NITROGEN-SALT INTERACTION IN RYEGRASS. IMPLICATIONS FOR SOIL POTASSIUM TESTING

J. M. MURILLO
M. J. DIAZ
F. CABRERA
R. LOPEZ
Instituto de Recursos Naturales y Agrobiología, CSIC, PO Box 1052. 41080
Sevilla (España)

SUMMARY

Split additions of NO_3-N (irrigation with a solution of 50 mg Nl^{-1}) under saline conditions (irrigation with a 10 mM NaCl solution, which did not negatively affect plant growth) and non-saline conditions (water), enhanced the Na uptake by Italian ryegrass (*Lolium multiflorum* Lam. cv. “Barwoltra”) grown in two soils potentially rich in K. The Mg uptake was also enhanced. This was not observed for split additions of P. After an initial “luxury” K plant uptake, the K supply could be insufficient to cope with the vigorous growth of the ryegrass resulting from the addition of NO_3-N, so that K was partially replaced by Na (and Mg) for achieving plant growth in treatments adding N.

KEY WORDS: Italian ryegrass
Nutrients
Salinity
Soil K

INTRODUCTION

As pointed out by Mengel, Kirkby (1987), it is only in highly developed agricultural systems with top level yields that the amount of K returned to the soil is equal to or in excess of that removed by crops, which means that in many cases soil K reserves are being depleted. Depletion may be enhanced by the fact that the more available is K in the soil the more plants take up, frequently leading to a “luxury consumption”. Since K availability is influenced not only by those factors inherent to the soil (temperature and moisture are very important parameters in this respect), it may be that many ratings for soil K found in literature are far from the real needs of a particular crop under determined management and climatic conditions.

Many plants, as ryegrass, are able to replace K by Na when K supply becomes insufficient to support a consistent growth (Griffith *et al.*, 1965; Nowakowski *et al.*, 1974; Smith *et al.*, 1980a, 1980b; Barraclough, Leigh, 1993). This question is not only of academic inte-

Recibido: 7-4-97
Aceptado para su publicación: 3-7-97

rest but also of practical importance in relation to fertilizer usage. Fertilizers including N, capable of promoting vigorous plant growth, may cause a certain shortage in the K supply during crop performance, natrophilic species then being able to achieve growth by using Na, assuming that this element is present in the substrate at a sufficient level.

Nitrogen fertilization schedule and management under particular crop and climate may thus be important factors conditioning K availability, even in soils potentially well provided in K. The present work deals with N-Na interactions in ryegrass grown in two soils with this character (potentially well provided in K) when NO_3-N is supplied by split applications. Phosphorus applications were included for comparison.

MATERIAL AND METHODS

The experiment was performed in a greenhouse, using plastic pots of black colour with a capacity of 1.5 kg of dry soil. The surface horizon of two representative soils of southwest Spain (Aljarafe, Seville) was used as a substrate. The soils were a light yellowish-brown and a red sandy clay loam soil (Soil Survey Manual, 1993), which will be called calcareous and red soil, respectively, throughout this work. The soils were air-dried and ground to pass a 2mm sieve to make the particle size uniform. Table 1 shows some properties of the soils.

TABLE 1

SOILS DESCRIPTION

Características de los suelos

	Calcareous	Red
pH (H_2O)	7.8	7.7
$CaCO_3$ (%)	30.0	12.0
Organic matter (%)	0.6	1.1
N (%)	0.03	0.06
P-Olsen (mg kg^{-1})	4.0	9.0
K-Total (%)	1.7	1.9
K-Acetate (mg kg^{-1})	200	270
Cation exchange capacity ($cmol_c$ kg^{-1})	10.0	12.0
K-Exchangeable ($cmol_c$ kg^{-1})	0.45	0.65
Ca-Exchangeable ($cmol_c$ kg^{-1})	9.20	11.07
Sand (2 - 0.2 mm, %)	45	45
Sand (0.2 - 0.02 mm, %)	12	15
Silt (0.02 - 0.002 mm, %)	21	10
Clay (< 0.002 mm, %)	22	30
Illite (%)	50	55
Montmorillonite (%)	34	28

