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Forage yield and quality under irrigation with saline-sodic drainage water: Greenhouse evaluation

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ABSTRACT

Reuse of saline-sodic drainage water (DW) to irrigate salt-tolerant forages is an attractive option for growers in California's drainage-impaired, San Joaquin Valley since it will reduce the volume of drainage water requiring disposal and supply feed to expanding dairy and beef cattle industries. Five forages (tall wheatgrass, paspalum, creeping wildrye, bermudagrass and alfalfa) were evaluated in a greenhouse study to compare forage species for biomass yield, mineral composition, and quality as ruminant feeds when irrigated with freshwater (EC_w = 0.85 dS/m) and saline DW (EC_w = 11 and 18 dS/m) and grown in a field soil mix characteristic of the drainage-impaired areas. Tall wheatgrass was highly salt-tolerant with a relative yield of 85% under high salinity, whereas the relative yield of alfalfa was 43%. Metabolizable energy (ME in MJ/kg DM), the potential energy that the ruminant can obtain from consuming the forage, was higher in this greenhouse study as compared to our prior field study (Suyama et al., 2006). ME differed among the forage species and was ranked as: tall wheatgrass and alfalfa > paspalum > bermudagrass and creeping wildrye. All forages were deemed suitable as feeds for beef cattle and goats fed at maintenance energy levels. However, with long term consumption, the high selenium and sulfur content of these forages could potentially affect animal physiology, unless they were fed in a mixed ration.

1. Introduction

On the Westside of the San Joaquin Valley (WSJV) in California, many farmlands have been threatened by soil salinization and water-logging due to highly, saline shallow water tables. Salt-affected lands are generally less productive, and less profitable if salt-sensitive and often more valuable crops such as lettuce and tomatoes, cannot be grown. Although subsurface drainage systems can effectively lower water tables and facilitate salt leaching, their use is limited by difficulties with disposal of the drainage water (DW) collected. Evaporation ponds are an economical way to store and reduce DW, but high levels of selenium (Se) present in DW from many parts of the WSJV have caused deaths and deformities in migratory waterfowl (Ohlendorf, 1989), thereby limiting this option. Among the remaining options proposed for drainage management, reuse for the irrigation of salt-tolerant forages and biodiesel crops such as canola, has emerged as a viable strategy to reduce both the area affected by shallow water tables and the volume of drainage effluent requiring disposal (SJVDIP, 2000). The

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Abbreviations: CP, crude protein; DM, dry matter; $dNDF_{30}$, *in vitro* digestibility of NDF at 30 h; DW, drainage water; EC, electrical conductivity; ME, metabolizable energy; NDF, neutral detergent fibre; SAR, sodium adsorption ratio; WSJV, Westside San Joaquin Valley

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feasibility of using DW as a resource to produce marketable crops, and at the same time, minimize environmental impacts, has been demonstrated (Shannon and Grieve, 2000; Kaffka et al., 2004; Qadir and Oster, 2004), and one form of sequential re-use, called integrated on-farm drainage management (IFDM), has been operating on two commercial farms on the WSJV: Red Rock Ranch in Five Points since 1996 (Cervinka et al., 1999) and Andrew's Ag Inc., in Kern County since 2002 (Jacobsen et al., 2004).

However, the negative aspects of irrigating with saline waters include elevation of soil salinity and boron (B) which can severely reduce plant growth. Furthermore, crops grown in DW-irrigated fields on the WSJV must be tolerant of soils with hard surface crusts, water-logging, and low oxygen in the root zone following irrigation (Oster and Grattan, 2002). Research has shown that salt tolerant forages can grow well in DW reuse systems on the WSJV (Suyama et al., 2006) and support beef cattle production (Kaffka et al., 2004). Increased forage production in the SJV would also meet the needs of the local dairy industry which has expanded rapidly in recent years. However, candidate forages need to be not only salt- and boron-tolerant, but they must possess sufficient nutritive value as animal feeds. The selection of suitable cultivars is one of the key needs to maintain sustainable forage production systems using saline-sodic waters in the WSJV (Grattan and Oster, 2003) and in other parts of the world (Qadir et al., 1996).

Several species of salt-tolerant forages were evaluated at the USDA-ARS, Salinity Laboratory in Riverside California (USSL), and their salt-tolerance and nutritional values were determined. Bermudagrass (*Cynodon dactylum*), tall wheatgrass (*Thinopyrum ponticum* var. 'Jose') and paspalum (*Paspalum vaginatum*) had higher salt-tolerance and nutritive values among the forages tested (Grattan et al., 2004a; Robinson et al., 2004b), but the potential risk of nutritional disorders in ruminants consuming them due to sulfur and molybdenum in the forage tissues, remained a concern (Grattan et al., 2004b).

Suyama et al. (2006) reported forage performance in a field study conducted at Red Rock Ranch where most fields had been irrigated with DW for five to six years and the soils were in poor physical condition. In that study, tall wheatgrass grew well under highly saline conditions (18–20 dS/m EC_e), as well as creeping wildrye (*Leymus triticoides* var. 'Rio') in a field with lower salinity. Salt-tolerant alfalfa cultivars (*Medicago sativum*, mix of vars. 'Salado' and '801S') also grew well and forage quality was very high, but only under irrigation with non-saline or blended DW resulting in soil salinity less than 7 dS/m EC_e. Field evaluation of these forages provided information to describe forage characteristics under certain salinity and management conditions. However, comparisons of forage performance amongst the species was difficult because the forages on this commercial farm grew in fields with different soil salinity and B levels, as well as different field management.

Consequently, we conducted a greenhouse study to evaluate forages that performed well in the earlier sand tank study (Grattan et al., 2004a) and in the field study at Red Rock Ranch (Suyama et al., 2006) when grown in a field soil mix characteristic of the drainage-impaired areas and irrigated with DW under uniform conditions. Specific objectives were to measure the yield, forage quality and mineral accumulation of these candidate forages under irrigation with saline-sodic DW to ascertain their salt-tolerance, as well as their nutritional value for use in ruminant production systems.

2. Materials and methods

2.1. Experimental setup

Five forages were evaluated in a mix of field soil and sand in a greenhouse at California State University (CSUF) in Fresno, California from January 2004 to January 2005. Ambient temperatures in the greenhouse ranged from 7 to 47 °C, but averaged 22 °C during the experiment. The forages tested were tall wheatgrass [*T. ponticum*, formerly *Agropyron elongatum* (Host) Beauv] var. 'Jose', creeping (syn. beardless) wildrye [*L.* (syn. *Elymus*) *triticoides* (L. Buckl.) Pilger] var. 'Rio', paspalum (*P. vaginatum* Swartz) var. 'SeaIsle 1', bermudagrass [*C. dactylum* (L.) Pers.] var. 'Giant', and alfalfa (*M. sativum* L.) vars. 'Salado' and '801S' in a 50:50 mix. Three irrigation water treatments [non-saline (0.85 dS/m), moderate saline (11 dS/m) and high saline (18 dS/m)] were applied, and each treatment was replicated four times in a randomized, complete-block design where plants on separate greenhouse benches were treated as blocks.

