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Bermudagrass (*Cynodon dactylon* (L.) Pers.) yield and quality under different levels of salinity, nitrogen and trace minerals: A container trial evaluation

Rendimiento y calidad del pasto Bermuda (*Cynodon dactylon* (L.) Pers.) bajo distintos niveles de salinidad, nitrógeno y minerales traza: Un ensayo en contenedores

Alonso, M.F.[a], Kaffka, S.R.[b]*

[a] Institute of Animal Production, Austral University of Chile, Valdivia 567, Chile
[b] Department of Plant Sciences, University of California, Davis, CA 95616, USA

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**Corresponding author:*
Stephen R. Kaffka
E-mail address:
srkaffka@ucdavis.edu

ABSTRACT

Salinity and shallow saline groundwater threaten agricultural sustainability in many irrigated regions of the world. We studied Bermudagrass (*Cynodon dactylon* (L.) Pers.) yield and quality under different soil salinity, nitrogen, boron, selenium and molybdenum contents in a container trial at the University of California, Davis campus in 2007 and 2008 to simulate its use on marginal, salt-affected lands in California and worldwide. Soils used in containers were derived from an on-farm research site with variable salinity levels (7, 14 and 22 dS m^{-1} ECe). Bermudagrass growth rate and cumulative yield responded to increasing soil salinity and nitrogen levels while increasing levels of trace minerals had no effect on aboveground biomass accumulation. There was a significant interaction between salinity and nitrogen. Total-N, CP, NDF and ADF were significantly different between fertilized and unfertilized plants, but ash content did not vary among treatments. Leaf-stem ratios were significantly different between unfertilized and fertilized treatments. Fertilization with nitrogen in saline soils increased dry matter allocation to leaves. At salinity levels within its salt-tolerance range, yields >1,200 g DM m^{-2} y^{-1} were produced over a two-year period. Despite soil and irrigation water salinity (6 ± 1 dS m^{-1} EC_{iw}), proper harvest or grazing management and N applications can result in good quality forages on marginal lands.

RESUMEN

La salinidad y napas freáticas salinas amenazan la sostenibilidad de sistemas agrícolas en muchas zonas regadas del mundo. Estudiamos el rendimiento y la calidad del pasto Bermuda (*Cynodon dactylon* (L.) Pers.) en suelos con distintos niveles de salinidad, nitrógeno, boro, selenio y molibdeno en un ensayo en contenedores en la Universidad de California, Davis durante 2007 y 2008, para simular su uso en los terrenos marginales y salinos de California y alrededor del mundo. Los suelos utilizados en los contenedores provinieron de un ensayo de campo y tenían distintos niveles de salinidad (7, 14 y 22 dS m^{-1} ECe). Los niveles de salinidad y nitrógeno del suelo tuvieron un efecto significativo en la tasa de crecimiento y rendimiento del pasto Bermuda, mientras que los niveles de minerales traza no afectaron su producción de biomasa aérea. La interacción entre la salinidad y el nitrógeno del suelo fue significativa. N-Total, PC, FDN y FDA fueron significativamente diferentes entre las plantas fertilizadas y no fertilizadas, pero el contenido de ceniza no varió entre los distintos tratamientos. La relación hoja-tallo fue significativamente diferente entre los tratamientos con y sin fertilización. La fertilización nitrogenada de suelos salinos aumentó la proporción de biomasa de hojas. A niveles de salinidad dentro de su rango de tolerancia, rendimientos >1.200 g MS m^{-2} año^{-1} fueron producidos durante un período de dos años. A pesar de la alta salinidad de los suelos y el riego con agua salina (6 ± 1 dS m^{-1} EC_{iw}), adecuados manejos de cosecha o pastoreo y fertilización nitrogenada pueden producir forrajes de buena calidad en tierras marginales.

Palabras clave: Riego salino, pradera, partición de biomasa.

INTRODUCTION

In California, the supply of forage is insufficient for its expanding dairy and beef herds, sheep production, and cellulosic biomass for bioenergy production to meet new greenhouse gas reduction targets. The Western San Joaquin Valley (WSJV) in California has large areas with shallow saline water tables that reduce productivity and lead to abandonment of agricultural land (USDA, 1986). Reusing saline waste waters to produce biomass suitable for ruminant livestock or for bioenergy purposes would help alleviating these shortages, create a use for saline drainage water, and provide an economic use for marginal land and an alternative to land retirement in the WSJV (SJDVIP, 2000). Furthermore, cultivation of pasture grasses on salt-affected lands has the benefit of reducing evaporative water loss from soil and surface salinization.

The value of forages grown with saline waste waters depends upon forage yield and quality under saline conditions (Grattan *et al*., 2002; Grattan *et al*., 2004a; Grattan *et al*., 2004b; Suyama *et al.*, 2007a; Alonso *et al.*, 2013). Previous studies have demonstrated that low quality drainage and waste waters can be used to produce forages on a salt-affected site in the WSJV (Corwin *et al*., 2003; Kaffka *et al*., 2004; Robinson *et al*., 2004; Suyama *et al*., 2007b;). Soil quality at the site has improved in the process (Corwin *et al*., 2008; Corwin, 2012).

However, there is insufficient detailed knowledge about the effects of fertilization and salinity on salt-tolerant grass growth rates and correlated forage quality. For better forage management and use, more knowledge is required about the relationship between grass growth and quality and salt, nitrogen and trace mineral content when forages are produced on saline soils or with saline waste water for irrigation. The objective of this study was to quantify the effect of salinity, nitrogen, boron (B), selenium (Se) and molybdenum (Mo) contents of soil and irrigation water on Bermudagrass (*Cynodon dactylon* (L.) Pers.) growth and forage chemical composition.

