Soybean Root Growth and Nutrient Uptake as Affected by Lime Rates and Plant Age II. Ca, Mg, K, Fe, Cu and Zn[1]

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ABSTRACT

A growth chamber study was conducted to determine the effect of lime rates and plant age on soil nutrient availability and nutrient uptake by a certain soybean cultivar (*Glycine max* Merr.). The experiment consisted of three lime rates and four plant ages in four randomized complete blocks. Shoot nutrient concentrations increased for Ca and Mg but decreased for K, Fe, Cu, and Zn, when lime was applied at the recommended rate. Lower shoot K concentrations as a result of liming were attributed to an antagonistic effect of Ca and Mg present in the soil. Liming at twice the recommended rate reduced shoot concentrations for all nutrients except Mg. Shoot nutrient concentrations, as a function of plant age, either increased, remained constant, or decreased slightly because of nutrient demands by the plant. An exception was Fe, which decreased considerably during the first four weeks. Nutrient uptake per meter of root generally followed a decreasing trend with plant age. These results were attributed to dilution by shoot growth and decreasing root activity. The decline in root activity was attributed to aging of roots and increasing length of young roots, which reduced the uptake demands by each meter of root. Nutrient uptake rates per meter of root related better to shoot nutrient concentrations than to shoot nutrient accumulation rates. Nutrient parameters of shoots generally increased with liming at the recommended rate. These increases were attributed to improved soil nutrient availability in the case of the macronutrients, and to longer and finer root systems in the case of macronutrients and micronutrients. Liming with twice the recommended rate generally depressed shoot nutrient parameters. These decreases were ascribed to small root systems in the case of macronutrients and micronutrients, and to limited soil nutrient supply in the case of the micronutrients.

COMPENDIO

Un estudio fue conducido en cámara de crecimiento para determinar el efecto del encalamiento y la edad de la planta sobre la disponibilidad de nutrimentos en el suelo y su absorción por una variedad determinante de soya (*Glycine max* Merr.). El experimento consistió de tres niveles de cal dolomítrica y cuatro edades de la planta, con cuatro repeticiones en un diseño de bloques randomizados completos. La concentración de nutrimentos en el tallo aumentó para el Ca y Mg pero disminuyó para el K, Fe, Cu y Zn, debido al encalado recomendado. Cuando el encalado recomendado fue doblado, la concentración de nutrimentos disminuyó, con la excepción del Mg. La concentración de nutrimentos en el tallo, en función de la edad de la planta, tendió a disminuir para el Mg, K, Fe y Zn pero tendió a aumentar para el Ca y Cu. La absorción de nutrimentos por metro de raíz, generalmente, disminuyó con la edad. Estos resultados fueron atribuidos a la dilución debida al crecimiento del tallo y a la disminución de la actividad absortiva de las raíces. El decaimiento de la actividad radicular fue acreditada a la edad de las raíces y al aumento del largo de las raíces, lo cual redujo la necesidad de absorción por metro de raíz. Los parámetros pertinentes a los nutrimentos del tallo, generalmente, aumentaron con el encalado recomendado. Estos aumentos fueron atribuidos a una mayor solubilidad en el caso de los macro-nutrimentos, y a sistemas radiculares largos y finos en el caso de todos los nutrimentos.

INTRODUCTION

For plants to attain their genetic yield potentials, they must be grown under optimum environmental conditions, both above ground and in the soil. Among the most limiting soil factors are the stresses imposed by unfavorable soil conditions such as high acidity, low fertility and poor physical properties. These adverse conditions are detrimental not only to soil nutrient availability but also to root growth and development, perhaps the single most important factor in determining crop yields.

There are many soils in the southeastern United States which are acid, low in fertility, shallow, and underlain by acid and dense subsoils. Such conditions restrain root growth and nutrient uptake, and have motivated a great deal of research effort. Relationships among soil acidity, elemental toxicities, nutrient availability, liming and crop performance have been studied by Foy *et al.* (3, 8) Perkins *et al* (20), Kamprath *et al* (7, 12, 13), and Martini *et al* (14, 15). The effects of soil properties on root growth and nutrient uptake have been scrutinized by Kamprath *et al.* (9, 22, 23), Brown *et al* (10, 21), Scott and Brewer (24), Adams and Moore (2), Barber *et al* (4, 6, 11, 18, 25, 28) and Martini *et al* (16, 17).

