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Biomass accumulation and potential nutritive value of some forages irrigated with saline-sodic drainage water

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Abstract

A controlled study using a sand-tank system was conducted to evaluate 10 forage species (bermudagrass, ‘Salado’ and ‘SW 9720’ alfalfa, ‘Duncan’ and ‘Polo’ Paspalum, ‘big’ and ‘narrow leaf’ trefoil, kikuyugrass, Jose tall wheatgrass, and alkali sacaton). Forages were irrigated with sodium-sulfate dominated synthetic drainage waters with an electrical conductivity of either 15 or 25 dS/m. Forage yield was significantly reduced by the higher (25 dS/m) salinity level of irrigation water compared to the lower (15 dS/m) level. There was wide variation in the sensitivity of forage species to levels of salinity in irrigation water as reflected by biomass accumulation. With the exception of bermudagrass, which increased accumulation at the higher level of salinity, and big trefoil, which failed to establish at the higher level of salinity, ranking of forages according to the percent reduction in biomass accumulation due to the higher level of salinity of irrigation water was: Salado alfalfa (54%) = SW 9720 alfalfa (52%) > Duncan Paspalum (41%) > narrow leaf trefoil (30%) > alkali sacaton (24%) > Polo Paspalum (16%) > Jose tall wheatgrass (11%) = kikuyugrass (11%). Bermudagrass and Duncan Paspalum were judged to be the best species in terms of forage yield and nutritive quality. Kikuyugrass, which had the third highest biomass accumulation, was judged to be unacceptable due to its poor nutritional quality. Although narrow leaf trefoil had a relatively high nutritional quality, its biomass accumulation potential was judged to be unacceptably low. Alfalfa cultivar’s biomass accumulations were the most sensitive to the higher level of salinity, among

Abbreviations: CP, crude protein; DM, dry matter; dNDF, in vitro digestibility of NDF at 30 h; DW, dry weight; EE, ether extract; IVTD, in vitro true digestibility of DM; ME, metabolizable energy (ME, MJ/kg DM); OM, organic matter; NDF, neutral detergent fibre

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forages that survived at the higher salinity level, although actual accumulations at the higher salinity were high relative to other forages. Increased salinity influenced several forage quality parameters, including organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), and in vitro gas production, generally leading to higher nutritional quality at the higher salinity level, although their significance varied amongst species and cuttings.

Keywords: Drainage; Salinity; Forage; Sodicity; Gas production

1. Introduction

Reuse of saline-sodic drainage water for irrigation is a necessary management option on the west side of the San Joaquin Valley in California to reduce the volume of drainage water requiring disposal, without sacrificing the potential productivity of the land (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, 2003). Reuse of drainage water is challenging from an irrigation management perspective in that this water is both saline (i.e. the electrical conductivity (EC) of the water is over 4 dS/m) and sodic (i.e. the sodium adsorption ratio (SAR)[1] is greater than 15) (Grattan and Oster, 2003). Salinity reduces crop growth and sodicity can adversely affect soil structure thereby indirectly affecting plant growth by poor soil aeration and increased surface crust formation.

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 grow well under irrigation with saline drainage water would not only increase forage supplies, but would play a key role in drainage water management. Actual suitability of forages for reuse systems, however, will depend upon their production potential under saline-sodic conditions and the nutritional quality of the resulting forage. Although some studies have been conducted that address forage quality in salt-affected 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).

An interdisciplinary research team was developed involving scientists from the University of California (Davis), USDA-ARS Salinity Laboratory (Riverside), and the California State University (Fresno) with expertise in soils and irrigation management, plant physiology, salinity, plant nutrition, and ruminant nutrition. The overall objective of this study is to evaluate a number of promising forage crops in terms of their biomass accumulation potential and nutritional quality when irrigated with saline-sodic drainage water dominated by sodium-sulfate.

[1] $SAR = Na^{+}/[(Ca^{2+}+Mg^{2+})/2]^{1/2}$ when units are meq/l.

2. Materials and methods

2.1. Experimental procedure

This experiment was conducted in greenhouse sand-tanks at the USDA-ARS Salinity Laboratory located on the campus of the University of California (Riverside, CA). The sand-tank system creates a uniform and controlled rootzone environment such that actual biomass accumulation among test forages can be compared. There were 30 tanks (1.2 m × 0.6 m × 0.5 m deep) filled with washed sand that had an average bulk density of 1.4 g/cm^3. Each tank was irrigated with a complete nutrient solution salinized to either 15 or 25 dS/m (Table 1). The salt solutions were prepared to simulate the composition of potential drainage waters, dominated by sodium and sulfate, common in the San Joaquin Valley of California and based upon long term simulation predictions using UNSATCHEM (Suarez and Simunek, 1997), after establishment of cation exchange equilibrium. Tanks were irrigated thrice daily at 8 h intervals for 15 min durations. The irrigations resulted in water saturation, after which the solutions drained to 765 l reservoirs below the sand-tanks for reuse in the next irrigation. Thus, the salinity of the irrigation water was similar to that of the sand water. The irrigation waters were regularly analyzed by inductively coupled plasma optical emission spectrometry to confirm that target ion concentrations were maintained (Table 1). Chloride in the solutions was determined by coulometric–amperometric titration (Cotlove, 1963). Water lost by evapo-transpiration was replenished automatically to maintain constant volumes and osmotic potentials in the irrigation waters.

