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SLASH PINE SEEDLING RESPONSE TO POTASSIUM AND CALCIUM ON IMPERFECTLY DRAINED COASTAL PLAIN SOIL

by W. H. McKEE, Jr.*

ABSTRACT

In a greenhouse study, increases in dry weight and N, P, K, Ca, and Mg content of seedlings from a preplanting application of 0.16 meq K/100 g of Caddo silt loam topsoil were markedly greater on soil containing 0.06 meq K, than on soil containing 0.09 meq K/100 g. Except for further increasing K and reducing Ca content of seedlings, applications of 0.32 and 0.48 meq K/100 g added little to growth or nutrient accumulation. Additions of 1 to 5 meq Ca/100 g either did not affect or slightly reduce dry weight and uptake of all nutrients except Ca. Potassium and calcium treatments did not interact to influence growth or nutrient uptake. Dry weight and accumulation of N, P, and K were all associated with the amount of K available; Ca accumulation was related only to available Ca.

INTRODUCTION

Imbalances between K and Ca in the soil cause physiological disorders and poor growth in many plants[3 11]. Also, antagonisms have been found between K and Ca in 5-year-old loblolly pine (*Pinus taeda* L.) growing on Piedmont soils in North Carolina, where increased foliar concentration of one depressed the level of the other and increased soil Ca depressed foliage K levels[10].

This study determines how K and Ca, individually and collectively, affect growth and nutrient recovery by slash pine (*P. elliottii* Engelm. var. *elliotti*) seedlings in pots of silt loam topsoil. The soil

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used is characteristic of imperfectly drained Pleistocene terrace profiles in the West Gulf Coastal Plain. Results help determine whether or not levels of these two nutrients influence the effectiveness of fertilizers containing N and P, nutrients that have promoted slash pine growth[6].

MATERIALS AND METHODS

Slash pine seedlings were grown in a greenhouse for one year at four levels of K and six levels of Ca. Potassium levels were 0, 0.16, 0.32, and 0.48 meq/100 g soil; calcium levels were 0, 1.0, 2.0, 3.0, 4.0, and 5.0 meq/100 g. Treatments were imposed in factorial combination on Caddo silt loam (Typic Glossaqualf, fine-silty, siliceous, thermic) topsoil (3 to 10 cm depth) from two locations in central Louisiana. Sampling at each location was confined to a 10 m^2 area. Treatments were replicated twice in a randomized block design.

Both sites were originally covered with longleaf pine (*Pinus palustris* Mill.) and native grasses, principally *Andropogon* spp. Pines had been clearcut about 65 years previously, and present vegetation consisted of native grasses, post (*Quercus stellata* Wangenh) and blackjack (*Q. marilandica* Muenchh) oaks, longleaf, and loblolly pine saplings, and waxmyrtle (*Myrica cerifera* L.). Both sites occupied a low topographical position with imperfectly drained soils and had never been cultivated.

TABLE 1

Physical and chemical soil properties

Item	Unit	Site 1	Site 2
Physical properties			
Sand	%	32	23
Silt	%	61	61
Clay	%	7	16
Organic matter	%	3.0	4.0
Water content at 1/3 atm.	%	21	24
Chemical properties			
pH	—	4.40	4.20
CEC*	meq/100g	5.87	4.78
Exch. Ca	meq/100g	1.23	1.95
Exch. Mg	meq/100g	.54	.40
Exch. K	meq/100g	.09	.06
Exch. Na	meq/100g	.04	.06
Exch. Mn	ppm	200	28

* Potassium saturated and buffered at pH 7.

Physical and chemical properties are summarized in Table 1 for soils from the two sites. Calcium occupied about 20 percentage points more of the exchange sites in soil from site 2 than from site 1 and exchangeable K was only two-thirds as abundant in site 2 soil. Actual values for individual properties and variations between samples were characteristic of the soil series[9].

Soil samples were air-dried, shredded to pass a 2.5 mm screen, and thoroughly mixed. Six and six-tenths kg of soil (oven-dry basis) were placed in each of 96 25-cm plastic pots lined with polyethylene bags. Potassium as reagent grade K_2SO_4 and Ca as reagent grade $CaCO_3$ were applied as dry salts and mixed with soil at indicated levels for each pot. Each pot received 2.63 g $(NH_4)H_2PO_4$ which supplied N at 48 ppm and P at 108 ppm. All materials were thoroughly mixed with the soil in a twin-shell blender.

Four equal surface applications of an aqueous NH_3NO_4 solution in the first, second, third, and tenth months supplied additional N at 83 ppm. The soil thus received a total of 131 ppm N. The N and P were applied to ensure that responses to Ca and K would not be masked by insufficiencies of other nutrients; applied levels of N and P were based on amounts found adequate in a previous study[6].

