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Effect of watertable depth and salinity on growth dynamics of Rhodes grass (*Chloris gayana*)

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Abstract. Depending on their depth, watertables can have a positive effect on plants by supplying water, a negative effect by creating waterlogged and/or saline conditions or a neutral effect. Rhodes grass (*Chloris gayana*), a tropical perennial forage adapted to saline soils, floods and droughts, is a viable choice for the lowlands in the Pampas region of Argentina. The effects of the depth and salt concentration of the watertable on the growth dynamics and biomass accumulation of Rhodes grass were quantified in a greenhouse experiment. The experiment consisted of 10 treatments, resulting from the factorial combination of five watertable depths (25, 75, 125, 175 and 225 cm) and two salt treatments (EC 1.4 and 20.5 dS m^{-1}). The presence of non-saline watertable at a depth of 25 cm produced a 5-fold greater biomass and showed an increase in water consumption of equal magnitude compared with deeper watertables. The increase in shoot biomass was explained primarily by higher tiller and stolon density, which increased 3.3- and 7.7-fold respectively, at watertables that were 25 cm deep compared with deeper treatments. Furthermore, groundwater use efficiency was 30% higher in non-saline watertables at 25 cm depth. Similarly, at this depth, the leaf blades were 50% longer compared with the deepest watertables evaluated. In contrast, the presence of saline watertables at 25 cm depth had a detrimental effect on the production of biomass and its components, whereas the effect at 125 cm and greater depths was neutral. Therefore, Rhodes grass is a species that can take advantage of the widespread shallow watertable environments of the Pampas region as long as the salinity levels are low.

Additional keywords: accumulated biomass, water stress, water use efficiency.

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Introduction

The Pampas region of Argentina is one of the flattest plains on the planet and is playing an increasingly important role in global food production. A low regional slope, together with a poor system for surface water and salt evacuation (Taboada *et al*. 1998), causes floods and high watertables (Jobbágy *et al*. 2008), as well as vertical water movements (Lavado and Taboada 2009). These effects cause salt redistribution in the soil profile and generate soil salinity (Gorgas and Bustos 2008) with a highly heterogeneous spatial distribution (Lavado and Taboada 2009).

The depth of watertables and their salt concentration are dynamic attributes in space and time that can affect plants in various ways. Deficient plant soil cover, together with climate fluctuations, may favour bare soils with high watertables because of low water consumption, and can lead to a greater accumulation of salts in the surface (Cisneros *et al*. 2008). These can have direct effects on the vegetation (due to osmotic and/or toxic effects; Passioura and Munns 2000; Munns 2002), indirect effects on the soil (clay dispersion, loss of organic matter, occlusion of macro pores and decreased infiltration; Cisneros *et al.* 1999, 2008) or both plant and soil effects leading to poor ground cover and creating a negative feedback loop. Selecting suitable pasture species, in combination with effective management, could result in better ground cover and root development, adequate water consumption, improved infiltration and salt leaching and a decrease in capillary salt rise to the surface (Cisneros *et al.* 2008).

The watertable can interact with vegetation to various extents. Depending on its depth, it can be a valuable source of water or it can become a stress agent by creating conditions of waterlogging and/or salinity (Narain *et al.* 1998; Mueller *et al.* 2005; Nosetto *et al.* 2009). In addition, changes in vegetation can alter the balance of water and salt flow in the ecosystem (Scanlon *et al.* 2005) causing, in some cases, salt concentration and watertable depression (Jobbágy and Jackson 2004). In such environments, it is common to find plants stressed by water shortage (manifested as decreased leaf growth and expansion and less tillering) or by water excess (where hypoxic conditions affect root and shoot growth) or by salinity.