MATERIALS AND METHODS

In 2007 a container trial was established at the University of California (UC), Davis to determine Bermudagrass growth rate, yield and quality under different soil salinity and nitrogen levels. Forty-eight large containers (56.8 L) with drainage holes were filled with disturbed soil collected at a field site on Westlake Farms (WLF) in Kings County on the west side of California's San Joaquin Valley. The soil is part of the Lethent clay loam series (USDA, 1986) and corresponded to three salinity levels: 7 (S1), 14 (S2) and 22 (S3) dS m^{-1} of soil electrical conductivity (ECe) occurring naturally at a related on-farm research site (Corwin *et al*., 2008). Total-N of the soil used was 0.09 %. The NH_4-N content was 4.8 mg kg^{-1} and the NO_3-N content was 6.2 mg kg^{-1}.

Containers were seeded with common Bermudagrass on May 2007 and irrigated with 2 L of a synthetic saline water solution of 6 ± 1 dS m^{-1} (EC_{iw}) 2-3 times a week during the growing season to keep the soil at field capacity, while allowing for a 10 % of leaching fraction. The water solution was made by mixing 230.06 g NaCl, 111.88 g Na_2SO_4, 193.82 g $MgSO_4$ and 203.27 g $CaSO_4{\cdot}2H_2O$ per 100 L of water, to simulate the dominant water quality used for irrigation at the on-farm site (Corwin *et al.*, 2008). Urea was used and the fertilization levels were 0 (N0; control), 30 (N1) and 60 g N m^{-2} (N2) with 4 replicates for each treatment. For all treatments, fertilizer was applied in three equal applications during the growing season, on July 16th, August 23rd and September 29th. Plants were harvested to a height of 1 cm every 4-6 weeks to estimate grass growth for the different treatments. Since leaf-stem ratio (LSR) is a traditional index of forage quality, grass samples were divided into leaves and stems and sub-samples were analyzed at the UC Davis Analytical Laboratory (www.anlab.ucdavis.edu) on the UC Davis Campus to determine their nutritional value through total-N, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), minerals and ash contents. After the last harvest containers were moved to a greenhouse on campus to avoid leaching of salts by winter rainfall, and then placed outside once again in spring after the rains had ceased.

The trial was repeated in 2008 using the same containers with Bermudagrass established the year before. The saline water solution was made and applied to the containers as in the previous year. To study the effect of B, Se and Mo on forage yield and quality we added trace minerals to the irrigation water for half of the replicates for each salinity x nitrogen treatment at a concentration of 10 mg L^{-1} of H_3BO_3, 0.5 mg L^{-1} of Na_2SeO_4 and 0.5 mg L^{-1} of $(NH_4)_6Mo_7O_{24}$ $4H_2O$. The fertilization regime was the same as in the previous year and was divided into three equal applications on March 21st, June 6th and July 11th. The plants were again harvested at 1 cm every 4-6 weeks through the 2008 growing season. Forage samples were divided into leaves, stems and also inflorescences and sub-samples were analyzed as in 2007, but also including trace minerals content.

Aerial growth, dry matter yield and quality were evaluated by a two-way ANOVA and a *post-hoc* Student´s test ($P<0.05$) to detect differences among treatments. Data were checked for normality and homoscedasticity. Basic statistical methods were followed (Sokal and Rohlf, 1995) and implemented using the JMP® (2010) statistical software.

RESULTS

Plant yield

Results obtained during two consecutive growing seasons showed that cumulative Bermudagrass yields were dependent on the baseline soil salinity and applied nitrogen levels, and that both factors interacted ($P<0.05$).

In 2007 the aboveground dry matter (DM) yield of Bermudagrass growing in containers with an initial ECe of 7 dS m^{-1} (S1) irrigated with saline water of 6 ± 1 dS m^{-1} and fertilized with 30 g N m^{-2} (N1) was 1,233.4 g DM m^{-2} (Figure 1). A fertilization increase to 60 g N m^{-2} (S1N2) did not further increase yield. The average aerial biomass on fertilized Bermudagrass growing at 14 dS m^{-1} of EC_e (S2N1 & S2N2) was 925.3 g DM m^{-2} (not shown). There was no difference in yield between both fertilization regimes, but yield declined significantly ($P<0.05$) when fertilizer was not used. At the highest salinity level (S3), aerial biomass in fertilized treatments (N1 & N2) averaged 675 g DM m^{-2}. Unfertilized grass produced, on average, 574 g DM m^{-2} with no differences between salinity levels.

In 2008 the effect of trace minerals on biomass yield was not significant (P>0.05) thus, treatments were combined for yield analysis. Within the fertilization range of this trial, treatments with larger amounts of applied N resulted in higher yields at each salinity level, as expected (Figure 2). Bermudagrass under frequent irrigation with synthetic saline water (6 ± 1 dS m^{-1}) and fertilized with 60 g N m^{-2} (N2) produced 2,059 g DM m^{-2}

