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Evaluation of salt-tolerant forages for sequential water reuse systems I. Biomass production

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Abstract

Reuse of saline drainage waters is a management option that has been suggested for the San Joaquin Valley (SJV) of California in order to reduce both the area affected by shallow water tables and the volume of drainage effluent requiring disposal. Salt-tolerant forages may play an important role in this strategy, while at the same time producing a food source for sheep and cattle. Crop selection for reuse systems, however, will depend upon production potential under saline-sodic conditions. To identify potentially suitable crops, a controlled study using an elaborate sand-tank system was conducted at the US Salinity Laboratory to evaluate ten promising forage crops irrigated with synthetic drainage waters dominated by Na_2SO_4 with an EC of either 15 or 25 dS/m each containing 500 μg/L Se and Mo as SeO_4^{2-} and MoO_4^{2-}. Forages were cut several times over the year-long duration of the experiment. The forage species tested performed differently in terms of absolute biomass accumulation and biomass production relative to salinity level. Cumulative biomass production of alfalfa (*Medicago sativa* L.), a relatively salt sensitive crop, was higher than most other forages at moderate salinity. As salinity increased to 25 dS/m, however, cumulative biomass of the alfalfa cultivars were reduced by nearly half whereas biomass of the most salt tolerant grasses was reduced between 0 and 20%. Although most forage species tested showed promise, those that performed particularly well based on biomass accumulation, overall salt-tolerance, and forage quality were 'Jose' tall wheatgrass, bermudagrass and 'PI 299042' paspalum.
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Keywords: *Agronpyron elongatum*; *Cynodon dactylon*; Drainage water reuse; *Lotus glaber*; *L. ulginosus*; *Medicago sativa*; *Paspalum vaginatum*; *Pennisetum clandestinum*; *Sporobolus airoides*; Salinity; Salt-tolerance

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1. Introduction

Reuse of saline drainage water is a management option on the west side of the San Joaquin Valley (SJV) that is necessary for reducing the volume of drainage water (San Joaquin Valley Drainage Implementation Program, 2000). Objectives of the approach are to manage salt and drainage water on the farm or regional scale, reduce areas affected by shallow water tables, reduce volumes of drainage water requiring disposal and maximize the potential productivity of these lands.

High quality forages for dairy cattle, beef cattle, and sheep are in short supply in the SJV. Salt-tolerant forage crops that could grow well under saline irrigation would not only increase forage supplies, but could play a key role in drainage water management. Crop suitability for reuse systems, however, will depend upon the production potential under saline-sodic conditions and the resulting forage quality.

In this greenhouse sand-culture study, ten forages were irrigated with waters prepared to simulate typical SJV saline drainage effluents. Overall objectives of the project were to determine the effects of saline-sodic substrates on: (1) forage growth (this report), and (2) quality (Robinson et al., 2004), (3) forage mineral nutritional status (Grieve et al., this issue), (4) the potential effects and implications of plant ion composition on ruminant mineral nutrition (Grattan et al., this issue). Our ultimate goal is to provide growers and agency groups in the SJV with potential candidates that will reduce saline drainage effluent volumes, and at the same time, fill the unmet need for high quality forages.

