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Biophysical properties and biomass production of elephant grass under saline conditions

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Elephant grass (*Pennisetum purpureum* Schum.) is a new fast-growing alternative forage crop. However, salinity is a major concern for its production in the arid south-western United States. This study was conducted in the arid Imperial Valley of Southern California to evaluate salt tolerance of elephant grass. Salinity treatments were created in field plots irrigated with water possessing an electrical conductivity (EC_{iw}) of 1·5, 5, 10, 15, 20, and 25 $dS\,m^{-1}$, respectively. Canopy spectral reflectance, temperature, plant height, leaf area index (LAI), chlorophyll-SPAD meter readings, and dry weights were measured over time. Results indicated that canopy reflectance in the near-infrared spectral region was reduced incrementally with increasing levels of salt stress. Canopy temperature increased with increasing salinity, especially at longer times after salinity treatment. Plant height and LAI were reduced with increasing salinity. Biomass accumulation was reduced incrementally with increasing salinity. About 50% yield reduction was found when EC_{iw} increased from 5 to 25 $dS\,m^{-1}$. The study shows that elephant grass is sensitive to salt stress, and relatively low salinity must be maintained to achieve a high rate of growth and biomass production.

Keywords: Saline irrigation; *Pennisetum purpureum* Schum.; remote sensing; salinity

Introduction

Large growing day degrees associated with warm temperature and abundant solar energy in the south-western United States promote crop productivity. However, salinity has been a major concern for plant growth, and significant research has been carried out on salt tolerance for many conventional existing crop species (Maas & Hoffman, 1977).

Elephant grass (*Pennisetum purpureum* Schum.) is a tropical C4 bunchgrass with high rates of growth and biomass production. It has been considered as a new

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alternative for animal feed in South America, and much effort has been devoted to determine its palatability and nutritional values as an alternative forage crop (Aroeira *et al.*, 1999; Ebong *et al.*, 1999). A recent feeding study conducted in California indicated that the palatability of elephant grass was superior to that of Sudan grass and alfalfa hay in finishing cattle (Alvarez *et al.*, 2000). Therefore, there exists a potential for elephant grass production in the south-western United States. The high growth rate of elephant grass also requires large amount of nutrients such as nitrogen, making it a potential border crop as a nitrogen scavenger. This is especially effective in reducing nitrogen contamination to surface and ground-waters for land application of animal wastes that contain high amounts of both nitrogen and salts.

Very little information is available on water quality requirements or on soil and plant interactions for elephant grass. A study by Imhoff *et al.* (2000) showed that animal trampling increased soil bulk density in areas between the elephant grass plants compared to areas directly below the grasses. The increased bulk density would exert a mechanical stress for root expansion beyond the crop rows, and possibly enhance denitrification. Martinez *et al.* (1994) reported that biomass production of elephant grass was related to cutting frequency and varietal differences. Whereas investigations were conducted to evaluate the suitability of using saline water to grow *Atriplex* (Watson *et al.*, 1994; Glenn *et al.*, 1998) and some grass species (Ashour *et al.*, 1997) as alternative forage crops, no information is available in the literature on the potential impact of salinity on elephant grass. Salinity is a main concern for potential commercial production of elephant grass in the arid south-western United States, and in other arid regions of the world. High levels of soil and water salinity can significantly inhibit plant growth and reduce yield due to the combined effects of high osmotic potential and specific ion toxicity (Greenway & Munns, 1980; Yeo & Flowers, 1989). The objectives of the study were (1) to characterize effects of salinity on biophysical variables such as canopy spectral reflectance, temperature, leaf area index and chlorophyll content, and to (2) determine the cumulative effect of salinity on biomass production of elephant grass.

Materials and methods

Field experiments were carried out at the Imperial Valley Research Center at Brawley, California (32° 59′N; 115° 56′W). The desert climate is characterized by hot, dry summers and mild winters with a mean annual temperature of 23°C and a mean rainfall of 60 mm per year. Daily maximum temperatures exceed or equal 38°C for more than 100 days per year (Spencer *et al.*, 1985). This climate is ideal for irrigated agriculture and allows a 365-day growing season. The soil at the field site was Holtville silty clay (Typic, montmorillonitic, hyperthermic Torrifluvent) (Perrier *et al.*, 1974). Salinity is one of the major soil management concerns in the area.