2.2. Forage growth and harvest

Ten forages were grown in the sand-tanks at salinity levels of 15 or 25 dS/m, and each treatment was replicated thrice. The forage species were alfalfa (*Medicago sativa*) cvs. Salado and SW 9720, narrow leaf trefoil (*Lotus glaber*), big trefoil (*L. ulginosus*), kikuyugrass (*Pennisetum clandestinum*) cv. Whittet, alkali sacaton (*Sporobolus airoides*), Paspalum (*Paspalum vaginatum*) cvs. Polo and Duncan, tall wheatgrass (*Agropyron elongatum*) cv. Jose, and bermudagrass (*Cynodon dactylon*) cv. Tifton. Forages were planted in the sand-tanks in July or August, with the exception of bermudagrass which was planted the following January. Salinization began 4–6 week after planting, except for the Paspalum varieties, which were salinized 20 week after planting, and bermudagrass which was directly planted in salinized tanks. In each tank, two different forages were planted in a 0.6 m × 0.6 m area, separated by a plastic partition extending 20 cm below and 10 cm above

Table 1
Ionic composition of the simulated drainage water treatments (mean and standard error)

Salinity	Ca (mmol/l)	Mg (mmol/l)	Na (mmol/l)	K (mmol/l)	SO_4 (mmol/l)	Cl (mmol/l)	B (mg/l)	Se (mg/l)	Mo (mg/l)
15 dS/m	12.1	14.4	126	3.7	56	57.8	0.25	0.50	0.50
S.E.	0.1	0.1	1	0.2	0.2	0.6			
25 dS/m	11.9	27.6	246	4.7	98	106	0.25	0.50	0.50
S.E.	0.1	0.1	3	0.2	1	2			

the sand surface. With the exception of bermudagrass, all species were established in the tanks by irrigation with a complete nutrient solution prior to application of the salinity treatments.

Harvest scheduling depended on the growth pattern of each forage species. For example, alfalfa cultivars were sampled at first flowering while alkali sacaton, kikuyugrass and tall wheatgrass were harvested based upon plant height, and the trefoils, Paspalums and bermudagrass were based upon estimated biomass accumulation. At each harvest, herbage was cut 5–9 cm above the sand surface, weighed, washed in deionized water, and dried in a forced air oven at 70 °C for 72 h. Biomass is reported based on forage dry weight (DW).

2.3. In vitro and chemical analyses

In vitro gas production was completed using 30 ml of buffered rumen fluid according to an in vitro gas method (Menke and Steingass, 1988). In this method, 200 mg of sample was incubated in glass syringes with added rumen inoculum in a 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). Procedures of the Association of Official Analytical Chemists (AOAC, 2000) were used for dry matter (DM), organic matter (OM; AOAC ID 967.05), and crude fat (EE; AOAC ID 920.39). Crude protein (CP) was calculated from N determined by sample combustion at high temperature in pure oxygen and measured by thermal conductivity detection (AOAC, 2000; ID 990.03). In vitro true degradability (IVTD), neutral detergent fiber (NDF), and in vitro digestibility of NDF at 30 h of incubation (dNDF) were determined by incubating the samples in multi-layer polyethylene polyester cloth bags as described by Robinson et al. (1999). Metabolizable energy (ME) values were predicted using 24 h in vitro gas values combined with CP, and fat contents (Menke and Steingass, 1988).

2.4. Statistical analysis

Forage quality determinations were statistically analyzed as a factorial experiment with salinity, forage species, cut number and the forage species by harvest interaction as factors in the model. Means separation was carried out using Tukey's studentized range test (SAS, 1996). In a number of forage nutritive value descriptors, the cut number by forage interaction was statistically significant (i.e. $P < 0.05$). Therefore, forages were statistically analyzed within cut number and data presented represent all forages at their first, third, and fifth cuts.

3. Results

3.1. Biomass accumulation

Biomass accumulations of different forage species irrigated with saline water of 15 and 25 dS/m are in Figs. 1–5. Except in bermudagrass (Fig. 2), the biomass yield of forages at 15 dS/m was higher than at 25 dS/m. The biomass yield of bermudagrass tended to increase at the higher level of salinity in the irrigation water. There were strong linear relationships