2. Materials and methods

The experiment was conducted in sand tanks in a greenhouse at the USDA-ARS, George E. Brown Jr., Salinity Laboratory located in Riverside, California. The facility consisted of 30 large tanks (1.2 m × 0.6 m × 0.5 m deep) filled with washed sand having an average bulk density of 1.4 Mg m^{-3}. At saturation, the sand had an average volumetric water content of 0.34 m^3 m^{-3}. Each tank was irrigated with a complete nutrient solution salinized at either 15 or 25 dS/m. Prior to salinization, the complete nutrient solution contained in mol m^{-3}, 2.5 Ca^{2+}, 1.5 Mg^{2+}, 13.8 Na^+, 3.0 K^+, 7.0 $SO_4{}^{2-}$, 7.0 Cl^-, 3.0 $NO_3{}^-$, 0.2 $H_2PO_4{}^-$, 0.050 Fe as sodium ferric diethylenetriamine pentaacetate (NaFeDTPA), 0.005 $MnSO_4$, 0.0004 $ZnSO_4$, 0.0002 $CuSO_4$, 0.0001 H_2MoO_4, and 0.02 H_3BO_3 made up with city of Riverside municipal water. Each treatment was replicated three times. The salt solutions (Table 1) were prepared to simulate the composition of typical drainage water in the San Joaquin Valley and from predictions based on appropriate simulations of what the long-term composition of the water would be upon further concentrations by plant-water extraction and evapotranspiration (Suarez and Simunek, 1997). Actual composition would vary depending on site-specific conditions, such as depth to drains and existing composition of waters in the unsaturated zone above the drain as well as temporal trends. Selenium and molybdenum were also added at 0.50 mg/L as selenate and molybdate representing the high concentration range these potentially toxic trace elements may be found in SJV drainage water. The pH of the solutions was slightly alkaline and ranged between 7.8 and 8.4.

Table 1
Ionic composition of the simulated drainage water treatments. Both means and standard errors (S.E.) are provided

Salinity	Ca ($mmol_c$/L)	Mg ($mmol_c$/L)	Na ($mmol_c$/L)	K ($mmol_c$/L)	SO_4 ($mmol_c$/L)	Cl ($mmol_c$/L)	B (mg/L)	Se (mg/L)	Mo (mg/L)
15 dS/m	24.2	28.8	126	3.7	112	57.8	0.25	0.50	0.50
S.E.	0.3	0.2	1	0.3	0.6	0.6			
25 dS/m	23.8	55.3	246	4.7	195	106	0.25	0.50	0.50
S.E.	0.3	0.3	4	0.2	2	3			

Tanks were irrigated three times daily for a sufficient duration to completely saturate the sand. After irrigations, the solutions drained to 765 L reservoirs below the sand tanks for reuse in the next irrigation. Calculations, accounting for maximum evapotranspiration, soil water holding capacity and intervals between irrigations, indicate that the salinity of the irrigation water was more or less equivalent to that of the sand water. Previous studies (Wang, 2002) have indicated that the EC of the sand water is approximately 2.2 times the EC of the saturated soil extract (ECe), the salinity parameter used to characterize salt-tolerance in most studies (Ayers and Westcot, 1985). The soil–water dynamics in this river sand are similar to those found in field soils (Wang, 2002). Therefore our salinity treatments may be estimated as 7.0 and 11.7 dS/m expressed as ECe, representing a range in values that these crops could encounter under field conditions. Water lost by evapotranspiration was replenished automatically to maintain constant volumes and osmotic potentials in the irrigation waters in each reservoir. The irrigation waters were analyzed by inductively coupled plasma optical emission spectrometry (ICPOES) to confirm that target ion concentrations were maintained. In this study, potassium and phosphorus concentrations decreased over time and supplements were applied as KH_2PO_4 and KNO_3 to reservoirs in need, twice during the course of the experiment, to bring the concentrations back to the targeted level. Chloride in the solutions was determined by coulometric-amperometric titration.

Ten forage species were chosen for this study: alfalfa (*Medicago sativa* L.) cvs. ‘Salado’ and ‘SW 9720’, narrowleaf trefoil (*Lotus glaber* Greene), broadleaf trefoil ‘Big’ (*L. ulginosus* Schk.), kikuyugrass (*Pennisetum clandestinum* Hochst. Ex Chiov.) cv. Whittet, alkali sacaton (*Sporobolus airoides* Torr.), paspalum (*Paspalum vaginatum* Swartz) cvs. ‘Polo’ and ‘PI 299042’, tall wheatgrass (*Agropyron elongatum* (Host) Beauv). cv. ‘Jose’, and bermudagrass (*Cynodon dactylon* (L.) Pers.) cv. ‘Tifton’. The dates of planting and salinization are provided in Table 2. 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 the surface

Table 2
Schedule for planting and salinization, and number of harvests of forages grown in greenhouse sand cultures irrigated with saline waters