There is some information available about optimal watertable depths for different species, and their relationship with root architecture, exclusion of solutes and water use efficiency (WUE) that provide key insights into land use management and improved production efficiency, both at the field and regional level (Narain *et al.* 1998; Jobbágy and Jackson 2004; Mueller *et al.* 2005; Nosetto *et al.* 2009). In general, C4 species are more water use efficient than C3 species (Beale *et al.* 1999) and perennial pastures offer longer periods of activity and greater root exploration than annual crops (Jobbágy *et al.* 2008) and may have higher water consumption (Narain *et al.* 1998; Mueller *et al.* 2005). Rhodes grass, a C4 species, combines several favourable features: vigorous initial growth that mitigates weed competition, which is advantageous for early establishment; and a high natural spreading potential (through stolons and/or seeds) and long persistence (Bogdan 1969; FAO 2011). In addition, this species is suitable for saline environments (Priano and Pilatti 1989) and temporary droughts (Bogdan 1969; Taleisnik *et al.* 1997). These characteristics make it especially suitable for halohydromorphic environments.

Biomass production in Rhodes grass established on saline soils in the area of Marcos Juárez, located in the south-east of Córdoba province (32°S, 62°W), Argentina, may vary between 5 and 15 t dry matter (DM) ha^{-1} (Bertram *et al.* 2010). This wide range may be attributed, in part, to salinity, which exerts negative effects on the establishment and persistence of pastures (Pérez *et al.* 1999; Bertram *et al.* 2010). Currently, there are no experimental data to assess the extent to which spatial and temporal variations in the depth and salinity of watertables can affect pasture productivity. The aim of the present study was to describe the interaction between watertable conditions and Rhodes grass biomass production.

Materials and methods

Site and experimental material

The experimental research was performed under semi-controlled conditions in a greenhouse at the INTA Marcos Juárez Experimental Station (32°43′S, 62°6′W) in Argentina. The average mean daily temperature during the evaluation period was 22.7°C (Fig. 1), whereas the average daily effective heliophany (daylight hours) was 7.7 h. The temperature was measured in the greenhouse, whereas heliophany was registered in a weather box.

Treatments and experimental design

Individual *Chloris gayana* cv. Topcut plants were used for these experiments. Pots (polyvinyl chloride (PVC) plastic tubes, 20 cm diameter and 50, 100, 150, 200 or 250 cm long) were filled with typical argiudol soil Marcos Juárez series, representing the different profile horizons, and mixed with sand (3 : 1 soil : sand volume) in order to reduce water retention and ease root measurements (Table 1). Subsequently, 2-year-old *C. gayana* plants were transplanted from field plots to the pots, and kept at field capacity for approximately 60 days until the beginning of the experiment in order to restore capillarity, stabilise pore spaces and allow for new root growth. The surface of each pot was covered with a 4 cm layer of dry plant residues to minimise evaporation.

Watertable depth

Watertable depth simulation was performed by immersing the pots in buckets containing water columns of 25 cm of either tap water (electrical conductivity (EC) 1.4 dS m^{-1}) or a 10 g L^{-1} NaCl solution in tap water (EC 20.5 dS m^{-1}). These levels were maintained throughout the entire experiment by periodically adding water or NaCl solution (depending on the treatment). There were 10 treatments, resulting from the factorial combination of five watertable depths (25, 75, 125, 175 and 225 cm) and two salt treatments. The experiment lasted for 71 days, period during which 1082 degree-days were accumulated, and where two biomass harvests were made. The first harvest occurred when all the accumulated water in the soil profile was consumed and occurred 27 days (498 degree-days) after the experiment commenced, and the second harvest occurred at 44 days (584 degree-days) with the plants only using watertable water. The design of the experiment was a completely randomised block design (RCBD), with each treatment consisting of four replicates.

