EFFECTS OF N–CARRIERS AND Al–LEVELS ON DRY MATTER PRODUCTION AND NUTRIENT CONTENT OF TWO PASTURE GRASSES[1] /

*M. L. R. ARRUDA**
*M. S. FERNANDES***
*R. O. P. ROSSIELLO****

Resumo

*Em casa de vegetação, e sob solução nutritiva, foi estudada a resposta de duas gramineas forrageiras (*Cenchrus ciliaris *e* Brachiaria decumbens*) a doses crescentes de Al (0 – 0.75 – 1.5 – 3.0 – 6.0 ppm), usando-se NO_3 ou NH_4 como fonte de N.*

Ambas as gramineas sofreram redução de peso seco com doses crescentes de Al. Em termos absolutos, Brachiaria *apresenta maior produção de matéria seca sob NH_4 do que sob NO_3, acontecendo o inverso com* Cenchrus. *Quando entretanto a redução do peso com doses crescentes de Al é tomado em termos relativos (% do máximo),* Brachiaria *sob NO_3 mostra maior estabilidade, enquanto que* Cenchrus *é mais estável quando sob NH_4. A fonte de N afetou diferencialmente a acumulação de Al, e N na raiz e parte aérea das plantas estudadas. O maior acúmulo de Al ocorre nas raízes, sendo maior nas plantas sob NO_3 do que nas NH_4. Em ambas as espécies houve maior acúmulo de P na parte aérea das plantas sob NH_4 do que sob NO_3, enquanto que nas raizes foi observada uma tendência inversa. Acúmulos de N e K nos tecidos das plantas parecem estar relacionados com a tolerância à toxidez de Al.*

Introduction

In acid soils, high levels of exchangeable aluminum is one of the principal factors limiting plant growth. This condition is usually associated with low fertility levels (15) in such a way that the direct and indirect effects of Al on root growth and nutrient absorption are referred as "Al toxicity".

Aluminum appears to affect root growth more closely than top growth. Interferences in the process of cell division due to high Al concentrations result in abnormal development of root tissue (5). In the tops the symptoms are less characterized and can be mistaken for P or Ca deficiency (11, 18).

The effects of high Al levels on the solubility of P in the growth medium and its absorption are well known (8). Clarkson (5) suggests that there are two reactions between Al and P; one at the cell surface or in the free space and the other within the cell, possibly within the mithocondria. Soluble Al may reduce the uptake of other plant nutrients. In rice, Al toxicity is associated with lower concentrations of Ca, Mg, K and Si and higher concentrations of N and P in plant tops (16). Reductions in the concentration of K in tops of leguminous plants are associated with Al sensibility (2). High Al concentration in the nutrient solution decreased the concentrations of P, K, Ca, Mg and increased Fe and Al concentrations in roots as well as in top of oats (1). Zn, Fe, Mn an Cu concentrations were affected in rye, barley and wheat according to age and cultivar sensibility to increasing levels of Al (13).

Since Al tolerance and nutrient utilization and absorption are controlled by genetic factors (5), an association between Al tolerance and nutrient utilization efficiency seems probable. However, both processes (Al exclusion and nutrient absorption) are conditioned to pH fluctuations in the medium. Since

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Contribution from the Department of Soil Science U.F.R.R.J. km 47 Rod. Rio-São Paulo. Seropédica, 23460, Rio de Janeiro-RJ

* Agronomist from EPAMIG, MG-Brasil

** Associate professor and Assistent professor respectively UFRRJ km 47 Rod. Rio-São Paulo, 23460, Rio de Janeiro-RJ.

N is the nutrient of highest metabolic demand in plants, its rate of uptake greatly effects pH changes in the root-solution interface (7, 11, 19).

In this work we examined the effects of the two ionic forms of nitrogen absorption (NH_4^+ or NO_3^-) on dry matter production and Al, N, P, and K absorption by *B. decumbens* and *Cenchrus ciliaris*. These two species are known to differ in their Al tolerance (20).

