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The growth response of tropical and subtropical forage species to increasing salinity

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Introduction

There is currently a growing coal seam gas (CSG) industry in Queensland, Australia. The industry requires beneficial-use strategies to consume the significant volumes of water released during CSG extraction. Irrigation of tropical and subtropical forage species for beef production is one option; however, quality of coal seam (CS) water varies due to moderate–high salinity and alkalinity. The application of chemically amended CS water over time could potentially increase soil salinity, which is known to reduce plant biomass production (Shabala and Munns 2012). While the salinity tolerance of many tropical and subtropical forage species has been investigated over the last 30 years (Russell 1976; Keating et al. 1986; Kitamura 1986; Hansen and Munns 1988; Deifel et al. 2006), there is a need to examine the tolerance of more recently released species and cultivars, which are suitable for planting in the Queensland CSG area.

Methods

A flood and drain hydroponic system was used to study the dry matter (DM) response of several tropical and subtropical forage species: 2 cultivars of Rhodes grass, *Chloris gayana*; 4 cultivars of alfalfa, *Medicago sativa*; and 1 cultivar of leucaena, *Leucaena leucocephala* (Table 2) to increasing salinity in a semi-controlled environment at Cleveland, Australia from December 2011 to June 2012. Three hundred and thirty-six pots (180 mm deep, 90 mm wide) were arranged as a split-plot incomplete block design with 7 salinity treatments (Table 1). There were 3 duplicates of each treatment and 2 replications. Within each of the 7 salinity treatments, species were segregated based on growth rate and habit to prevent shading. Otherwise species and cultivars were randomized.

Salinity treatments were established based on increasing rates of NaCl and $CaSO_4 \cdot 2H_2O$ to prevent sodium-induced calcium deficiency. The calcium activity ratio (CAR) of the bulk solution was maintained at ≥0.03 (Deifel et al. 2006). The electrical conductivity (EC) of the control solution was ~1.1 dS/m and comprised 5.1 g ‘Flowfeed EX7’, 10.2 g KNO_3, 13 g $MgSO_4$ and 51.1 g CaH_3NHNO_3 in 92 L of water. Plants were grown for 10 weeks before salinity treatments were increased incrementally (by a maximum of 1.5 dS/m/day) until the desired level was attained. The pH of the solutions was adjusted to 6 every second day and the solutions replaced every 7 days. To prevent an overestimation of salinity tolerance, salinity estimates were based on total accumulated regrowth (DM) over 100 days at the maximum salinity treatment (Deifel et al. 2006). Four intermittent harvests occurred during this period.

Table 1. Concentrations of NaCl and Ca (as $CaSO_4 \cdot 2H_2O$) used to achieve the respective solution electrical conductivities (ECs) (approximate) and maintain a CAR ≥0.03.

Soil solution EC (dS/m)	1.1	2.4	4.8	11.5	14.4	17.3	20.1
NaCl (mM)	2.6	18.5	46.6	97.7	124.4	151.1	177.7
[1]Ca^{2+} (mM)	2.6	2.6	2.6	8.4	10.1	11.7	12.6

[1]Includes 2.6 mM Ca^{2+} from the basal nutrient solution.

Results and Discussion

The relationship between salinity and DM yield was non-linear for all species as observed by Steppuhn et al. (2005) and Kopittke et al. (2009). DM yield response with

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increasing salinity was modeled as DM yield = A(ln(salinity))+B. EC_{75} and EC_{50} thresholds were calculated (Table 2) for each species to demonstrate the salinity level that reduced growth by 25% and 50%, respectively, relative to the control. As anticipated, *Chloris gayana* was the most salt-tolerant species. The maximum salinity treatment failed to cause an EC_{50} in *C. gayana* cv. Finecut, with a maximum biomass reduction of 44% at the highest salinity treatment of 20.1 dS/m. The EC_{50} of *C. gayana* cv. Toro (19 dS/m) was lower than the published threshold for *C. gayana* cv. Pioneer (Table 3). The EC_{50} of between 6.4 and 5.2 dS/m observed in *Medicago sativa* cultivars was significantly lower than the published threshold of 10.2 dS/m for *M. sativa* cv. Hunter River grown in soil media. There was no significant difference in DM yield among the cultivars of *M. sativa* (P=0.168) or *C. gayana* (P=0.241). *Leucaena leucocephala* had an EC_{50} of 4.9 dS/m, consistent with findings of Hansen and Munns (1988) in similar experimental conditions.

Differences in salinity thresholds between studies may be attributed to a number of factors: (1) methodology (it is suggested that the effect of salinity may be exacerbated in solution culture due to the absence of matric potential and cation exchange capacity present in soil-based systems); (2) failure to account for sodium-induced calcium deficiency; (3) differences in evapotranspiration demand (ETD) (low ETD results in reduced salt uptake and an increased ability to grow at a given salinity); (4) duration of exposure (short-term studies may not wholly reflect the effect of specific ion toxicity); (5) choice of model to explain results; and (6) intraspecific variation (Deifel et al. 2006; Kopittke et al. 2009; Tavakkoli et al. 2010).

Conclusions

Rhodes grass (*Chloris gayana*) was the most salt-tolerant species tested, followed by alfalfa (*Medicago sativa*) and then leucaena. Intraspecific variation was not evident within cultivars of *C. gayana* and *M. sativa*. The lower EC_{50} thresholds obtained for *C. gayana* and *M. sativa* in comparison with those published by Russell (1976) may be due to the different cultivars tested and also to differences in the experimental system and ETD.

On-going analysis of specific ion uptake will provide further understanding of the response of the forage species to increasing salinity. Further work is also needed to identify improved salinity tolerance within alfalfa and leucaena cultivars.

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Table 2. Estimated salinity levels (dS/m) in solutions when growth of several tropical and subtropical forage species was reduced by 25% (EC_{75}) and 50% (EC_{50}) relative to the control.

Species	EC_{75}	EC_{50}	Variance explained by model
Chloris gayana cv. Finecut	5.8	*	0.87
Chloris gayana cv. Toro	4.6	19.0	0.73
Medicago sativa cv. Multileaf	2.6	6.4	0.99
Medicago sativa cv. Titan 9	2.5	5.7	0.95
Medicago sativa cv. L91	2.5	5.7	0.95
Medicago sativa cv. Force 10	2.4	5.2	0.94
Leucaena leucocephala cv. Tarramba	2.3	4.9	0.96

*DM yield reduction <50% at 20.1 dS/m.

Table 3. Published salinity tolerance thresholds (dS/m) based on 50% yield reduction relative to the control.

Species	EC_{50}	Experimental system	Reference
Chloris gayana cv. Pioneer	23.2	Small pots − soil media	(Russell 1976)
Medicago sativa cv. Hunter River	10.2	Small pots − soil media	(Russell 1976)
Leucaena leucocephala cv. K8	~5	Sand culture	(Hansen and Munns 1988)

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