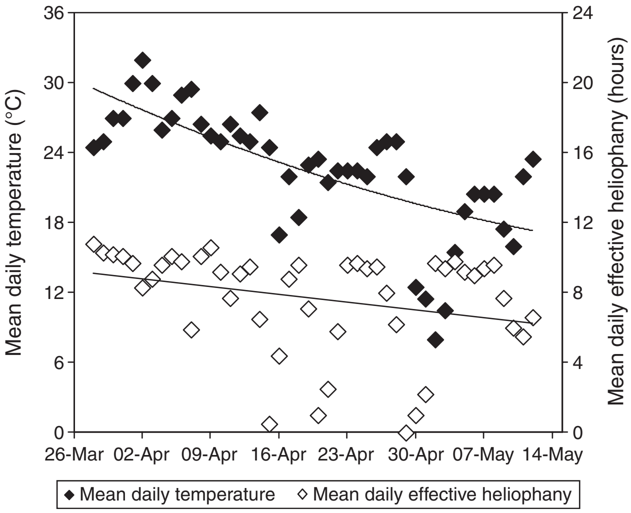

Fig. 1. Mean daily temperature and mean daily effective heliophany from 28 March to 12 May.

Table 1. Textural characteristics of the different horizons of the soil profile of Marcos Juárez Series in its natural composition (Series MJ) and after the addition of 25% sand (Series MJ + 25% sand)

Horizon		Series MJ	Series MJ + 25% sand
A (0–20 cm)	Clay (%)	25.1	20.1
	Silt (%)	68.9	55.1
	Sand (%)	6.0	24.8
B (20–80 cm)	Clay (%)	29.7	23.8
	Silt (%)	61.4	49.1
	Sand (%)	8.9	27.1
C (+80 cm)	Clay (%)	18.9	14.9
	Silt (%)	70.8	56.7
	Sand (%)	10.3	28.4

Shoot growth

After each growth period (~500 degree-days from the initial cut), plants were cut to 9 cm above the ground surface. Harvested biomass was dried at 60°C to a constant weight. Shoots were separated into tillers and stolons. The number of tillers and stolons was counted, and separated into pseudostems and blades.

Root growth

At the end of the trial, the pots were cut longitudinally and split into two halves without damaging the soil column. The substrate in one half was cut into layers (0–10, 10–20, 20–40, 40–60 and 60–100 cm). Roots in each layer were isolated by washing them in a centrifuge stream washing table before suspending them in 10% ethanol and storing them at 4−5°C. Subsequently, roots were passed through a 0.25-mm sieve and placed on a 30 × 40 cm transparent tray with a water film to extract impurities. Clean root samples were scanned with a HP 1000 scanner and images were analysed with 2007 WinRHIZO Pro. The following variables were estimated: root length, area, volume and density. Scanned samples were then dried at 60°C to constant weight.

Leaf elongation

Representative tillers from each treatment were selected and marked. The length of all the blades was measured every 3 days and rates of leaf elongation were calculated.

Water consumption

The amount of water consumed by the plants was measured weekly by recording water that was added to each bucket by means of a graded cylinder. The direct evaporation from pots was reduced to negligible levels by the addition of a mulch layer in each pot.

Statistical analysis

Accumulated biomass, biomass components, leaf elongation and root biomass variables were analysed using linear mixed models in SAS version 9.2 (SAS Institute Cary, NC, USA) taking into consideration, where necessary, heterogeneous variances for depth. To calculate WUE, simple linear regression was applied to biomass and water consumption for each treatment. Fisher's least significant different test was used to compare measurements. A two-sided $P < 0.05$ was considered significant.

Results

Effects on plant mortality

The shallowest watertable (25 cm deep) caused 50% plant mortality, probably due to waterlogging effects. However, in the treatment with the non-saline watertable depth of 25 cm, surviving plants showed the highest growth rates, producing 5-fold more biomass than in any of the other treatments (Fig. 2).

Effects on biomass production and yield components

A significant interaction was found between watertable depth and salinity for accumulated biomass ($P = 0.0005$), but not for the density of tillers ($P = 0.0714$) and stolons ($P = 0.0725$). Nevertheless, tiller density was 3.3-fold higher at the most shallow non-saline watertable (Fig. 3*a*). Salinity in the 25- and 75-cm deep watertables significantly reduced tiller density (to ~50%), but there were no negative effects of salinity when the watertable was deeper than 75 cm. Tillers that grew at the most shallow watertables (25 and 75 cm) were approximately twice as big as in the deeper watertables (Fig. 3*b*), but salinity did not exert a significant effect on tiller size.