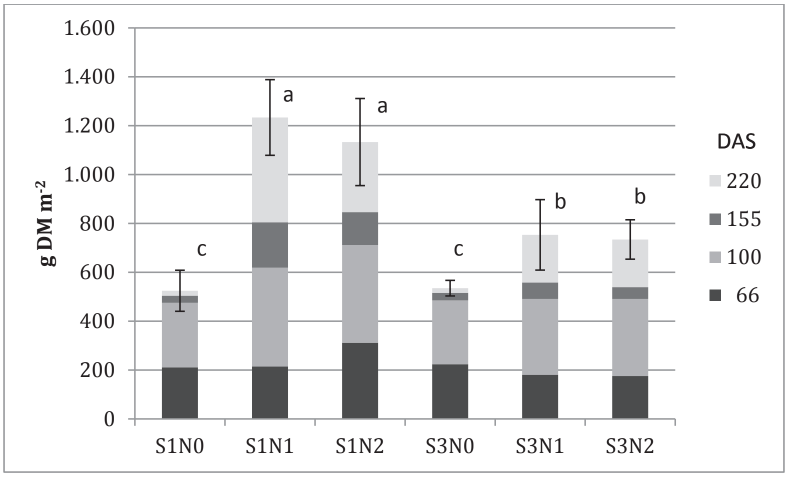

Figure 1. Cumulative above-ground biomass (g DM m^{-2}) for Bermudagrass grown in 56 L containers under different soil salinity (S) and nitrogen (N) levels in 2007. S1: 7 dS m^{-1} ECe; S3: 22 dS m^{-1} ECe; N0: 0 N m^{-2}; N1: 90 g N m^{-2}; N2: 180 g N m^{-2}; DAS: Day after seeding. Bars represent mean + S.E. Different letters indicate significant difference between treatments (Student test P<0.05).

Figura 1. Biomasa aérea acumulada de pasto Bermuda (g DM m^{-2}) en un ensayo en contenedores con diferentes niveles de salinidad (S) y nitrógeno (N) en el suelo en 2007. S1: 7 dS m^{-1} ECe; S3: 22 dS m^{-1} ECe; N0: 0 N m^{-2}; N1: 90 g N m^{-2}; N2: 180 g N m^{-2}; DAS: Días después de sembrada. Barras representan la media + E.S. Letras diferentes indican diferencia significativa entre tratamientos (test Student P<0.05).

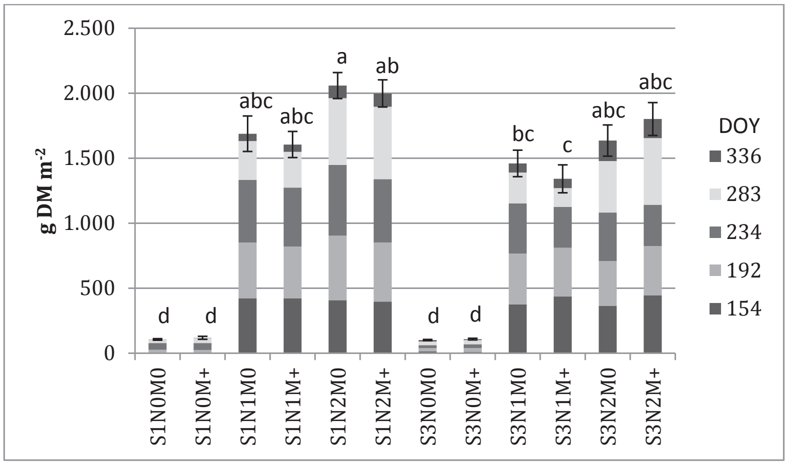

Figure 2. Cumulative above-ground biomass (g DM m^{-2}) for Bermudagrass grown in 56 L containers under different soil salinity (S) and nitrogen (N) levels in 2008. S1: 7 dS m^{-1} ECe; S3: 22 dS m^{-1} ECe; N0: 0 g N m^{-2}; N1: 30 g N m^{-2}; N2: 60 g N m^{-2}; M0: No trace minerals; M+: Trace minerals. DOY: Day of the year. Bars represent mean + S.E. Different letters indicate significant difference between treatments (Student test P<0.05).

Figura 2. Biomasa aérea acumulada de pasto Bermuda (g DM m^{-2}) en un ensayo en contenedores con diferentes niveles de salinidad (S) y nitrógeno (N) en el suelo en 2008. S1: 7 dS m^{-1} ECe; S3: 22 dS m^{-1} ECe; N0: 0 g N m^{-2}; N1: 30 g N m^{-2}; N2: 60 g N m^{-2}; M0: Sin minerales traza; M+: Con minerales traza. DOY: Día del año. Barras representan la media + E.S. Letras diferentes indican diferencia significativa entre tratamientos (test Student P<0.05).

in a soil of 7 dS m^{-1} of ECe (S1). The same fertilization level (N2) in a soil of 14 dS m^{-1} of ECe (S2) and 22 dS m^{-1} of ECe (S3) yielded 1,992 and 1,719 g DM m^{-2} of aerial biomass respectively. Unfertilized plants yielded on average 149.8 g DM m^{-2}, showing no difference (P>0.05) between salinity levels (S1, S2 & S3).

At the lowest salinity treatment (S1) Bermudagrass yielded 1,647 g DM m^{-2} when fertilized with 30 g N m^{-2} (N1). With the same fertilization level yield was significantly lower (1,401 g DM m^{-2}) at the highest salinity (S3). When fertilized with 60 g N m^{-2} (N2) yield of Bermudagrass growing on the most saline soil (S3) increased to 1,719 g DM m^{-2}, a value not significantly different (P>0.05) from the 1,647 g DM m^{-2} observed at S1.

Plant growth rate

Similar to cumulative yield, Bermudagrass growth rates were dependent on soil salinity and nitrogen levels. In 2007 the maximum growth rate of 12.4 g DM m^{-2} d^{-1} was reached by plants growing at an initial ECe of 7 dS m^{-1} (S1) and fertilized with 60 g N m^{-2} (N2). At intermediate salinity levels (S2N1) plants grew at a maximum rate of 11.9 g DM m^{-2} d^{-1}, while unfertilized (N0) Bermudagrass growing at an initial ECe of 22 dS m^{-1} (S3) showed a maximum growing rate of only 0.9 g DM m^{-2} d^{-1}.