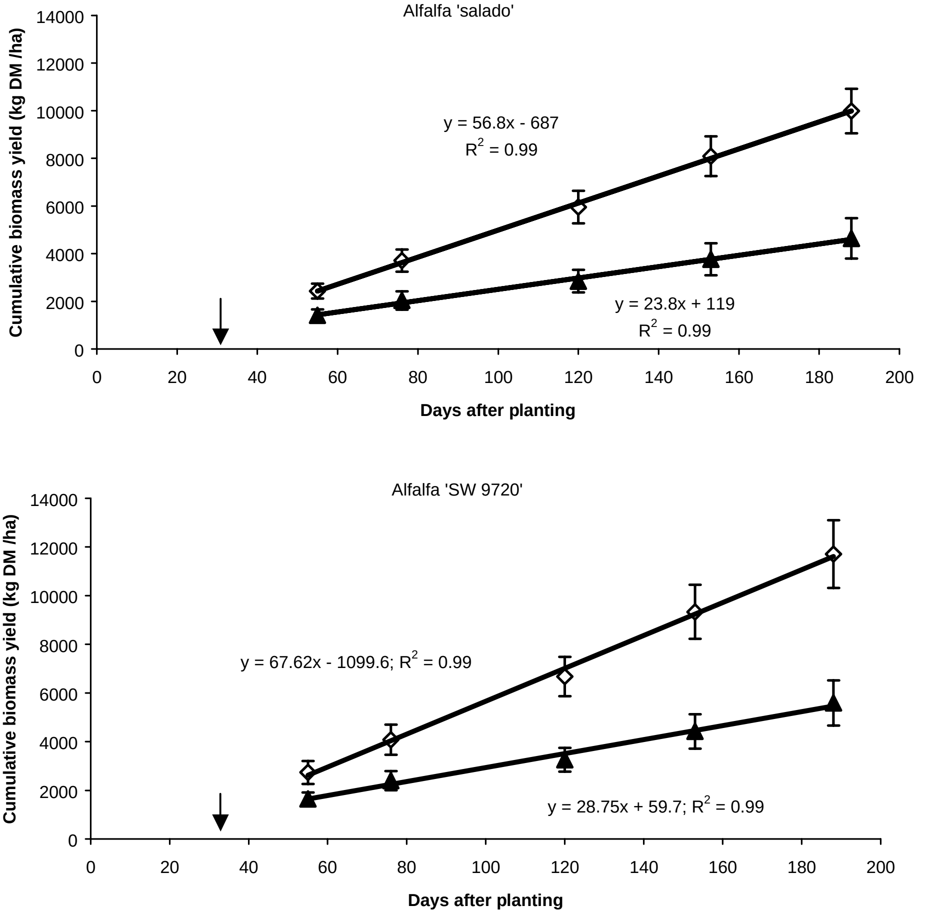

Fig. 1. Cumulative forage biomass in relation to days after planting for the alfalfa cultivars at salinity level of 15 dS/m (◇) and 25 dS/m (▲) (arrow indicates day of salinization).

between cumulative biomass accumulation of the forages and days after salinization (r^2 0.84–0.99). The larger the slope difference of the relationships between the 15 dS/m treatment and the 25 dS/m treatments, the more sensitive the crop is to salinity. With the exception of bermudagrass, which increased yield at higher level of salinity, and big trefoil, which failed to establish at the higher level of salinity, ranking of forages according to the percent reduction in biomass yield due to higher level of salinity of the irrigation water was in order; Salado alfalfa (54%) = SW 9720 alfalfa (52%) > Duncan Paspalum (41%) > narrow leaf trefoil (30%) > alkali sacaton (24%) > Polo Paspalum (16%) > Jose tall wheatgrass (11%) = kikuyugrass (11%). Although there was a significant reduction in yield due to the higher level of salinity in the irrigation water, except bermudagrass, all forage species except big trefoil were able to establish, survive, and accumulate considerable amounts of biomass. At higher levels of salinity, forage species ranked in the order: bermudagrass (10.7 t/ha)

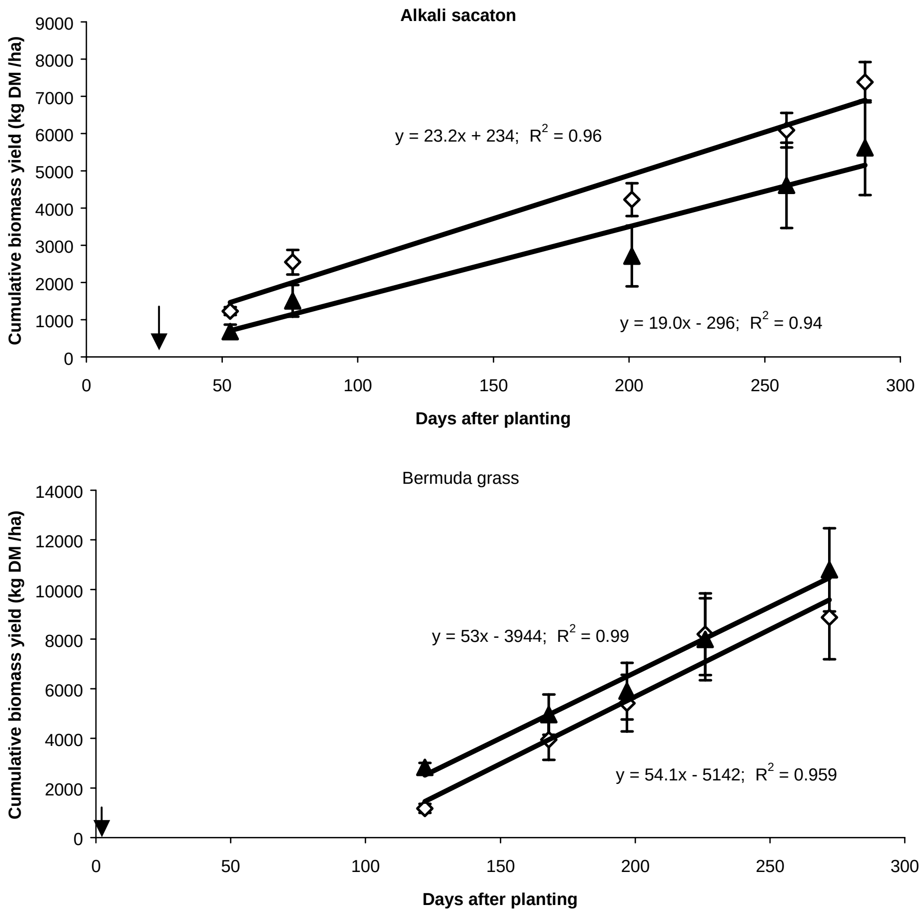

Fig. 2. Cumulative forage biomass in relation to days after planting and days after planting for alkali sacaton and Bermuda grass at salinity level of 15 dS/m (◇) and 25 dS/m (▲) (arrow indicates day of salinization).

= Duncan Paspalum (10.5 t/ha) > kikuyugrass (8.8 t/ha) > Polo Paspalum (7.8 t/ha) > Jose tall wheatgrass (6.6 t/ha) > narrow leaf trefoil (5.9 t/ha) = alkali sacaton (5.6 t/ha) = SW alfalfa (5.6 t/ha) > Salado alfalfa (4.6 t/ha).