Forage	Planting date	Salinization date	First harvest	Number of harvests	Days under treatment
Alfalfa, ‘Salado’	17 July 2000[a]	14 August 2000	11 September 2000	12	351
Alfalfa ‘SW 9720’	17 July 2000[a]	14 August 2000	11 September 2000	12	351
Narrowleaf trefoil	17 July 2000[a]	25 August 2000	2 October 2000	7	302
Broadleaf trefoil ‘Big’	17 July 2000[a]	25 August 2000	2 October 2000	3	302
Tall wheatgrass ‘Jose’	28 July 2000[a]	25 August 2000	20 September 2000	10	340
Alkali sacaton	28 July 2000[a]	25 August 2000	20 September 2000	8	340
Kikuyugrass ‘Whittet’	3 August 2000[a]	22 August 2000	19 September 2000	10	343
Paspalum PI 299042	31 August 2000[b]	9 October 2000	18 January 2001	5	295
Paspalum ‘Polo’	31 August 2000[b]	9 October 2000	18 January 2001	5	295
Bermudagrass ‘Tifton’	5 October 2000[b,c]	5 October 2000	15 February 2001	6	299

[a] Seeded.
[b] Sprigs.
[c] Planted in pre-salinized sand tanks.

of the sand. With the exception of bermudagrass, all species were established in the tanks by irrigation with complete nutrient solution prior to application of salinity. Bermudagrass cuttings were planted in pre-salinized tanks after bermudagrass was chosen to replace another forage species that failed to achieve a vigorous stand due to poor seed quality.

Ambient conditions within the greenhouse varied throughout the experimental period. From 17 July 2000 to 1 August 2001, daytime greenhouse air temperatures ranged from 7.2 to 45.6 °C (mean = 26.6 °C); nighttime temperatures ranged from 6.1 to 32.2 °C (mean = 19.2 °C). Relative humidity ranged from 39 to 50%, with a mean of 44.9% during the day and 44.3% during the night.

Shoots were sampled periodically from September 2000 to August 2001. Harvest scheduling depended on growth pattern of the forage in question. For example, alfalfa cultivars were sampled at first flowering; alkali sacaton, kikuyugrass, tall wheatgrass, on plant height; the trefoils, paspalums, and bermudagrass on biomass production (Table 2). At each harvest, herbage was cut 5–10 cm above the surface of the sand. Shoot material was weighed, washed in deionized water, dried in a forced-air oven at 70 °C for 72 h, and reweighed. Final harvest of all species occurred on 30 July 2001.

Cumulative biomass was compared between treatments and among forages from days after salinization. Statistical analyses were performed by analysis of variance with mean comparisons at the 95% level based on Tukey's studentized range test.

Relative salt tolerance was compared among forages using slope ratios (linear cumulative biomass in relation to days after salinization) between the 15 and 25 dS/m treatment. The smaller the slope ratio (slope 25 dS/m:slope 15 dS/m) the more sensitive the crop is to salinity while ratios approaching unity indicate high tolerance to salinity. For example a ratio of 0.5 indicates that cumulative biomass is reduced by half as salinity increases from 15 to 25 dS/m.

3. Results and discussion

A review by Maas and Grattan (1999) provides quantitative salt tolerance data derived from the threshold-slope model for five of the ten plant species screened in this study. Although alkali sacaton, paspalum and kikuyugrass are all considered salt tolerant, no quantitative information is available. Growth of broadleaf trefoil, a forage classified as moderately salt-sensitive, was severely inhibited by moderate salinity and none of the plants survived the 25 dS/m treatment. Although improvements in the salt tolerance of this species have recently been reported (Stelljes, 2000), the response observed in our study indicates that the parameters are not appreciably different from those determined by Ayers (1948).

Cumulative biomass increased linearly ($r^2 = 0.84$–0.99) with days after salinization (Figs. 1–10). Biomass accumulation represents 'potential' accumulation if the average rootzone salinity of the soil water is either 15 or 25 dS/m (ECe 7.0 and 11.7 dS/m) and no other stress is affecting crop performance. 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.