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The main objective of this investigation was to determine the effect of lime rates and time on soil nutrient availability and nutrient uptake by a determinate soybean cultivar (*Glycine max* Merr.). Root length, as opposed to root weight or volume, was selected as the most useful parameter to characterize root growth and its impact on nutrient uptake and shoot performance.

MATERIALS AND METHODS

A growth-chamber study was conducted with soil from the A horizon of a Cecil sandy loam (Typic Hapludult). A factorial design in four randomized complete blocks was used. The experimental factors were: three lime rates (0, 3 and 6 mg/ha) applied 2 weeks before planting and four plant ages (2, 4, 6, and 8 weeks after emergence). Three mg/ha was the recommended amount of lime based on the Adams-Evans buffer method (1). Dolomitic limestone with a 100% calcium carbonate equivalent was applied. All posts received 25 $\mu g/g$ of N, 100 $\mu g/g$ of P and 50 $\mu g/g$ of K, applied as 5-10-10 and 0-20-0 at planting time. Soil and materials were mixed in a twin-shell dry blender to insure uniform distribution. The treated soil was packed to a bulk density of approximately 1.15 g/cc in white plastic containers (PVC pipes) 10 cm in diameter and 60 cm deep. The soil columns were placed on sand-filled aluminum plates and maintained at or near field capacity with distilled water.

Inoculated Bragg soybean (*Glycine max.* Merr.) seeds were planted at the rate of eight seeds per pot and the seedlings were thinned to four plants per pot two days after emergence. The growth chamber was maintained at 27°C, 50% relative humidity, and 15 hours of light per day with an intensity of 2000 to 3000 cd.

Fresh roots were collected by wet-sifting the soil through stainless steel sieves. Root samples were washed with distilled water, blotted dry and weighed. Root volume was measured by water displacement in a graduated cylinder. The average root diameter was calculated from the volume equation for a cylinder ($V = \pi r^2 L$). Root length was determined by the root-line intersection method proposed by Newman (19) and Tennant (27), using the equation: $L = N (\pi A/2H$, where L = root length, N = number of intercepts (average of 50 readings), A = sieve area, and H = length of intercepting line. Nutrient influx in μmol/m or root per day was calculated using the Williams equation (5, 29): $I = [(U_2 - U_1)/(t_2 - t_1)] [(\ln L_2/L_1)/(L_2 - L_1)]$, where I = nutrient uptake rate, U = nutrient in the plant, t = uptake time, and L = root length.

Soil analysis: Plant nutrients including Ca, Mg, K, Fe, Cu, and Zn were extracted with 40 ml of the Mehlich I solution (0.05 M HCl and 0.013 M H_2SO_4) from a 10 g soil sample (26) and measured by atomic absorption spectrophotometry.

Tissue analysis: one gram of finely ground plant tissue (whole shoots) was digested using the double acid (HNO_3 and $HClO_4$) method and nutrients determined by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

The effect of lime rates, as a function of time, on the various nutrient elements in the soil are depicted in Fig. 1. The results comply with the general trends reported in the literature cited. Liming at the recommended rate of 3 mg/ha (1X) promoted an increase of Ca and Mg up to week 6, relative to the no lime treatment (OX). The decline of Ca and Mg after week 6 was attributed to high plant uptake during the first six weeks and to some precipitation as phosphates (see Part I of this paper which appeared in Vol. 39(1), Fig. 3c). Liming with twice the recommended rate (2X) resulted in the highest soil Ca and Mg levels throughout the 8-week experiment. Soil K increased up to week 2, due to fertilization, and then decreased as a result of high plant uptake and possible interactions with the soil colloids. Liming at the recommended rate favored higher soil K availability. Soil Fe increased with time, while Cu and Zn

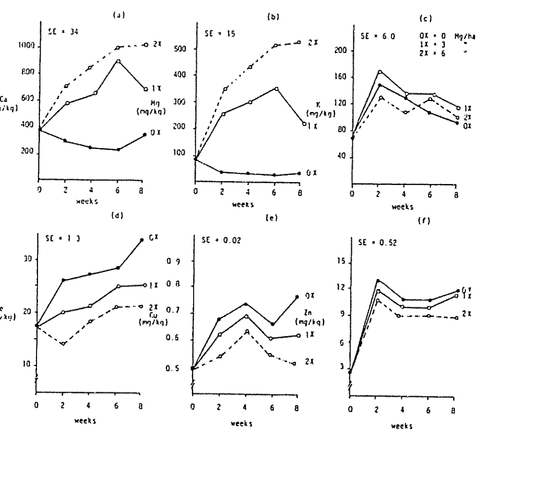

Fig. 1. Effect of lime rates and time on soil nutrient levels.