3.2. Forage quality

The potential nutritive value of the forages was evaluated based on their content of organic matter, neutral detergent fiber, in vitro (at 30 h) digestible NDF (dNDF), in vitro (at 30 h) true digestibility of dry matter (IVTD) and in vitro (at 24 h) gas evolution. The NDF is an estimate of the cell wall minus pectin and the dNDF is an estimate of the NDF that is digestible in cows at low level of production. Gas evolution at 24 h in vitro estimates its digestion when fed to cows at a maintenance level of production and is used to estimate

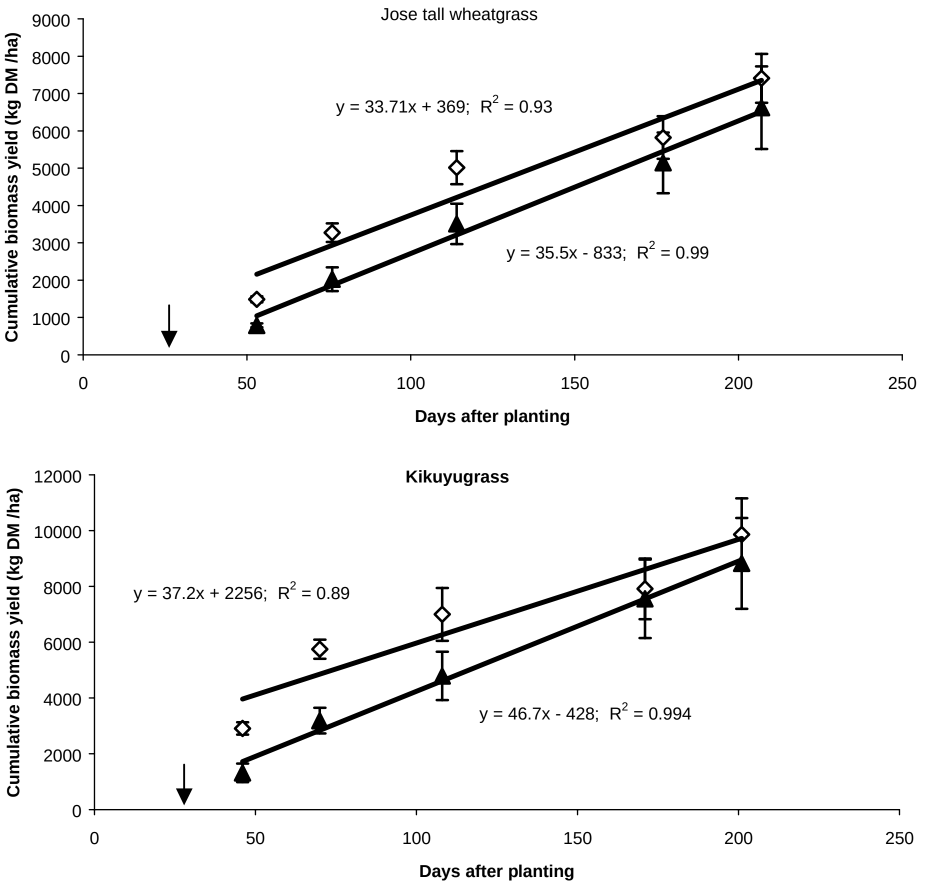

Fig. 3. Cumulative forage biomass in relation to days after planting for Jose tall wheat and Kikuyugrass at salinity level of 15 ds/m (◇) and 25 ds/m (▲) (arrow indicates day of salinization).

energy value at a maintenance level of energy intake. In general the quality, or energy value, of the forage increases as: OM increases, NDF decreases, dNDF increases, IVTD increases and/or gas production increases. All forage quality parameters for each of the three cuttings significantly differed among species tested ($P < 0.001$). However, salinity had differential effects depending upon the species, forage quality parameter and harvest date.

At the first cutting, the OM content of bermudagrass was higher at 25 dS/m than at 15 dS/m, but the reverse was true for big trefoil ($P < 0.05$; Table 2). The NDF levels of Salado alfalfa, big trefoil and Jose tall wheatgrass were lower ($P < 0.05$) when grown at 25 dS/m versus 15 dS/m, but the opposite was true for Bermuda grass ($P < 0.05$). 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 of the forage, was higher ($P < 0.05$) in Jose tall wheatgrass and kikuyugrass at 25 dS/m versus biomass from the 15 dS/m treatment. The overall metabolizable energy for the forages was