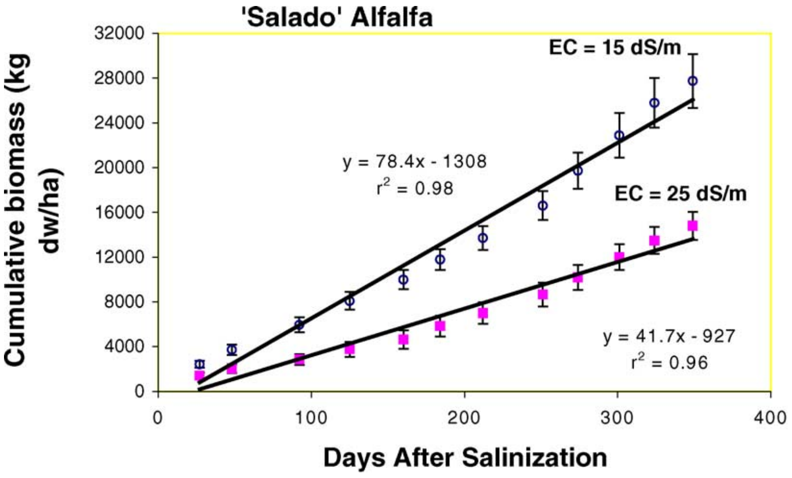

Fig. 1. Cumulative biomass production of alfalfa 'Salado' (kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

We have ranked the forage production potential based on dry matter production rates (kg ha^{-1} d^{-1} dry wt.) in relation to days after salinization (Table 3). At 15 dS/m, 'SW 9720' alfalfa and 'PI 299042' paspalum were the greatest biomass producers, followed closely by 'Salado' alfalfa. Tall wheatgrass 'Jose' fell into the next highest class. Bermudagrass and kikuyugrass, followed closely by 'Polo' paspalum, fell into the next largest growth-rate class. Narrow leaf trefoil and alkali sacaton fell into the third largest group and broadleaf trefoil 'Big' was in a class by itself as the lowest biomass producer. At 25 dS/m, the ranking

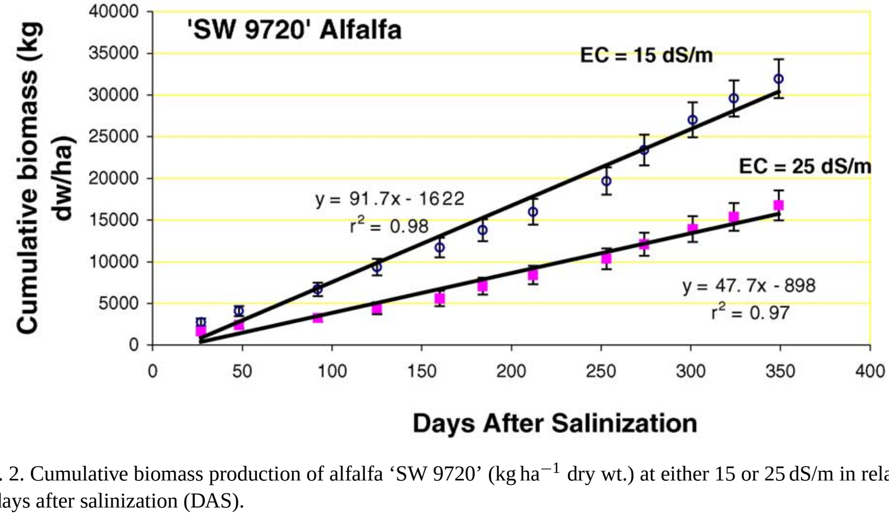

Fig. 2. Cumulative biomass production of alfalfa 'SW 9720' (kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