Material and methods

The experiment was conducted in a greenhouse at mean air temperature of 24°C and 70% relative humidity. A fatorial design of two species, two nitrogen sources and five Al concentration replicated three times was used. The nutritive solution used was similar to that described by Andrew *et al.* (2). The main modifications were that $(NH_4)\ Mo_7O_{24}\ 4H_2O$ was substituted by H_2MoO_4. Ca was supplied as $CaCl_2$ and plants supplied amonium received N as $(NH_4)\ SO_4$ (Table 1).

The species studied were *C. ciliaris* obtained from the Centro Nacional de Gado de Leite – EMBRAPA collections, and *B. decumbens* obtained from commercial sources.

Seeds were germinated in plastic plates containing sand and vermiculite and irrigated when necessary with nutrient solution. After 15 days 300 plants from each species were selected and transferred to 60, 8-liter plastic pots, whose outside were painted silver to prevent light penetration. Seedlings were supported in holes in the lids of the pots by rubber foam. Plastic perforated tubing was attached to the base of each solution container to provide an aereation system operating at a frequency of 3 periods (60 minutes) each 24 hours. Each pot was thinned to 6 seedlings 15 days after germination. The culture medium was similar to that described above but containing in addition either 0; 0.75; 1.5; 3.0 or 6.0 ppm Al as $Al_2\ (SO_4)_3 \cdot 18H_2O$. The solutions were adjusted to pH 4.2 with 0.1 N NaOH or 0.1 N H_2SO_4. The P and N concentrations were determined each 2 days. The plants were exposed to the treatments solutions for 4 weeks and then harvested.

Roots were separated from tops and washed with deionized water. Plant tops and roots were dried at 70°C in a forced-air oven for at least 36 hours. Dried tops and roots were ground in a Wiley mill to pass a 40 mesh screen and analysed for N, P, Ca, K and Al.

After dry digestion at 500°C, P was determined as described by Leece and Short (12); Al by the method of Otomo (17); K by flame photometry and Ca by complexometry with EDTA. Nitrogen was determined by destillation (3).

Table 1. Nutrient solution composition prepared from modified Andrew's solution.

Elements	Concentrations	Salt
K	1.0 mM	K_2SO_4
Cl	0.5 mM	NaCl
Mg	0.5 mM	$MgSO_4 \cdot 7H_2O$
Cu	0.02 ppm	$CuSO_4 \cdot 5H_2O$
Zn	0.05 ppm	$ZnSO_4 \cdot 7H_2O$
Mn	0.25 ppm	$MnSO_4 \cdot H_2O$
B	0.5 ppm	H_3BO_3
Mo	0.01 ppm	H_2MoO_4
Fe	1 ppm	Fe-citrate
P	2 ppm	KH_2PO_4
Ca* e N*	1 mM	$Ca\ (NO_3)_2 \cdot 4H_2O$
Ca**	1 mM	$CaCl_2$
N**	1 mM	$(NH_4)_2\ SO_4$

* Plants receiving N-nitrate

** Plants receiving N-ammonium

Results and discussion

Dry matter production. There was a significant reduction in dry matter accumulation for both plant species as Al in solution increased (Table 2). N-form also affected plant dry weight. Plants under nitrate had higher dry weight than plants under ammonium. There was no difference in dry matter accumulation by the roots of the two species, but *Brachiaria* plants accumulated more dry matter in the tops than did *Cenchrus*.

There was a significant N x genotype interaction. *Cenchrus* plants accumulated more top and root dry matter when under NO_3 –N, while *Brachiaria* plants showed no response to N–form.

When the total dry matter production was examined in terms of percentage reduction to the treatment of maximum production (0 ppm Al = 100%), it was verified that the production of *B. decumbens* was more stable when receiving nitrate than when treated with ammonium (Figure 1). In the first case, the production decreased 15% up to 3.0 ppm of Al and decreased 67% at the highest level the production was 60% of the maximum whereas for *C. ciliaris* the relative production was more stable when ammonium was the source of N. The yields relative to the highest level of Al were 67.0 and 48.3% of the 0 level for plants treated with ammonium and nitrate respectively. These results

Table 2. Effects of Al and N source on root and top dry weights (g/pot) of *Brachiaria decumbens* and *Cenchrus ciliaris*