In 2008 plants established at the S1 treatment and fertilized with 60 g N m^{-2} (N2) reached a growing rate of 12.52 g DM m^{-2} d^{-1} (Figure 3a). On the same soil, plants fertilized with 30 g N m^{-2} grew up to 11.15 g DM m^{-2} d^{-1} (Figure 3b), whereas unfertilized Bermudagrass grew at a maximum rate of 1.24 g DM m^{-2} d^{-1} (Figure 3c).

Plant quality

Total-N

In 2007, total-N content of the aerial biomass was not influenced by salinity level (P>0.05). Combining leaves and stems unfertilized plants contained 10.5 g kg^{-1} total-N, whereas fertilized treatments (N1 & N2) contained 23.4 g kg^{-1} total-N. The difference in total-N between fertilized and unfertilized treatments was significant (P<0.05), but the difference between treatments with 30 and 60 g N m^{-2} (N1 & N2) was not significant (P>0.05). Combining all treatments, total-N in leaves and stems were 22.5 and 15.9 g kg^{-1}, respectively. This difference was significant (P<0.05).

In 2008, differences in total-N content in the forage due to salinity and trace minerals were not significant (P>0.05). Total-N in leaves, inflorescences and stems were 20.7, 19.1 and 14.0 g kg^{-1}, respectively. Differences in total-N content between leaves and inflorescences were not significant (P>0.05). Differences between leaves and stems and between inflorescences and stems were significant (P<0.05). The effect of fertilization level on total-N content of the aerial biomass was significant (P<0.05). Unfertilized plants contained 11.8 g kg^{-1} of total-N. Plants fertilized with 30 and 60 g N m^{-2} contained 16.3 and 21.0 g kg^{-1} of total-N, respectively.

Crude Protein (CP)

In 2007 differences in CP content between leaves and stems and between fertilized and unfertilized treatments were significant (P<0.05), but differences in

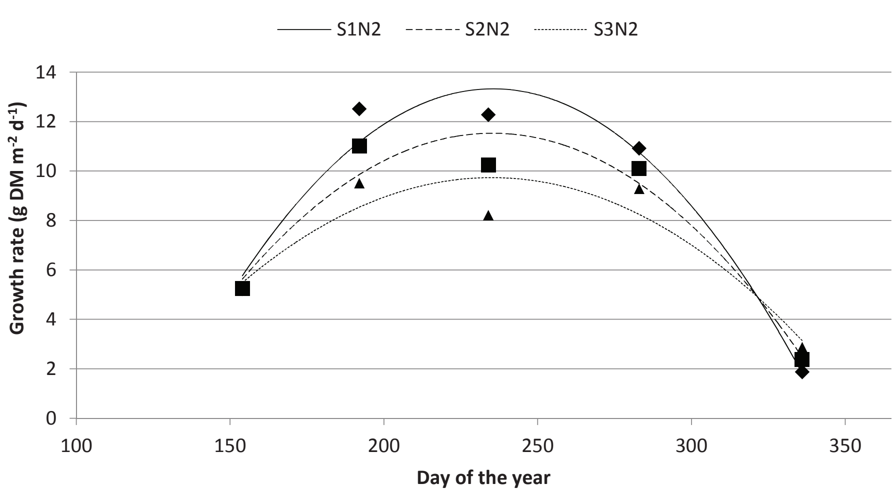

Figure 3a. Bermudagrass growth rate in 2008 with 60 g N m^{-2} (N2) and different soil salinity levels. S1N2: $y = -0.113x^2 + 53.65x - 4984$ ($R^2 = 0.964$); S2N2: $y = -0.089x^2 + 42.02x - 3791$ ($R^2 = 0.939$); S3N2: $y = -0.064x^2 + 30.38x - 2597$ ($R^2 = 0.864$).

Figura 3a. Tasa de crecimiento de pasto Bermuda en 2008 con 60 g N m^{-2} (N2) y diferentes niveles de salinidad del suelo. S1N2: $y = -0.113x^2 + 53.65x - 4984$ ($R^2 = 0.964$); S2N2: $y = -0.089x^2 + 42.02x - 3791$ ($R^2 = 0.939$); S3N2: $y = -0.064x^2 + 30.38x - 2597$ ($R^2 = 0.864$).

CP between salinity levels were not significant (P>0.05). CP in leaves was 140.4 g kg^{-1} and in stems was 99.4 g kg^{-1}. Combining leaves and stems, unfertilized plants contained 65.6 g kg^{-1} CP, and fertilized treatments (N1 & N2) contained approximately 147 g kg^{-1} CP. Differences in CP content between plants fertilized with 30 and 60 g N m^{-2} (N1 & N2) were not significant (P>0.05).

In 2008 differences in CP content due to salinity and trace minerals were also not significant (P>0.05). CP content in leaves, inflorescences and stems were 129.6, 119.4 and 87.9 g kg^{-1} respectively. Differences in CP between leaves and inflorescences was not significant (P>0.05). Differences between leaves and stems and between inflorescences and stems were significant (P<0.05). CP content increased significantly with fertilization level (P<0.05). Unfertilized plants, and plants fertilized with 30 and 60 g N m^{-2} contained 73.9, 102.4 and 131.8 g kg^{-1} CP, respectively.