2.1.1. *Preparation of the field soil mix*

Soil was collected from an area of Red Rock Ranch that had not been previously irrigated with DW and was transported to the CSUF greenhouse where it was sieved through a 25.4 mm screen prior to mixing with sand. Sand was needed to improve drainage in the pots and to ensure a minimum level of leaching. Textural analysis showed that the resulting 60:40 mix of field soil and sand was 64% sand, 18% silt and 17% clay, which would be classified as a sandy loam to sandy clay loam.

2.1.2. *Plant establishment and salinization*

Seeding, transplanting, and salinization dates are shown in Table 1. Seeds were germinated in a greenhouse soil mixture with equal volumes of peat, perlite and vermiculite and then transplanted into large pots (30.5 cm diameter × 35.6 cm deep) containing the field soil and sand mix described above. All pots were irrigated with tap water supplemented with basic nutrients (3 mmol/L of KNO_3, 0.5 mmol/L of KH_2PO_4) and 10 μmol/L of iron-diethylene triamine pentaacetic acid (Fe-DTPA) (Sprint® 330 10% Iron; Becker Underwood Inc., Ames, IA) for four weeks to establish the seedlings. Saline water was then introduced in weekly, step-wise increments (1/4, 1/2, 3/4 strength) until the target irrigation water salinities were reached. On the day when the final salinity level was reached in all treatments (January 5, 2004), all forages were trimmed to 10 cm and this was considered as time zero for the measurement of cumulative dry matter (DM) accumulation.

2.1.2.1. Salinity concentrations of the irrigation waters. The non-saline (NS) treatment with an electrical conductivity (EC) of 0.5–0.9 dS/m consisted of tap water with added nutrients (i.e., N, P, K, and Fe). The moderately saline (MS) and highly saline (HS) irrigation waters were made by diluting concen-

Table 1 – Dates of planting, transplant, salinization and harvest and heights and total number of cuttings

Forage	Planting[a]		Transplanting	Salinization	Harvest dates												Cutting height (cm)	# of cuts
	July 2003	September 2003	November 2003	January 2004	March 2004	April 2004	May 2004	June 2004		July 2004		August 2004	September 2004	October 2004	November 2004	January 2005		
Tall wheat grass	22nd		4th	5th	3rd	29th	20th		21st		27th		15th	8th	24th	5th	58.4	8
Paspalum		3rd	4th	5th		8th	7th	10th		12th		18th		8th		5th	33.0	6
Creeping wildrye	22nd		4th	5th	3rd	8th	20th		21st			18th		18th	29th	5th	63.5	7
Bermudagrass	29th		4th	5th	15th	16th	6th	1st		6th	27th	18th	24th		24th	5th	50.8	9
Alfalfa	22nd		4th	5th	15th	8th	6th	1st	21st	12th		6th	15th	18th	24th	5th	52.5	10

[a] Forages were grown from seed with the exception of paspalum which was grown from sprigs.

trated DW taken from the solar evaporator at Red Rock Ranch to the target salinities. The composition of the saline treatments is shown in Table 2. The irrigation water salinities were chosen with the objective of maintaining soil salinities in the pots of 13 and 20 dS/m EC_e for the MS and HS treatments, respectively. These were considered to be at the middle and high end of the range of soil salinities likely to occur in fields irrigated with saline DW for multiple years (Suyama et al., 2006). Taking into account that root zone salinity is a function of the irrigation water salinity, the leaching fraction, and soil texture, irrigation water salinities of 8–10 dS/m for the MS treatment and 18–20 dS/m for the HS treatment were chosen, along with a leaching fraction of 20–30% in order to achieve the target soil salinities.

2.1.2.2. Nutrient concentrations of the irrigation waters. For the NS and MS treatments, the N concentration of the irrigation water was targeted at 64 mg/L of nitrate nitrogen (NO_3-N) which is approximately 30% of Hoagland's solution. For the HS treatment which utilized more concentrated DW, the N concentration was 120 mg/L NO_3-N which is about 60% of Hoagland's solution. Much of the nitrogen in the MS and HS irrigation waters was from the concentrated DW, and the rest was from N fertilizer added to balance the N concentration of the NS and MS treatments equally and to provide double the amount of N for the HS treatment. We decided not to match all treatments to the NO_3-N concentration of the HS treatment because this water had extremely high levels of NO_3-N (127 mg/L NO_3-N), as is found in some drainage waters from the WSJV. Potassium nitrate (KNO_3) and calcium nitrate ($Ca(NO_3)_2$), fertilizers were used in a 3:2 molar ratio for all N additions. Phosphorus (0.5 mmol/L) was added as potassium mono-phosphate (KH_2PO_4) and 20 μmol/L iron was added as Fe-DTPA (Sprint 330®) to all three irrigation waters. Because the MS and HS treatments required smaller additions of the N sources (KNO_3 and $Ca(NO_3)_2$) to reach target N concentrations, potassium sulfate (K_2SO_4) and calcium chloride ($CaCl_2$) were added to equally balance K (2.74 mmol/L) and Ca (0.78 mmol/L) concentrations in all three irrigation water treatments. Final nitrate concentrations were approximately 50 mg/L NO_3-N in the NS and MS irrigation waters, and 127 mg/L in the HS treatment. Potassium and PO_4-P concentrations were similar in all three irrigation waters (Table 2).

2.1.3. *Irrigation and leaching fraction*

Large plastic irrigation tanks (378.5 L) were used in a re-circulating system in which all drainage water was returned to the source tank. The tanks were painted black and covered with a reflective material to reduce heating and avoid algal growth in the tank waters. Tap water was used to replenish the water lost to evapotranspiration when the tank water volume fell below 90% of the original volume. The irrigation water salinity was measured weekly using an EC meter (YSI Model 3100 Conductivity system, Yellow Springs, OH) to ensure that target levels were maintained. Tank waters were changed monthly and fresh nutrients were added.

Each pot was uniformly irrigated by drip emitters (0.5 GPH Netafim PC Drippers, Netafim Irrigation Inc., Fresno, CA). The forages were irrigated three to four days per week, except during the summer (i.e., June to August) when the plants were

Table 2 – Average (±S.E.) irrigation water salinity (EC_w), sodium adsorption ratio (SAR), and ion composition of the non-saline, moderately saline, and highly saline treatments during a greenhouse study in the San Joaquin Valley of California in late 2003 through 2004

Treatments	EC_w (dS/m)	SAR	Cl^- (mmol/L)	SO_4^{2-} (mmol/L)	Na^+ (mmol/L)	Ca^{2+} (mmol/L)	Mg^{2+} (mmol/L)	K^+ (mmol/L)	B (mg/L)	Se (mg/L)	NO_3-N (mg/L)	PO_4-P (mg/L)
Non-saline	0.85	1.2	0.35	0.13	1.6	1.3	0.48	2.1	0.07	<0.01	50.6	10.3
	±0.02	±0.2	±0.01	±0.01	±0.2	±0.1	±0.04	±0.3	±0.03	±<0.01	±7.2	±2.4
Moderately saline	11	30.3	67.7	25.7	96.8	4.7	6.1	2.4	15.2	0.62	49.5	9.2
	±0.3	±1.2	±5.6	±3.2	±5.3	±0.7	±0.4	±0.3	±0.7	±0.05	±8.1	±2.4
Highly saline	18	41.9	113	45.3	170	5.9	10.7	2.5	27.6	1.19	127	10.3
	±0.5	±1.5	±9.5	±3.6	±9.3	±0.8	±0.7	±0.2	±1.5	±0.09	±8.8	±1.8

Irrigation water samples were taken every other month.

irrigated daily. At the beginning of the experiment, 20–25 min of irrigation (0.63–0.79 L/pot) was applied in order to maintain a leaching fraction of 20–30%, thereby avoiding salinity and B accumulation in the soil. Excessive salt accumulation was a concern because of the high salinity of the HS treatment and the poor drainage of the field soil used. To maintain the target soil salinities in the pots, the leaching fraction was increased to 40–50% in June for the MS and HS treatments and the number of emitters per pot was also adjusted to account for differential growth rates and water use among the forages.