Open-pollinated seeds from a single tree were germinated in vermiculite, and 10 seedlings were planted in each pot in mid-July. Pots received distilled water as needed to maintain soil moisture at 50 to 90 per cent of the 1/3 atm. moisture percentage. Root inspection at the end of the study indicated that the entire soil mass maintained adequate moisture for good root development. Temperature was maintained above 16°C during winter and below 35°C during summer. Pots were rotated weekly within blocks to offset shading and other positioning effects.

Plants were harvested at 51 weeks. At that time, 4 2.5-cm soil cores were taken from each pot. Samples were dried, ground to pass a 2.5-mm screen, and thoroughly mixed. Soil pH was measured with a glass electrode on a 1:2 soil/water mixture. Exchangeable bases were determined by atomic absorption on extracts made with $1N$ NH_4OAc[2].

Roots were washed and plant material was dried at 70°C for 24 hours. Seedlings were segmented into roots, stems, and needles. The material was then weighed, and ground to pass a 1-mm screen. One g of plant material was dry-ashed at 450°C for two hours and taken up in $0.3N$ HNO_3. Phosphorus was determined by the vanadomolybdate procedure[5], N by Kjeldahl analysis[5], and Ca, Mg, and K by atomic absorption. Values were then summed to determine total nutrients extracted from the soil.

RESULTS AND DISCUSSION

Fertilization with either K or Ca produced significant* changes in growth and nutrient uptake. Response patterns to the two nutrients

* Significance was tested at 0.05 level.

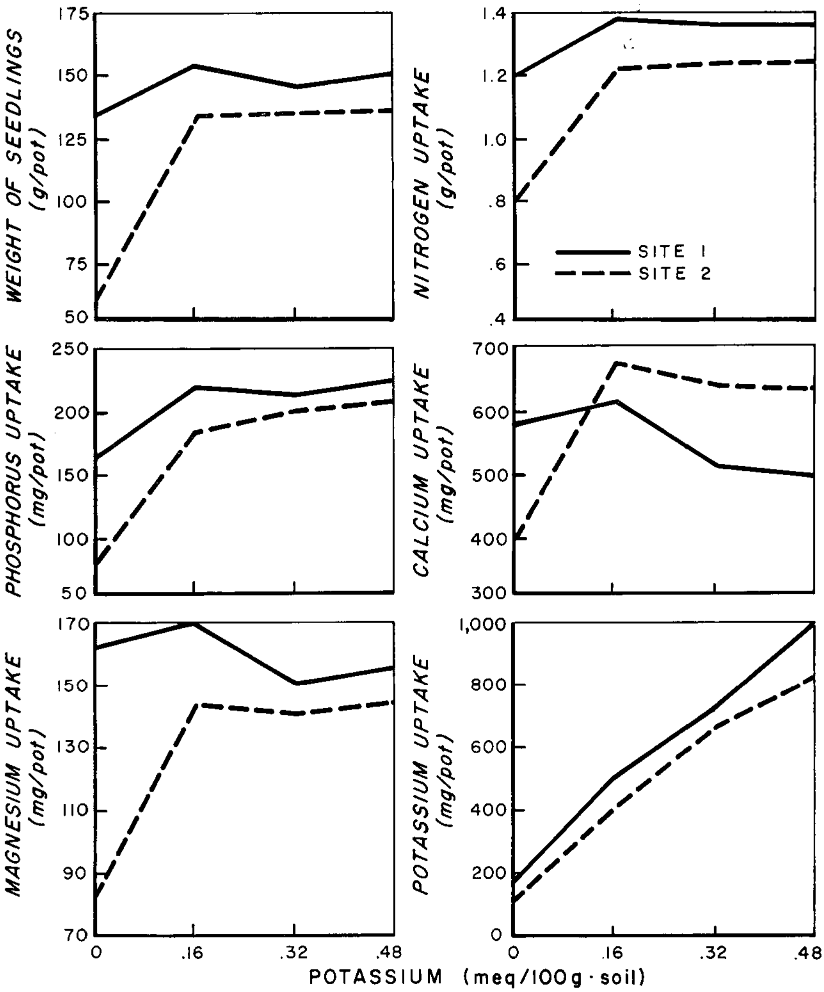

Fig. 1. Effect of potassium on total dry weight of seedlings and uptake of nutrients.

were markedly different, however, and responses to additions of one nutrient were not related to additions of the other.

Addition of 0.16 to 0.48 meq K/100 g soil generally increased growth and uptake of N, P, and K (Fig. 1). Levels about 0.16 depressed uptake of Ca and Mg. There were, however, significant differences in the plant response to K between soil from the two sites.

