Cumulative forage biomass as a function of thermal time.

Forage quality

Forage quality was evaluated based on five parameters; organic matter (OM), neutral detergent fiber (NDF), digestible NDF (dNDF), *in vitro* true digestibility (IVTD) and gas evolution. The NDF is an estimate of the cell wall minus pectin and the dNDF is a measure of the NDF that is digestible *in vitro* at 30 h. Gas evolution at 24 h *in vitro* estimates potential digestion when fed to cows at high levels of production and is used to estimate forage energy content. In general, the quality, or energy value, of the forage increases as: OM increases, NDF decreases, dNDF increases, IVTD increases and as gas production increases

First Cut. The OM content of Bermuda grass was higher at 25 dSm^{-1} than it was at 15 dSm^{-1}, but the reverse was true for Big trefoil ($P<0.05$). The NDF levels of 'Salado' Alfalfa, Big Trefoil and Jose Tall Wheatgrass were lower ($P<0.05$) for 25 dSm^{-1} vs. 15 dSm^{-1} material, but the opposite was true for Bermudagrass ($P<0.05$). The digestibility of NDF (i.e. dNDF) and the *in vitro* digestibility of DM (IVTD) were not influenced by salinity. However, gas production, an indicator of the energy value, was higher ($P<0.05$) in Jose tall Wheat grass and Kikuyu grass at 25 dSm^{-1} as compared to material from the 15 dSm^{-1} treatment.

Table 1 Effect of salinity level on nutritive value of different species of forages at first cut.

Forage Species	Salinity dSm^{-1}	OM (% DM)	NDF (%DM)	dNDF (% NDF)	IVTD (% DM)	Gas (mL g^{-1} DM)
Alfalfa 'SW 9720'	15	88.5	34.1	47.5	81.7	220
	25	88.5	25.1	49.6	87.2	233
Alfalfa 'salado'	15	88.8	31.6^{a}	50.4	84.3	239
	25	88.7	26.5^{b}	49.8	86.7	229
Alkali Sacaton	15	86.6	55.8	55.6	75.3	209
	25	87.4	53.9	61.6	79.3	201
Bermuda Grass	15	87.5^{b}	55.9^{b}	67.3	81.8	216
	25	89.3^{a}	60.9^{a}	64.4	78.3	221
Big Trefoil	15	82.4^{a}	19.1^{a}	59.8	92.3	188
	25	77.4^{b}	16.1^{s}	61.0	93.7	175
Duncan Paspalum	15	88.0	59.9	81.7	89.0	277
	25	86.0	59.7	79.9	87.9	267
Jose Tall Wheat Grass	15	86.2	46.2^{a}	77.4	89.6	187^{b}
	25	87.1	43.5^{b}	76.9	89.9	205^{a}
Kikuyu Grass	15	82.6	49.5	56.1	78.3	99^{b}
	25	84.0	43.9	55.2	80.2	133^{a}
Narrow Leaf Trefoil	15	87.5	25.1	55.8	88.9	221
	25	88.0	22.9	54.8	89.7	219
Polo Paspalum	15	87.3	53.8	75.0	86.5	230
	25	86.5	51.8	72.8	85.9	214
SEM		0.27	0.53	1.20	0.59	2.6
Salinity		NS	***	NS	NS	NS
Species		***	***	***	***	***
Species x Salinity		*	*	NS	NS	*

Different letters between salinity levels within species indicate significant differences ($P < 0.05$).

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

Table 2 Effect of salinity level on nutritive value of different species of forages at third cut.

Forage Species	Salinity dSm^{-1}	OM (% DM)	NDF (%DM)	dNDF (% NDF)	IVTD (% DM)	Gas (mL g^{-1} DM)
Alfalfa 'SW 9720'	15	88.2	31.1	56.6	85.9	215
	25	88.2	24.3	56.3	89.3	232
Alfalfa (solado)	15	87.9	25.5	55.4	88.7	212
	25	88.3	22.4	55.9	90.1	234
Alkali sacaton	15	87.9	59.8	46.0	67.8	203
	25	88.4	59.4	52.7	71.9	212
Jose tall wheat grass	15	84.4	46.1	75.7	88.8	228
	25	86.5	40.2	77.2	90.9	208
Kikuyu grass	15	83.3	48.0	68.4	84.8	168
	25	84.4	40.6	70.4	88.0	148
Narrow leaf trefoil	15	85.3	22.6	65.1	92.1	245
	25	85.9	21.8	60.5	91.4	250
SEM		0.02	0.77	2.00	0.97	5.5
Salinity		NS	***	NS	*	NS
Species		***	***	***	***	***
Salinity x Species		NS	NS	N.S	NS	NS

Different letters between salinity levels within species indicate significant differences (P <0.05).

*, P < 0.05; **, P < 0.01; ***, P < 0.001

Third Cut. The NDF levels of forage biomass decreased as salinity increased from 15 dSm^{-1} to 25 dSm^{-1} (P<0.001). However, IVTD in all forage biomass increased (P <0.05). Other nutritive descriptors were not influenced by the salinity of the applied water.