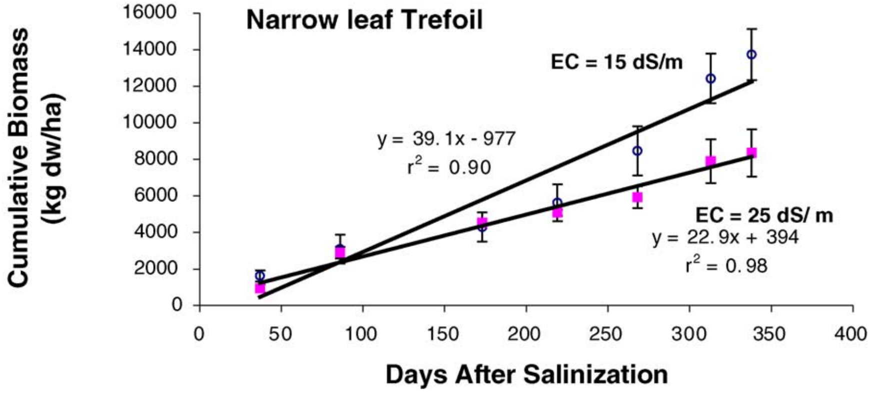

Fig. 3. Cumulative biomass production of narrowleaf trefoil (kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

differed slightly: Bermudagrass, 'PI 299042' paspalum and tall wheatgrass 'Jose' were the top biomass-rate producers followed closely by 'SW 9720' alfalfa. Kikuyugrass, 'Salado' alfalfa and 'Polo' paspalum fell into the next largest growth-rate class. Alkali sacaton and narrowleaf trefoil were in the lowest class with the exception of broadleaf trefoil which died at the 25 dS/m salinity level.

Relative salt tolerance was compared among forages using the slope ratios (linear cumulative biomass in relation to DAS) between the 15 and 25 dS/m treatments (Table 3). In

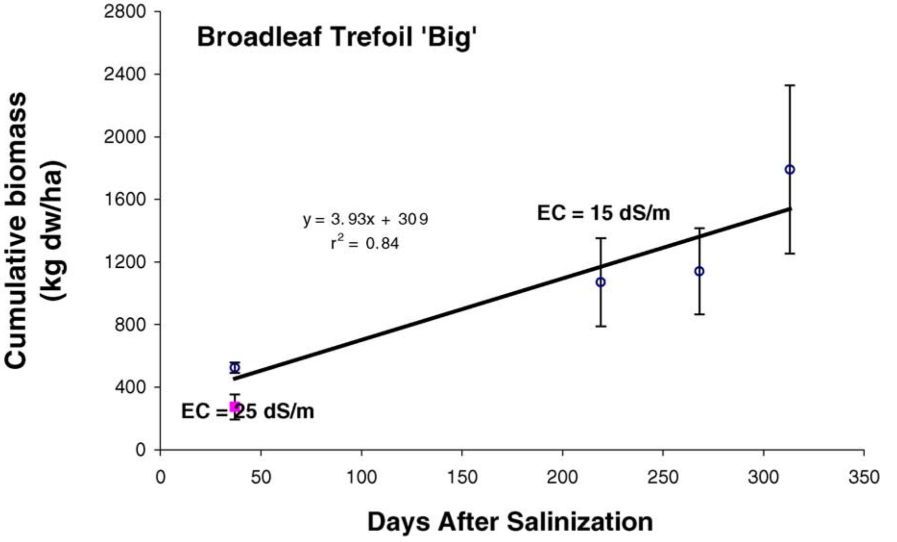

Fig. 4. Cumulative biomass production of broadleaf trefoil 'Big' (kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