Based on our previous experience with salt tolerance of grass species, six salinity levels from 5 to 25 $dS\,m^{-1}$, including a non-saline control with canal water or $1{\cdot}5\,dS\,m^{-1}$ treatment, were selected for the study. Elephant grass has been established at the experimental location for over 5 years, and has been irrigated via furrow irrigation using canal water possessing an electrical conductivity (EC_{iw}) value of less than $1{\cdot}5\,dS\,m^{-1}$. A new furrow irrigation system was installed at the experimental site to impose the salinity treatment by selectively mixing the irrigation water between direct intake from the canal and a brine mix (Fig. 1). Three-way valves were used for adjustment of salinity levels. The experimental treatments were established in an existing elephant grass field where each salinity treatment consisted of a four-row wide

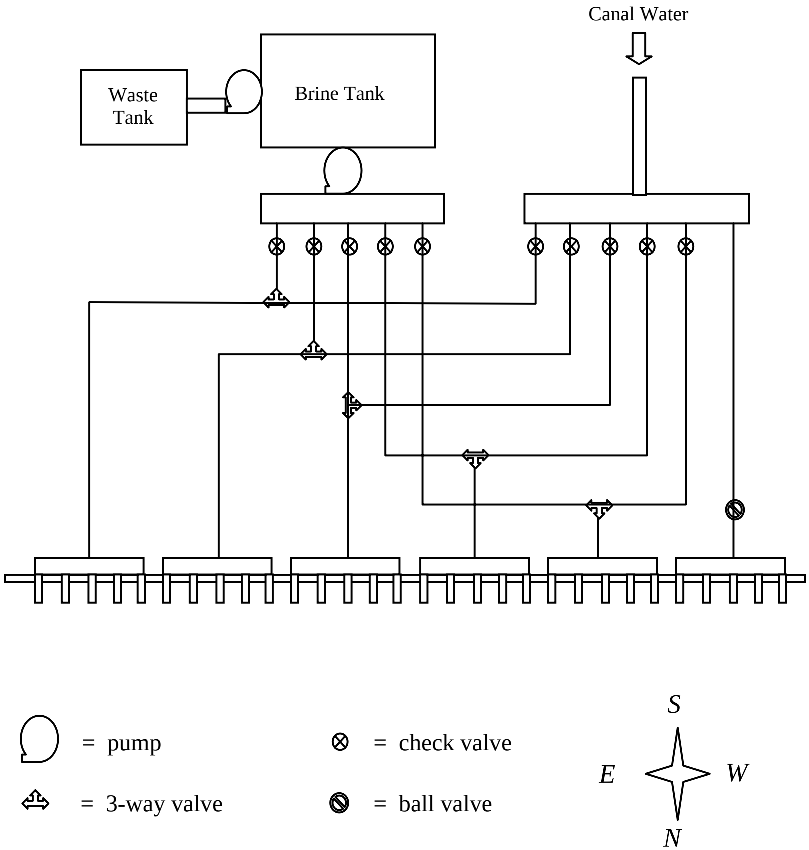

Figure 1. Schematic of the furrow irrigation system for implementation of six levels of irrigation water salinities.

(1-m row spacing) × 40-m long section. Prior to each irrigation event, concentrated solution mixtures of sodium chloride and calcium chloride (at 1:1 weight ratio) were prepared to create the brine mixture. By adjusting the three-way flow control valves the non-salinized canal water was mixed with the brine, to create the irrigation water at the outlets with an EC_{iw} value of 5, 10, 15, 20, and 25 $dS\,m^{-1}$, respectively. The non-saline control was irrigated with only the canal water ($EC_{iw} < 1{\cdot}5\,dS\,m^{-1}$).

To provide a correlation assessment between the saline irrigation water and substrate salinity, the recently developed Geonics dual-dipole synchronized electromagnetic (EM) inductance meter or EM-38DD was used on a mobilized soil salinity assessment platform, similar to the dubbed 'Salt Sniffer' of Corwin & Lesch (2001), to collect soil vertical EM conductivity information in the experimental plots. Replicated soil vertical EM readings (EMV) from each treatment were correlated against the EC_{iw} values. The EMV readings were also used to provide a relative assessment of averaged rootzone salinity.