	Mean Al effect	
Al (ppm)	Roots	Tops
0.00	2.74 a *	22.56 a
0.75	2.35 ab	19.61 b
1.50	2.31 ab	16.84 b
3.00	2.16 b	16.00 bc
6.00	1.60 c	13.38 c

	Mean N effect	
N-carrier	Roots	Tops
NO_3	2.80 a	18.91 a
NH_4	1.66 b	16.18 b

	Mean genotype effect	
	Roots	Tops
Brachiaria	2.12 a	16.37 b
Cenchrus	2.34 a	18.71 a

	Mean N x genotype effect			
	Roots		Tops	
	Brach	*Cench*	*Brach*	*Cench.*
NO_3	2.28 a	3.32 a	15.5 a	22.3 a
NH_4	1.96 a	1.36 b	17.2 a	15.1 b

* Means in a column group (tops or roots) not followed by the same letter differ significantly at the 5% level according to Tukey's test.

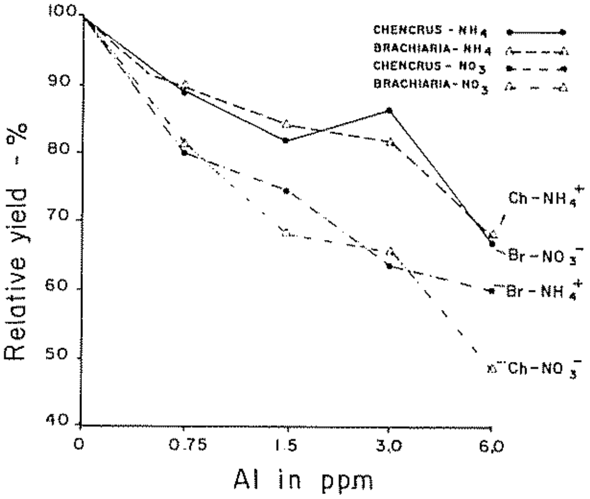

Fig. 1. Effects of Al levels and N source on relative growth of *Cenchrus ciliais* and *Brachiaria decumbens*

stress the metabolic interrelationship of Al tolerance and the mechanism that regulates nitrogen absorption by plants. It must be noted, however, that the growth period (pre-stress) of 4 weeks must reduce the toxic effects of Al for *C. ciliaris*, since the effects are more drastic at the seedling stage after the radicle emergence (11). In another experiment, it was observed (data not shown) that *C. ciliaris* exposed to soil Al saturation levels higher than 10% does not grow beyond the seedling stage, whereas *B. decumbens* grows satisfactorily.

Aluminium concentration

There is a significant increase in Al concentration in roots, but not in tops as Al concentration increases in the nutrient solution (Table 3). Accumulation of Al in roots of both species was higher in plants supplied nitrate than in plants supplied ammonium (Table 3). For both species the concentration of Al was higher in roots than in tops. This fact has been previously documented by Foy and Brown (9) and Nunns (14). The major part or this Al in roots must be absorbed in the cellular wall or precipitated in the free space of the roots, specially in the epidermis (2, 5, 11, 18).

Regardless of N source *B. decumbens* accumulated significantly more Al than *C. ciliaris* suggesting that root Al accumulation might be associated with higher Al tolerance.

Phosphorus concentration

Phosphorus concentration of plant roots was significantly increased at or above 1.5 ppm of Al in solution (Table 4). For the two sets of treatments and for both species, plants receiving N as ammonium accumulated more P in the tops than plants under nitrate (0.183 x 0.296) whereas in the roots an inverse relationship was obtained ($N-NH_4$ = 0.326; $N-NO_3$ = 0.375). The higher concentration of P in the roots than in the tops must be due to P precipitation at the surface or internally within the roots (14). The effects of Al on root P content differ between the two species and N sources. With either nitrate or ammonium nutrition the P concentration of roots for *B. decumbens* was increased at or above 1.5 ppm of Al. Regardless of N source, the P concentration of roots for *C. ciliaris* was not affected by Al concentration in solution (Table 4).