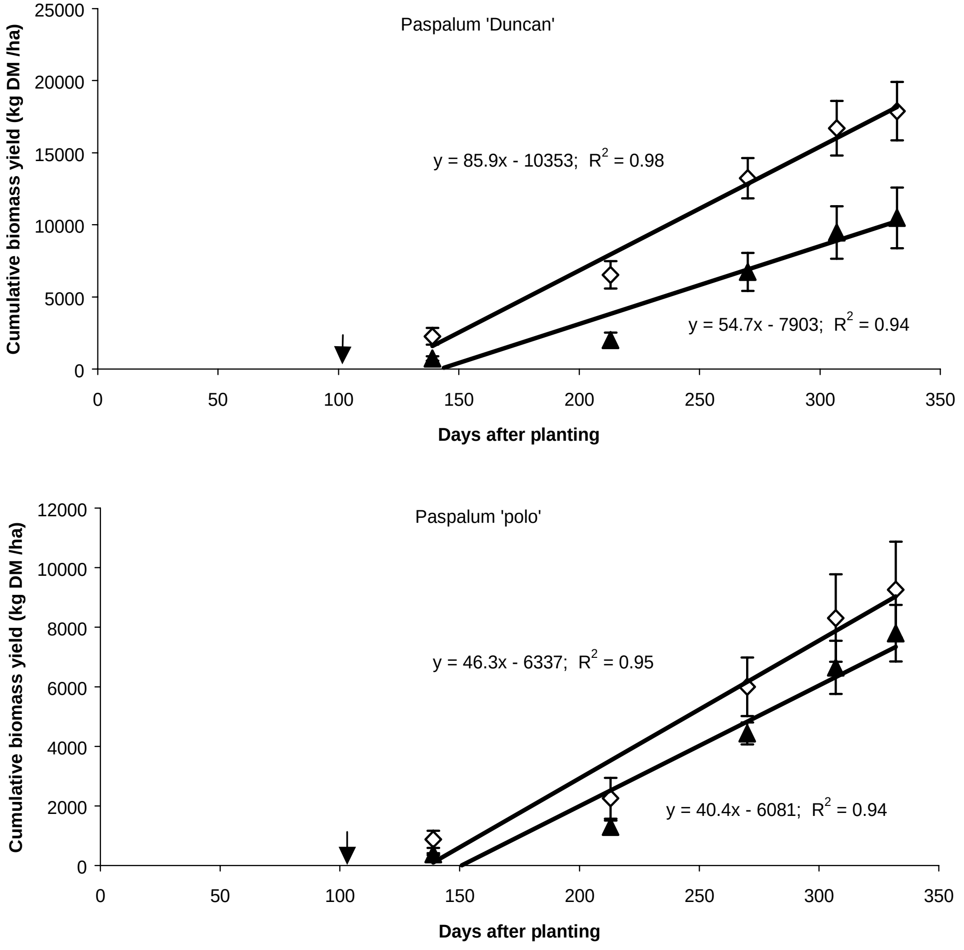

Fig. 4. Cumulative forage biomass in relation to days after planting for Paspalum cultivars at salinity level of 15 ds/m (◇) and 25 ds/m (▲) (arrow indicates days of salinization).

not influenced by salinity, except in Jose tall wheatgrass where higher salinity increased the ME value.

In the third cutting, higher salinity generally increased OM content ($P < 0.01$) and reduced NDF ($P < 0.001$; Table 3). Increased salinity tended to decrease fat (EE) content ($P < 0.05$) but this effect was slight. Other nutritive descriptors were not influenced by salinity of the applied water, except in Salado alfalfa where increased salinity increased the ME ($P < 0.05$).

For the fifth harvest, increased salinity increased the OM and CP content of the forages ($P < 0.05$; Table 4). The NDF content of SW 9720 alfalfa was lower ($P < 0.05$), and the gas production was higher ($P < 0.05$), at 25 dS/m than at 15 dS/m. This resulted in a higher ($P < 0.05$) ME in SW 9720 alfalfa grown at the higher salinity level. NDF digestibility and

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

	Salinity (dS/m)	OM (g/kg DM)	CP (g/kg DM)	EE (g/kg DM)	NDF (g/kg DM)	IVTD[a]	dNDF[b]	Gas (ml/200 mg DM)	ME (MJ/kg DM)
Alfalfa Salado	15	888	204	32	316a	0.843	0.504	47.7	9.9
	25	887	288	34	265b	0.867	0.498	45.8	10.1
Alfalfa SW 9720	15	885	239	34	341	0.817	0.475	43.9	9.6
	25	885	302	33	251	0.872	0.496	46.6	10.3
Alkali sacaton	15	866	259	44	558	0.753	0.556	41.7	9.4
	25	874	254	51	539	0.793	0.616	40.2	9.2
Bermudagrass	15	875b	232	28	559b	0.818	0.673	43.2	9.4
	25	893a	211	22	609a	0.783	0.644	44.1	9.4
Big trefoil	15	824a	232a	27	191a	0.923	0.598	36.0	8.5
	25	774b	185b	23	161b	0.937	0.610	34.9	8.0
Duncan Paspalum	15	880	136	16	599	0.890	0.817	55.3	10.5
	25	860	129	17	597	0.879	0.799	53.3	10.2
Jose tall wheatgrass	15	862	306b	66	462a	0.896	0.774	37.3b	9.1b
	25	871	334a	77	435b	0.899	0.769	41.0a	9.8a
Kikuyugrass	15	826	265	29	495	0.783	0.561	19.8	6.4
	25	840	279	28	439	0.802	0.552	17.7	6.2
Narrow leaf trefoil	15	875	263	29	251	0.889	0.558	44.1	9.7
	25	880	282	30	229	0.897	0.548	43.8	9.8
Polo Paspalum	15	873	164	20	538	0.865	0.750	45.9	9.4
	25	865	184	25	518	0.859	0.728	42.8	9.1
S.E.M.		2.70	5.20	1.00	5.30	0.006	0.012	0.95	0.13
Salinity		NS	*	NS	***	NS	NS	NS	NS
Species		***	***	***	***	***	***	***	***
Salinity × species		**	**	NS	**	NS	NS	NS	NS

OM: organic matter; CP: crude protein; EE: ether extract; NDF: neutral detergent fiber. Means with different letters between salinity levels within species differ ($P < 0.05$). NS: not significant.

[a] IVTD: in vitro true digestibility (proportion of dry matter incubated).