2.2. Sampling and analysis

2.2.1. Water and soil

Water samples were collected every other month for analysis of salinity and nutrients. The samples were filtered through a 0.22 μm pore size, nylon filter (Fisherbrand 25 mm syringe filter; Fisher Scientific, Tustin, CA) prior to chemical analysis and the portion used for analysis of Na^+, Ca^{2+}, Mg^{2+}, K^+, B and Se was acid fixed using 1 ml of 70% nitric acid. Chloride, SO_4^{2-} and NO_3^- were measured using Dionex DX-500 ion chromatography (IC; Sunnyvale, CA) according to EPA method 300.0 and PO_4^- was measured using EPA method 365.1 (EPA, 1993). Sodium, K^+, Ca^{2+}, Mg^{2+} and B were measured using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) according to EPA method 200.7 and Se was measured according to EPA method 200.8 (EPA, 1994).

At the end of the experiment, a soil sample covering the entire depth of each pot (0–36 cm) was collected from each pot, air-dried, and the soil was ground to pass a 1 mm screen. Soil salinity (EC_e) and pH were measured on saturated soil paste extracts. Sodium, Ca^{2+} and Mg^{2+} were then measured using a GBC 902 AES atomic absorption and emission spectrophotometer (GBC Scientific Equipment Pty Ltd, Melbourne, Victoria, Australia) to obtain the sodium adsorption ratio (SAR). Chloride, SO_4^{2-} and B were also measured on the saturated paste extracts using the same method described for the water samples. A separate sample of ground, air-dried soil was obtained to measure total Se using ICP-AES (Tracy and Moeller, 1990) and NO_3^- using a flow injection analyzer method (Knepel, 2003).

2.2.2. Forage dry matter and tissue analysis

The cutting time for each forage species was set as the time when the plants in the NS treatment reached their maximum height prior to heading, or 10% flowering for alfalfa (minimum of 10% of stems with open blooms). When this height occurred in the NS treatment, plants in the MS and HS treatments of the same forage species were also cut. Heights of the forages at harvest are shown in Table 1. Because each forage species grew at a different rate, the cutting dates differed among plant species. When harvested, the forage herbage was cut to 10 cm, except for TWG which was only cut to 15 cm from the soil surface because our prior experience had shown that TWG grows back very slowly if cut below 15 cm.

After the forage tissue was cut, it was rinsed briefly in deionized water to remove surface salts and dust. Samples were dried in a forced air oven at 60 °C for 48 h, and dry weights were determined. The dried tissues were ground to pass a 1 mm screen in a Thomas–Wiley laboratory Mill (Model

4, Thomas Scientific, Swedesboro, NJ) and then composited for subsequent tissue analysis. Ion analysis was conducted twice in the experiment using composited tissue samples. The first composite sample (harvest one) consisted of the material harvested from March to August 2004, and the second composite sample (harvest two) was material from the September to December harvests.

Metabolizable energy (ME) was utilized as the main index of the nutritive value of the forages. The ME value of the forage was calculated from its crude protein (CP), neutral detergent fiber, (NDF), *in vitro* digestion of NDF ($dNDF_{30}$) at 30 h, fat, and ash contents. Procedures for in vitro digestion of $dNDF_{30}$, and prediction of the ME values followed Robinson et al. (1999, 2004a). Analytical procedures used to measure organic forage quality (i.e., CP, fat, NDF and $dNDF_{30}$) and inorganic forage quality (i.e., Ca^{2+}, Mg^{2+}, NO_3^-, and total-P,-B,-S and -Se) followed Suyama et al. (2006).

2.2.3. *Data and statistical analysis*

Harvested DM of the forages was summed across all harvest dates for individual pots to determine total DM production throughout the experiment. To determine relative yield (RY) of forages in the MS and HS treatments, total DM production of each pot was divided by the DM of the same forage species in the NS treatment, which was considered to be the potential yield. These RY values were used as an indicator of the forage's salt tolerance, with higher values indicating higher salt tolerance.

Total DM production, RY, organic forage quality, and mineral accumulation were analyzed using a general linear model with salinity treatment, species, and interaction (salinity $\times$ species) as fixed factors and with block as a random factor using SPSS for Windows version 11.5 (SPSS Inc., Chicago, IL, USA). Two factor ANOVA was used and only when interactions were significant ($P \leq 0.05$), were means compared within the salinity treatments by using Tukey's HSD test.

3. Results

3.1. *Accumulation of salinity, boron and selenium in soil*

Soil salinities (EC_e) at the end of the season for the NS, MS and HS treatments were 1.1, 14.7, and 21.5 dS/m, respectively (Table 3). The ratio of the soil salinity to irrigation water salinity (EC_e/EC_w) was between 1.2 and 1.4 for all treatments which would indicate a leaching fraction of about 18–25% (Ayers and Westcot, 1985); however, measured leaching fractions averaged 35, 47, and 52% for the NS, MS, and HS treatments, respectively (data not shown). Discrepancies between measured values and those predicted based on Ayers and Westcot (1985) steady-state relationships may be due to excess bypass flow through cracks and the soil–pot interface. Selenium in the MS irrigation water was 0.62 mg/L, about half that of the HS irrigation water (1.19 mg/L). However in the soil there was little difference in total-Se between the MS treatment (1.78 mg/kg) and the HS treatment (1.61 mg/kg). Boron concentrations in the soil were 20 mg/L under MS and 29 mg/L under HS irrigation.

3.2. *Forage yield*

Two factor ANOVA of forage yield detected significant species (mean square = 4729, F value = 3.1 and sig. = 0.027) and salinity treatment (mean square = 45,766, F value = 29.5 and sig. < 0.001) effects, but no significant species $\times$ salinity interaction (mean square = 2029, F value = 1.3 and sig. = 0.266) therefore means were not compared within the salinity treatments.

Bermudagrass under NS irrigation produced 262 g DM/pot over the course of the study while the other forages produced only 201–220 g DM/pot (Fig. 1). Under MS irrigation (EC_e = 15 dS/m) bermudagrass and tall wheatgrass had equivalent biomasses averaging about 200 g DM/pot. However under HS irrigation (final EC_e = 22 dS/m), tall wheatgrass produced 1.6 times the dry matter as bermudagrass and twice the biomass as the more salt-sensitive alfalfa.