Pots were filled with the same amount of the corresponding soil, and then 1 g of *Lolium multiflorum* Lam. cv. “Barwoltra” seeds was sown per pot. A week after seedling emergence, the treatments were established, and were the following:

– Treatment **0**: irrigation with deionized water.
– Treatment **0 + salt**: irrigation with a 10 mM NaCl solution.
– Treatment **P**: irrigation with a 0.81 mM $Ca(H_2PO_4)_2$ solution (50 mg Pl^{-1}).
– Treatment **P + salt**: irrigation with a 0.81 mM $Ca(H_2PO_4)_2$ + 10 mM NaCl solution.
– Treatment **N**: irrigation with a 1.79 mM Ca $(NO_3)_2$ solution (50 mg Nl^{-1}).
– Treatment **N + salt**: irrigation with a 1.79 mM Ca $(NO_3)_2$ + 10 mM NaCl solution.

There were three randomized replicates (pots) per treatment and soil. At harvest (two cuts at 40-day intervals after sowing) plant dry weight was recorded for each pot and cut (drying the above-ground fraction of the ryegrass at 70° C for 48 h). Throughout the assay, temperature during the day (maximum photon flux density of 500 μmol m^{-2} s^{-1}) ranged from 20 to 25° C and during the night from 15 to 20° C. Total amounts of Na and nutrients applied per pot were 760 mg of Na and 165 mg of P in treatments 0 + salt, P and P + salt and 875 mg of Na and 190 mg of N in treatments N and N + salt. These treatments (N and N +salt) required more irrigation than the other treatments because of the vigorous plant growth derived from the N application.

Plant material was ground after drying and N was determined by Kjeldahl digestion. Mineral elements were determined following dry ashing and solution in HCl (Jones *et al.,* 1991). Potassium and Na were determined by flame emission, P by colorimetry using the phospho-vanadomolybdic complex, and Ca and Mg by atomic absorption spectrophotometry. A reference ryegrass CRM 281 (Commission of the European Communities, 1988) was also analyzed for N, P and K for comparison. Results were, in percentage, 3.46 ± 0.09 (N), 0.22 ± 0.01 (P) and 3.12 ± 0.38 (K) [indicative, not certified, values are 3.32 ± 0.05 (N), 0.23 ± 0.005 (P) and 3.05 ± 0.11 (K)]. Data analysis was conducted performing analysis of variance. Mean separations were determined by the Tukey test ($P < 0.05$).

RESULTS

The addition of salt (treatments 0 + salt, P + salt and N + salt, 2, 4 and 6 respectively) did not significantly reduce dry matter production of the ryegrass, in comparison with the corresponding treatments without salt (0, P and N). In the calcareous soil the dry matter production was even in general slightly higher in treatments with salt than in treatments without salt, although differences were not significat (Table 2).

This means that when analyzing the nutritional status of the plants it is not necessary to consider the “dilution effect” or its inverse “concentration effect” for each pair of treatments (e.g. N and N + salt), which could arise from differences in plant growth. Thus, the variation in concentration or accumulation of a particular nutrient for each pair or treatments will be a consequence of interactive effects on the nutrient uptake mechanisms, as was described by Jarrel, Beverly (1981).

Except for treatment 0 + salt (treatment 2) in the first cut, the presence of salt did not reduce the N concentration of the ryegrass in either soil assayed. In general, saline treatments did not introduce important changes in the P concentrations of ryegrass, except a slight but significan decrease derived from the P + salt treatment in the calcareous soil (treatment 4, 1st cut, Fig. 1). Decreases in the P concentration were also observed in the red soil (2nd cut, Fig. 2), but without significant differences as a consequence of the results dispersion obtained in the six treatments.