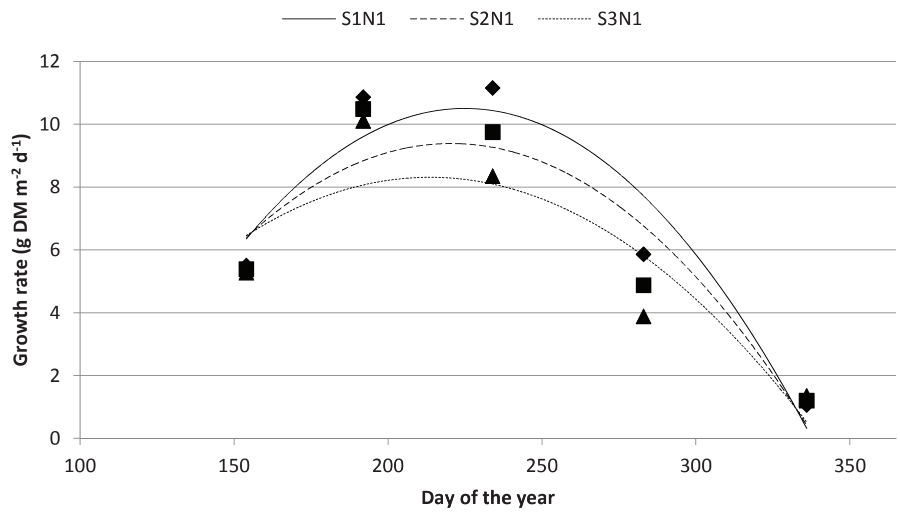

Figure 3b. Bermudagrass growth rate in 2008 with 30 g N m^{-2} (N1) and different soil salinity levels. S1N1: $y = -0.082x^2 + 37.13x - 3125$ ($R^2 = 0.904$); S2N1: $y = -0.067x^2 + 29.69x - 2335$ ($R^2 = 0.859$); S3N1: $y = -0.052x^2 + 22.25x - 1546$ ($R^2 = 0.795$).

Figura 3b. Tasa de crecimiento de pasto Bermuda en 2008 con 30 g N m^{-2} (N1) y diferentes niveles de salinidad del suelo. S1N1: $y = -0.082x^2 + 37.13x - 3125$ ($R^2 = 0.904$); S2N1: $y = -0.067x^2 + 29.69x - 2335$ ($R^2 = 0.859$); S3N1: $y = -0.052x^2 + 22.25x - 1546$ ($R^2 = 0.795$).

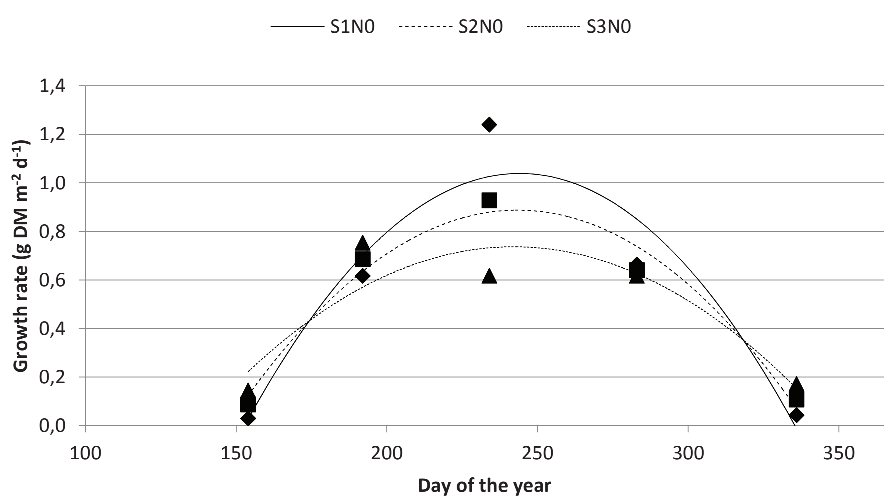

Figure 3c. Bermudagrass growth rate in 2008 without fertilization (N0) and different soil salinity levels. S1N0: $y = -0.012x^2 + 6.080x - 638.2$ ($R^2 = 0.910$); S2N0: $y = -0.009x^2 + 4.643x - 476.4$ ($R^2 = 0.969$); S3N0: $y = -0.006x^2 + 3.207x - 314.6$ ($R^2 = 0.832$).

Figura 3c. Tasa de crecimiento de pasto Bermuda en 2008 sin fertilización (N0) y diferentes niveles de salinidad del suelo. S1N0: $y = -0.012x^2 + 6.080x - 638.2$ ($R^2 = 0.910$); S2N0: $y = -0.009x^2 + 4.643x - 476.4$ ($R^2 = 0.969$); S3N0: $y = -0.006x^2 + 3.207x - 314.6$ ($R^2 = 0.832$).

Neutral Detergent Fiber (NDF)

In 2007 differences in NDF between leaves and stems and between fertilized and unfertilized treatments were significant (P<0.05), while differences between salinity levels were not significant (P>0.05). NDF in leaves was 598.2 g kg^{-1} and in stems was 544.1 g kg^{-1}. When pooling the samples across salinity levels, plants fertilized with 60 g N m^{-2} contained 546.1 g kg^{-1} NDF, plants fertilized with 30 g N m^{-2} contained 550.9 g kg^{-1} NDF and unfertilized plants contained 616.3 g kg^{-1} NDF. Only the differences between fertilized (N1 & N2) and unfertilized plants (N0) were significant (P<0.05).