Table 3. Effects of Al and N source on Al concentration of roots and tops (µg/g of dry matter) of *Brachiaria decumbens* and *Cenchrus ciliaris*

	Mean Al effect	
Al (ppm)	Roots	Tops
0 00	690 d*	198 a
0.75	1 854 cd	223 a
1 75	3 184 c	238 a
3.00	5 366 b	228 a
6 00	7 281 a	270 a

	Mean N effect	
N-carrier	Roots	Tops
NO_3	6 186 a	242 a
NH_4	1 292 b	221 a

	Mean genotype effect	
	Roots	Tops
Brachiaria	4 715 a	254 a
Cenchrus	2 762 b	208 b

	Mean Al x genotype effect			
	Roots		Tops	
Al (ppm)	*Brach*	*Cench*	*Brach*	*Cench*
0 00	1 145 d	1 140 c	200 b	198 a
0 75	2 186 cd	1 523 bc	228 b	219 a
1 50	4 058 c	2 309 bc	237 b	240 a
3.00	6 867 b	3 595 ab	245 ab	210 a
6 00	9 319 a	5 244 a	360 a	180 a

	Mean N x genotype effect			
	Roots		Tops	
N-carrier	*Brach*	*Cench*	*Brach*	*Cench*
NO_3	7 916 a	4 456 a	285 a	200 a
NH_4	1 514 b	1 069 b	223 b	220 a

* Means within a colum not followed by the same letter differ significantly at the 5% level according to Tukey's test

Potassium concentration

Table 5 shows the effects of Al on K concentration of roots and tops. Increasing Al levels affected K-content of roots but not of tops. Response of roots K to Al levels had a quadratic fit with a maximum at 3 0 pp. Al.

When nitrate was the source of N the K concentration in plant tops was significantly affected by Al concentration in solution, but each specie showed differential responses (Table 5). K concentration of tops for *B. decumbens* with nitrate as the source of N increased with increasing Al levels, whereas the K content of the tops for *C. ciliaris* decreased as the Al in solution increased. K content of roots for *B. decumbens* and *C. ciliaris* was also affected by Al concentration and the effects of the two forms of N were similar to those observed on tops (Table 5).

The effects of higher levels of Al on K concentration of plant tops and roots of *B. decumbens* have been reported for other vegetable species (2, 5) and suggest that Al tolerance might be related to the root capacity to absorb K. The results of this experiment (Table 6) show that increasing levels of Al in solution favors an increase in K concentration of tops and roots for species less sensible to Al (*B. decumbens*). Andrew *et al.* (2) observed that in tolerant species the reduction of Ca concentration of tops due to an excess of Al in solution was balanced by an increase of K and Mg. In this experiment it was observed a marked effect of Al upon the reduction of Ca concentration of tops (data not shown) and the increase in K content of tops and roots (Table 5), suggesting that this effect represents a way by which the plant preserve its ionic equilibrium.

The reduction in K content of plant tops for *C. ciliaris* as a result of increasing levels of Al can be associated with the reductions of dry matter (Table 2 and 5). Andrew *et al.* (2) observed marked reductions in K concentrations of species more sensible to Al in solution.

Nitrogen concentration

There was an increase in N-concentration of roots and tops as Al in solution increased. Maximum N concentration was reached at the 3.0 ppm level. However, responses of plant-N to Al was affected by N-carrier and plant genotype. Plants under NH_4 –N had significantly higher N than those under NO_3 –N, and *B. decumbens* accumulated more N than did *C. ciliaris* (Table 6). A significant interaction was found between Al-levels and N-carriers.

Brachiaria decumbens showed an increase in the absorption and translocation of nitrogen as the level of Al in solution was increased, whereas the nitrogen content for *C. ciliaris* was decreased whenever Al was added to the solution. An increase in N concentration for *B. decumbens* with increasing Al levels in solution could result from the reduction in plant dry weight. However, under the same experimental conditions the

Table 4. Effects of Al and N source on phosphorus concentration of roots and tops (% dry matter) of *Brachiaria decumbens* and *Cenchrus ciliaris*

	Mean Al effect	
Al (ppm)	Roots	Tops
0.00	0.256 b*	0.254 a
0.75	0.295 b	0.227 a
1.50	0.376 a	0.209 a
3.00	0.414 a	0.244 a
6.00	0.403 a	0.260 a