Salinity effects on plant biophysical variables related to canopy development can be determined with remote sensing techniques (Wiegand *et al.*, 1992; Peñuelas *et al.*, 1997). In this study, canopy reflectance of elephant grass was measured with a hand-held Cropscan® Multi-Spectral Radiometer (MSR) equipped with waveband sensors centered at 460, 560, 660, 710, 810, 830, 900, and 950 nm. Reflectance was computed from simultaneous radiance measurements of paired sensors: one downward-facing and one upward-facing for each band. The reflectance measurements were made just prior to harvest on 17 July, 30 August and 18 October 2000, respectively, to provide a temporal assessment. During each measurement, the MSR was held 50 cm above the canopy at an angle perpendicular to the horizontal plane. The reflectance measurements were made at five locations evenly spaced within each treatment. Six replicated readings were taken at each location. Vegetation indices have been widely used in remote sensing to describe the degree of plant cover and growth conditions. A recent study indicated that the simple ratio vegetation index (SRVI) was more sensitive than other indices to reflect salinity stress in soybeans (Wang *et al.*, 2002). In this study, SRVI was calculated as a ratio of the reflectance measurement between 830 and 660 nm wavebands.

The osmotic effect of salinity on plant growth can reduce water transpiration resulting in increased canopy temperature. Concurrent with the reflectance measurement, an infrared thermometer was used to obtain temperature measurement of the elephant grass canopy. Using air temperature measurement from an adjacent weather station, temperature differences were obtained between the elephant grass canopy and the ambient air. Plant height and leaf area index (LAI) were also measured for all treatments. The LAI measurement was carried out with an LICOR® LAI-2000 plant canopy analyser. To assess the effect of salinity on leaf chlorophyll, a Minolta® hand-held SPAD-502 meter was used to take replicated readings from each salinity treatment. The SPAD meter readings have been found to correlate closely to leaf chlorophyll content (Markwell *et al.*, 1995), and a greater SPAD meter reading corresponds to higher chlorophyll content per unit leaf area. For plant height, LAI, and SPAD meter readings, two replications were used at each measurement location within each salinity treatment.

Biomass dry weights were determined concurrently with cuttings on 17 July, 30 August and 18 October 2000. Total fresh weight was measured with a scale immediately after each cutting. Subsamples were taken to determine the moisture content and to calculate the total dry weight per sample.

Results and discussion

Soil EMV readings from the salinity plots correlated positively with the EC_{iw} values ($r^2 = 0{\cdot}996$, Fig. 2). A slightly non-linear relationship was found in the $1{\cdot}5$–$10\ \mathrm{dS\,m^{-1}}$ range. This confirmed that the actual substrate salinity that the elephant grass was subjected to at each treatment plot was maintained at different levels that were proportional to the imposed irrigation water salinity.

Increasing the irrigation water salinity reduced canopy reflectance in the near-infrared (NIR) spectrum region for the 30 August harvest (Fig. 3(b)) when the grass was in the fastest growing period and the maximum reflectance in the NIR reached about 80% in the control plot. The largest difference was in the 830 and 900 nm bands. Less separation was found in the NIR reflectance for the 17 July and 18 October harvests when the maximum reflectance in the NIR reached only about 50% (Fig. 3(a, c)). Salinity-induced reflectance reductions in NIR were also observed in other crops such as in barley (Peñuelas *et al.*, 1997) and in soybean (Wang *et al.*, 2002). In the NIR spectrum domain, differences in canopy reflectance have been attributed to variations in leaf anatomical structure such as the number of palisade cell layers, cell sizes and orientation (Gausman, 1974). Further, it has been found that the transmissivity-related leaf absorbance at 1000 nm is positively correlated to increases in specific leaf mass or total dry matter per unit surface area (Méthy *et al.*, 1998).