In 2008 NDF in inflorescences, leaves and stems were 641.0, 632.9 and 595.6 g kg^{-1}, respectively. Differences in NDF between inflorescences and leaves were not significant (P>0.05). Differences between inflorescences and stems and between leaves and stems were significant (P<0.05). Differences in the NDF of the aerial biomass amongst the N treatments were significant (P<0.05). Unfertilized plants contained 653.2 g kg^{-1} NDF. Plants fertilized with 30 and 60 g N m^{-2} contained 623.4 and 606.9 g kg^{-1} NDF, respectively. Differences in NDF due to salinity or trace mineral (B, Se, or Mo) supplementation were not significant (P>0.05).

Acid Detergent Fiber (ADF)

In 2007 differences in ADF between leaves and stems and between fertilized and unfertilized treatments were significant (P<0.05). Differences in ADF between salinity levels were not significant (P>0.05). ADF in leaves was 254.6 g kg^{-1} and in stems was 233.0 g kg^{-1}. When pooling samples across salinity treatments, plants fertilized with 60 g N m^{-2} contained 227.2 g kg^{-1} ADF, plants fertilized with 30 g N m^{-2} contained 231.8 g kg^{-1} ADF and unfertilized plants yielded 272.3 g kg^{-1} ADF. However, only differences between fertilized (N1 & N2) and unfertilized plants (N0) were significant (P<0.05).

In 2008, ADF in inflorescences, leaves and stems was 307.5, 283.6 and 249.3 g kg^{-1} respectively and these differences were significant (P<0.05). When pooling samples, unfertilized plants contained 308.1 g kg^{-1} ADF. Plants fertilized with 30 and 60 g N m^{-2} contained 275.8 and 259.3 g kg^{-1} ADF respectively. Differences in the ADF of the aerial biomass in response to N fertilization were significant (P<0.05). Differences in ADF due to salinity or trace mineral supplementation were not significant (P>0.05).

Ash

In 2007, differences in ash content between leaves and stems were significant (P<0.05). Differences in ash content between N fertilizer treatments and between salinity levels were not significant (P>0.05). Leaves had 95.6 g kg^{-1} and stems had 66.4 g kg^{-1} of ash.

In 2008, leaves, stems and inflorescences contained 115.0, 67.5 and 66.5 g kg^{-1} of ash, respectively. Differences in ash content between leaves and stems and between leaves and inflorescences were significant (P<0.05). Differences in ash content between stems and inflorescences were not significant (P>0.05). Differences in ash content between N fertilizer or salinity treatments were also not significant (P>0.05).

Mineral Nutrients

In 2007 and 2008, fertilization and salinity levels did not produce significant differences in P and K concentrations in leaves and stems (Table 1). However, differences in P and K content in the aerial biomass between fertilized and unfertilized treatments were significant (P<0.05) in 2008. Thus, as N fertilizer increased, P and K content in aerial biomass decreased and increased, respectively.

In 2007, differences in S, Ca, Mg, Na, Zn, Mn, Fe, Cu and Mo content in the forage due to fertilization and salinity levels were not significant (P>0.05). However, they were significant (P<0.05) when comparing leaves and stems (Table 2), except for Na content which was not significantly different (P<0.05) between the plant organs.

In 2008, differences in S, Ca, Mg, Na, Zn, Mn, Fe, Cu and Mo content in the aerial biomass due to fertilization and salinity levels were also not significant (P>0.05). However, differences in these minerals between leaves, stems and inflorescences showed different levels of significance. As expected, due to the addition of trace minerals during the second growing season, differences in Mo and Se content in plant biomass were significant (P<0.05). Mo content in aerial biomass was 1.16 and 0.58 mg kg^{-1} with and without mineral addition, respectively. Se content in the forage of untreated plants was 0.05 mg kg^{-1} and of plants irrigated with trace minerals was 0.99 mg kg^{-1}.

In 2007 and 2008 there was a significant interaction (P<0.05) between plant structure and salinity in the case of B. In both years, the highest B content was found in leaves of plants growing at 22 dS m^{-1} of ECe, and the lowest B content was found in stems growing at 7 dS m^{-1} of ECe (Table 3). B content in aerial biomass of treated and untreated plants was 81.99 and 70.96 mg kg^{-1} respectively, although this difference was not significant (P>0.05).

Plant leaf-stem ratio (LSR)

LSR results were similar in 2007 and 2008. LSR was significantly different (P<0.05) between fertilized (max LSR = 4.3) and unfertilized (max LSR = 2.2) treatments, but the difference between fertilized treatments (30 and 60 g N m^{-2}) was not significant (P>0.05). Salinity levels did not influence LSR (P>0.05) either. LSR in unfertilized and fertilized treatments in pooled samples from 2007 and 2008 are shown in Figure 4.

Table 1. P and K content in Bermudagrass aerial biomass in fertilized and unfertilized treatments in 2007 and 2008

Tabla 1. Contenido de P y K en la biomasa aérea de pasto Bermuda en tratamientos con y sin fertilización en 2007 y 2008

Year	Mineral	Unit	0 g N m^{-2}	30 g N m^{-2}	60 g N m^{-2}
2007	P	g kg^{-1}	2.4 a	2.1 a	2.0 a
	K	g kg^{-1}	12.1 a	19.7 a	18.7 a
2008	P	g kg^{-1}	3.0 a	1.8 b	1.7 b
	K	g kg^{-1}	11.1 b	17.8 b	21.0 a

Different letters indicate significant difference (Student test P<0.05).