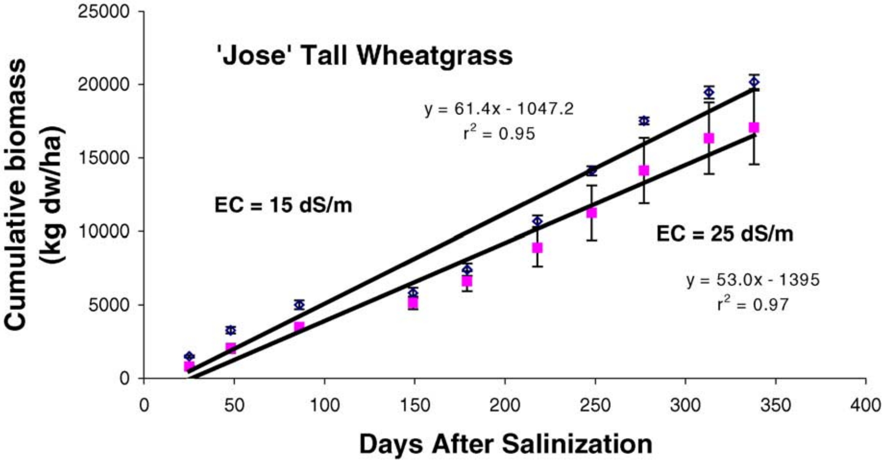

Fig. 5. Cumulative biomass production of tall wheatgrass ‘Jose’ (kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

this study, the legumes were the most salt-sensitive species. For example, broadleaf trefoil ‘Big’ died at 25 dS/m shortly after salinization, both alfalfa cultivars slope ratios were between 0.52 and 0.53 and narrowleaf trefoil’s slope ratio was 0.59. ‘PI 299042’ paspalum showed more sensitivity to salinity (slope ratio 0.64) than the other, more salt-tolerant grasses (0.85–1.11) despite its exceptional growth rates at both salinity levels.

These relative tolerance rankings are consistent with published values (Maas and Grattan, 1999). Among those with both high salt-tolerance rankings and high biomass production potential were bermudagrass, ‘Jose’ tall wheatgrass and kikuyugrass.

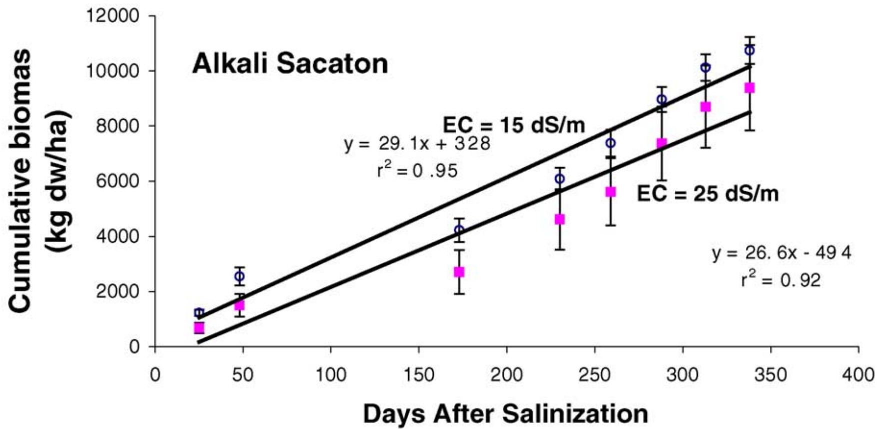

Fig. 6. Cumulative biomass production of alkali sacaton (kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

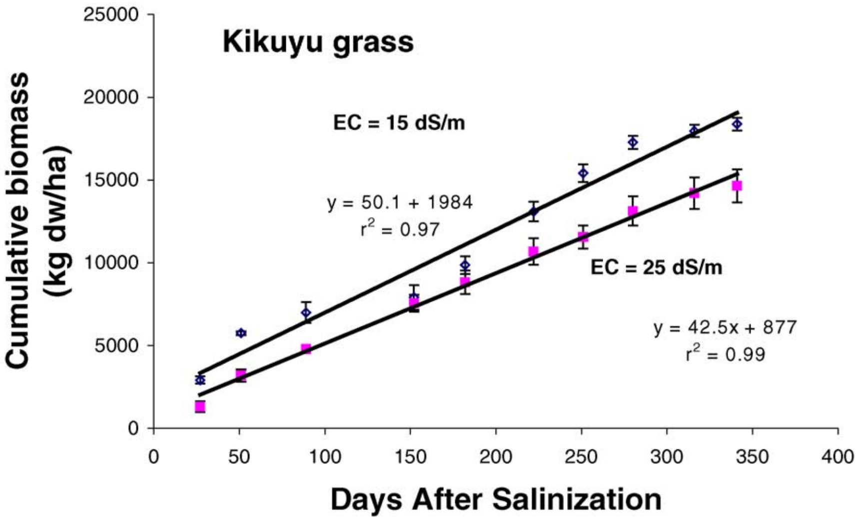

Fig. 7. Cumulative biomass production of kikuyugrass (kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