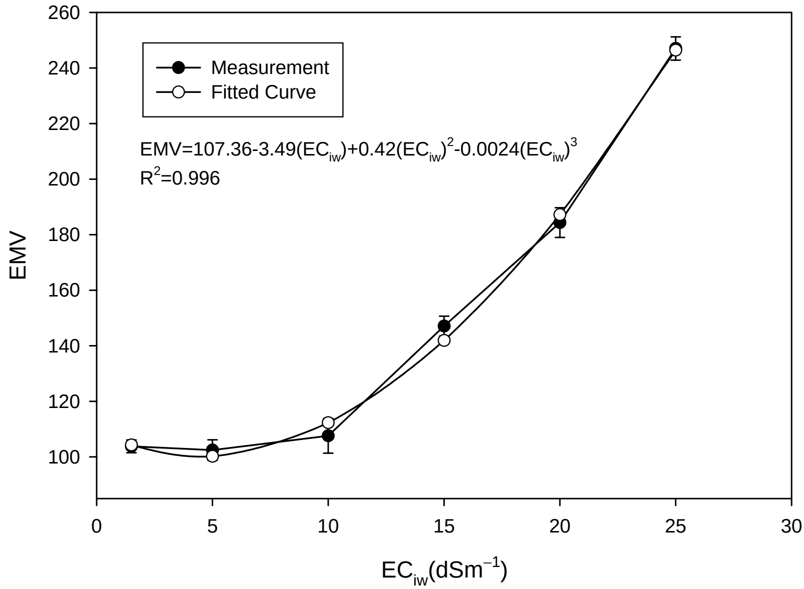

Figure 2. Comparison between average *in situ* soil vertical electromagnetic conductivity (EMV) and the electrical conductivity of irrigation water (EC_{iw}). Error bars represent standard errors ($n = 15$).

Therefore, reductions in NIR would indicate more dry materials per unit leaf area. This is often a result of reduced growth in cell expansion that concentrated the cell and cell wall materials. Based on the reflectance measurement at the 830 and 660 nm wavebands, large reductions were found in SRVI with increasing salinity from 5 to 10 dS m^{-1}and 20 to 25 dS m^{-1} (Table 1). Because of a lack in spatially randomized replications, no formal statistical tests were performed for mean comparisons. Reflectance in the red (660 nm) band became substantially higher in the 25 dS m^{-1} treatment and to some extent in the 20 dS m^{-1} treatment just before the 18 October harvest (Fig. 3(c)). This resulted from the cumulative effect of salinity on overall growth and size reductions in the elephant grass.

The temperature of elephant grass canopy on 17 July was about 2–3°C below the ambient air temperature (41·3°C) for all salinity treatments at the time of measurements (Fig. 4(a)). The undistinguishable temperature differences between different levels of salinity were attributed to the extremely high air temperature. The extremely high air temperature would result in stomata closures regardless of the degree of salt stress. In addition, the cumulative time after salinity treatment was likely insufficient to show significant differences among treatments. Canopy temperatures of the elephant grass on 30 August were much higher in the 15, 20 and 25 dS m^{-1} plots than those of the ambient air (32·4°C), the ontrol, or in the 5 and 10 dS m^{-1} plots (Fig. 4(b) and Table 1). High salt input in the 15, 20 and 25 dS m^{-1} plots likely resulted in significant reductions in transpiration. By 18 October (Fig. 4(c)), the cumulative effect of salinity had created a gradual temperature increase above the ambient air temperature (33·2°C).

On 30 August, consistent reductions in plant height (PHt) were found with increasing salinity from the control to the 25 dS m^{-1} treatment (Table 1). A similar linear decreasing trend was observed for plant leaf area index (LAI) with increasing salinity (Table 1). Both variables indicated a size reduction in elephant grass, and the