Table 2. Trace minerals content in Bermudagrass leaves, stems and inflorescences in 2007 and 2008

Tabla 2. Contenido de minerales traza en hojas, tallos e inflorescencias de pasto Bermuda en 2007 y 2008

Year	Trace Mineral	Unit	Leaves	Stems	Inflorescences
2007	S	g kg^{-1}	6.31 a	4.79 b	N/A
	Ca	g kg^{-1}	5.8 a	0.25 b	N/A
	Mg	g kg^{-1}	3.1 a	0.21 b	N/A
	Na	g kg^{-1}	4.64 a	4.28 a	N/A
	Zn	mg kg^{-1}	30.05 b	44.73 a	N/A
	Mn	mg kg^{-1}	68.19 a	50.55 b	N/A
	Fe	mg kg^{-1}	309.03 a	109.72 b	N/A
	Cu	mg kg^{-1}	12.93 b	14.2 a	N/A
	Mo	mg kg^{-1}	1.1 a	0.43 b	N/A
2008	S	g kg^{-1}	7.2 a	4.3 b	3.7 b
	Ca	g kg^{-1}	7.7 a	2.3 b	3.1 b
	Mg	g kg^{-1}	3.0 a	1.8 b	1.7 b
	Na	g kg^{-1}	4.57 a	3.36 b	1.40 c
	Zn	mg kg^{-1}	32.33 b	56.45 a	32.13 b
	Mn	mg kg^{-1}	76.40 a	39.46 b	50.14 b
	Fe	mg kg^{-1}	231.43 a	73.88 b	132.15 b
	Cu	mg kg^{-1}	7.01 a	7.41 a	7.12 a
	Mo	mg kg^{-1}	0.14 a	0.07 b	0.06 b

N/A: Not available. Different letters indicate significant difference (Student test P<0.05).

Table 3. B content in leaves, inflorescences and stems of Bermudagrass growing under different salinity levels in 2007 and 2008

Tabla 3. Contenido de B en hojas, inflorescencias y tallos de pasto Bermuda cultivado bajo distintos niveles de salinidad en 2007 y 2008

Year	Trace Mineral	Unit	7 dS m^{-1}		14 dS m^{-1}		22 dS m^{-1}	
2007	B in leaves	mg kg^{-1}	92.50	b	93.80	b	261.67	a
	B in stems	mg kg^{-1}	17.80	c	23.25	c	41.08	b
2008	B in leaves	mg kg^{-1}	79.73	bcd	85.32	bc	163.78	a
	B in inflorescences	mg kg^{-1}	61.30	bcde	67.00	bcde	114.22	ab
	B in stems	mg kg^{-1}	33.08	e	47.25	de	51.45	cde

Different letters indicate significant difference (Student test P<0.05).

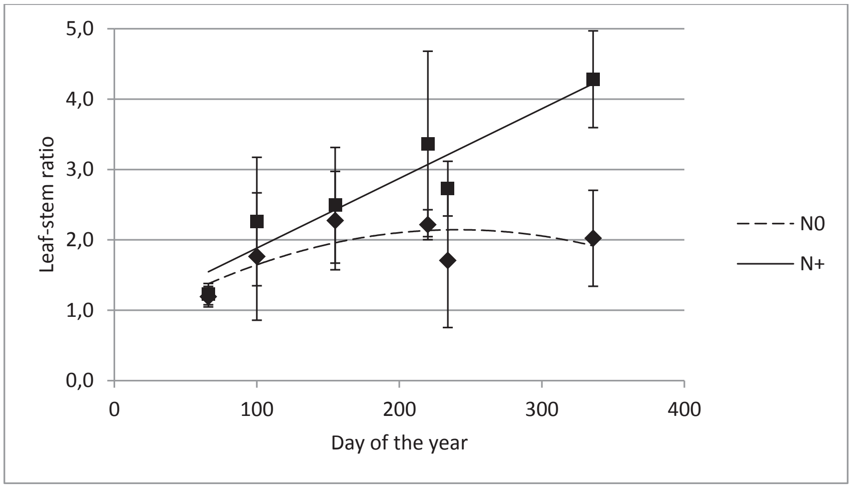

Figure 4. Leaf-stem ratio of fertilized (N+) and unfertilized (N0) Bermudagrass in pooled samples from 2007 & 2008. N+: $y = 0.009x + 0.89$ ($R^2 = 0.893$). N0: $y = -3E\text{-}05x^2 + 0.012x + 0.687$ ($R^2 = 0.558$).

Figura 4. Relación hoja-tallo de pasto Bermuda fertilizado (N+) y si fertilizar (N0) en muestras combinadas de 2007 y 2008. N+: $y = 0.009x + 0.89$ ($R^2 = 0.893$). N0: $y = -3E\text{-}05x^2 + 0.012x + 0.687$ ($R^2 = 0.558$).

Plant above ground biomass distribution

Nitrogen fertilization does not only increase yield, but compensates yield reduction by high soil salinity and alters the aerial composition of Bermudagrass (Figure 5) affecting its quality. Results from 2008 indicate that N fertilization increases the proportion of leaves and decreases the proportion of inflorescences by 20 %. The proportion of stems is not affected. Although differences in the aerial composition between fertilized and unfertilized treatments were significant ($P<0.05$), differences between treatments fertilized with 30 and 60 g N m^{-2} were not significant ($P>0.05$). Differences in aerial composition between soil salinity levels were not significant either ($P>0.05$).

Soil quality

After two consecutive growing seasons irrigated with a water solution of 6 ± 1 dS m^{-1} and a leaching fraction of 10 %, the soil of all treatments showed significant reductions in ECe (Table 4). Total-N also was reduced from 0.09 to 0.08 %, NH_4-N from 4.8 to 3.7 mg kg^{-1}, and NO_3-N from 6.2 to 2.2 mg kg^{-1}.