For site 1 soil, the analysis of variance indicated a significant increase in seedling dry weight from the first increment of potassium but no additional gain from the second or third, The increase from 0.16 meq averaged 17 per cent or 22 g/pot.

For this soil, second or third degree polynomials best described the effects of K treatments on total N, P, and K uptake. For N and P, the curve forms reflected a positive response to 0.16 meq but little or no additional response to 0.32 or 0.48 meq. Uptake of K increased with each increment of added K, but the curve leveled slightly as greater amounts were applied. The depression of Ca and Mg by K, especially at higher levels, was significantly linear.

For site 2 soil third degree polynomials best described the effects of added K on seedling dry weights and uptake of all nutrients except K. Weights increased 135 per cent and uptake of N, P, Ca, and Mg increased 52 to 135 per cent by adding 0.16 meq K. Higher levels produced little or no additional gain. As with site 1 soil, there was a substantial increase in K uptake with each increment of added K and only a slight leveling of the curve at the higher levels. Thus, in both samples and at the two higher K treatments, plants removed more K from the soil than they utilized in additional growth.

This may be explained by the results of Hipp and Thomas[4]. They found that most K in weakly charged or mixed clay soils of this type is in the soil solution. Thomas[8] indicates that K in such soils is readily available to plants if exchangeable K remains above about 0.05 meq/100 g. In the 0.16 meq treatment, soils from sites 1 and 2 exceeded 0.07 meq of exchangeable K/100 g when plants were harvested.

The difference between 0.06 and 0.09 meq of exchangeable K/100 g soil (sites 1 and 2) was apparently responsible for the 74 g/pot difference in the final dry weights of seedlings that received no additional K.

Seedlings growing in soils from both sites responded similarly to additions of Ca. For all Ca treatments, there was a significant linear decrease in seedling dry weights and uptake of N and P and a significant linear increase in uptake of Ca (Table 2). Compared to no additional Ca, the 5 meq treatment reduced dry weights by 7 per cent, N uptake 6 per cent, and P uptake 14 per cent. It increased Ca uptake 82 per cent. Plants removed 0.23 and 0.74 meq Ca/100 g soil from the 0 and 5 meq treatments respectively. Potassium and Mg

TABLE 2

Seedling dry weight and nutrient uptake by calcium treatment

Calcium level meq/100g	Dry weight g/pot	Nutrient uptake (mg/pot)				
		N	P	K	Ca	Mg
0	135.1	1.27	200	586	380	142
1	138.5	1.27	197	576	485	151
2	135.2	1.24	187	551	551	145
3	126.5	1.21	175	527	579	136
4	132.0	1.20	187	573	670	146
5	126.3	1.19	172	554	692	139

uptake were not significantly affected by Ca levels. These results indicate that 1.2 and 1.9 meq Ca/100 g unamended soil were adequate for seedling growth even when N and P were at near optimum levels.

To learn how efficient seedlings were in recovering the two nutrients, recovery percentages of applied plus native exchangeable K and Ca were computed by dividing nutrient amounts in the plant material by amounts in plants plus amounts that remained in the soil in exchangeable form. This gave values for native plus applied K that were higher than those computed from initial test values and actual amounts applied. The difference may reflect slow release of fixed K, contamination through watering and handling pots, or release of potassium by micro-organisms during the study.

Seedlings were able to compete favorably with soil microorganisms for K and recovered 40.7 to 76.6 per cent of the total amount available (Table 3). Statistical analysis showed a significant

TABLE 3

Effect of potassium treatments on per cent of applied plus exchangeable calcium and potassium taken up by slash pine seedlings

Potassium level applied	Nutrient recovery (per cent)			
	Potassium		Calcium	
meq/100g	Site 1	Site 2	Site 1	Site 2
0	54.8	40.7	13.8	8.6
0.16	73.9	69.3	13.1	13.9
0.32	73.4	76.6	12.3	13.1
0.48	67.3	73.7	12.5	12.9

quadratic relationship between recovery percentages and amounts applied. Applications of 0.16 and 0.32 meq increased ratios 19 and 36 percentage points. Potassium recovery was unaffected by Ca level.

Plants recovered only about 9 to 14 per cent of the available Ca. Potassium fertilization significantly increased recovery of Ca from site 2 soil but had no effect on recovery from site 1 soil. Differences in growth response between soil samples to K additions were probably responsible for the discrepancy. While all additions of K to site 2 soil increased recovery rates, 0.16 meq produced the highest rate of 13.9 per cent. Calcium recovery from the two soils declined about 1.2 and 0.9 percentage points for each meq of applied Ca.