The most shallow watertables also favoured stolon generation, which was 7.7-fold higher than at deeper depths (Fig. 3*c*), but it was significantly reduced by salinity (to ~30%). Stolon weights also reflected these effects (Fig. 3*d*).

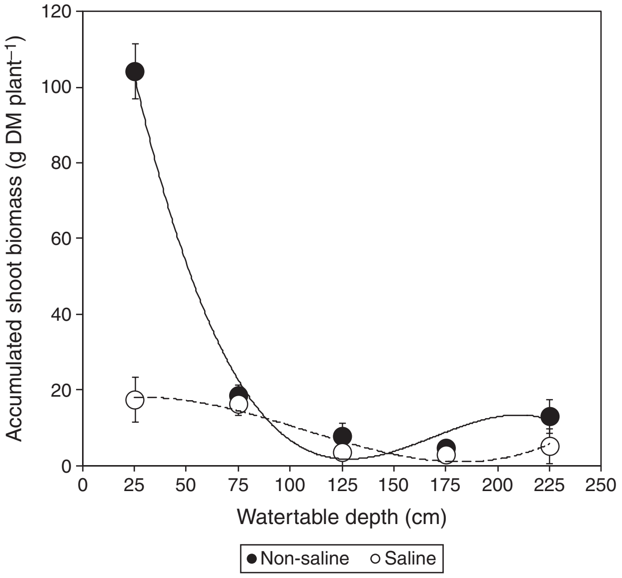

Fig. 2. Accumulated shoot biomass in *Chloris gayana* grown at various watertable depths and at two salinity levels (non-saline: 1.4 dS m^{-1}; saline: 20.5 dS m^{-1}). The vertical bars represent the standard error of the mean.

Effects on leaf blade length

Leaf blade lengths were 25% and 50% longer in plants growing in non-saline watertables close to the surface (i.e. 25 and 75 cm deep) than in plants growing in saline watertables at the same depths (Fig. 4), and were longer than in plants growing in soil with watertables exceeding 75 cm depth, regardless of salinity. Therefore, plants growing under conditions with a non-saline watertable near the surface had leaf elongation rates (2 mm per degree-day) that were 2-fold higher than in plants that were growing under conditions with a saline watertable that was close to the surface and 4-fold higher than in plants growing under conditions where the watertable was >75 cm deep.

Effect on root growth

There was a direct relationship between root proportion and shoot and depth of the watertable, since as the depth of watertable increases, root biomass increases and shoot biomass decreases (Fig. 5). A 70 : 30 (aerial part : root part) relationship was found in saline watertables at both 25 and 75 cm depths ($P = 0.0012$), whereas in the treatments in which the watertables were >125 cm deep, the relationship was reversed. With non-saline watertables the effect was similar but of a lesser magnitude;