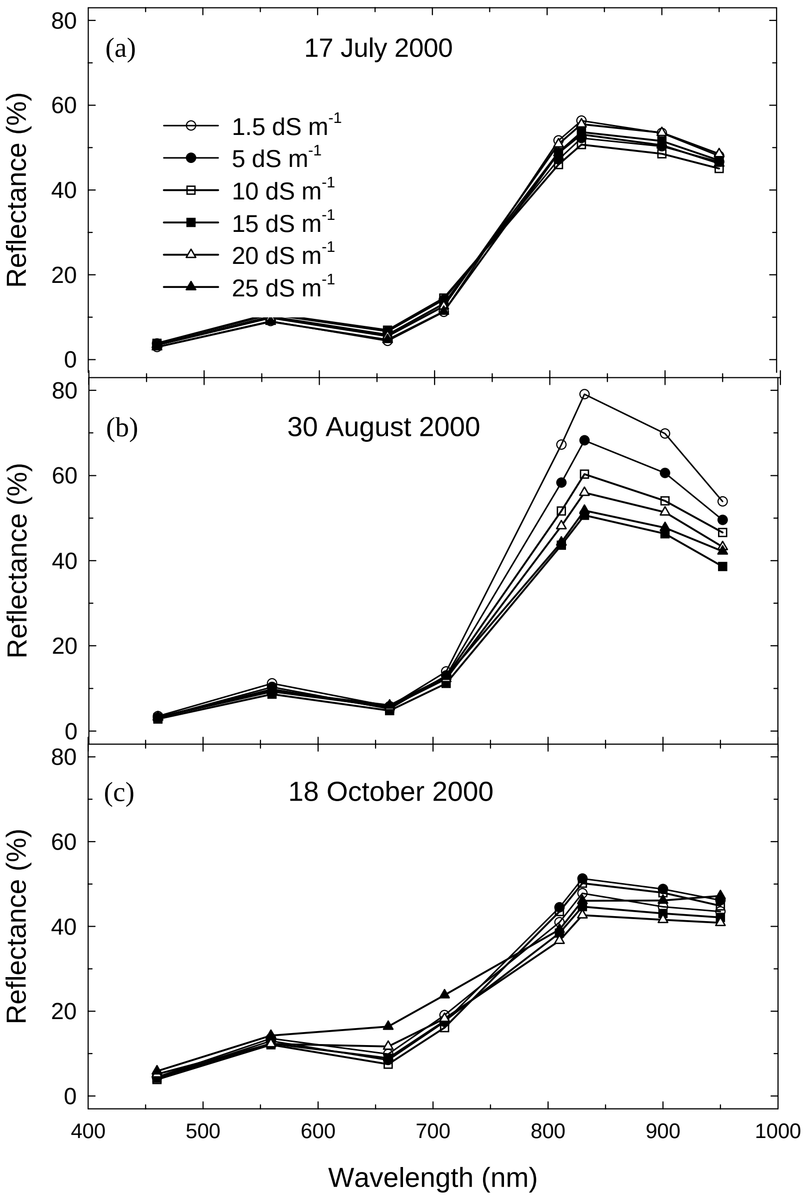

Figure 3. Spectral reflectance of elephant grass canopy on (a) 17 July, (b) 30 August, and (c) 18 October 2000 for six irrigation water salinities.

degree of reduction was related to the severity of the salinity stress. The size reduction is consistent with the reduced SRVI computed from the reflectance measurements.

The lowest SPAD meter readings were found at $EC_{iw} = 10$ and $15\,dS\,m^{-1}$ (Table 1). The SPAD meter readings reflect chlorophyll content per unit leaf area (Markwell *et al.*, 1995). The total chlorophyll content on a per plant basis can be described on a relative basis as a product of the LAI and SPAD reading. This product decreased from 181 for the control, to 125 for $EC_{iw} = 10\,dS\,m^{-1}$, and to 91 for $EC_{iw} = 20\,dS\,m^{-1}$.

Table 1. *Salinity effects on biophysical properties of elephant grass harvested on 30 August 2000 at Brawley, California, U.S.A**

EC_{iw} ($dS\,m^{-1}$)	SRVI (–)	$T_c - T_a$ (°C)	PHt (m)	LAI (–)	SPAD (–)
1·5	13·6 (0·2)	−0·2 (0·2)	1·11 (0·02)	5·2 (0·4)	34·9 (0·6)
5	13·3 (0·2)	−0·7 (0·5)	0·99 (0·02)	5·6 (0·3)	32·3 (0·6)
10	11·3 (0·4)	−2·2 (0·3)	0·74 (0·03)	4·2 (0·4)	29·7 (0·6)
15	10·6 (0·2)	3·4 (0·3)	0·58 (0·03)	4·0 (0·3)	29·7 (0·7)
20	10·1 (0·3)	4·7 (0·4)	0·51 (0·01)	2·8 (0·2)	32·4 (0·9)
25	8·9 (0·3)	6·5 (0·6)	0·43 (0·02)	3·0 (0·4)	32·7 (0·5)