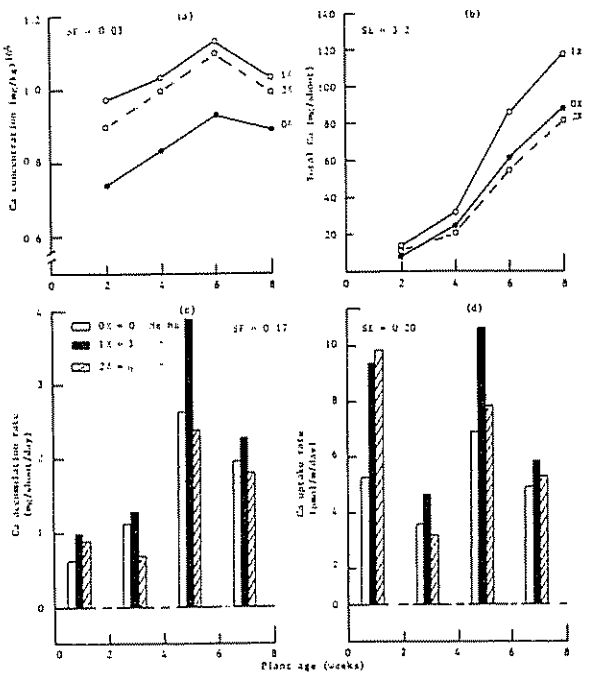

Fig. 2 Shoot Ca parameters as affected by lime rates and plant age.

increased and then decreased, mostly as a result of plant uptake. Liming reduced the availability of all three micronutrients.

The effects of lime rates and plant age on the various shoot nutrient parameters are presented in Figs. 2 through 7. Shoot Ca concentrations (Fig. 2a) in the 1X treated pots were higher than in the unlimed pots, regardless of plant age, because of higher Ca availability (Fig. 1a) and longer, finer root systems (Part I, Fig. 1). Lower shoot Ca concentrations in the 2X pots, relative to the 1X treatment and despite higher soil Ca levels, were attributed to smaller root systems. Shoot Ca concentrations increased with plant age up to week 6 and then decreased, regardless of treatment. Shoot growth failed to dilute shoot Ca concentrations up to week 6. These results were related to high nutrient uptake rates (Fig. 2d), and fast growing root systems (Part I, Fig. 1). The reduction in shoot Ca concentrations after week 6 was ascribed to lower uptake rates, and larger shoots (Part I, Table 1).

Total shoot Ca (Fig. 2b) increased with plant age, regardless of treatment, particularly after week 4 because of the high shoot growth rates (Part I, Table 1) and high shoot Ca concentrations (Fig. 2a). Lower total shoot Ca was related to low soil Ca levels (Fig. 1a) and small root systems (Part I, Fig. 1) in the unlimed soils, and to small root systems in the 2X soils. Lower shoot weight (Part I, Table 1) was also a contributing factor in both cases.

Shoot Ca accumulation (Fig. 2c) increased with age up to week 6, regardless of treatment, because of the high nutritional demands of the soybean plant and high root activity. The high Ca uptake rate per meter of root between weeks 4 and 6 (Fig. 2d), despite increasing root length (Part I, Fig. 1b), was associated with high root activity and large nutrient demands by the plant. The increase in shoot to root ratios with time (Part I, Table 2) in spite of increasing root length up to week 6 (Part I, Fig. 1b) was related to large nutrient demands and high root activity. The reduction in Ca uptake per meter of root after week 6 (Fig. 2d), despite no increase in root length (Part I, Fig. 1b), was attributed to lower nutrient demands (Fig. 2c), and to diminishing root activity associated with an aging root system and lower root growth rates (Part I, Fig. 1).