ANOVA of relative yield detected significant species (mean square = 0.13, F value = 6.6 and sig. = 0.001) and salinity treatment (mean square = 0.56, F value = 28.0 and sig. < 0.001) effects, but no significant species $\times$ salinity interaction (mean square = 0.03, F value = 1.3 and sig. = 0.289). The RY of tall wheatgrass was 95% under MS irrigation and 85% under HS irrigation (Fig. 2). Bermudagrass, on the other hand, had 81% RY under MS irrigation, but its RY was only 43% under HS irrigation indicating lower salt tolerance than tall wheatgrass. An even larger decline in RY occurred for alfalfa, a crop known to be less tolerant to salinity than either wheatgrass or bermudagrass. The RY of paspalum and creeping wildrye were intermediate in ranking.

3.3. *Forage quality*

For the first composite sample (i.e., March to August harvests), the ANOVA of our forage quality indices, all displayed

Table 3 – Average (±S.E.) soil salinity (EC_e), sodium adsorption ratio (SAR), and ion composition at the end of a greenhouse study in the San Joaquin Valley of California

Treatments	EC_e (dS/m)	SAR	pH_e	Cl^- (mmol/L)	SO_4^{2-} (mmol/L)	B (mg/L)	Total-Se[a] (mg/kg)	NO_3-N[a] (mg/kg)
Non-saline	1.1 (0.1)	3.4 (0.4)	8.4 (<0.1)	4.2 (0.6)	4.3 (0.6)	0.36 (0.03)	0.57 (0.04)	3.3 (0.4)
Moderately saline	14.7 (0.8)	36.9 (1.6)	8.5 (<0.1)	95.1 (6.2)	92.7 (7.2)	20.1 (1.1)	1.78 (0.16)	10.5 (0.9)
Highly saline	21.5 (0.8)	58.3 (1.5)	8.4 (<0.1)	139 (9.4)	132.2 (9.9)	29.1 (1.9)	1.61 (0.08)	47.6 (1.5)

[a] Total-Se and NO_3-N were measured on air-dried soil. EC_e, pH_e and all other soil ions were measured on saturated paste extracts.

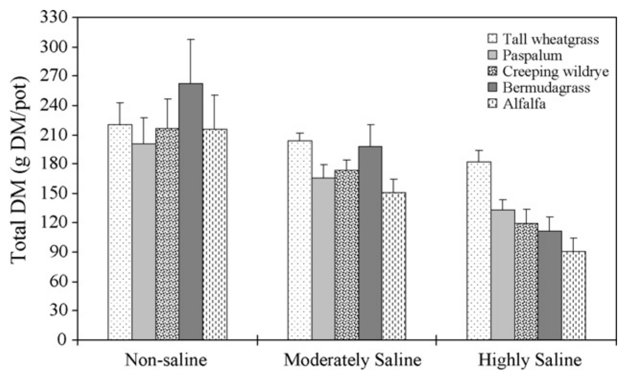

Fig. 1 – Average total dry matter (DM) production of forages growing for one year under non-saline, moderately saline, and highly saline irrigation in a greenhouse experiment in the San Joaquin Valley of California. Mean comparisons within the salinity treatments were not conducted because the interaction (salinity × species) was not significant ($P > 0.05$). Error bars represent the standard error.

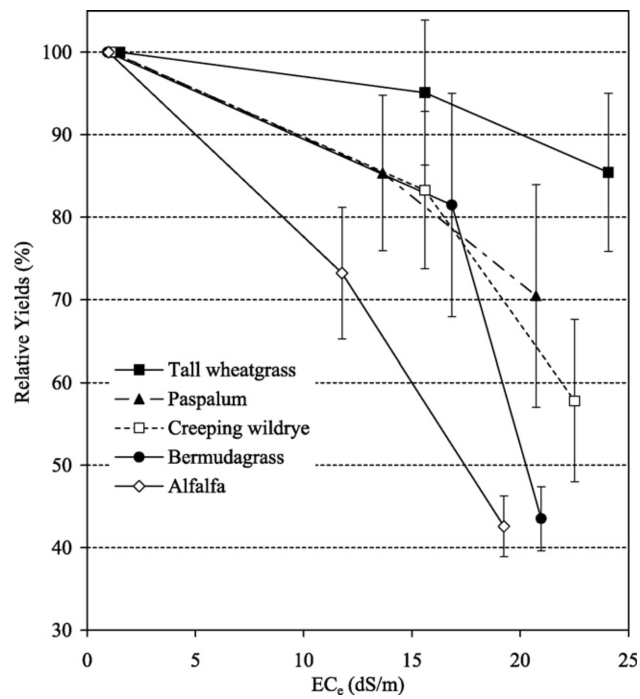

Fig. 2 – Average relative yields of forages under non-saline (0.9–1.5 dS/m), moderately saline (12–17 dS/m) and highly saline (19–24 dS/m) irrigation during a greenhouse study in the San Joaquin Valley of California. Error bars represent the standard error. Relative yields were calculated as the ratio between the saline-irrigated and the non-saline treatment.

significant main effects and a significant species by salinity interaction ($P < 0.05$) (Tables 4 and 5) for all of the forage quality indices measured. However, within species, most forage quality parameters were similar, with the exception of increasing ME as salinity increased for all species except paspalum.

A potential effect of salinity may not have been observed for the September to December harvests because in the HS treatment the plants had insufficient tissue to conduct most forage quality analyses. The ME of most forages was generally higher in the second composite sample than in the first, but the species ranking for forage quality remained similar.

3.4. *Mineral composition*

In the ANOVA for mineral composition (Ca^{2+}, P, Mg^{2+}, NO_3-N and total-B), all displayed significant main effects and a significant species by salinity interaction ($P < 0.05$) (Tables 6 and 7).

The Ca^{2+} content of the herbage decreased as the irrigation water salinity increased for all forages except paspalum (Tables 6 and 7). Alfalfa had the highest concentrations of Ca^{2+} and total-P in the herbage at all salinity levels and in both harvest sets. Boron concentration in the forage tissues ranged from 10.8 to 130 mg/kg under NS irrigation and from 254 to 606 mg/kg under HS irrigation. Tall wheatgrass accumulated more than 388 mg/kg total-B under MS irrigation and up to 585 mg/kg total-B under HS irrigation. Paspalum accumulated more than 430 mg/kg total-B under HS irrigation in both harvest sets.

3.4.1. *Selenium*

ANOVA of herbage Se for harvest one and two detected significant effects for species (mean square = 8.57 and 5.39, F value = 6.28 and 3.09 and sig. < 0.001 and 0.03, respectively), salinity treatment (mean square = 78.4 and 153, F value = 57.4 and 87.6 and sig. <0.001 and <0.001, respectively) and the species × salinity interaction (mean square = 6.70 and 6.09, F value = 4.90 and 3.49 and sig. < 0.001 and 0.004, respectively). Under NS irrigation, the total-Se content of all forages was less than 1.1 mg/kg (Fig. 3). The total-Se concentrations in the forage tissues increased in the MS and HS treatments, and they were all higher than 2.7 mg/kg in the first harvest period and 3.9 mg/kg in the second harvest period. Relative differences in total-Se concentrations in the herbage among species were neither consistent between the MS and HS treatments, nor from harvest period one to two. However, in both harvest periods, the highest concentrations of total-Se were accumulated by tall wheatgrass (7–8 mg/kg) under MS irrigation; and in harvest period two, creeping wildrye also accumulated 7.6 mg/kg total-Se under HS irrigation.