Similar to 'PI 299042' paspalum, both alfalfa cultivars exhibited high biomass production rates at both levels of salinity despite showing less overall tolerance to salinity. Differences in salt-tolerance among forages suggest that the performance rankings would differ from those given in Table 3 should the salinity increase further. Since soil salinities (expressed as

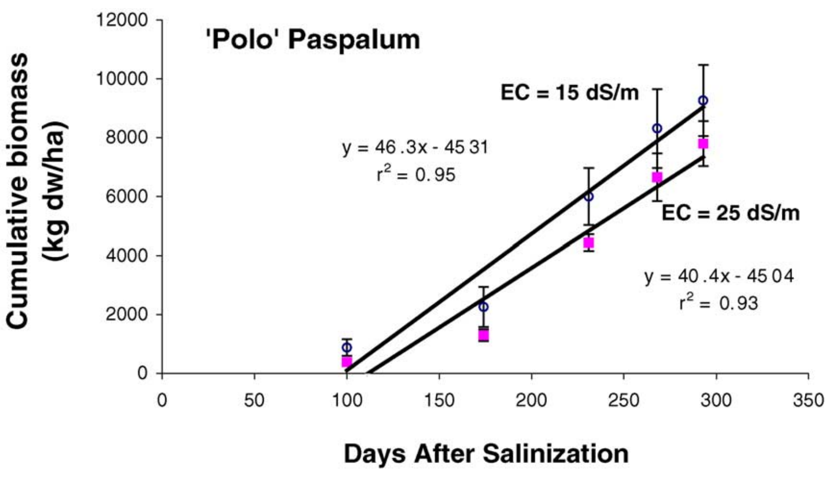

Fig. 8. Cumulative biomass production of paspalum 'Polo'(kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

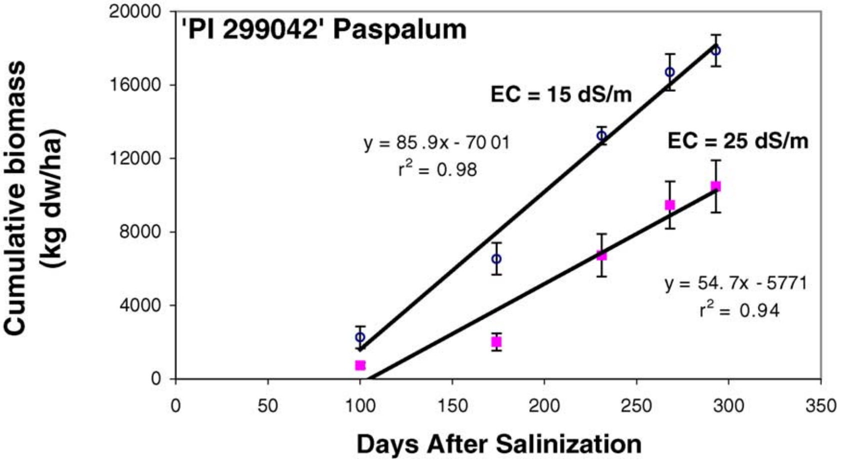

Fig. 9. Cumulative biomass production of paspalum ‘PI 299042’ (kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

ECe) in reuse systems in the SJV can readily exceed 11.7 dS/m (equivalent to our 25 dS/m ECw treatment), particularly when drainage water is used sequentially (Grattan and Oster, 2003), caution is advised when selecting forages (i.e. the legumes) whose biomass may be reduced substantially once ECe exceeds that level. In these cases, more weight needs to be placed on the salt-tolerance ranking (i.e. slope ratio) when selecting a particular forage.