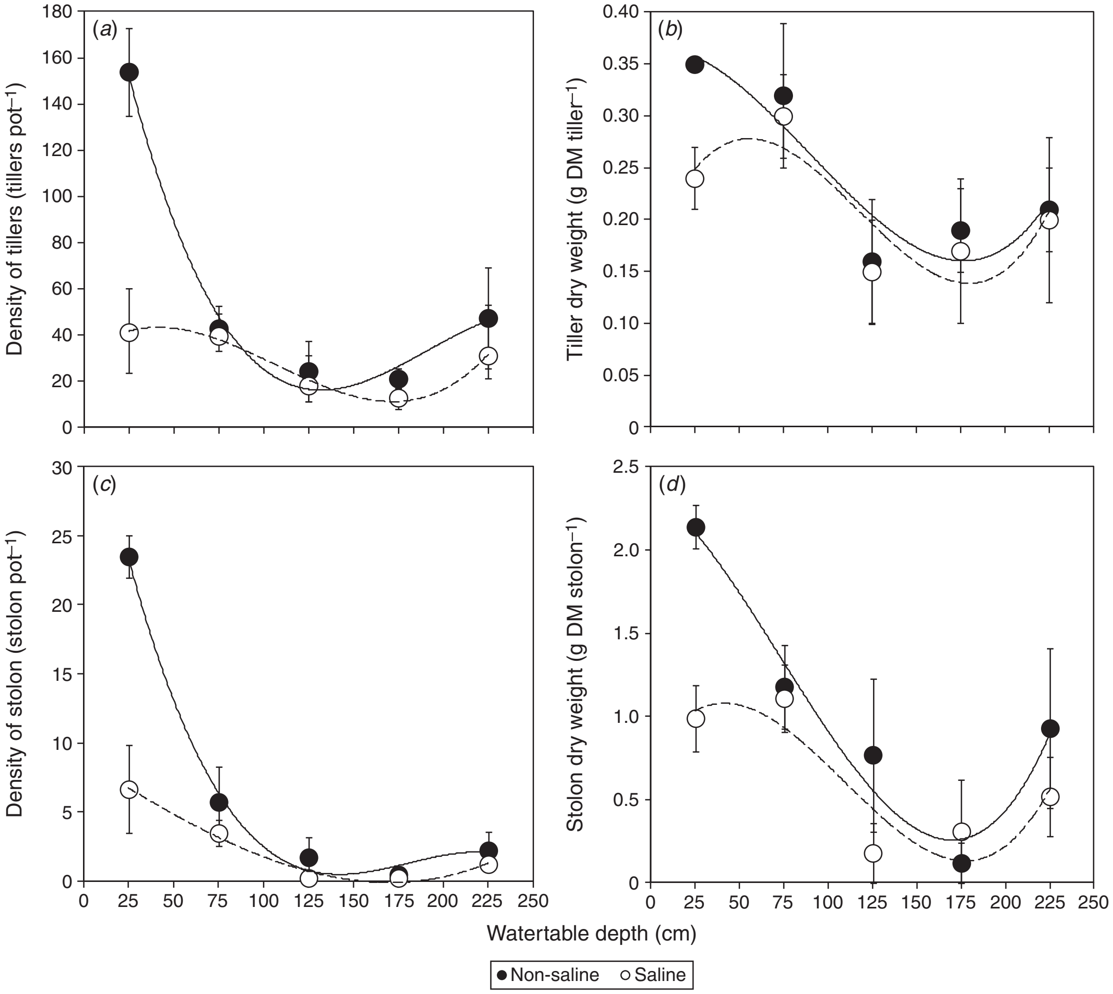

Fig. 3. (*a*) Density of tillers, (*b*) tiller dry weight, (*c*) density of stolons and (*d*) stolon dry weight of *Chloris gayana* grown at various watertable depths and two salinity levels (black dots 1.4 dS m^{-1}, white dots 20.5 dS m^{-1}). The vertical bars represent the standard error of the mean. DM, dry matter.

for example, at the depths of 125 and 225 cm the ratio of aerial parts : root parts was 60 : 40.

Effect on WUE

Rhodes grass showed a greater efficiency in the use of the watertable when it was not saline, showing efficiencies 30% higher compared with values for plants in saline watertables (Fig. 6). An increase of 4.62 g DM was observed per litre of water consumed per plant. Plants grown in non-saline watertable environments consumed 3-fold more water, which led to biomass production that was 6-fold higher than for plants growing in saline watertables.

Discussion

The present study evaluated the effect of watertable depth and salinity on the growth and production of Rhodes grass. As with other forage species (Vignolio *et al.* 1994), there was a higher level of plant mortality (50%) at superficial watertable depths (25 cm). However, it was observed that when these watertables had low salinity levels, both biomass production and watertable consumption were 5-fold higher compared with situations where the watertable was deeper, possibly due to a positive feedback in the watertable–soil–plant interaction, where more living coverage and root development resulted in increased water consumption, improved soil aeration and a reduction in capillary salt rise to surface compared with shallow watertable conditions (Cisneros *et al.* 2008).