3.4.2. *Sulfur*

ANOVA of herbage S in harvests one and two detected significant effects for species (mean square = 82,847 and 54,728, F value = 1142 and 514 and sig. <0.001 and <0.001, respectively), salinity treatment (mean square = 40,315 and 83,337, F value = 556 and 783 and sig. <0.001 and <0.001, respectively) and for the species × salinity interaction (mean square = 14,664 and 13,811, F value = 202 and 130 and sig. <0.001 and <0.001, respectively).

Total-S concentrations in the herbage were mostly below the maximum tolerable concentration of 93.6 mmol/kg (0.3%) for most ruminant animals (NRC, 1996) under NS irrigation,

Table 4 – Average organic forage quality and two factor ANOVA for the first of two harvests (March–August 2004) during a greenhouse study in the San Joaquin Valley of California

Forage Species	ME (% DM)			CP (% DM)			NDF (% DM)			$dNDF_{30}$ (% NDF)			Ash (% DM)			Fat (% DM)		
	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS
Tall wheatgrass	10.17^{a}	10.61^{a}	10.73^{a}	20.5^{b}	20.6^{b}	22.9^{b}	54.9^{c}	57.6^{d}	56.2^{d}	65.1^{a}	66.5^{a}	66.5^{a}	14.9^{a}	12.2^{bc}	12.0^{b}	5.1^{a}	4.9^{a}	5.4^{a}
Paspalum	10.10^{a}	9.52^{c}	9.46^{b}	15.4^{c}	16.5^{c}	21.5^{bc}	66.4^{b}	62.6^{c}	60.7^{c}	69.1^{a}	67.1^{a}	66.9^{a}	13.2^{bc}	16.6^{a}	16.4^{a}	3.4^{b}	3.8^{b}	4.0^{b}
Creeping wildrye	7.66^{c}	7.61^{e}	7.78^{c}	17.3^{c}	18.4^{bc}	20.4^{c}	65.2^{b}	65.5^{b}	64.8^{b}	47.5^{c}	45.0^{c}	45.4^{c}	11.9^{c}	10.5^{d}	10.1^{c}	3.2^{b}	3.5^{b}	3.8^{b}
Bermudagrass	8.24^{bc}	8.61^{d}	9.18^{b}	14.8^{c}	16.5^{c}	21.5^{bc}	70.7^{a}	68.6^{a}	69.4^{a}	55.8^{b}	56.8^{b}	62.5^{b}	11.8^{c}	11.4^{c}	11.0^{c}	2.8^{c}	3.0^{c}	3.1^{d}
Alfalfa	9.22^{ab}	10.03^{b}	10.35^{a}	25.6^{a}	25.9^{a}	30.3^{a}	36.6^{d}	32.4^{e}	30.5^{e}	42.9^{c}	44.8^{c}	47.2^{c}	14.4^{ab}	13.3^{b}	12.4^{b}	3.2^{b}	3.5^{b}	3.6^{c}
Two factor ANOVA																		
Species																		
Mean square	14.74			196.3			2,490.6			1,394.3			38.9			7.9		
F value	167.22			153.5			2,839.0			315.2			102.9			336.5		
Pr > F	<0.001			<0.001			<0.001			<0.001			<0.001			<0.001		
Salinity																		
Mean square	0.89			120.2			31.0			17.9			3.6			1.1		
F value	10.14			94.0			35.4			4.0			9.6			46.1		
Pr > F	<0.001			<0.001			<0.001			0.025			<0.001			<0.001		
Species × Salinity																		
Mean square	0.56			4.0			13.7			17.1			7.1			0.1		
F value	6.33			3.1			15.7			3.9			18.9			2.6		
Pr > F	<0.001			0.007			<0.001			0.002			<0.001			0.022		
Residual mean square	0.09			1.3			0.3			4.4			0.4			0.0		

Organic forage quality parameters: ME, metabolizable energy; CP, crude protein; NDF, neutral detergent fiber; $dNDF_{30}$, in vitro digestible NDF at 30 h of incubation (estimates NDF digestion of cattle fed at maintenance); ADF, acid detergent fiber. Salinity treatments: NS, non-saline; MS, moderately saline and HS; highly saline irrigation water. Means within columns sharing a common letter are not significantly different ($P > 0.05$). Comparisons are amongst forage species.

Table 5 – Average organic forage quality and two factor ANOVA for the second of two harvests (September–December 2004) during a greenhouse study in the San Joaquin Valley of California

Forage species	ME (% DM)			CP (% DM)			NDF (% DM)			$dNDF_{30}$ (% NDF)			Ash (% DM)			Fat (% DM)		
	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS
Tall wheatgrass	11.24	11.74	11.38	23.1	23.8	22.8	54.0	54.2	56.6	70.3	73.2	71.9	13.7	12.2	12.2	5.49	5.41	4.69
Paspalum	10.43	9.79	nes[a]	15.5	15.3	nes	68.0	65.2	nes	69.6	68.6	nes	12.5	15.8	nes	3.52	3.22	nes
Creeping wildrye	9.54	9.82	nes	21.0	21.2	nes	60.0	62.3	nes	58.2	59.1	nes	12.5	10.6	nes	4.09	4.13	nes
Bermudagrass	8.95	9.50	nes	12.1	15.5	nes	69.9	69.6	nes	55.5	59.7	nes	9.07	9.02	nes	2.38	2.68	nes
Alfalfa	10.57	10.96	nes	27.6	27.6	nes	32.7	28.3	nes	53.8	51.9	nes	15.3	14.3	nes	4.01	3.83	nes
Two factor ANOVA																		
Species																		
Mean square	na[b]			na			na			na			na			na		
F value	na			na			na			na			na			na		
Pr > F	na			na			na			na			na			na		
Salinity																		
Mean square	na			na			na			na			na			na		
F value	na			na			na			na			na			na		
Pr > F	na			na			na			na			na			na		
Species × Salinity																		
Mean square	na			na			na			na			na			na		
F value	na			na			na			na			na			na		
Pr > F	na			na			na			na			na			na		
Residual mean square	na			na			na			na			na			na		

Organic forage quality parameters: ME, metabolizable energy; CP, crude protein; NDF, neutral detergent fiber; $dNDF_{30}$, in vitro digestible NDF at 30 h of incubation (estimates NDF digestion of cattle fed at maintenance); ADF, acid detergent fiber. Salinity treatments: NS, non-saline; MS, moderately saline and HS, highly saline irrigation water.enough sample due to insufficient dry matter accumulation.applicable: unable to do statistical comparisons due to the absence of data for HS.