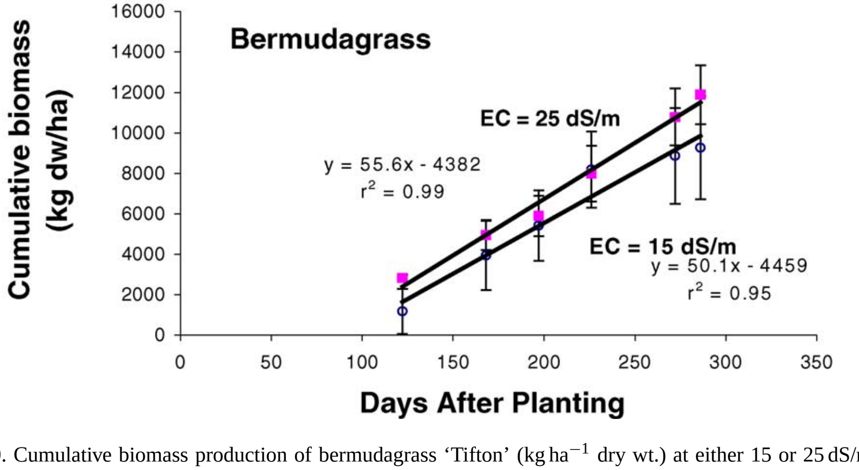

Fig. 10. Cumulative biomass production of bermudagrass ‘Tifton’ (kg ha^{-1} dry wt.) at either 15 or 25 dS/m in relation to days after salinization (DAS).

Table 3
Forage growth rates (kg ha^{-1} d^{-1}) based on cumulative biomass production in relation to days after salinization (DAS) and the ratio of slopes between cumulative biomass and DAS at 25 and 15 dS/m

Forage	Cumulative shoot biomass		
	Biomass production rates (kg ha^{-1} d^{-1} dry wt.)		Slope[a] ratio (salt-tolerance indicator)
	15 dS/m	25 dS/m	
‘SW 9720’ alfalfa	91.7	47.7	0.52
‘PI 299042’ paspalum	85.9	54.7	0.64
‘Salado’ alfalfa	78.4	41.7	0.53
‘Jose’ tall wheatgrass	61.4	53.0	0.86
Bermudagrass	50.1	55.6	1.11
Kikuyugrass	50.1	42.5	0.85
‘Polo’ paspalum	46.3	40.4	0.87
‘Narrow leaf’ trefoil	39.1	22.9	0.59
Alkali sacaton	29.1	26.6	0.91
Broadleaf trefoil ‘Big’	3.9	0	–

[a] Linear regression slope at 25 dS/m: linear regression slope at 15 dS/m.

4. Concluding remarks

An ideal forage for use in saline water reuse systems would be one with a high biomass production potential, high salt-tolerance, and high forage quality. The forage species tested performed differently in terms of absolute biomass accumulation, and biomass accumulation relative to salinity level. At 25 dS/m, ‘PI 299042’ paspalum, ‘Jose’ tall wheatgrass and bermudagrass produced that largest amount of biomass over time, followed closely by the alfalfas and kikuyugrass. While kikuyugrass produced well under these conditions, its forage quality was among the lowest (Robinson et al., 2004). Those forages that were of good to high quality from an organic, nutritive perspective were the two alfalfa varieties, ‘PI 299042’ paspalum, narrow leaf trefoil, bermudagrass, ‘Jose’ tall wheat grass and ‘Polo’ paspalum. Although the alfalfa cultivars performed well under these controlled conditions, their performance will likely decline at higher salinity because these cultivars were found to be the most salt-sensitive. Most of the forages tested could easily fill a niche within a drainage water reuse system, particularly the grasses. Based on overall salt-tolerance, biomass accumulation rates and forage quality of the crops we tested, top candidates for reuse systems are ‘Jose’ tall wheatgrass, bermudagrass and ‘PI 299042’ paspalum.

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