Shoot Mg concentrations (Fig. 3a) in the limed pots were higher than in the unlimed pots, regardless of plant age. Liming with twice the recommended rate did not have the detrimental effect on shoot Mg concentrations noted for Ca (Fig. 2a). Shoot Mg concentrations decreased slightly with plant age in the limed pots due to dilution by shoot growth. High plant demands for this nutrient minimized this dilution effect.

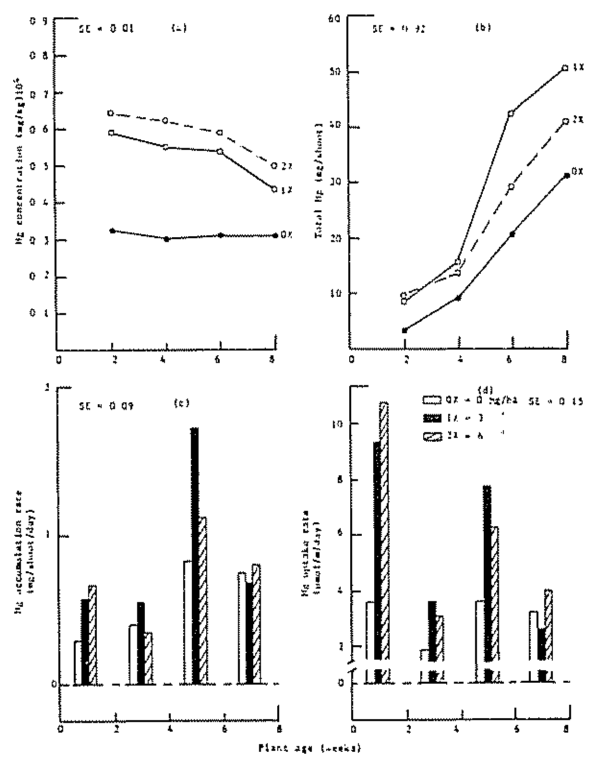

Fig. 3 Shoot Mg parameters as affected by lime rates and plant age.

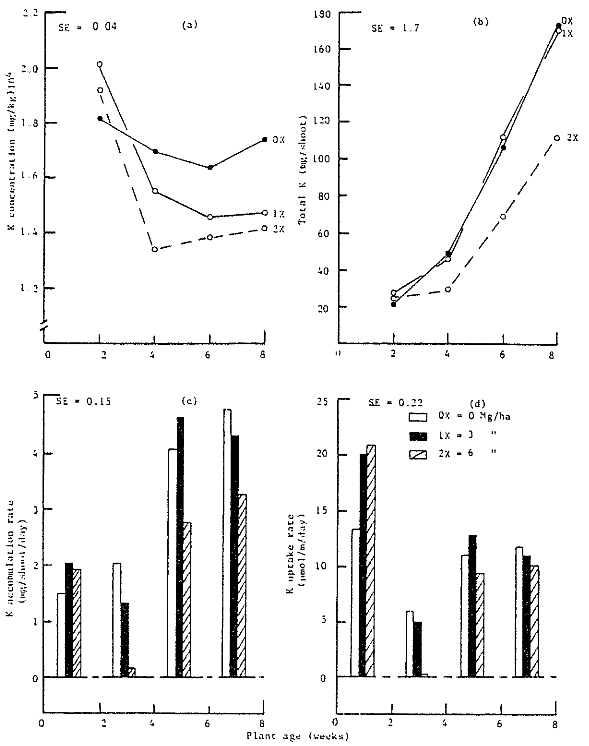

Fig. 4. Shoot K parameters as affected by lime rates and plant age.