[b] dNDF: digestible fiber (proportion of fiber incubated); ME: metabolizable energy.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

Table 3
Effect of salinity level on nutritive value of different species of forages at third cut

	Salinity (dS/m)	OM (g/kg DM)	CP (g/kg DM)	EE (g/kg DM)	NDF (g/kg DM)	IVTD[a]	dNDF[b] (% NDF)	Gas (ml/200 mg DM)	ME (MJ/kg DM)
Alfalfa Salado	15	879	279	34	255	0.887b	0.554	42.3b	9.6b
	25	883	275	27	224	0.900a	0.559	46.7a	10.2a
Alfalfa SW 9720	15	882	249	26	311	0.859	0.566	43.0	9.5
	25	882	223	24	243	0.893	0.563	46.3	9.8
Alkali sacaton	15	879	164	30	598	0.678	0.460	40.6	8.7
	25	884	179	29	594	0.719	0.527	42.4	9.0
Bermudagrass	15	891b	258	20	574	0.822	0.691	38.8	9.0
	25	894a	241	17	577	0.791	0.641	37.5	8.7
Big trefoil	15	851	198	28	229	0.799	0.120	33.7	8.0
	25	–	–	–	–	–	–	–	–
Duncan Paspalum	15	859	130	18	588	0.786	0.637	40.2a	8.4
	25	862	153	20	573	0.796	0.644	37.7b	8.2
Jose tall wheatgrass	15	844b	203b	39	461a	0.888	0.757	45.5a	9.6
	25	865a	308a	32	402b	0.909	0.772	41.6b	9.6
Kikuyugrass	15	833b	225	25	480a	0.848	0.684	33.6	8.1
	25	844a	256	26	406b	0.880	0.704	29.5	7.7
Narrow leaf trefoil	15	853	273	37	226	0.921	0.651	49.0	10.5
	25	859	272	37	218	0.914	0.605	49.9	10.6
Polo paspalum	15	851	161	28	573	0.779	0.616	33.9	7.7
	25	848	174	26	555	0.813	0.663	36.0	8.1
S.E.M.		1.20	6.06	0.80	5.60	0.010	0.014	0.75	0.09
Salinity		**	NS	*	***	NS	NS	NS	NS
Species		***	***	***	***	***	***	***	***
Salinity × species		*	*	NS	*	NS	NS	NS	NS

OM: organic matter; CP: crude protein; EE: ether extract; NDF: neutral detergent fiber. Means with different letters between salinity levels within species differ. NS: not significant.

[a] IVTD in vitro true digestibility (proportion of dry matter incubated).

[b] dNDF, digestible fiber (proportion of fiber incubated); ME: metabolizable energy.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

Table 4

Effect of salinity level on nutritive value of different species of forages at fifth cut

Forage species	Salinity (dS/m)	OM (g/kg DM)	CP (g/kg DM)	EE (g/kg DM)	NDF (g/kg DM)	IVTD[a]	dNDF[b]	Gas (ml/200 mg DM)	ME (MJ/kg DM)
Alfalfa Salado	15	875b	282	45	252	0.894	0.572	45.9	10.1
	25	88.6a	294	44	222	0.907	0.582	48.1	10.5
Alfalfa SW 9720	15	878	270	42	276a	0.889	0.598	43.9b	9.8b
	25	884	276	40	243b	0.894	0.566	48.9a	10.5a
Alkali sacaton	15	903	127b	24	640	0.696	0.525	35.8	7.8
	25	887	159a	27	620	0.711	0.533	35.7	8.0
Bermudagrass	15	891b	80b	17b	652	0.676	0.503	41.3	8.3
	25	906a	108a	22a	666	0.673	0.509	41.7	8.5
Big trefoil	15	–	–	–	–	–	–	–	–
	25	–	–	–	–	–	–	–	–
Duncan Paspalum	15	868	114	23	574	0.768	0.596	41.6	8.5
	25	872	116	24	594	0.776	0.623	40.9	8.5
Jose tall wheatgrass	15	863	332	52a	422	0.919	0.807	45.7	10.4
	25	87.3	313	43b	442	0.906	0.788	48.0	10.6
Kikuyugrass	15	826b	293	32	446	0.820	0.597	27.9	7.7
	25	83.8a	295	34	433	0.773	0.479	22.2	6.9
Narrow leaf trefoil	15	849	242b	39	307a	0.844b	0.493b	40.1b	9.1b
	25	849	327a	46	173b	0.925a	0.566a	43.7a	9.9a
Polo Paspalum	15	866	132	26	590	0.798	0.658	39.2	8.3
	25	875	129	26	587	0.785	0.634	40.6	8.5
S.E.M.		2.10	2.50	0.60	3.50	0.006	0.013	0.58	0.08
Salinity		*	***	NS	***	NS	NS	NS	*
Species		***	***	***	***	***	***	***	***
Salinity × species		NS	***	***	***	*	NS	*	*

OM: organic matter; CP: crude protein; EE: ether extract; NDF: neutral detergent fiber. Means with different letters between salinity levels within species differ. NS: not significant.

[a] IVTD in vitro true digestibility (proportion of dry matter incubated).

[b] dNDF, digestible fiber (proportion of fiber incubated); ME: metabolizable energy.

* $P < 0.05$.