TABLE 2

MEAN VALUES OF DRY WEIGHT (g) PER POT OF THE RYEGRASS FOR THE DIFFERENT TREATMENTS

Valores medios de materia seca (g) de ryegrass en función de los tratamientos aplicados

Soil	Treatments	First cut	Second cut	Total
Calcareous	**1** (0)	1.72 a	0.90 a	2.62 a
	2 (0 + salt)	1.90 a	0.99 a	2.89 a
	3 (P)	2.05 ab	0.96 a	3.01 a
	4 (P + salt)	2.33 b	0.96 a	3.28 a
	5 (N)	2.86 c	3.51 b	6.37 b
	6 (N + salt)	3.16 c	3.26 b	6.42 b
Red	**1** (0)	2.00 ab	1.15 a	3.13 a
	2 (0 + salt)	1.68 a	1.11 a	2.78 a
	3 (P)	1.70 a	1.28 a	2.98 a
	4 (P + salt)	1.60 a	1.34 a	2.94 a
	5 (N)	3.03 c	3.49 b	6.51 b
	6 (N + salt)	2.75 bc	3.17 b	5.92 b

Values followed by the same letter in the same column (for each soil and cut) do not differ significantly ($P < 0.05$)

On the other hand, and except for the N + salt treatment (treatment 6) in the calcareous soil (2nd cut, Fig. 1), the saline treatments tended to increase the Ca concentration of the ryegrass, without significant differences. The same tendency was also observed for Mg in the first cut carried out in both soils.

The presence of salt also tended to increase the K concentration in the second cut carried out in the two soils in those treatments which did not include N (0 + salt and P + salt, 2 and 4 respectively), with, in general, significant differences compared with those treatments without salt (0 and P) (Figs. 1 and 2). At the same time, the K concentration tended to decrease in the treatments adding N, as a consequence of salt addition, although differences were not significant in either soil assayed (Figs. 1 and 2).

It is possible that after an initial "luxury" K uptake (K concentrations in the first cut were always around 6-7 p. 100, Figures 1 and 2, much higher than the "critical" concentration of 3.5 p. 100 established by Hylton *et al.* (1967), for Italian ryegrass grown in absence of Na), the K supply became insufficient to cope with the increased growth of the ryegrass resulting from the N application, so that K was partially replaced by Na in those treatments adding N. Nitrogen enhanced the Na uptake even without salt application, as shown by the results obtained in the second cut, in which the Na concentration of the ryegrass was clearly increased by the sole application of N in both soils (treatment 5, N, Figs. 1 and 2) although the difference compared with the concentrations obtained in the 0 and P treatments (1 and 3, respectively) was significant only in the red soil (Fig. 2). The opposite trend was observed in the case of K.

Magnesium could also replace K in treatments adding N since their Mg concentrations were significantly higher than those obtained for the other treatments, without N, in both soils and cuts (Figs. 1 and 2). A generally opposite trend was observed for Ca in the second

