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Growth and nutrient concentrations of alfalfa and common bean as influenced by soil acidity

N. K. FAGERIA, V. C. BALIGAR[1] and R. J. WRIGHT
USDA-ARS-Appalachian Soil and Water Conservation Research Laboratory, Beckley, WV 25802-0867, USA. [1]Corresponding author

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Abstract
Growth and nutrient utilization of alfalfa (*Medicago sativa* L. cv. Arc) and common bean (*Phaseolus vulgaris* L. cv. Carioca) were studied in an acid soil adjusted to eight levels of soil acidity by lime addition. Application of lime significantly ($P < 0.05$) increased shoot and root growth for both species. However, common bean was far less sensitive to soil acidity than alfalfa. Maximum alfalfa growth was obtained at a soil pH of 5.8 and maximum bean growth was achieved at pH 5.0. Root and shoot growth of both legumes was positively correlated ($P < 0.01$) with soil pH, exchangeable Ca and exchangeable Mg and negatively correlated ($P < 0.01$) with soil exchangeable Al. Common bean had a lower internal P requirement for maximum growth and was more efficient than alfalfa in taking up Ca and Mg. These characteristics would contribute to the favorable growth of common bean in acid-infertile soils.

Introduction

A complex of factors are responsible for reduced plant growth in acid soils. Growth limiting factors include deficiencies of P, Ca and Mg and toxicities of Al and Mn (Foy, 1984). Further, activities of beneficial microorganisms are also restricted in acid soils and thus may limit plant growth.

Yield reductions on acid soils vary with soil physical and chemical properties and with plant species and genotypes (Clark, 1982). Soil acidity, particularly levels of Al, alters the nutrient uptake efficiency of most crop plants (Baligar *et al.*, 1987; Baligar *et al.*, 1989; Foy, 1984). The objective of this study was to investigate the growth and nutrient concentrations of alfalfa and common bean under different levels of soil acidity.

Materials and methods

The surface 15 cm of a Porters soil (coarse-loamy, mixed, mesic Umbric Dystrochrept) from Tennessee was adjusted to eight levels of soil acidity by lime addition. Dolomitic lime was added at rates of 0, 0.5, 1, 2, 4, 5, 10 and 20 g kg^{-1}. All treatments received a basal application of fertilizer containing: 75 mg N kg^{-1}, 100 mg P kg^{-1}, 126 mg K kg^{-1}, 86 mg S kg^{-1}, 5 mg Zn kg^{-1}, 5 mg Cu kg^{-1}, 1 mg B kg^{-1} and 0.1 mg Mo kg^{-1}. Lime and fertilizer were mixed with the soil and incubated for three weeks at a moisture content corresponding to 33 kPa tension. The limed soils were then analyzed (Table 1) for soil pH 1:1 H_2O, exchangeable bases (Thomas, 1982), exchangeable acidity (Yuan, 1959) and P soluble in dilute acid-fluoride (Olsen and Sommers, 1982).

Three replications of each lime treatment were planted with "Arc" alfalfa and "Carioca" common bean. After germination, the plants were thinned to 20 and 3 plants per 2 kg of soil for alfalfa and beans, respectively. The plants were placed in a climatically controlled growth chamber with the following conditions: 70% relative humidity, 14 h

Table 1. Influence of lime on soil chemical properties after 3 weeks incubation

Lime rate ($g\ kg^{-1}$)	pH (1:1 H_2O)	P ($mg\ kg^{-1}$)	Exchangeable cations ($c\ mol\ kg^{-1}$)				Total acidity
			K	Ca	Mg	Al	
0	4.11e[a]	29.6a	0.52a	0.66d	0.14e	4.62a	4.89a
0.5	4.26de	24.8bcd	0.50ab	1.15d	0.52de	4.20b	4.51b
1	4.36de	24.5bcd	0.49bc	1.33d	0.81de	3.59c	3.81c
2	4.55cd	26.4ab	0.50ab	1.97cd	1.42cd	2.64d	2.79d
4	4.88bc	26.6ab	0.49bc	3.06bc	2.34bc	1.28e	1.43e
5	5.04b	26.0bc	0.49bc	3.67b	2.89b	0.70f	0.86f
10	5.77a	22.5cd	0.48bc	6.43a	5.54a	0.00g	0.07g
20	6.06a	21.9d	0.47c	7.11a	6.07a	0.00g	0.05g

[a] Means in the same column followed by the same letter are not significantly different at $P = 0.05$ by the t test.

day length, 28°C day temperature, with 530 μmol $s^{-1}\ m^{-2}$ light intensity. During the night the temperature was 22°C with 80% relative humidity.