	Mean N effect	
N-carrier	Roots	Tops
NO_3	0.375 a	0.183 b
NH_4	0.326 b	0.296 a

	Mean Al x genotype effect			
	Roots		Tops	
Al (ppm)	*Brach*	*Cench*	*Brach*	*Cench*
0.00	0.268 b	0.309 a	0.221 a	0.287 a
0.75	0.297 b	0.294 a	0.241 a	0.213 a
1.50	0.417 a	0.336 a	0.209 a	0.209 a
3.00	0.439 a	0.394 a	0.236 a	0.254 a
6.00	0.353 a	0.459 a	0.270 a	0.250 a

	Mean N x genotype effect			
	Roots		Tops	
N-carrier	*Brach*	*Cench*	*Brach*	*Cench*
NO_3	0.429 a	0.320 a	0.214 b	0.152 b
NH_4	0.297 b	0.354 a	0.257 a	0.334 a

* Means in a column group (tops or roots) not followed by the same letter differ significantly at the 5% level according to Tukey's test.

Table 5. Effects of Al and N source on potassium concentration of roots and tops (% dry matter) of *Brachiaria decumbens* and *Cenchrus ciliaris*

	Mean Al effect	
Al (ppm)	Roots	Tops
0.00	3.10 c*	5.28 a
0.75	3.81 ab	5.00 a
1.50	4.07 a	5.33 a
3.00	4.14 a	5.07 a
6.00	3.35 bc	5.01 a

	Mean N effect	
N-carrier	Roots	Tops
NO_3	3.57 b	5.17 a
NH_4	3.82 a	5.11 a

	Mean genotype effect	
	Roots	Tops
Brachiaria	3.39 b	4.44 b
Cenchrus	4.00 a	5.11 a

	Mean Al x genotype effect			
	Roots		Tops	
Al (ppm)	*Brach*	*Cench*	*Brach*	*Cench*
0.00	2.48 b	3.72 ab	4.13 b	6.43 a
0.75	3.36 a	4.26 a	3.97 b	6.04 ab
1.50	3.78 a	4.37 a	4.58 ab	6.08 ab
3.00	3.93 a	4.35 a	4.57 ab	5.58 b
6.00	3.41 a	3.29 b	4.98 a	5.04 c

	Mean N x genotype effect			
	Roots		Tops	
N-carrier	*Brach*	*Cench*	*Brach*	*Cench*
NO_3	3.40 a	3.74 b	4.70 a	5.64 b
NH_4	3.38 a	4.26 a	4.19 b	6.02 a

* Means within a column not followed by the same letter differ significantly at the 5% level according to Tukey's test

Table 6. Effects of Al and N source on nitrogen concentrations of roots and tops (% dry matter) of *Brachiaria decumbens* and *Cenchrus ciliaris*

	Mean Al effect	
Al (ppm)	Roots	Tops
0.00	2.32 b*	2.07 bc
0.75	2.50 ab	2.13 ab
1.50	2.57 ab	2.21 ab
3.00	2.60 a	2.28 a
6.00	2.31 b	1.96 c

	Mean N effect	
N-carrier	Roots	Tops
NO$_3$	2.31 b	2.07 b
NH$_4$	2.61 a	2.19 a

	Mean genotype effect	
	Roots	Tops
Brachiaria	2.58 a	2.31 a
Cenchrus	2.34 b	1.96 b

	Mean Al x N effect			
	Roots		Tops	
Al (ppm)	NO$_3$	NH$_4$	NO$_3$	NH$_4$
0.00	2.42 ab	2.22 b	1.97 bc	2.19 bc
0.75	2.29 ab	2.71 a	2.22 a	2.05 bc
1.50	2.48 a	2.68 a	2.17 ab	2.27 ab
3.00	2.36 ab	2.85 a	2.12 abc	2.44 a
6.00	2.04 b	2.60 ab	1.90 c	2.04 c

	Mean Al x genotype effect			
	Roots		Tops	
Al (ppm)	*Brach*	*Cench*	*Brach*	*Cench*
0.00	2.29 b	2.35 ab	2.14 b	2.02 a
0.75	2.65 ab	2.36 ab	2.24 ab	2.03 a
1.50	2.66 ab	2.49 a	2.42 a	2.00 a
3.00	2.69 a	1.53 a	2.37 ab	2.19 a
6.00	2.63 ab	1.98 b	2.36 ab	1.58 b

* Means within a column group (tops or roots) not followed by the same letter differ significantly at the 5% level according to Tukey's test

Al treatments reduced the dry weight of *C. ciliaris* that had also less N concentration suggesting that N accumulation is a characteristic of Al tolerant species.