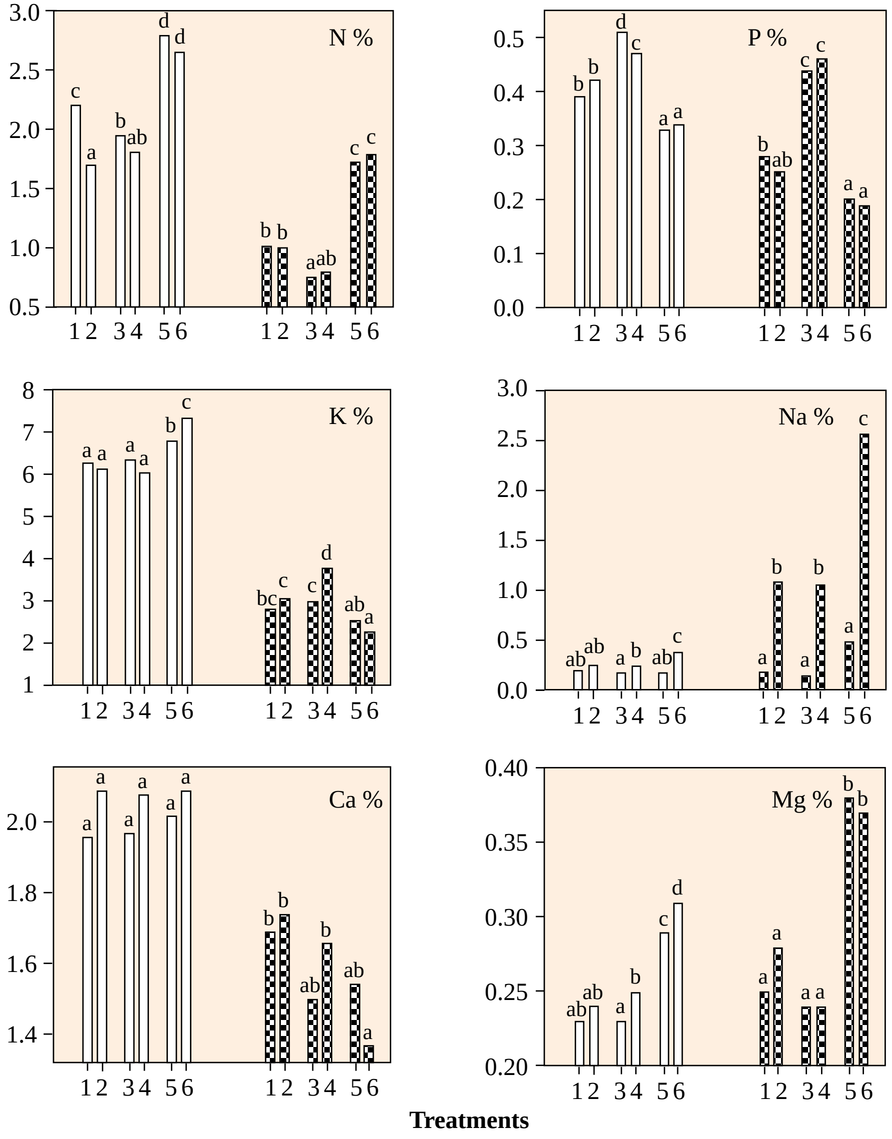

Fig. 1.–Nutrient concentration (mean values on a dry matter basis) in the ryegrass grown in the calcareous soil for the different treatments: 1 (0); 2 (0 + salt); 3 (P); 4 (P + salt); 5 (N); 6 (N + salt)

Concentración de nutrientes (valores medios sobre materia seca) en el ryegrass del suelo calcáreo en función de los tratamientos: 1 (0); 2 (0 + sal); 3 (P); 4 (P + sal); 5 (N); 6 (N + sal)

White bars correspond to the first cut and black bars to the second cut. Bars with the same letter, for each cut, do not differ significantly ($P < 0.05$)

Las barras blancas corresponden al primer corte y las negras al segundo. Barras con una misma letra, para un mismo corte, no son diferentes significativamente ($P < 0,05$)