DISCUSSION

Bermudagrass is a salt tolerant species. At salinity levels within its tolerance range, potentially economic amounts of DM were produced over a two-year period in this container study, confirming results observed at a larger field site in the WSJV (Corwin *et al*., 2003; Kaffka *et al*., 2004; Robinson *et al*., 2004; Suyama *et al*.,

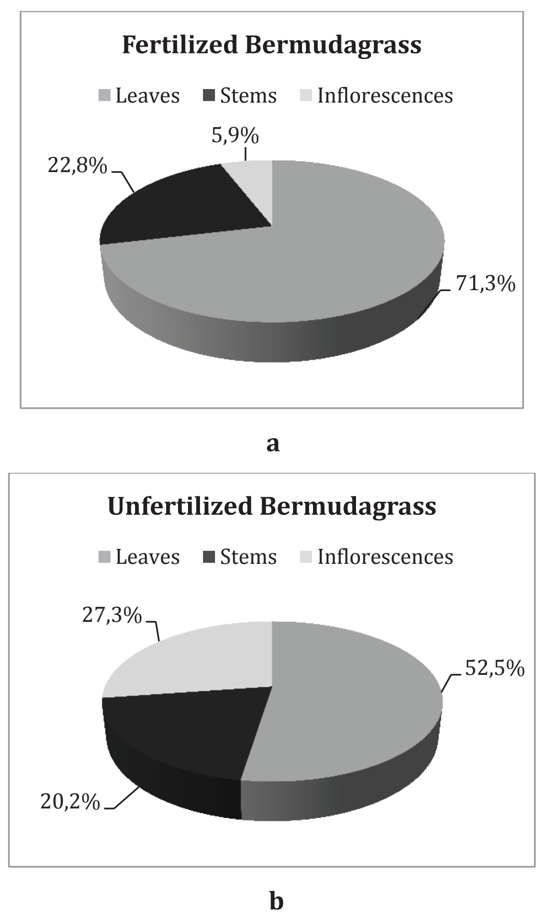

Figure 5. Aboveground DM distribution of fertilized (**a**) and unfertilized (**b**) Bermudagrass in a container trial in 2008.

Figura 5. Distribución aérea de MS de pasto Bermuda fertilizado (a) y sin fertilizar (b) en un ensayo en contenedores en 2008.

Table 4. Initial and final average ECe (dS m^{-1}) of the soils (S1, S2 & S3) used in the trial

Tabla 4. ECe (dS m^{-1}) promedio inicial y final de los suelos (S1, S2 & S3) usados en el ensayo

Treatment	Initial ECe (dS m^{-1})	Final ECe (dS m^{-1})
S1	7	4.7 ± 0.64
S2	14	5.0 ± 0.82
S3	22	5.1 ± 0.93

2007b) and elsewhere in the literature (Grattan *et al*., 2002; Grattan *et al*., 2004a; Grattan *et al*., 2004b; Suyama *et al.*, 2007a; Alonso *et al.*, 2013). Here, N application influenced above ground DM yields across the range of salinity levels, with a potential up to 2,059 g DM m^{-2} y^{-1} in a soil that varied from 7 dS m^{-1} to 4.7 dS m^{-1} ECe during two years of measurements.

Yields of fertilized plants were larger in 2008 than in 2007 for two reasons. First, the growing season started earlier in 2008 (end of March) than in 2007 (middle May), and plants were well established by the second year. Thus, there was enough biomass for a fifth harvest in 2008. Second, after one season irrigating the containers with a leaching fraction of 10 %, some soil reclamation had occurred, as was observed at the on-farm site as well (Corwin, 2012). On the other hand, yield differences among unfertilized treatments (N0) between 2007 and 2008 could be explained by the depletion of nitrogen by forage harvesting and N leaching from the unfertilized containers after two growing seasons.

N application also influenced DM allocation to leaves, the more valuable part of the plant from a grazing and livestock consumption perspective. When fertilized, leaf DM increased from 52.5 to 71.3 % of the total aboveground biomass. This increase was compensated mostly by a reduction in inflorescence DM which decreased with fertilization from 27.3 to 5.9 % of the total aerial biomass. Fertilization did not have an important effect on stem yield, which was 20 % of the aboveground biomass with and without N applications. N stress stimulated a reproductive response in Bermudagrass, which reduced the LSR by decreasing leaf biomass while increasing inflorescence DM.

Trace minerals did not influence yield or traditional measures of forage quality, but care must be given to manage any potentially harmful levels of trace minerals accumulation in livestock (Robinson *et al*., 2004; Juchem *et al.*, 2012). In this study, Se, of high concern at the WSJV, and the other minerals reached concentrations in the aerial biomass below the maximum tolerable levels (MTL) suggested by the NRC (2005). Total-N, CP, NDF, ADF and ash did not increase with increasing salinity levels. However, NDF, ADF and ash increased slightly but significantly ($P<0.05$) in 2008, when compared with 2007.

Crop production on saline soils has long been reported as a means of soil reclamation, primarily by facilitating leaching of salts from the rooted soil profile (Kaffka *et al*., 2004; Corwin *et al*., 2008; Corwin, 2012). While not as large, reductions in soil salinity were observed over time due to the production of Bermudagrass at this trial, as well as at the on-farm research site of which this trail was a part (Corwin *et al*., 2003; Corwin, 2012; Alonso *et al.*, 2013).

CONCLUSIONS

Even under very saline conditions, N application and proper harvest or grazing management can result in high yields and good quality forages that can support grazing animals at acceptable levels of production. At the soil salinity levels of this study, a leaching fraction of 10 % allowed the use of saline water in the irrigation of Bermudagrass without salt accumulation in the root zone.

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