*** $P < 0.001$.

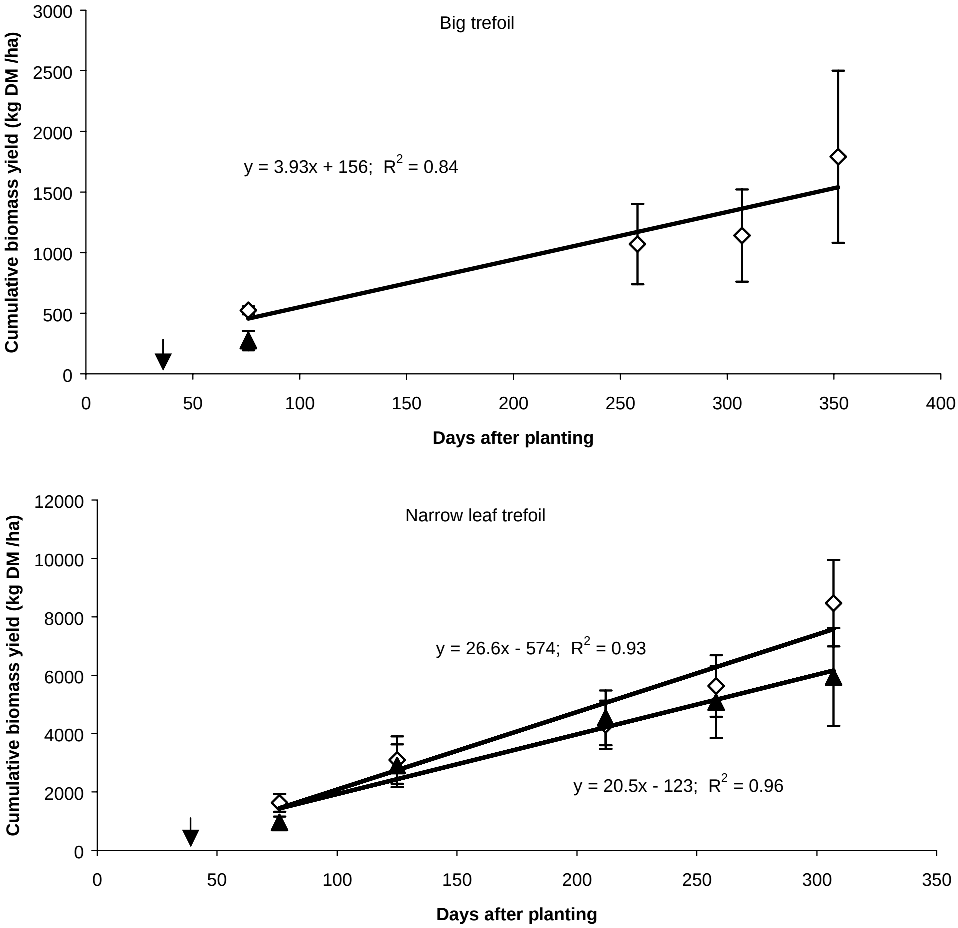

Fig. 5. Cumulative forage biomass in relation to days after planting for the trefoil cultivars at salinity level of 15 ds/m (◇) and 25 ds/m (▲) (arrow indicates day of salinization.)

IVTD were not influenced by the salinity of applied water. Salinity influenced various forage quality parameters, including NDF, OM, gas production and CP, but their significance varied among species and cuttings. However, whenever higher salinity significantly influenced these quality parameters, it did so positively except for NDF in Bermuda grass and OM in Big trefoil in first cutting biomass.

4. Discussion

4.1. Forage biomass yield

The forages varied considerably in their overall tolerance to salinity. Based on relative differences in the slopes of the cumulative biomass functions at 15 and 25 dS/m, big trefoil was the most sensitive to salinity followed by the alfalfa cultivars. Duncan Paspalum was the next most sensitive to salinity followed by narrow leaf trefoil, alkali sacaton and Polo Paspalum. Exhibiting the highest salt-tolerance were bermudagrass, kikuyugrass, and Jose tall wheatgrass. Although salt-tolerance ratings are not available in the literature for all these species, these rankings are in general agreement for those where data are available (Maas and Grattan, 1999).

The forages varied dramatically in DM biomass accumulation potential under moderate (15 dS/m) and high (25 dS/m) salinity. Under moderate salinity conditions, the alfalfa cultivars produced substantial amounts of biomass. However as salinity increased to 25 dS/m, biomass was substantially reduced while the more salt-tolerant cultivars were little affected. For example kikuyugrass, one of the most tolerant species tested, produced more biomass at the higher salinity at any period after salinization. This suggests that the actual forage species preference in saline drainage water reuse systems will be dependent upon the salinity of the water being reused, as well as management practices that affect salinity in the crop root zone.

It is also important to emphasize that these production functions reflect production potentials when the average root zone salinity of the soil water is 15 or 25 dS/m. If it is assumed that soil water salinity is about twice that of the saturated soil extract (Ayers and Westcot, 1985), an expression most frequently used among plant and soil scientists, corresponding average root zone salinities would be 7.5 and 12.5 dS/m. Since soil salinities in reuse systems in the San Joaquin Valley can exceed 12.5 dS/m, caution is advised in selecting cultivars whose biomass was reduced substantially as salinity increased (i.e. big trefoil and the alfalfas).

Plants growing in a saline and/or sodic environment may face growth limitations, particularly in terms of root establishment and biomass yield. Soluble salts in either irrigation water or in soil can be toxic to plants grown in such situations (Clark et al., 1999). Reduction in biomass yield due to higher level of salinity observed in the current study, is in agreement with Qadir and Qureshi (1996) and Clark et al. (1999). Measurable effects of soil salinity on plants can include poor root development and reduced root growth, hence leading to reduction in biomass accumulation (Zeng and Shannon, 2000). Plant species able to colonize salt-affected soils are important for stabilization and reclamation of degraded land. The ability of some plant species to grow under a wide range of stress conditions has greatly increased their adaptability. Hussain et al. (1995) compared different cultivars of alfalfa and reported a biomass accumulation decrease due to higher level of saline irrigation water, but no difference among cultivars in salt-tolerance.

