Potassium, Magnesium, and Calcium

REQUIREMENTS *of* VIRGINIA PINE

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STATION PAPER NO. 169 • NORTHEASTERN FOREST EXPERIMENT STATION • 1962
FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE • UPPER DARBY, PA.
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Nutrients and Growth

FOR most forest tree species, nutrient requirements have not been investigated beyond general field observations and empirical tests of fertilizers in nurseries and plantations. For Virginia pine (*Pinus virginiana* Mill.), the first work on nutrition under controlled conditions was a sand-culture study of nitrogen and phosphorus requirements by Fowells and Krauss (1959). The present study extends and complements their work by using similar sand-culture procedures to investigate the potassium, magnesium, and calcium requirements of Virginia pine. And, like the work of Fowells and Krauss, it deals with the relationships between (1) nutrient supply and growth, (2) nutrient supply and uptake, (3) concentrations of elements in the needles and growth, and (4) deficiencies of elements and visual symptoms, as expressed in reduced growth.

Procedures

Seedlings for the experiments were grown from fresh seed collected locally in 1956 in Prince George's County, Maryland. Seeds that were noticeably larger or smaller than average were discarded. Seedlings were started and grown for 2 months in acid-washed white quartz sand in flats, watering only with distilled water. On 15 April 1957, when epicotyls had just begun to elongate and roots were 5 to 10 cm. long, the seedlings were transplanted into 27-liter polyethylene containers filled with water-washed white quartz sand. Twelve seedlings were planted in each container; these were reduced to four in September by a systematic thinning. The containers were set up in a greenhouse (fig. 1) at the University of Maryland in College Park.

The study involved two separate experiments. In one, plant responses were compared for six levels of potassium (K); in the other, for all combinations of three levels of magnesium (Mg) and five levels of calcium (Ca). The potassium experiment was set up in a randomized-block design, with three replicate containers of each nutrient level. The magnesium-calcium experiment was not replicated.[1] The different levels of the three elements were (in parts per million) as follows:

Potassium: 0.4, 4, 40, 136, 235, and 585 ppm.
Magnesium: 0.15, 24, and 243 ppm.
Calcium: 0.2, 2, 20, 100, and 300 ppm.

Potassium and calcium were supplied as the chlorides, magnesium as the sulphate. In both experiments, all essential elements that were not experimental variables were supplied in amounts considered to be adequate for normal growth (table 1).

The initial pH of all culture solutions was 5.7. Solutions were replaced with fresh ones every 2 or 3 weeks. Between solution changes, sodium hydroxide or calcium hydroxide was added to keep the pH above 4.0.

From 15 April till the following January, each container of seedlings was irrigated hourly with 1.5 liters of nutrient solution

[1]This experiment was begun with 2 replicates, but 1 replicate was dropped because of accidental seedling mortality in 5 containers.

Figure 1.—The plastic containers (foreground) in the greenhouse 1 month after the Virginia pine seedlings were transplanted.

drawn from individual 25-liter reservoirs. The automatic irrigation system described by Gauch and Wadleigh (1943) was employed in both experiments. Actuated by a time clock, the system forced solution from each reservoir into its container through a perforated plastic ring resting on top of the sand (fig. 2).

To break the natural dormancy that became evident during the short days of October and to prevent its recurrence, the seedlings were given 4 hours of supplemental light (10 p.m. to 2 a.m.) for the rest of the experiment. This was provided by 18 incandescent 200-watt bulbs suspended over the containers. The light intensity was 40 to 60 foot-candles at the root-collar level.

In January 1958 the seedlings were harvested and oven-dried at 70° C. for at least 24 hours. The four pines in each container (after thinning in September) were weighed together and all their needles were composited for analyses. Needles were ground

Figure 2.—Close-up of one of the containers. The nutrient solution was fed to the seedlings through the plastic tubing and the perforated plastic ring.

in a Wiley mill and 1000-mg. samples were ashed in a muffle furnace at 525° C. and then dissolved in 2 to 5 ml. of 1:5 HCl. All analyses are reported on the basis of oven-dry weight.