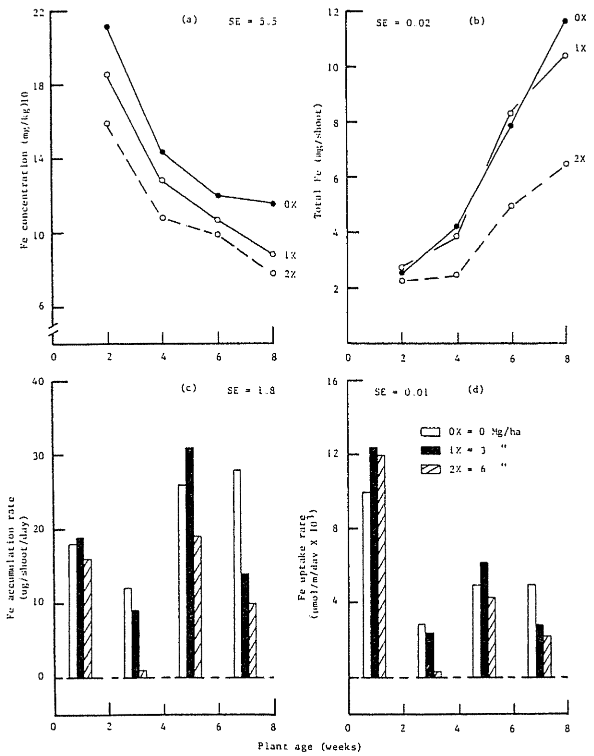

Fig. 5. Shoot Fe parameters as affected by lime rates and plant age.

Total shoot Mg (Fig. 3b) increased with plant age despite decreasing shoot Mg concentrations (Fig. 3a) because of fast shoot growth rates (Part I, Table 1). Liming favored total shoot Mg levels because of larger plants and higher soil Mg availability (Fig. 1b). Total shoot Mg in the 1X plants was higher than in the 2X plants despite lower shoot Mg concentrations (Fig. 3a) because of larger shoots (Part I, Table 1).

Shoot Mg accumulation (Fig. 3c) and uptake (Fig. 3d) paralleled the performance of shoot Ca. Liming favored these two parameters between weeks 0 and 2, and weeks 4 and 6, because of large plant nutrient demands, high root growth and activity, and ample Mg supply in the soil (Fig. 1b).

Shoot K concentrations (Fig. 4a) in the limed pots were lower than in the unlimed pots after week 3 because of reduced K uptake (Fig. 4d). The reduction in K uptake was attributed to the antagonistic effect of Ca and Mg ions present in the soil around the roots (rhizocylinder) and at the absorption sites on the roots. Calcium and Mg ions compete with K ions for space, both in the soil and on the roots. Shoot K concentrations decreased with plant age due to dilution by shoot growth and then increased by week 6 or 8 as a result of higher K uptake (Fig. 4d) under less

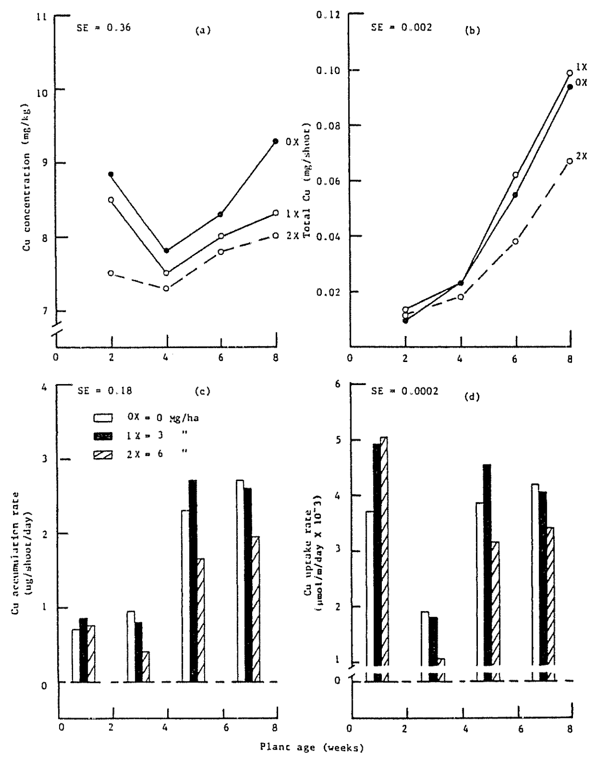

Fig. 6. Shoot Cu parameters as affected by lime rates and plant age.

Ca and Mg interference. Shoot K concentrations were lowest between weeks 4 and 6, despite high soil K supply (Fig. 1c), presumably because of high Ca and Mg uptake (Figs. 2, 3). Shoot K concentrations were more closely related to Ca and Mg parameters than to soil K availability.