Table 6 – Average mineral content and two factor ANOVA of harvest one (March to August 2004) of the forages under non-saline (NS), moderately saline (MS), and highly saline (HS) irrigation during a greenhouse study in the San Joaquin Valley of California

Forage species	Ca^{2+} (mmol/kg)			Total-P (mmol/kg)			Mg^{2+} (mmol/kg)			NO_3-N (mg/kg)			Total-B (mg/kg)		
	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS
Tall wheatgrass	76.3^{c}	52.5^{c}	40.6^{d}	109^{a}	93.7^{b}	92.1^{c}	96.5^{b}	78.9^{c}	78.9^{c}	3830^{a}	1466^{a}	3,348^{ab}	49.5^{b}	395^{a}	404^{a}
Paspalum	71.9^{c}	97.5^{b}	78.8^{c}	80.8^{b}	79.1^{b}	101^{bc}	158^{a}	155^{a}	142^{a}	1819^{bc}	1504^{a}	4,595^{a}	10.8^{d}	135^{b}	439^{a}
Creeping wildrye	70.0^{c}	50.6^{c}	46.9^{d}	79.9^{b}	86.4^{b}	88.0^{c}	63.3^{c}	75.7^{c}	78.9^{c}	3243^{ab}	1539^{a}	2,592^{b}	40.8^{c}	193^{b}	254^{b}
Bermudagrass	123^{b}	113^{b}	106^{b}	89.6^{b}	94.5^{b}	109^{b}	65.4^{c}	86.1^{c}	103^{b}	1160^{c}	750^{a}	2,658^{b}	16.5^{d}	203^{b}	308^{b}
Alfalfa	334^{a}	244^{a}	213^{a}	121^{a}	117^{a}	128^{a}	85.1^{b}	99.6^{b}	113^{b}	3249^{ab}	2273^{a}	2,831^{b}	86.8^{a}	225^{b}	284^{b}
Two factor ANOVA															
Species															
Mean square	90,312.5			2641.0			18,585.0		3,579,330.0			26,479.0			
F value	1,093.7			58.0			361.8		7.0			16.3			
Pr > F	<0.001			<0.001			<0.001		<0.001			<0.001			
Salinity															
Mean square	7,375.0			505.9			696.8		15,041,531.0			452,547.5			
F value	89.5			11.1			13.6		29.4			278.5			
Pr > F	<0.001			<0.001			<0.001		<0.001			<0.001			
Species × Salinity															
Mean square	2,877.5			260.5			1087.4		2,679,962.4			20,465.0			
F value	34.9			5.7			21.2		5.2			12.6			
Pr > F	<0.001			<0.001			<0.001		<0.001			<0.001			
Residual mean square	82.6			45.5			51.4		511,574.5			1,625.2			

Means within columns sharing a common letter are not significantly different ($P > 0.05$). Comparisons are amongst forage species.

Table 7 – Average mineral content and ANOVA of harvest two (September to December 2004) of the forages under non-saline (NS), moderately saline (MS), and highly saline (HS) irrigation during a greenhouse study in the San Joaquin Valley of California

Forage species	Ca^{2+} (mmol/kg)			Total-P (mmol/kg)			Mg^{2+} (mmol/kg)			NO_3-N (mg/kg)			Total-B (mg/kg)		
	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS	NS	MS	HS
Tall wheatgrass	90.6^{c}	43.1^{c}	44.4^{c}	132^{ab}	105^{b}	97.7^{bc}	85.1^{bc}	75.7^{d}	70.6^{c}	$6,125^{a}$	3541^{a}	$3,185^{a}$	44.5^{b}	388^{a}	585^{a}
Paspalum	70.6^{c}	113^{b}	96.9^{b}	89.6^{cd}	71.9^{c}	83.2^{c}	157^{a}	169^{a}	150^{a}	$2,673^{b}$	1528^{ab}	$1,821^{bc}$	16.0^{c}	236^{b}	606^{a}
Creeping wildrye	90.0^{c}	59.4^{c}	48.1^{c}	105^{bc}	99.3^{bc}	103^{b}	68.5^{cd}	97.5^{c}	102^{b}	$5,228^{a}$	3093^{a}	$2,475^{ab}$	40.8^{bc}	258^{b}	383^{b}
Bermudagrass	127^{b}	104^{b}	83.1^{b}	75.1^{d}	84.0^{bc}	98.5^{bc}	63.3^{d}	93.4^{cd}	102^{b}	675^{b}	560^{b}	$1,051^{c}$	27.8^{bc}	341^{ab}	493^{ab}
Alfalfa	328^{a}	193^{a}	158^{a}	147^{a}	139^{a}	125^{a}	99.6^{b}	138^{b}	163^{a}	$5,464^{a}$	2425^{ab}	$1,805^{bc}$	130^{a}	394^{a}	578^{a}
Two factor ANOVA															
Species															
Mean square	54,983.5			5921.1			23,832.5			23,411,660.0			35,149.9		
F value	513.7			44.4			235.8			23.5			16.3		
Pr > F	<0.001			<0.001			<0.001			<0.001			<0.001		
Salinity															
Mean square	16,087.9			549.9			5,008.5			23,803,276.3			1,145,749.6		
F value	150.3			4.1			49.6			23.9			531.1		
Pr > F	<0.001			<0.001			<0.001			<0.001			<0.001		
Species × Salinity															
Mean square	6,220.6			530.2			1,787.1			2,963,343.4			14,209.5		
F value	0.0			4.0			17.7			3.0			6.6		
Pr > F	<0.001			0.001			<0.001			0.010			<0.001		
Residual mean square	107.0			133.4			101.1			995,261.9			2,157.3		

Means within columns sharing a common letter are not significantly different ($P > 0.05$). Comparisons are amongst forage species.