*Values are means (S.E.) of 30 replications of simple ratio vegetation index (SRVI $= \rho830/\rho660$) and the temperature difference between elephant grass canopy and the ambient air ($T_c - T_a$); and 10 replications of Plant Height (PHt), leaf area index (LAI), and SPAD meter readings under six levels of electrical conductivity for irrigation water (EC_{iw}).

The total chlorophyll content on a per plant basis is more important because it is directly proportional to the rate of plant photosynthesis for biomass production.

Yield reductions started to occur at the 5 $dS\,m^{-1}$ level, where biomass dry weight decreased from about 5·2 for the control to 3·5 $Mg\,ha^{-1}$ averaged over the July and August cuttings (Table 2). Less difference was found for the October harvest when the grass did not achieve as much growth as the first two harvests. Yield reductions continued when increasing salinity from 10 to 15 $dS\,m^{-1}$ or higher levels. Average dry weight at 25 $dS\,m^{-1}$ was only 35% of that at 1·5 $dS\,m^{-1}$ for the first two cuttings. About 50% yield reduction occurred when salinity increased from 5 to 25 $dS\,m^{-1}$.

The effect of salinity on yield reductions of elephant grass was further analysed using the exponential model of van Genuchten (1983) in the form of $Y = Y_m \exp(a\,EC_{ar} - b\,EC_{ar}^2)$, where Y was the actual yield, Y_m was the maximum yield under non-saline conditions, EC_{ar} was the average rootzone salinity, a and b were empirical parameters. EC_{ar} was related to *in situ* EM readings in the form of $EC_{ar} = 1{\cdot}1\ EC_{iwf}$; $EC_{iwf} = (2{\cdot}54 + (SQRT(2{\cdot}54^2 - 4{\star}0{\cdot}32{\star}(105{\cdot}6\text{-}NEMVavg))))/0{\cdot}64$, where NEMVavg was the average of the three EMV measurements normalized for temperature. The low-end EM data from the control treatment was normalized with respect to temperature between the three surveys, so that the treatment data would be more directly comparable. The coefficients found for elephant grass were $Y_m = 4{\cdot}771\ Mg\,ha^{-1}$, $a = -0{\cdot}028$, $b = 0{\cdot}0006$, and the least-squares non-linear test indicated that the model prediction was highly correlated to the measured yield data ($(Pr > F) < 0{\cdot}0001$).

In summary, field experiments were conducted to evaluate salt tolerance of elephant grass and to determine its production potential in the arid south-western United States. Salinity reduced elephant grass canopy reflectance in the near-infrared spectrum region, which resulted in reduced simple ratio vegetation index values. Canopy temperature of the elephant grass under saline conditions, in general, was much higher than the control. Plant height and leaf area index were reduced by the salinity treatments, and the degree of reduction was proportional