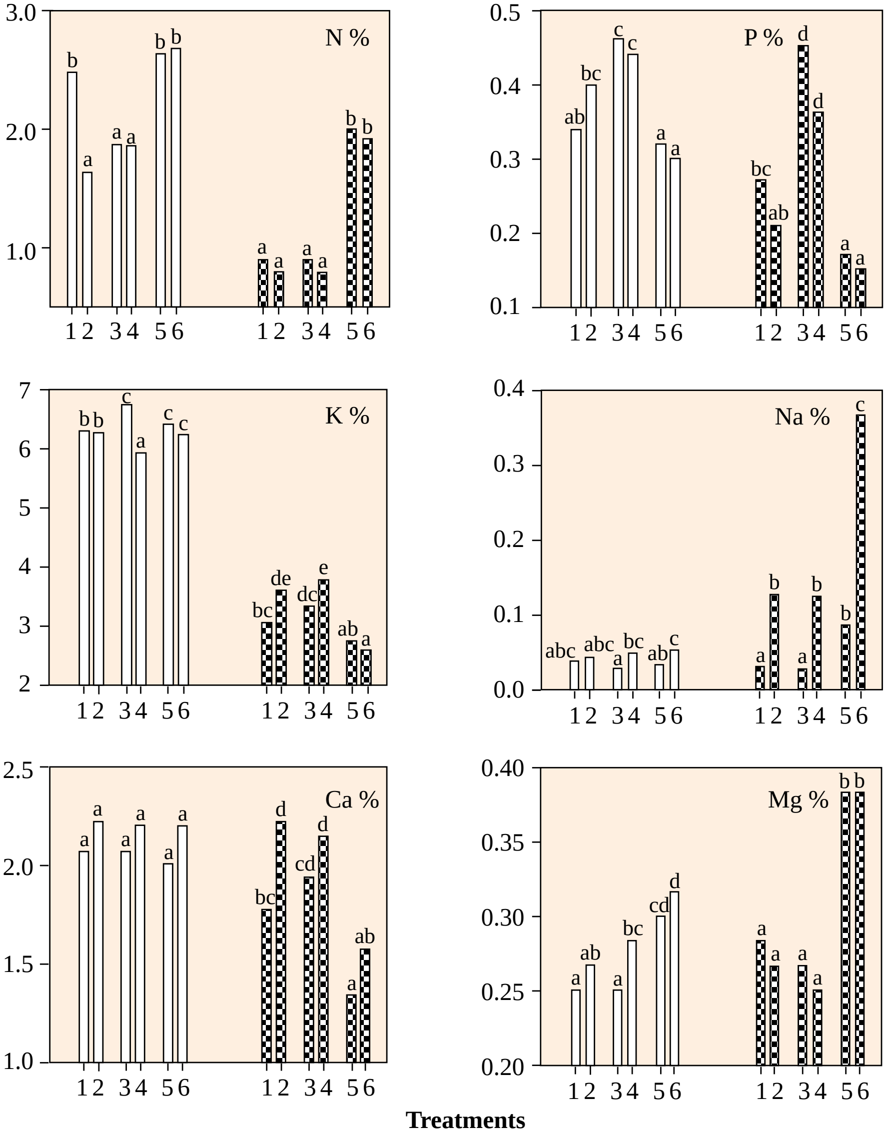

Fig. 2.–Nutrient concentration (mean values on a dry matter basis) in the ryegrass grown in the red soil for the different treatments: 1 (0); 2 (0 + salt); 3 (P); 4 (P + salt); 5 (N); 6 (N + salt)

Concentración de nutrientes (valores medios sobre materia seca) en el ryegrass del suelo rojo en función de los tratamientos: 1 (0); 2 (0 + sal); 3 (P); 4 (P + sal); 5 (N); 6 (N + sal)

White bars correspond to the first cut and black bars to the second cut. Bars with the same letter, for each cut, do not differ significantly ($P < 0.05$)

Las barras blancas corresponden al primer corte y las negras al segundo. Barras con una misma letra, para un mismo corte, no son diferentes significativamente ($P < 0,05$)

cut for the two soils, perhaps derived from a Ca-Mg competitition in the plant uptake process. On the other hand, Ca absorption was not limited by the initial “luxury” K plant uptake, since Ca concentration was generally high in the first cut for both soils (Figs. 1 and 2).

The total above-ground Mg accumulation in the ryegrass was high in the treatments adding N (Table 3). However, the Na accumulation was even higher in those treatments adding N without Na (values of 1.3 and 1.7 were obtained in the second cut for the ratio Na / Mg in the calcareous and red soils, respectively, when the results were expressed in meq).