Further insight into the Ca effect on this soil can be seen where application of calcium carbonate failed to change soil pH, in spite of the fact that 5 meq Ca should have been more than enough to completely saturate the exchange complex based on exchangeable base properties initially observed. The pH values of the two soils at the end of the study ranged from 4.65 to 5.80 over the six calcium levels indicating the exchange complex was not saturated. This discrepancy can probably be explained by the highly pH-dependent nature of the exchange sites on this soil, and the tendency for the soil to undergo complexing of polyvalent cations with organic matter or amorphous metal oxides[1].

Because native as well as added K and Ca seemed to influence growth and uptake of nutrients, final dry weights and nutrient contents of seedlings in all treatments were related by correlation analysis to selected chemical properties of amended and unamended soils (Table 4). Soil properties used in the analyses were: (1) exchangeable K or Ca in the soil at the end of the test (soil K or Ca), (2) exchangeable K or Ca in the soil at the end of the test plus K or Ca taken up by plants (soil + plant K or soil + plant Ca/, and (3) potassium absorption ratio, PAR[7], based on residual soil levels of K, Ca, Mg (PAR 1) or residual soil plus plant values (PAR 2). Soil plus plant values approximate the level of nutrients available to plants at the beginning of the study after fertilizers were added. The PAR values were computed as follows with all values in meq/100 g soil:

$$\mathrm{PAR} = \mathrm{K}^{+}/\sqrt{(\mathrm{Ca}^{++} + \mathrm{Mg}^{++}\ /2}$$

Log_{10} transformations of the six parameters were also compared with seedling dry weights and nutrient uptake.

TABLE 4

Correlation coefficient of seedling dry weights and uptake of nutrients to selected soil and plant properties*

Item	Dry wt. of seedlings	Nutrient uptake			
		N	P	K	Ca
		Correlation coefficient (r)**			
Soil K (residual at harvest)	0.26	0.21	0.31	0.69	−0.07
Soil (residual) + plant K	.59	.55	.69	.94	.11
Soil Ca (residual at harvest)	−.20	−.25	−.23	−.07	.61
Soil (residual) + plant Ca	−.15	−.15	−.19	−.85	.67
PAR 1	.38	.36	.48	.66	−.22
PAR 2	.59	.57	.70	.90	−.11
Log residual soil K	.40	.34	.50	.70	−.01
Log (residual soil + plant K)	.72	.68	.80	.95	.24
Log soil Ca	−.21	−.26	−.24	−.06	.63
Log (residual soil + plant Ca)	−.17	−.23	−.20	−.05	.67
Log PAR 1	.51	.47	.61	.74	.15
Log PAR 2	.72	.69	.80	.90	.08

* All cations are in meq/100 g soil.

** Based on 96 observations, an r of ± 0.20 is significant at 0.05 level.

Correlation analyses indicated a significant linear relationship between seedling dry weight and $\log_{10}$ of meq/100 g soil plus plant K at the end of the test (an approximation of available K at the beginning) which accounted for 52 per cent of the difference in seedling dry weights. Except for the $\log_{10}$ of PAR based on residual soil plus plant K, Ca, and Mg, no other soil property was more closely related to seedling dry weights. The soil plus plant K or its log accounted for 30 to 90 per cent of the variation in N, P, and K uptake while exchangeable K or the log of this value accounted for 4 to 49 per cent. The PAR values for the residual soil plus plant K, Ca, and Mg accounted for 32 to 81 per cent of the variation while values for residual amounts in the soil accounted for 12 to 55.

The better correlations for K in plant material plus K in the soil at the end of the study or the PAR values derived from this quantity compared to correlations obtained with soil K levels alone reveal the effects of luxury consumption of K by the slash pine seedlings. Calcium uptake was more closely related to Ca levels than to other variables in the soil. Soil properties accounted for 37 to 46 per cent of the variation in uptake. The rather poor correlation of Ca with growth or uptake may be the result of the complexing of Ca by the soil and strong pH-dependent exchange capacity observed.

CONCLUSIONS

For Caddo silt loam soil, results indicate that low levels of available potassium may limit slash pine growth if adequate amounts of N and P are present. Findings indicate that Ca is not limiting and application of this nutrient could be detrimental at least for early slash pine growth. Slash pine requirements for Ca and K are low compared to requirements of agronomic crops.

These results were obtained under near optimum soil moisture conditions in which the root system, at least in the later stages of growth, was restricted. Hence, field-grown slash pine may be less sensitive to soil K levels. The high degree of K solubility and the ability of the seedlings to assimilate the nutrient indicate that whole tree harvesting could easily produce a deficient condition for K, if the soils were naturally low in K or other nutrients were either applied or adequate. The requirements for Ca appear less clear since at least part of the applied Ca is not present as an exchangeable base but in some way may be available to the plant. The slash pine requirements for Ca will require further study on these soils.

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