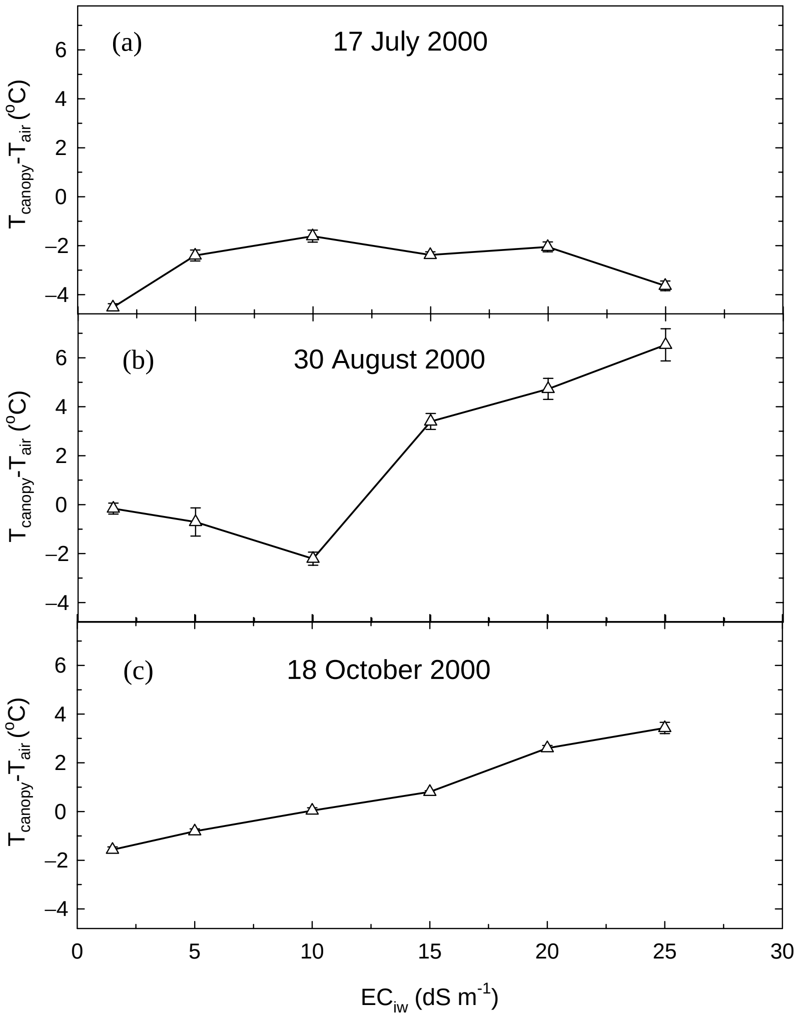

Figure 4. Temperature differences between elephant grass canopy and the ambient air on (a) 17 July, (b) 30 August, and (c) 18 October 2000 for six irrigation water salinities. Bars represent $\pm$S.E. ($n = 15$).

to the levels of salinity. Total plant chlorophyll was also reduced by the salt stress. Under non-saline conditions, elephant grass produced about $5{\cdot}2\,\mathrm{Mg\,ha^{-1}}$ dry matter per cutting in July and August. The yield was reduced more than half when salinity increased from 5 to $25\,\mathrm{dS\,m^{-1}}$. However, the high rate of biomass production may still justify it as a viable forage crop to grow under moderately saline conditions.

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Table 2. *Salinity effects on biomass production of elephant grass from three cuttings in year 2000 at Brawley, California, U.S.A**

EC_{iw} ($dS\,m^{-1}$)	17 July ($Mg\,ha^{-1}$)	30 August ($Mg\,ha^{-1}$)	18 October ($Mg\,ha^{-1}$)
1·5	5·1 (0·2)	5·3 (0·3)	1·6 (0·3)
5	3·2 (0·1)	3·9 (0·2)	1·8 (0·3)
10	3·9 (0·1)	3·3 (0·1)	1·5 (0·3)
15	2·1 (0·1)	2·5 (0·1)	1·1 (0·1)
20	2·4 (0·1)	2·0 (0·1)	1·1 (0·2)
25	2·0 (0·1)	1·6 (0·03)	0·6 (0·1)

*Values are means (S.E.) of five samples.

References

Alvarez, E.C., Montano, M.F. & Zinn, R.A. (2000). Comparative feeding value of elephant grass in growing diets for feedlot cattle. *Proceedings of the American Society Animal Sciences, Western Section*, **51**: 477–480.

Aroeira, L.J.M., Lopes, F.C.F., Deresz, F., Verneque, R.S., Dayrell, M.S., de Matos, L.L., Maldonado-Vasquez, H. & Vittori, A. (1999). Pasture availability and dry matter intake of lactating crossbred cows grazing elephant grass (*Pennisetum purpureum*, Schum.). *Animal Feed Science and Technology*, **78**: 313–324.

Ashour, N.I., Serag, M.S., Abd El-Haleem, A.K. & Mekki, B.B. (1997). Forage production from three grass species under saline irrigation in Egypt. *Journal of Arid Environments*, **37**: 299–307.