Total shoot K (Fig. 4b) increased with plant age, despite some decrease in shoot K concentration. Total shoot K was reduced by overliming the soil due to lower shoot K concentrations (Fig. 4a) and smaller shoot weights (Part I, Table 1). These results were associated with lower K uptake (Fig. 4d) resulting from less roots (Part I, Fig. 1) and Ca-Mg antagonisms.

Shoot Fe, Cu, and Zn parameters (Figs. 5, 6, 7) performed similarly to those of previous nutrients in terms of plant age, and liming. Shoot nutrient concentrations were consistantly lower with liming because of reduced nutrient solubility in the soil and lower uptake at higher soil pH values (Fig. 1). Shoot nutrient concentrations were not diluted appreciably by shoot growth because of high nutrient uptake. Shoot Fe concentrations were an exception in that they decreased considerably with plant age (Fig. 5a) because of decreasing Fe uptake (Fig. 5d), despite increasing soil Fe availability (Fig. 1d).

Total shoot Fe, Cu, and Zn (Figs. 5b, 6b, 7b) increased with plant age, regardless of lime treatment and shoot nutrient concentrations. These results were attributed to fast shoot growth rates, particularly after week 4 (Part I, Table 1). Total shoot nutrient levels were always lower in the 2X pots because of reduced nutrient solubility in the soil (Fig. 1), less root growth (Part I, Fig. 1) and lower nutrient uptake (Figs. 5d, 6d, 7d).

Shoot nutrient accumulation rates (Figs. 5c, 6c, 7c) were generally highest by week 6 or 8, regardless of lime treatment. Nutrient uptake rates per meter of root (Figs. 5d, 6d, 7d) generally decreased with plant age. The low uptake rates between weeks two and four were noted for all of the nutrient elements studied.

CONCLUSIONS

A difference in the performance of shoot parameters between nutrients and non-nutrients (Al) was established, based on plant requirements. When dealing with nutrient elements, plant demands were high

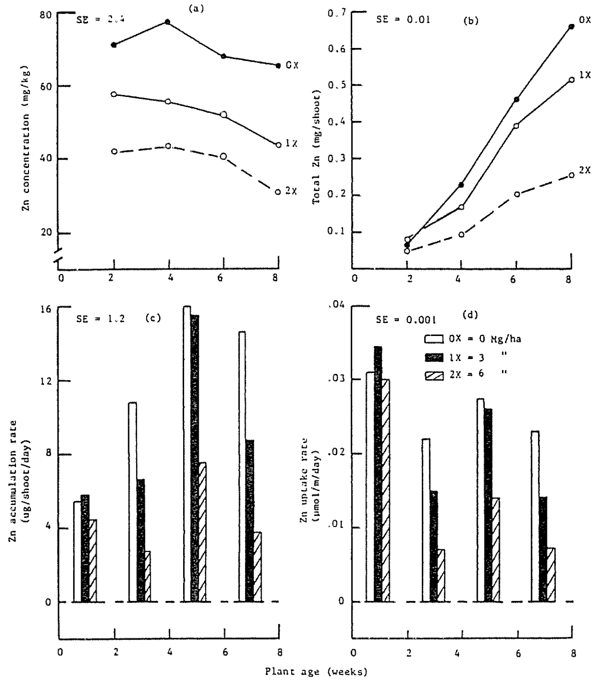

Fig. 7. Shoot Zn parameters as affected by lime rates and plant age.

and consequently nutrient uptake and concentration in the shoots increased, or remained constant. If a decrease occurred, it was not as drastic as with a non-nutrient.

Nutrient uptake per meter of root in the shoots generally followed a decreasing trend with plant age because of dilution by shoot growth and decreasing root activity. Lower root activity was attributed to aging of roots and increasing length of young roots which reduced the uptake demands by each meter of root. Nutrient uptake rates per meter of root related better to shoot nutrient concentrations than shoot nutrient accumulation rates.

Nutrient parameters of shoots generally increased with liming at the recommended rate. These results were related to increased soil nutrient availability in the case of the macronutrients, and to longer and finer root systems in the case of the macronutrients and micronutrients. Liming with twice the recommended rate generally depressed shoot nutrient parameters. These results were attributed to small root systems in the case of the macronutrients and micronutrients, and to limited soil nutrient supply in the case of the micronutrients.

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