K and Ca were determined with a Beckman DU hydrogen-flame spectrophotometer. Phosphoric acid was added in the Ca analyses so that both standards and samples had phosphorous concentrations of 100 to 200 ppm. Mg was determined by a modified titan-yellow test (Peech and English, 1944). Duplicate analyses for K were consistent within 5 percent; most of those for Ca and Mg were consistent within 10 percent, although a few varied as much as 20 percent.

The data were evaluated by analyses of variance, and differences among means were examined in accordance with Duncan's (1955) multiple-range test.

Table 1.—*Concentrations of the elements in the nutrient solution supplied to Virginia pine seedlings in sand culture*

Element[1]	Potassium experiment	Calcium-magnesium experiment
	Parts per million	*Parts per million*
K	0.4 to 585	137
Mg	24	0.16 to 243
Ca	100	0.20 to 300
Na	0	58
$N\text{-}NH_4$	37	37
$N\text{-}NO_3$	81	81
$P\text{-}PO_4$	19	19
$S\text{-}SO_4$	42	16 to 336
Cl	0.4 to 533	21 to 553

[1]The concentrations of the minor elements in both studies were: Fe—3.0 ppm., Cu—0.01 ppm., Zn—0.05 ppm., Mo—0.02 ppm., B—0.50 ppm., and Mn—0.50 ppm.

Results

Nutrient Supply and Growth

Concentrations of the three elements influenced growth of the Virginia pine seedlings only at the lowest levels of K and Mg. Thus it appears that some of the concentrations selected for testing were adequate or more than adequate for normal growth of this species. In the K experiment, seedlings grew significantly less at the 0.4-ppm. level than at the 4-ppm. and higher levels; differences among the levels higher than 0.4 ppm. mostly were insignificant (table 2).

In the magnesium-calcium experiment, seedlings grew less at 0.15 ppm. Mg than at the higher levels of Mg at all Ca levels (table 3). At the lowest level of Mg, growth was increasingly suppressed by increasing amounts of Ca—to the point of death at the highest (300 ppm.) Ca level.

Apart from this interaction at the low Mg level, Ca concentrations did not affect growth (table 3). However, spectrographic analyses of nutrient solutions indicated contamination with

Table 2.—*Growth of Virginia pine seedlings at six levels of supplied potassium*

Potassium in nutrient solution	Growth of seedlings	
	Height	Dry weight
Ppm.	*Cm.*	*Gm.*
0.4	7 a[1]	1.7 a
4	32 b	13.3 b
40	41 bc	16.8 b
135	45 c	21.6 b
236	39 bc	14.1 b
585	36 bc	15.4 b

[1]Means within a column having any letter in common are not significantly different from each other at the 5-percent level. Each figure is mean of 3 containers of seedlings, the 3 replicates.

Table 3.—*Growth of Virginia pine seedlings at five levels of supplied calcium x three levels of supplied magnesium*

Calcium in nutrient solution (ppm.)	Magnesium in nutrient solution (ppm.)		
	0.15	24	243
	DRY WEIGHT OF SHOOT (*Gm.*)		
0.2	10 abc[1]	21 de	18 cde
2	7 ab	21 de	17 bcd
20	7 ab	28 e	19 cde
100	4 a	19 cde	21 de
300	[2]	21 de	16 bcd
	HEIGHT OF SHOOT (*Cm.*)		
0.2	26 bc[1]	42 cd	33 bcd
2	20 ab	43 cd	43 cd
20	20 ab	52 d	40 cd
100	12 a	45 cd	44 cd
300	[2]	43 cd	38 bcd

[1]Means within each growth measure having any letter in common are not significantly different from each other at the 5-percent level. Each figure is the average of the 4 seedlings in a single container.
[2]Died.

additional Ca in amounts ranging up to 3 ppm. Hence the Ca concentrations were higher than designated in table 3.