Corwin, D.L. & Lesch, S.M. (2001). Application of soil electrical conductivity to precision agriculture: theory, principles, and guidelines. *Agronomy Journal*, **94**, (in press)

Ebong, C., Byenkya, S.G. & Ndikumana, J. (1999). Effects of substituting *Calliandra* leaf meal for soybean meal on intake, digestibility, growth and feed efficiency in goats. *Journal of Applied Animal Research*, **16**: 211–216.

Gausman, H.W. (1974). Leaf reflectance of near infrared. *Photogrammetric Engineering*, **40**: 57–62.

Glenn, E., Tanner, R., Miyamoto, S., Fitzsimmons, K. & Boyer, J. (1998). Water use, productivity and forage quality of the halophyte *Atriplex nummularia* grown on saline waste water in a desert environment. *Journal of Arid Environments*, **38**: 45–62.

Greenway, H. & Munns, R. (1980). Mechanisms of salt tolerance in nonhalophytes. *Annual Reviews of Plant Physiology*, **31**: 149–190.

Imhoff, S., da Silva, A.P. & Tormena, C.A. (2000). Spatial heterogeneity of soil properties in areas under elephant-grass short-duration grazing system. *Plant and Soil*, **219**: 161–168.

Maas, E.V. & Hoffman, G.J. (1977). Crop salt tolerance — current assessment. *Journal of Irrigation and Drainage Division, ASCE*, **103**: 115–134.

Markwell, J., Osterman, J.C. & Mitchell, J.L. (1995). Calibration of the Minolta SPAD-502 leaf chlorophyll meter. *Photosynthetic Research*, **46**: 467–472.

Martinez, R.O., Herrera, R.S., Cruz, R., Tuero, R. & Garcia, M. (1994). Biomass production with elephant grass (*Pennisetum purpureum*) and sugar cane (*Saccharum officinarum*) for tropical livestock production. 1. Yields. *Cuban Journal of Agricultural Science*, **28**: 221–229.

Méthy, M., Joffre, R. & Ourcival, J.M. (1998). Two ways of assessing absorbance of fresh leaves from near-infrared reflectance spectroscopy. *International Journal of Remote Sensing*, **19**: 1741–1750.

Peñuelas, J., Isla, R., Filella, I. & Araus, J.L. (1997). Visible and near-infrared reflectance assessment of salinity effects on barley. *Crop Science*, **37**: 198–202.

Perrier, E.R., Mackenzie, A.J. & Zimmerman, R.P. (1974). Physical and chemical properties of major Imperial Valley soils. USDA-ARS, Research Report W-17, Western Region.

Rahmatullah, M.K. (2000). Potassium release from mineral structures by H^+ ion resin. *Geoderma*, **96**: 291–305.

Spencer, W.F., Cliath, M.M., Blair, J.W. & LeMert, R.A. (1985). Transport of pesticides from irrigated fields in surface runoff and tile drain waters. USDA-ARS, Conservation Research Report 31, Riverside, CA, 71 pp.

van Genuchten, M. Th. (1983). Analyzing crop salt tolerance data: model description and user's manual. USDA-ARS, Research Report 120, Riverside, CA, 50 pp.

Wang, D., Wilson, C. & Shannon, M.C. (2002). Interpretation of salinity and irrigation effects on soybean canopy reflectance in visible and near-infrared spectrum domain. *International Journal of Remote Sensing*, **23**, 811–824.

Watson, M., Banuelos, G., O'Leary, J. & Riley, J. (1994). Trace element composition of *Atriplex* grown with saline drainage water. *Agriculture, Ecosystems and Environment*, **48**: 157–162.

Wiegand, C.L., Everitt, J.H. & Richardson, A.J. (1992). Comparison of multispectral video and SPOT-1 HRV observations for cotton affected by soil salinity. *International Journal of Remote Sensing*, **13**: 1511–1525.

Yeo, A.R. & Flowers, T.J. (1989). Selection for physiological characters — examples from breeding for salt tolerance. In: Jones, H.G., Flowers, T.J. & Jones, M.B. (Eds), *Plant under Stress: Biochemistry, Physiology and Ecology and their Application to Plant Improvement*, pp. 218–234. Cambridge, U.K.: Cambridge University Press. 257 pp.