TABLE 3

ABOVE-GROUND EXTRACTION OF NUTRIENTS BY RYEGRASS IN THE CALCAREOUS AND RED SOILS

Extracción epígea de nutrientes efectuada por el ryegrass en los suelos calcáreo y rojo

Treatment	**N**		**P**		**K**		**Na**		**Ca**		**Mg**	
	1st cut	**2nd cut**	**1st cut**	**2nd cut**	**1st cut**	**2nd cut**	**1st cut**	**2nd cut**	**1st cut**	**2nd cut**	**1st cut**	**2nd cut**
Calcareous soil												
1 (0)	37.7 a	9.2 a	6.8 a	2.5 a	107.8 a	24.8 a	2.8 a	1.4 a	33.5 a	15.2 a	4.0 a	2.2 a
2 (0 + salt)	32.3 a	9.9 a	7.9 ab	2.5 a	115.7 a	30.2 a	4.1 ab	10.9 b	39.5 ab	17.2 a	4.6 ab	2.8 a
3 (P)	39.8 a	7.3 a	10.5 c	4.2 b	129.5 a	28.2 a	3.1 a	1.2 a	40.1 ab	14.4 a	4.7 ab	2.3 a
4 (P + salt)	41.8 a	7.5 a	10.9 c	4.4 b	140.0 a	36.0 a	5.1 b	10.1 b	48.1 bc	15.8 a	5.7 b	2.3 a
5 (N)	79.8 b	60.9 b	9.4 bc	7.1 c	194.2 b	89.1 c	4.4 ab	16.5 c	57.5 dc	54.1 b	8.4 c	13.5c
6 (N + salt)	83.9 b	58.4 b	10.6 c	6.0 c	231.6 c	73.9 b	11.3 c	84.0 d	65.7 d	44.0 b	9.9 d	11.9 b
Red soil												
1 (0)	49.7 b	10.4 a	6.8 a	3.1 a	125.7 ab	35.0 a	3.8 a	1.7 a	41.3 ab	20.3 a	3.6 a	2.3 a
2 (0 + salt)	27.4 a	8.8 a	6.8 a	2.4 a	104.1 a	40.1 ab	3.6 a	7.1 b	37.1 a	24.7 ab	3.2 a	2.1 a
3 (P)	31.9 ab	11.4 a	7.8 a	5.7 b	114.6 a	42.5 ab	2.4 a	1.7 a	35.5 a	24.8 ab	3.1 a	2.4 a
4 (P + salt)	30.1 a	10.5 a	7.1 a	4.8 b	94.5 a	50.4 b	3.7 a	8.4 ab	35.4 a	28.7 b	3.2 a	2.4 a
5 (N)	79.8 c	69.1 b	9.8 a	5.8 b	193.8 c	95.3 d	4.8 ab	15.2 b	61.0 c	47.1 c	6.5 b	9.2 b
6 (N + salt)	73.1 c	60.2 b	8.1 a	4.6 b	170.9 bc	81.8 c	7.3 b	58.4 c	58.2 bc	50.0 c	6.0 b	8.4 b

Values followed by the same letter in the same column (for each soil and nutrient) do not differ significantly ($P < 0.05$).
(Mean values expressed as mg/pot on a dry matter basis).
(Valores medios expresados como mg/maceta, datos sobre materia seca).

The partial replacement of K by Na in ryegrass under the plentiful N supply could also be shown by the total above-ground K accumulation in ryegrass (Table 3). Such values in treatments 0 + salt and P + salt (treatments 2 and 4) tended to be higher than those in treatments 0 and P in the second cut carried out in both soils, while an opposite trend was observed in treatments adding N, a possible consequence of the mentioned partial replacement of K by Na.

It can also be deduced from Table 3 that, besides N in those treatments in which it was not added, K was the nutrient whose absorption was proportionally higher in the first cut, the difference between cuts being reduced to a certain extent in treatments adding N, perhaps due to the still high K requirement for plant growth. As expected, Mg, and especially Na, showed and opposite trend in those treatments adding N. Their uptake was higher in the second cut as a consequence of their possible role in K replacement (in the case of Na, treatments without salt addition are obviously those being considered).