Nutrient Supply and Uptake

Within limits, the uptake of K, Mg, and Ca by Virginia pine seedlings was positively related to the supply. The increase in uptake with increase in supply was measured in two ways: (1) as the percent dry weight of an element in the needles; and (2) as the total weight of an element in all the needles of a seedling.

In the potassium experiment, the percent of K in the needles increased with increasing supply up to the 40-ppm. level, and the weight of K in the needles increased from 3 to 80 mg. per plant with increase in the supply from 0.4 to 4 ppm. (table 4). The higher levels of supply did not result in corresponding increases in uptake.

In the magnesium-calcium experiment, seedlings absorbed significantly less Mg at the 0.15-ppm. level of supply than at the higher levels; this was true both in percent of dry weight and in absolute weight per plant (table 5). For Ca, the relationships

Table 4.—*Potassium in needles of Virginia pine seedlings grown in sand culture with six levels of potassium*

Potassium in nutrient solution	Potassium in needles	
	Concentration	Amount per plant
Ppm.	*% dry wt.*	*Mg.*
0.4	0.28 a[1]	3 a
4	.63 b	80 b
40	.99 c	121 b
135	.91 c	137 b
236	1.00 c	99 b
585	1.00 c	115 b

[1]Means within a column having any letter in common are not significantly different from each other at the 5-percent level. Each figure is mean of 3 containers of seedlings, the 3 replicates.

Figure 3.—Relationship between the height of the Virginia pine seedlings and the potassium concentration in their needles. Each point is the mean for one container. Two of the original 18 containers were lost during the experiment, so only 16 points appear in the diagram.

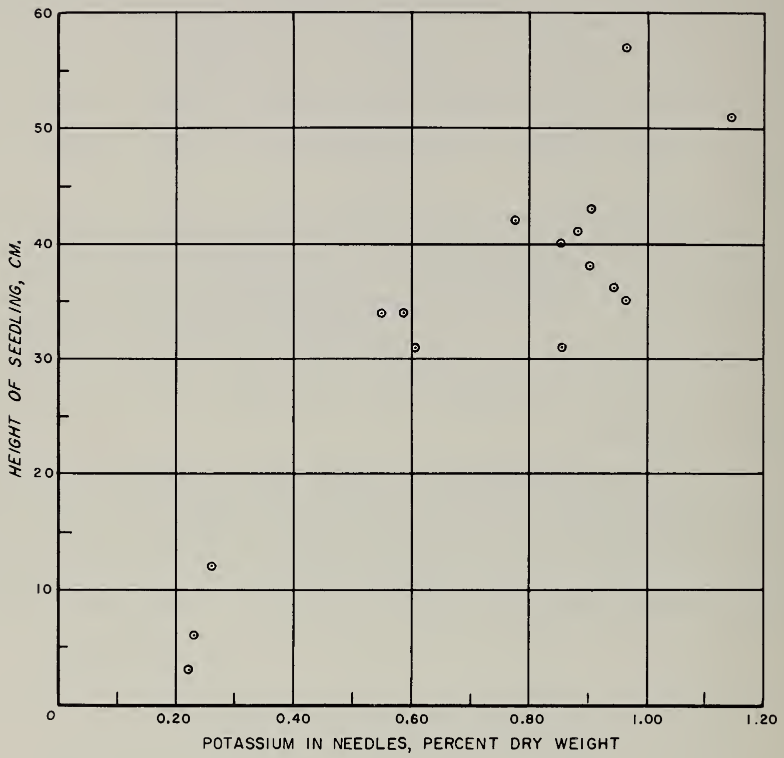

Table 5.—*Magnesium in needles of Virginia pine seedlings grown in sand culture with three levels of magnesium*

Magnesium in nutrient solution	Magnesium in needles	
	Concentration	Amount per plant
Ppm.	*% dry wt.*	*Mg.*
0.15	0.08 a[1]	4 a
24	.22 b	34 b
243	.25 b	32 b

[1]Means within a column having any letter in common are not significantly different from each other at the 5-percent level. Each figure is the mean of 5 containers of seedlings, the 5 levels of calcium.