The yield components that were most affected by the experimental treatments were the densities of tillers and stolons, which showed maximum values under shallow non-saline watertables and decreased in the presence of saline (Zeng *et al.* 2001; Castillo *et al.* 2007) or in deeper watertables (Chaturvedi *et al.* 1981; Assuero *et al.* 2000).

Even though Rhodes grass is a species that is characterised as tolerating salts (Bogdan 1969), in the presence of shallow watertables with a high salt concentration, there were marked reductions in biomass production, its components, and watertable consumption. However, it is suggested that this species may show great potential for waterlogged environments with low salinity under conditions where many annual crops fail (Nosetto *et al.* 2009).

Some anatomical and morphological changes occur in some species, such as Rhodes grass, in situations of stress and these could explain some of the responses that we saw in the present study. Thus, when there is oxygen deficiency caused by pore saturation in the soil profile, the diameter of the roots may increase and aerenchyma may form (Imaz *et al.* 2012). In addition, species may show other responses, such as some architectural adjustment in root systems. Some species tend to concentrate most of their roots in the surface soil layers (Beale *et al.* 1999; Craine *et al.* 2002; Gonzalez-Dugo *et al.* 2005; Durand *et al.* 2010), whereas in other species the roots exhibit greater penetration to deeper soil layers (Pagès and Pellerin 1994; Canadell *et al.* 1996; Palta and Watt 2009). Using the information from a number of research works as cited above, and including our own present studies, we found a positive relationship between the maximum depth of root exploration and the optimum watertable depth where potential yields are obtained across different forage and crop species (Fig. 7). Despite this general finding, we suggest that, within Rhodes grass, some plants showed active growth in areas with deeper watertables (125 and 225 cm), suggesting a possible coupling with the groundwater. However, this may not take place in every plant.

It should be noted that, in all cases, the optimal depth is found within the zone of root growth and, in the present greenhouse study, optimal watertable depths may be closer to the surface than in the field. In experiments conducted in pots in the greenhouse, an average of 70% of the final length of the plant root system was found within the watertable, whereas in experiments performed under field conditions only 15% of the root system was found within the watertable (Pagès and Pellerin 1994; Canadell *et al.* 1996; Narain *et al.* 1998; Beale *et al.* 1999; Mueller *et al.* 2005; Nosetto *et al.* 2009; Palta and Watt 2009). These differences can be related to the presence of side streams that favour water recharge and discharge, and the wetting and drying processes that manifest in the field in the presence of a fluctuating watertable, which do not occur in typical pot trials with an artificial watertable (Mueller *et al.* 2005). Therefore, even though the present study can help our understanding of some of the interactions of forage plants with watertables, under field

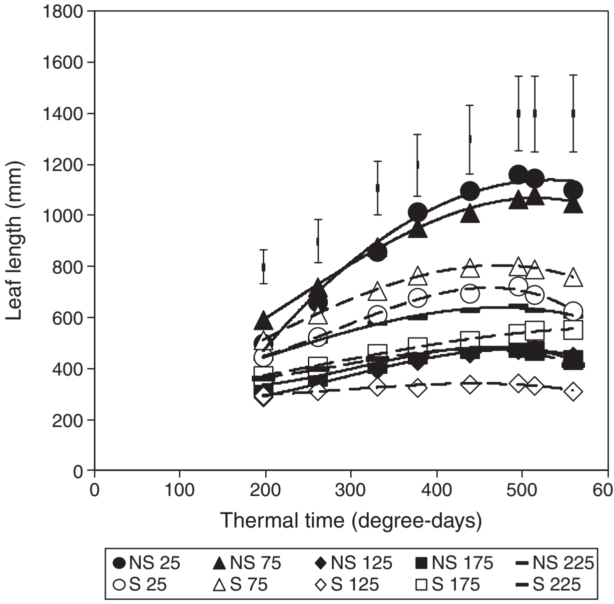

Fig. 4. Effect of watertable depth (25, 75, 125, 175 and 225 cm) and salinity (NS, non-saline (1.4 dS m^{-1}); S, saline (20.5 dS m^{-1})) on mean leaf length of *Chloris gayana* plants. Vertical lines indicate average standard errors of the means.