The alfalfa and beans were harvested 44 and 29 days after seeding, respectively. Tops and roots were washed in deionized water and dried to constant weight in a forced-draft oven at 65°C. Plant materials were then ground and digested in a $HNO_3/HClO_4$ (4:1) mixture. Elemental determinations were made by inductively coupled plasma emission spectroscopy (ICP). Statistical Analysis System (SAS) programs were used to perform mean comparison tests and to calculate correlation coefficients relating plant growth, nutrient uptake and soil properties.

Results and discussion

Liming increased soil pH, exchangeable Ca and exchangeable Mg, and reduced exchangeable Al (Table 1). Shoot and root dry weights of alfalfa and common bean are shown as a function of lime application in Table 2. Common bean was far less

Table 2. Influence of lime rates on growth and nutrient concentrations in the shoots of alfalfa and common bean[a]

Lime rate ($g\ kg^{-1}$)	Shoot dry wt (g)	Root dry wt (g)	Nutrient concentrations ($g\ kg^{-1}$)				
			P	K	Ca	Mg	S
Alfalfa							
0	0.14c[b]	0.02e	1.10c	14.3cd	5.3c	0.8d	1.1b
0.5	0.13c	0.09de	0.78d	11.2d	6.0c	2.5c	1.6b
1	0.14c	0.12cde	0.71d	14.5cd	6.7c	3.8bc	1.8b
2	0.18c	0.18cd	0.69d	14.5cd	9.2b	4.8b	1.9b
4	0.40bc	0.25bc	1.40b	24.0ab	13.4a	7.2a	3.4a
5	0.58b	0.35b	2.08a	26.3a	13.7a	7.6a	3.6a
10	1.02a	0.72	1.93a	24.3ab	14.2a	7.0a	4.2a
20	0.98a	0.61a	1.62b	19.0bc	14.0a	7.7a	3.8a
Bean							
0	1.25c	0.45b	0.87bc	23.2a	6.3e	1.5f	3.0ab
0.5	1.46bc	0.49ab	0.84c	21.8a	8.2de	3.7e	3.1ab
1	1.58b	0.49ab	0.94abc	22.1a	9.6d	4.5de	3.1ab
2	1.51b	0.50ab	0.89bc	22.1a	12.6c	5.7cd	3.3a
4	1.68b	0.50ab	0.92abc	18.5ab	14.3bc	6.5bc	3.0ab
5	2.04a	0.57a	0.97ab	16.1b	14.0bc	6.2cd	2.8b
10	2.01a	0.56ab	1.03a	15.8b	15.6ab	8.2ab	3.2ab
20	1.98a	0.59a	1.03a	16.2b	17.3a	9.5a	3.4a

[a] Mean values from three replications containing 20 alfalfa plants per pot or 3 common bean plants per pot.
[b] For a given legume means in the same column followed by the same letter are not significantly different at $P = 0.05$ by the t test.

sensitive to soil acidity than alfalfa. Shoot and root weight of common bean in the no lime treatment was 61% and 79% of the maximum growth, respectively. Shoot weight and root weight of alfalfa in the control treatment only represented 14% and 3%, respectively, of maximum growth. Application of lime increased shoot and root growth parameters for both species (Table 2). However, common bean achieved maximum growth at lower lime additions than alfalfa.

Simple correlation coefficients (data not shown) were calculated to relate plant growth parameters to soil properties. Shoot dry weight and root dry weight of alfalfa and common bean were positively correlated ($P < 0.01$) with soil pH, exchangeable Ca and exchangeable Mg. Exchangeable Al was negatively correlated ($P < 0.01$) with all growth parameters for both species.

Concentrations of P, K, Ca, Mg and S in the shoots of alfalfa and common bean are shown in Table 2. Calcium and Mg concentrations and uptake (data not shown) increased with lime rate for both legumes, but were consistently higher in common bean than alfalfa over all lime levels. The pattern of shoot P, K and S concentrations with lime level was different for alfalfa and common bean. Shoot concentrations of these three elements in alfalfa increased with lime levels greater than 2 g kg^{-1}. Potassium uptake by common bean (data not shown) was not significantly different ($P < 0.05$) across all the lime rates even though shoot K concentrations decreased with increasing lime rate (Table 2). Although common bean shoot P concentrations (Table 2) increased slightly with lime addition, shoot concentrations of P and S were largely independent of lime rate. Common bean apparently has a much lower internal P requirement than alfalfa. Shoot P concentration associated with maximum growth in common bean was approximately half the shoot P concentration associated with maximum growth in alfalfa. A low internal P rquirement for maximum growth and efficient utilization of Ca and Mg are factors that would contribute to the favorable growth of common bean in acid-infertile soils.

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