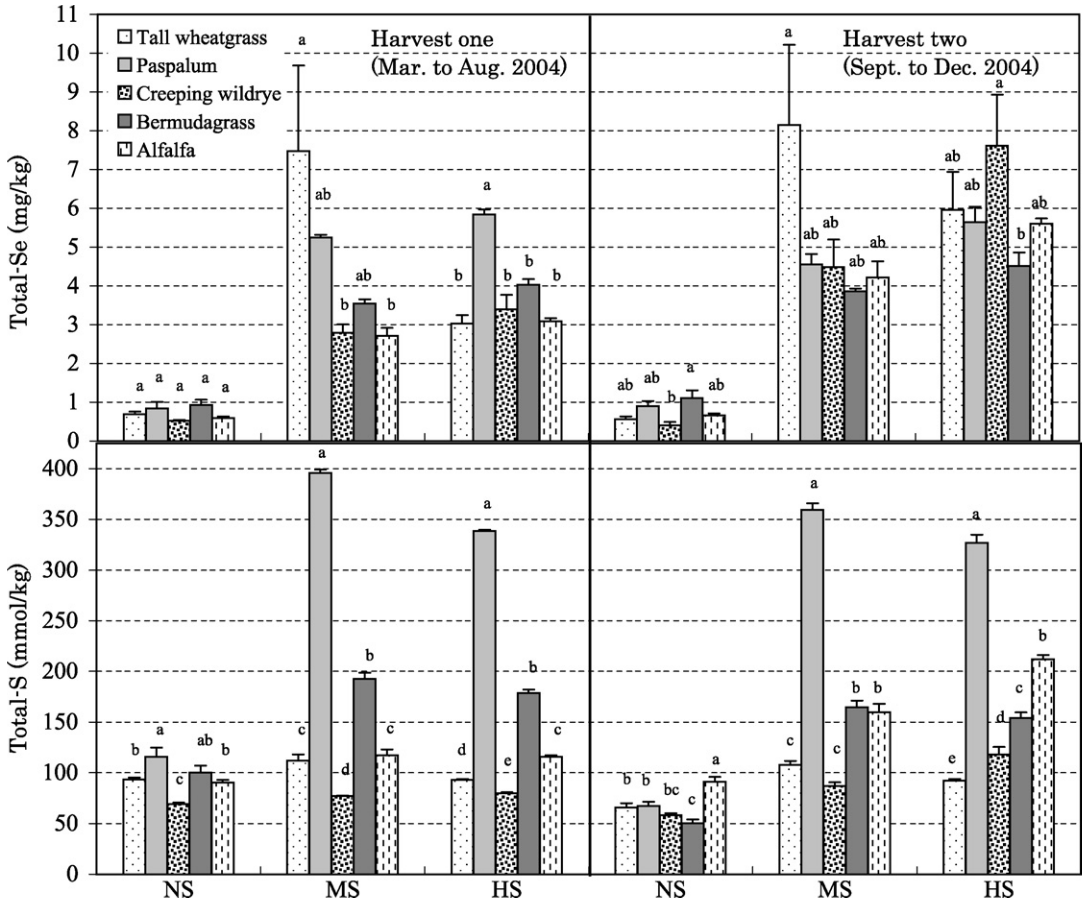

Fig. 3 – Average concentrations of selenium (Se) and sulfur (S) in forages under non-saline (NS), moderately saline (MS), and highly saline (HS) irrigation for harvest one and two in a greenhouse experiment in the San Joaquin Valley of California. Within treatments (NS, MS and HS), means with a common letter are not significantly different ($P > 0.05$). Error bars represent the standard error.

with the exception of bermudagrass (100.4 mmol/kg) and paspalum (115.8 mmol/kg) in harvest one (Fig. 3). Paspalum accumulated extremely high concentrations of total-S (>327 mmol/kg) under MS and HS irrigation in both harvests. Bermudagrass accumulated relatively high S (>156 mmol/kg) under MS and HS irrigation in both harvests, as did alfalfa in harvest two.

4. Discussion

4.1. *Applied treatments and similarity to field conditions in the WSJV*

In this experiment, the MS irrigation water ($EC_w = 10.7$ dS/m, $B = 15$ mg/L, Se = 0.6 mg/L) and the resulting soil salinities (average = 15 dS/m EC_e) were typical of the sequential DW reuse systems (IFDM) that have been developed in the WSJV (Suyama et al., 2006). The exception was the Se concentration which was higher than that found in most WSJV drainage waters, although localized areas with high concentrations of Se in soil and drainage water have been reported (SJVDIP, 2000). The HS irrigation water ($EC_w = 17.6$ dS/m, $B = 28$ mg/L, Se = 1.2 mg/L, and $SO_4^{2-} = 45$ mmol/L) is at the very high end of the range of DW salinities found in the WSJV and the resulting soil salinity (22 dS/m EC_e) would represent the most saline forage fields under IFDM management, such as at Red Rock Ranch and Westlake farms in Kings County, California (Kaffka et al., 2004). Although leaching occurred in the HS treatments, some salt accumulated in these greenhouse pots since the soil salinities were 1.2–1.4 times higher than in the irrigation water.

4.2. *Forage yield*

The forages examined had only numerical differences in DM production and RY which varied according to the salinity treatment.

Tall wheatgrass had the highest DM production and RY (salt tolerance) under both MS and HS irrigation. High salt tolerance was previously reported for tall wheatgrass in the USSL sand tank study at estimated soil salinities (EC_e) of 7 and 11.7 dS/m (Grattan et al., 2004a) and at Red Rock Ranch this forage has grown for several years in fields having soil salinities of 17–20 dS/m EC_e (Suyama et al., 2006). The results from this greenhouse study also indicate a high degree of salt tolerance for tall wheatgrass, as shown by yield decreases of only 15% under very high salinity (21 dS/m EC_e).

In contrast to tall wheatgrass, bermudagrass was less salt tolerant. Although its yield was high under NS irrigation, it was severely reduced (by 55%) under high salinity. In the prior sand tank study (Grattan et al., 2004a; Robinson et al., 2004b), the DM production of bermudagrass was not reduced at the higher salinity level (equivalent to $EC_e = 11.7$ dS/m), as compared to the low salinity level ($EC_e = 7$ dS/m). It appears that substantive reductions in bermudagrass yields do not occur when soil salinity is less than 7 dS/m. However, in our study, the RY of bermudagrass was less than 50% under HS irrigation ($EC_e = 22$ dS/m) which is consistent with Kaffka et al. (2004), who reported that the same cultivar of bermudagrass ('Giant') could not grow at soil salinities above 22 dS/m. Therefore to maintain high bermudagrass yields, we recommend that soil salinities should not exceed 12 dS/m EC_e.

Alfalfa was the most salt-sensitive among the forage species tested, which was similar to its performance in the prior sand tank study (Grattan et al., 2004a). Alfalfa had less than 75% RY under MS irrigation, as compared to the other forages that had RYs higher than 80% under MS irrigation. Under HS irrigation, alfalfa had less than 50% RY. In addition to poor salt tolerance, the very low DM production of the 'Salado' alfalfa under HS irrigation may have resulted from water-logging in the pots. Some water-logging also occurred in pots containing the other forages under MS and HS irrigation because of the need to maintain a high leaching fraction, but alfalfa appeared to the be the most sensitive to soil saturation (Lancaster and Orloff, 1995). Boron toxicity symptoms (i.e., marginal leaf burn on older leaves) were also observed on 'Salado' alfalfa under MS irrigation, and more severe B toxicity occurred under HS irrigation. Bañuelos et al. (2003) reported that 'Salado' alfalfa produced more than 13–16 t/ha/yr in a saline-sodic, DW-irrigated field, but the soil salinity (EC_e) was less than 7 dS/m. Based on these results, long term irrigation of 'Salado' alfalfa with DW higher than 8 dS/m (EC_e) would not be recommended.

Creeping wildrye and paspalum were moderately impacted by salinity under HS irrigation, with RYs of 58% and 71%, respectively. Suyama et al. (2006) reported that creeping wildrye growing at soil salinities just above 13 dS/m EC_e had economically viable biomass production (i.e., 10 to 13.8 t/ha/yr) under DW irrigation and IFDM management at Red Rock Ranch. Considering the large reduction in RY from our MS to HS irrigation treatments, a soil salinity of 14 dS/m appears to be very close to the maximum soil salinity that this forage can tolerate without substantive yield reduction.