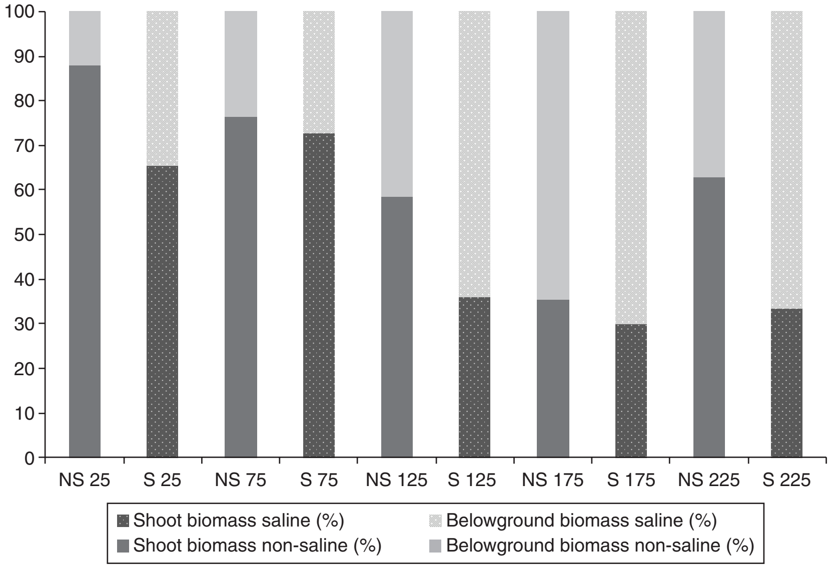

Fig. 5. Effect of watertable depth (25, 75, 125, 175 and 225 cm) and salinity (NS, non-saline (1.4 dS m^{-1}); S, saline (20.5 dS m^{-1})) on the proportion of shoot to root biomass in *Chloris gayana.*

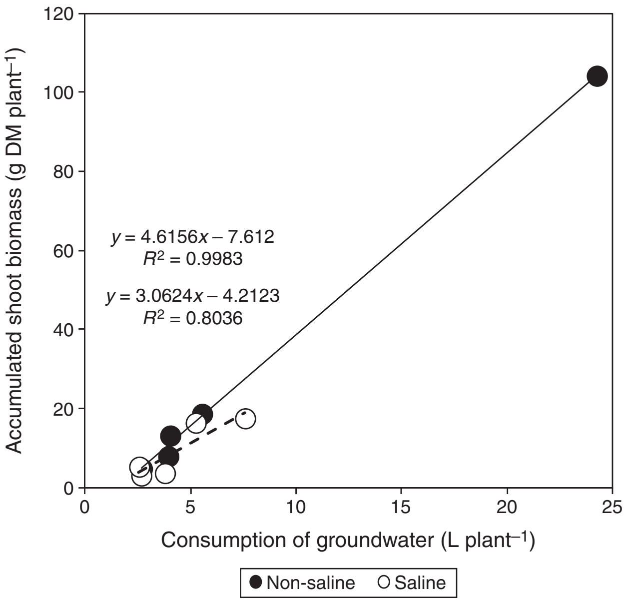

Fig. 6. Efficiency of watertable use by *Chloris gayana* for two salt concentrations (non-saline: 1.4 dS m^{-1}; saline: 20.5 dS m^{-1}).