The total above-ground K export per pot in treatments adding N was lower than the total amount of available K per pot in both soils (300 mg for the calcareous soil and 400 mg for the red soil, according to data in Tabla 1), and much lower than the corresponding total amounts of K per pot.

Although grasses are especially able to utilize the non-exchangeable K fraction of the soil —its contribution being greater the more the exchangeable fraction is exhausted (Mengel, Kirkby, 1987)— K diffusion could be insufficient to cope with the vigorous plant growth deriving from the split applications of NO_3-N, especially after an initial “luxury” plant K uptake. The ryegrass then had recourse to Na (and Mg) for achieving growth. In the long term even these sources of K could be depleted.

DISCUSSION

Using inherent soil factors alone may not result in consistent predictions of K availability to crops. Following the particular criteria in the literature, the soils utilized in this assay could be considered to possess “very high” or even “extremely high” contents of available K (CEBAC, 1962; Cope, Evans, 1985; Haby *et al.*, 1990). Although pot studies certainly overestimate nutrient dynamics found under field conditions, results obtained here seem to indicate that, under particular management and crops, “critical” values for K could be reached promptly even in soils considered well provided in K, if adequate fertilization is not applied.

Thus, it seems reasonable to include selected management parameters when rating soil K, as was established by JE-MP (1992), which defined a higher range of available K for intensive irrigation (a range of 355-585 mg kg^{-1} of exchangeable K is considered “high” form loamy soils) than for other agricultural practices, rainfed agriculture included. As pointed out by Haby *et al.* (1990), soil moisture content and temperature greatly affect K diffusion in the soil.

According to JE-MP criteria, the available K (exchangeable + soluble) of the soils in this assay would be rather low for intensive irrigation, and adequate K fertilization would be neccesary under such conditions. In this respect, KCl fertilizer types, which contain substantial amounts of NaCl, would therefore be suitable for natrophilic crops (Mengel, Kirkby, 1987), where Na may successfully replace K, as has been shown in this assay, and where Mg could also participate on this process.

However, it is important to take into account that although a reasonable presence of Na may be useful for replacing K in natrophilic species, its indiscriminate presence is not advisable, since Na (or Cl) could reach toxic levels for most crops, a probable occurrence in soils with a poor drainage. Plant growth could be drastically reduced by a Na uptake beyond the maximum salt compartmentation capacity (Gorham *et al.*, 1985), and the presence of Ca and/or Mg is desirable for a potential co-operation with Na for K replacement.

CONCLUSIONS

Particular managements (e.g. irrigation, mild temperatures) can promote a “luxury” K plant uptake. Potassium supply could then be insufficient to achieve a consistent plant growth if K fertilization was neglected relative to N fertilization, even in soils considered potentially well provided in K. A reasonable presence of Na (and Mg, according to this experiment) added or inherent to soil, would then be desirable for replacing K to achieve plant growth of natrophilic species. However, the non-exchangeable K fraction of the soil would not be excessively exhausted.

RESUMEN

Interacción N y salinidad en ryegrass. Implicaciones en la interpretación del contenido de K de los suelos

La adición fraccionada de N-NO_3 (irrigación con una solución de 50 mg N l^{-1}) bajo condiciones salinas (irrigación con una solución de 10 mM de NaCl, que no limitó el crecimiento de la planta) y no salinas, potenció la absorción de Na del ryegrass italiano (*Lolium multiflorum* Lam. cv. “Barwoltra”) en dos suelos potencialmente ricos en K. También aumentó la absorción de Mg. No se observó esta circunstancia en el caso de adiciones fraccionadas de P. Tras un “consumo de lujo” inicial de K por parte del ryegrass, la disponibilidad de K en el suelo pudo ser insuficiente para completar el vigoroso crecimiento impuesto por la adición de N, siendo el K parcialmente reemplazado por Na (y Mg, en los tratamientos con N) con el fin de que la planta pudiera completar su crecimiento.

PALABRAS CLAVE: Ryegrass italiano
Nutrientes
Salinidad
K en suelo

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