4.3. *Organic forage quality*

All forages had acceptable levels of ME (i.e., >7 MJ/kg DM) for beef cattle and goats fed at a maintenance energy level (NRC, 1996). The ME tended to increase as salinity treatments increased, possibly because the timing of forage harvests was based on plant heights in the NS treatment and so forages from the MS and HS treatments were slightly less mature than in the NS treatment. The maturity of plants is a major factor influencing forage quality (Minson, 1990). Forages in this greenhouse study were grown for less than two years and forage qualities were slightly higher as compared to the Red Rock Ranch study (Suyama et al., 2006) where forages had been growing in the field under DW irrigation for two to seven years and were exposed to drier and windier conditions. However, the species ranking for ME in this study agreed with both the field study (Suyama et al., 2006) and the prior sand tank study (Robinson et al., 2004b).

Generally, forage quality increases as ME and CP increase and as NDF decreases. As expected for a legume, alfalfa had higher CP (26–30% DM) than any of the grass forages; however, tall wheatgrass had at least 20% CP in all treatments and for both harvest periods. Differences in NDF among the forage species were similar to that for CP–those having lower CP tended to have higher NDF–and alfalfa had the lowest NDF values (28–37%) amongst the forages. Tall wheatgrass had less than 58% NDF (54–58%), but paspalum, creeping wildrye and bermudagrass had NDF ranging from 60% to 71% for both harvest periods. Because NDF includes the structural cell wall components of plants (except pectins) and consists of the slowest digesting fractions (cellulose, hemicellulose, lignin and cutin), its value is generally closely, and negatively, correlated with the DM intake of ruminants. High NDF limits average daily body weight gains of cattle (NRC, 2001).

Based on these results and those of our two earlier studies (Robinson et al., 2004b; Suyama et al., 2006), forage quality can be ranked as: tall wheatgrass and 'Salado' alfalfa (9–10 MJ/kg DM) > paspalum (8.5–10 MJ/kg DM) > bermudagrass (8–9.5 MJ/kg DM) and creeping wildrye (7.5–8 MJ/kg DM). The ME of tall wheatgrass is as high as alfalfa, but its DM intake by ruminants may be lower due to higher NDF values. However, tall wheatgrass also had higher $dNDF_{30}$, which may offset its high NDF content.

4.4. *Mineral composition*

The DW-irrigated forages contained much higher herbage Se concentrations than did forages irrigated with NS water. However, there was only a slight increase in herbage Se concentrations in forages irrigated with HS drainage water as compared to MS irrigation, in spite of the nearly two-fold higher concentration of Se in the HS water. A similar result was reported in the prior sand tank study (Grattan et al., 2004b). Sulfate inhibition of Se uptake which has often been reported (Grieve et al., 2001; Bañuelos et al., 2003), is the likely explanation for the similar Se contents in the MS and HS forages, because external SO_4^{2-} was also much higher in the HS irrigation water.

Interestingly, total-Se in the soil of the MS treatment (1.78 mg/kg) was numerically higher than that of HS treatment (1.61 mg/kg) and the cause of this is not known. One possible reason is that under MS treatment, plant water use may have been higher than in the HS treatment, and therefore more Se accumulated in the soil. This may also have contributed to the relatively small increase in total-Se in the herbage for the HS treatment as compared to the MS treatment.

All forages under MS and HS irrigation contained from 2.7 to 8.1 mg/kg of total-Se, which is well above the maximum tolerable concentration (MTC) of 2 mg/kg Se (Minson, 1990; NRC, 1996) for most ruminants. The very high Se concentration of tall wheatgrass under MS irrigation (8.1 mg/kg) was partly due to one pot, which accumulated extremely high levels of Se in both the soil and plant tissue. However, we found similarly high concentrations of Se in tall wheatgrass (6–7 mg/kg) and creeping wildrye (3–11 mg/kg) herbage after multiple years of DW irrigation in the field (Suyama et al., 2006). Retana et al. (1993) also reported high levels of Se (12 mg/kg) in tall wheatgrass growing on a highly saline soil in California. The high concentrations of Se found in the herbage of our forages could be toxic to ruminants if they were fed these forages exclusively. However, these same forages could also be fed as a Se supplement to deficient ruminants, thereby making their high Se content advantageous in feeding.

Under MS and HS irrigation, the total-S concentration of paspalum herbage was extremely high (>327 mmol/kg) suggesting that this forage should be mixed with other feeds prior to feeding to ruminants in order to have a total S concentration in the overall diet DM of less than 125 mmol/kg (0.4%). High levels of sulfur in forages can lead to increased sulfide production by ruminant microorganisms (Kandylis, 1984), which in turn increases the incidence of cerebrocortical necrosis, also known as polioencephalomalacia (Gould et al., 1991; Gould, 1998). High sulfide in the rumen can also reduce Cu availability by forming thiomolybdates, which are an non-absorbable form of Cu (Suttle, 1991). Bermudagrass and alfalfa also accumulated high levels of S (156–218 mmol/kg) under MS and HS condition, but these forages were more salt-sensitive and so are not likely to be grown under highly saline conditions ($EC_e > 10$–12 dS/m) whereby excessive S accumulation would likely occur.

Nitrate nitrogen (NO_3-N) concentrations in some of our forages reached levels where some restrictions might be placed on feeding to certain classes of ruminants. In the prior field study at Red Rock Ranch, NO_3-N levels of tall wheatgrass, creeping wildrye and 'Salado' alfalfa were less than 300 mg/kg (Suyama et al., 2006). Most forage NO_3-N concentrations were below 5,000 mg/kg, which would allow them to be fed to non-pregnant cattle (NRC, 2001). That high NO_3-N concentrations (>3000 mg/kg) occurred as often in the NS treatment as in the HS, may have been due to the relatively high level of NO_3-N added to the NS irrigation water in order to balance its N level with that of the MS irrigation water. Bermudagrass accumulated less NO_3-N under all salinity levels than the other forages which agrees with the findings of Wilkinson and Langdale (1974) that it is not common for bermudagrass to accumulate toxic levels of NO_3-N.

5. Conclusion

The salt-tolerance of the candidate forages varied among species, as did forage quality and ion composition. Tall wheatgrass and paspalum had the highest salt-tolerance and forage quality among the species examined, but the high S content in paspalum herbage may restrict its feeding level to cattle. Nevertheless, these two forages are better candidates for DW re-use systems than are bermudagrass and creeping wildrye. The high forage quality of 'Salado' alfalfa makes this forage attractive, but its yield is greatly reduced at higher DW salinities. Creeping wildrye was not the best in any of the selection criteria, but it had adequate yield and nutritional value, particularly when grown at salinity levels not exceeding 14 dS/m EC_e.

The high Se content in all these forages is a concern for their use as animal feeds, especially for the more salt tolerant forages (tall wheatgrass and paspalum) which tended to accumulate more Se. Se accumulation would certainly limit their feeding levels and require that these forages be fed in mixed rations – although it should be pointed out that in California's WSJV, very few farms have drainage water with Se levels equal to or higher than this area near Five Points, California.

The utilization of any of these forages in animal production depends on the salinity and ion composition of both the drainage water and the soils, and their potential impact on forage nutritive value and safety for feeding to ruminants. Selecting the most suitable forage to meet local conditions will provide maximum profits from forage production and maximum benefits from drainage management in IFDM systems.

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