4.2. Forage nutritional quality

The CP content of the alfalfa cultivars was higher than those reported by Robinson et al. (1999), and the ME content and gas production of our alfalfa cultivars were higher than those of Iantcheva et al. (1999). The higher CP and lower NDF contents of the tropical species kikuyugrass and bermudagrass in this study, compared to those reported of Kearl (1982), could be due to the stage of maturity of plants at harvest, as maturity is one of the major factors influencing forage quality. For example, Stefanon et al. (1996) reported a reduction in CP from 36.1 to 19.4%, and an increase in NDF from 18.6 to 42.6%, from early to late harvest in alfalfa.

The increase in OM content of forages in the third and fifth cutting due to increased level of salinity was similar to that reported by Ben-Ghedalia et al. (2001). While the effect of salinity on CP content of forages in the current study was not consistent, higher levels of salinity did increase the CP content of forages in the first and fifth cuttings, a finding that is consistent with Hussain et al. (1995).

The significant interaction between level of salinity and forage species on chemical composition and in vitro digestibility parameters indicates that considerable variation exists among species in metabolic response to the level of salinity of irrigation water. Overall, the level of salinity had little effect on IVTD, dNDF, gas production and the estimated ME value of these forages. However the general decrease in NDF with the higher salinity level of the irrigation water is consistent with Ben-Ghedalia et al. (2001), where NDF content of ryegrass was reduced, and in vitro digestibility was increased, due to irrigation with saline waters.

5. Conclusions

The forage species performed differently in terms of biomass accumulation and forage quality parameters relative to the salinity level of the applied irrigation water. Bermudagrass, Jose tall wheatgrass and Duncan Paspalum emerged as favorites based on combined attributes related to salt-tolerance, absolute biomass accumulation at high salinity and overall forage quality. Kikuyugrass, which had the third highest biomass accumulation, was judged to be unacceptable due to its poor nutritional quality. Although narrow leaf trefoil had a relatively high nutritional quality, its biomass accumulation potential was judged to be unacceptable. Alfalfa cultivars were found to be the most sensitive to the higher level of salinity of irrigation water relative to biomass accumulation.

References

AOAC (Official Methods of Analysis), 17th ed., Association of Official Analytical Chemists, Washington, D.C., 2000.

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

Ayers, R.S., Westcot, D.W., 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 Rev.1, Food and Agriculture Organization of the United Nations, Rome, 174 pp.

Ben-Ghedalia, D., Solomon, R., Miron, J., Yosef, E., Zomberg, Z., Zukerman, E., Greenberg, A., Kipnis, T., 2001. Effect of water salinity on the composition and in vitro digestibility of winter-annual ryegrass grown in the Arava desert. Anim. Feed Sci. Technol. 91, 139–147.

Clark, D.R., Green, C.J., Allen, V.G., Brown, C.P., 1999. Influence of salinity in irrigation water on forage sorghum and soil chemical properties. J. Plant Nutr. 22, 1905–1920.

Cotlove, E., 1963. Determination of true chloride content of biological fluids and tissues. II. Analysis by simple nonisotopic methods. Anal. Chem. 35, 101–105.

Grattan, S.R., Oster, J.D., 2003. Use and reuse of saline-sodic waters for irrigation of crops. In: Goyal, S.S., Sharma, S.K., Rains, D.W. (Eds.), Crop Production in Saline Environments: Global and Integrative Perspectives. Haworth Press, New York, pp. 131–162.

Hussain, G., Al-Jaloud, A.A., Al-Shammary, S.F., Karimulla, S., 1995. Effects of saline irrigation on the biomass yield, and protein, nitrogen, phosphorus, and potassium composition of Alfalfa in a pot experiment. J. Plant Nutr. 18, 2389–2408.

Iantcheva, N., Steingass, H., Todorov, N., Pavlov, D., 1999. Comparison of in vitro rumen fluid and enzymatic methods to predict digestibility and energy value of grass and alfalfa hay. Anim. Feed Sci. Technol. 81, 333–344.

Kearl, L.C., 1982. Nutrient requirements of ruminants in developing countries. Logan, International Feedstuffs Institute, Utah State University, UT, USA.

Maas, E.V., Grattan, S.R., 1999. Crop yields as affected by salinity. In: Skaggs, R.W., van Schilfgaarde, J. (Eds.), Agricultural Drainage. Agron. Monograph 38. ASA, CSSA, SSSA, Madison, WI, pp. 55–108.

Menke, K.H., Steingass, H., 1988. Estimation of the energetic feed value obtained from chemical analysis and in vitro gas production using rumen fluid. Anim. Res. Dev. 28, 7–55.

Qadir, M., Qureshi, R.H., 1996. Salt-tolerant forage cultivation on a saline-sodic field for biomass production and soil reclamation. Land Degradation Dev. 7, 11–18.

Robinson, P.H., Campbell-Mathews, M., Fadel, J.G., 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. 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 Joaquin Valley Drainage Implementation Program (SJVDIP). January 2000. SJVDIP and University of California Ad Hoc Coordination Committee, 87 pp.

Statistical Analysis Systems, 1996. User's Guide. SAS Inst. Inc., Cary, NC.

Stefanon, B., Pell, A.N., Schofield, P., 1996. Effect of maturity on digestion kinetics of water-soluble and water-insoluble fractions of alfalfa and brome hay. J. Anim. Sci. 74, 1104–1115.

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

Zeng, L., Shannon, M.C., 2000. Effects of salinity on grain yield and yield components of rice at different seeding densities. Agron. J. 92, 418–423.