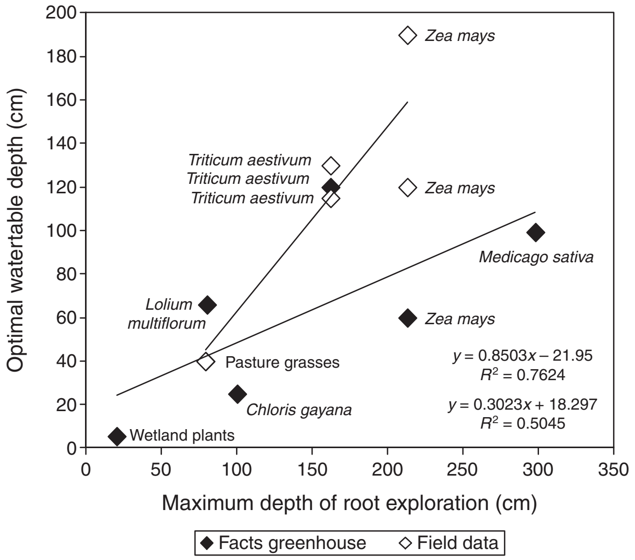

Fig. 7. Optimal watertable depth depending on the maximum depth of root exploration (cm) for different species (corn, wheat, alfalfa, Rhodes grass, grass-based pastures, wetland plants and ryegrass species) evaluated in the greenhouse (black diamonds) and in the field (white diamonds).

conditions the optimal watertable depths for Rhodes grass may be deeper than those observed under semi-controlled conditions (Mueller *et al.* 2005).

Growing Rhodes grass in low salinity environments with shallow watertables, which are common in the Pampas, would be an efficient use of the landscape, because the root growth of this species would cause a decrease in the capillary rise of the watertable (diminishing the contribution of salts to the surface), increased water consumption and salt leaching down the soil profile, resulting in increased biomass production (Cisneros *et al.* 2008). In contrast, in environments where the watertables are shallow and saline, Rhodes grass would survive, but would have very low water consumption and biomass production rates, suggesting that other species with higher salt tolerance may achieve better results.

It is important to highlight that in areas with deep watertables (>75 cm), the contribution of these watertables in providing water for biomass production is likely to be negligible for Rhodes grass, which is similar to that found in other forage grasses (Mueller *et al.* 2005). However, the high survival of our experimental plants (>50% after 35 days with no rainfall input) suggests that under deeper groundwater levels, individual Rhodes grass plants could persist through extended droughts when the soil profile water potential in which more than 90% of the roots are located is below the permanent wilting point. This also suggests that the deepest fine roots of Rhodes grass could have had access to soil layers with greater water content, which would be important in the survival of the species (Craine *et al.* 2002).

Although superficial watertables are favourable for biomass production, under these conditions management of grazing on Rhodes grass may be critical to its persistence. If the animal trampling that occurs under these conditions is to be avoided, the ideal time to use the species could be affected, which, in the summer season in the Pampas region, is ~500 degree-days, affecting the quality and durability of the species due to the reduction of tiller density.

Rhodes grass in the presence of a low salinity watertable is a viable option to stabilise biomass production of the lowlands in the Pampas, and would contribute to the regulation of hydrology and reduce the risk of flooding lowland environments where excess water is collected from higher topographic positions.

Conclusions

Rhodes grass is a species that can take advantage of watertable inputs when they are near the surface (<75 cm), provided that they are low in salinity. The species shows great plasticity and may use water resources strategically, being efficient in water use when water is widely available (increasing density of tillers and stolons) or very conservative when there is low water availability, diminishing the number of tillers, stolonisation or decreasing the length of leaves, without affecting survival in the short and medium term. This information will be useful to determine the environments in which this grass could be used and to express its full production potential, especially where there is great soil and climatic heterogeneity. Forage options designed to respond to the environmental conditions of each region are desired that are able to maximise both shoot and root production, improve infiltration, reduce the concentration of salts in the surface and reduce flood risk.

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