The results suggest that tolerance to Al-toxicity is related to the patterns of ion uptake. The effects of N-carriers on Al-toxicity are thus mainly due to its influence on the ion uptake patterns of the plants.

Summary

To study the effects of various Al levels and the possible role of nitrate or ammonium nutrition on the growth and nutrient accumulation of two gramineous species (*Brachiaria decumbens* and *Cenchrus ciliaris*) several rates of Al (0, 0.75, 1.5, 3.0 and 6.0 ppm) were added to nutrient solutions in a greenhouse experiment utilizing NH$_4$ or NO$_3$ as source of nitrogen.

For both species, dry weights decreased as the Al concentration was increased. In absolute terms, *B. decumbens* produced more dry matter when relying on NH$_4$ than when utiliizing NO$_3$, the inverse happened with *C. ciliaris*. However, when the reduction in dry weight with increasing Al levels is taken in relative term (% of the maximum) *B. decumbens* receiving NO$_3$ showed more stability whereas *C. ciliaris* was more stable when treated with NH$_4$. The Al and N concentrations of roots and tops of plants treated were differentialy affected by the form of nitrogen used. Plants receiving nitrate as the source of nitrogen, accumulated more Al in roots than those receiving ammonium. For both species, plants receiving nitrogen as NH$_4$ had higher P concentrations in tops than did nitrate plants, whereas in the roots an inverse relationship was observed. Nitrogen and potassium accumulation in plant tissue appear to be related to Al tolerance.

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Reseña de libros

KOOLEN, A. J. y KUIPERS, H. Agricultural soil mechanics. Springer-Verlag, New York. 1983. 241 p.

Este volumen preparado por dos prestigiosos colaboradores de la bien conocida Universidad Agrícola de Wageningen, Holanda, presenta una discusión original de tres campos de la Ingeniería Agrícola, dedicando a cada uno una parte del libro.

Las condiciones generales del suelo con el tópico de la primera parte, mucho más corta que las otras. Se enfoca aquí el suelo como un sistema que presenta oposición a fuerzas aplicadas a la misma.

La segunda parte que incluye un poco más que un tercio del volumen analiza el comportamiento mecánico de los elementos del suelo. Esta parte consiste en cinco subdivisiones que se refieren a:

a) Los aspectos generales del comportamiento mecánico de las unidades elementales del suelo.

b) Un tratamiento básico de la compactación.

c) Un análisis de la deformación del suelo.

d) Un estudio del rompimiento del suelo. y

e) Un estudio básico de la adherencia y fricción entre suelo y otros materiales.

La tercera parte se dedica al estudio de los procesos referentes a la capacidad del suelo de llevar cargas y de su desintegración. Esta parte es la más larga al incluir más de la mitad del volumen, tiene siete subdivisiones que son:

a) Aspectos generales de los procesos de arado.

b) Ruedas, llantas y rodillos.

c) Elementos que penetran al suelo (Cuñas, Conos, Placas, Alambre y Esferas).

d) Cuerpos cortantes

e) Orugas

f) Dientes

g) Cuerpos de arado

En todos los capitulos se discute los principios que se aplican en esta parte y la aplicación de los principios en las operaciones pertinentes. Tiene 231 referencias, y la mayoría de ellas son inglés con unas pocas en holandés y alemán, permiten al interesado a profundizarse en los diferentes tópicos, a los cuales se localiza fácilmente por medio de un buen índice de materiales al final.

El volumen es sin duda una adición útil a la no muy amplia bibliografía en Ingeniería Agrícola y por esto se le recomienda a todos los que se interesan en mecánica de suelos. El inglés de los autores es claro y la mayor parte del volumen es comprensible aún para no ingenieros agrícolas, siempre que tengan buenas bases en mecánica.

ELEMER BORNEMISZA S.
FACULTAD DE AGRONOMIA
UNIVERSIDAD DE COSTA RICA