Salinity influenced various forage quality parameters including NDF, OM, gas production and IVTD but their significance varied among species and cuttings. Whenever salinity influenced these quality parameters, it did so in a positive manner. The only exceptions were NDF for Bermuda and OM in Big trefoil in the first cutting biomass.

The ability to compare forages per se is limited statistically and we did not test for significant differences among forages between quality descriptors. Furthermore, we still need to integrate the gas with the CP and fat values to get an absolute energy value. Nevertheless, based on our forage quality results for the first and third cuttings, the quality rankings from highest to lowest as a first approximation are:

*First Cut :*Duncan paspalum >alfalfa 'SW 9720' = alfalfa 'salado' =bermuda =polo paspalum = narrow trefoil > alkali sacaton =Jose tall wheatgrass > big trefoil > kikuyu grass

*Third Cut :*Narrow leaf trefoil > Jose tall wheat grass = alfalfa 'SW 9720' = alfalfa 'salado' > alkali sacaton > kikuyu grass

Conclusions

The forage species tested performed differently in terms of absolute biomass accumulation, biomass accumulation relative to salinity level and various forage quality parameters, which also varied between cuttings.

At 25 dSm^{-1}, Kikuyu grass produced the largest amount of biomass at 5000°C-d, followed closely by alfalfa "SW 9720', Jose tall wheat grass, bermuda grass, alfalfa 'salado' and Narrow leaf trefoil. While Kikuyu produced the most biomass under these conditions, its forage quality was among the lowest. Those forages that were of good to high nutritive value were the two alfalfa varieties, Duncan paspalum, narrow leaf trefoil, bermuda grass, Jose tall wheat grass and polo paspalum. The overall quality and various quality descriptors varied between cuttings.

The difficulty in comparing species becomes complex when trying to rank cultivars by their combined forage production and quality potentials. Overall the alfalfa cultivars performed best (i.e. combination of biomass accumulation and nutritive value of the biomass) under these controlled conditions but their performance will likely decline at higher salinity because these cultivars were the most salt-sensitive. Narrow leaf trefoil and bermuda grass would fall into the second class followed closely by Jose tall wheatgrass.

References

AOAC (Association of Official Analytical Chemists International). 1990. Official Methods of Analysis. 15th ed. AOAC, Arlington, VA.

Atiz-ur-Rehman, J.B. Mackintosh, B.E. Warren and D.R. Lindsay 1999. Revegetated saline pastures as a forage reserve for sheep. 1. Effects of season and grazing on morphology and nutritive value of saltbush. Rangeland Journal 21:3-12.

Briggs, P.H. and J.G. Crock. 1986. Automated determination of total selenium in rocks, soils, and plants. U.S. Department of Interior, Geological Survey Report. 86-40.

Deverel, S.J., R.J. Gilliom, R. Fujii, J.A. Izbicki and J.C. Fields. 1984. Aereal distribution of selenium and other inorganic constituents in shallow groundwater of the San Luis Drain Service Area, San Joaquin Valley, California: a preliminary study. U.S. Geol. Surv. Water-Resour. Invest. Rep. 84:4319.

Grattan, S.R. and J.D. Oster. 2002. Use and Reuse of Saline-sodic Waters for Irrigation of Crops. *In* S.S. Goyal, S.K. Sharma and D.W. Rains (eds.). Crop Production in Saline Environments. Haworth Press, New York. (In Press).

Menke, K.H., L. Raab, A. Salewski, H. Steingass, D. Fritz and W. Schneider. 1979. The estimation of the digestibility and metableolizable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor *in vitro*. J. Agric. Sci. Camb. 93:217-222.

Oster, J.D., S.R. Kaffka, M.C. Shannon and S.R. Grattan. 1999. Saline-sodic drainage water: A resource for forage production. Proceeding of 17th International Congress on Irrigation and Drainage. 11-19 Sept., Granada, Spain.

Robinson, P.H., M. Campbell-Mathews and J.G. Fadel. 1999. Influence of storage time and temperature on *in vitro* digestion of neutral detergent fibre at 48 h, and comparison to 48 h in sacco neutral detergent fibre digestion. Anim. Feed Sci, and Technol. 80:257-266.

San Joaquin Valley Drainage Implementation Program. 2000. Evaluation of the 1990 Drainage Management Plan for the Westside San Joaquin Valley, California. Final Report submitted to the Management Group of the an Joaquin Valley Drainage Implementation Program (SJVDIP). January, 2000. SJVDIP and University of California Ad Hoc Coordination Committee. 87p.

Suarez, D.L. and J. Simunek. 1997. UNSATCHEM: Unsaturated water and solute transport model with equilibrium and kinetic chemistry. Soil Sci. Soc. Am. J. 61:1633-1646.

van Schilfgaarde, J. 1990. Irrigation agriculture: is it sustainable, pp. 584-594. *In* K.K. Tanji (ed.). Agricultural Salinity Assessment and Management ASCE Manu Rep Practices 71.