Table 6.—*Calcium in needles of Virginia pine seedlings grown in sand culture with five levels of calcium*

Calcium in nutrient solution	Calcium in needles	
	Concentration	Amount per plant
Ppm.	*% dry wt.*	*Mg.*
0.2	0.16 a[1]	18 a
2	.25 ab	26 ab
20	.39 ab	43 b
100	.47 b	34 ab
300	.42 b	34 ab

[1]Means within a column having any letter in common are not significantly different from each other at the 5-percent level. Each figure is the mean of 3 containers, the 3 levels of magnesium.

were not so clearly defined. However, a trend toward increasing uptake with increasing supply was evident, and some of the differences in uptake were significant (table 6).

Element Concentrations in Needles Related to Growth

Growth was positively related to concentrations of K and Mg in the needles: K concentrations below 0.28 percent dry weight were associated with retarded growth and concentrations above 0.75 percent with rapid growth (fig. 3)[2]; Mg concentrations near 0.08 percent dry weight were associated with retarded growth and concentrations above 0.18 percent with rapid growth (figs. 4 and 5)[2].

Ca concentrations in the needles varying from 0.10 to 0.44 percent (individual container averages) did not affect growth when foliar concentrations of Mg were 0.18 percent or more.

When foliar concentrations of Mg were around 0.08 percent, the seedlings grew progressively less as their Ca content rose from 0.25 percent to an observed maximum of 0.83 percent.

[2]Lines are not fitted to the points in these dot diagrams because the relationships are not linear and the data are insufficient to define the curves.

Deficiency Symptoms

Deficiency symptoms other than reduced growth appeared in seedlings grown at the lowest levels of K and Mg. They have been described elsewhere in detail (Sucoff, 1961) and are only summarized here.

The K-deficiency symptoms were discoloration and death of the needles and, in severe cases, top dieback. These symptoms were associated with K concentrations in the needles of 0.28 percent dry weight or less. They first appeared when the seedlings were 2 cm. tall. The needles purpled and browned from their tips and only a few fasicular needles developed.

Mg deficiency was characterized by yellowing of the needles and, in severe cases, by top dieback. Concentration of Mg in the needles of deficient plants was about 0.08 percent. The yellowing began at the needle tips and progressed stemward; it was followed by browning.

Ca deficiency symptoms were not produced in the experiment because that element never became limiting.

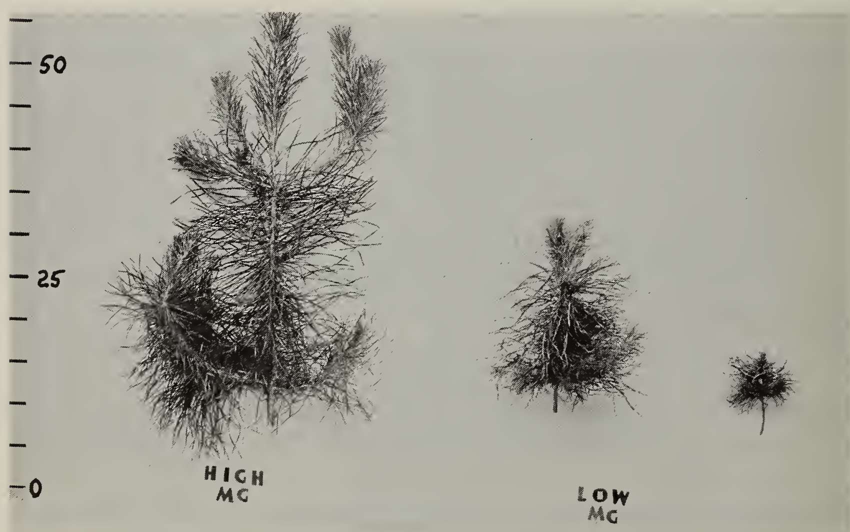

Figure 4.—The height of these Virginia pine seedlings was related to the concentration of magnesium in their needles. From left to right the concentrations were: 0.26 percent, 0.08 percent, and 0.07 percent dry weight.

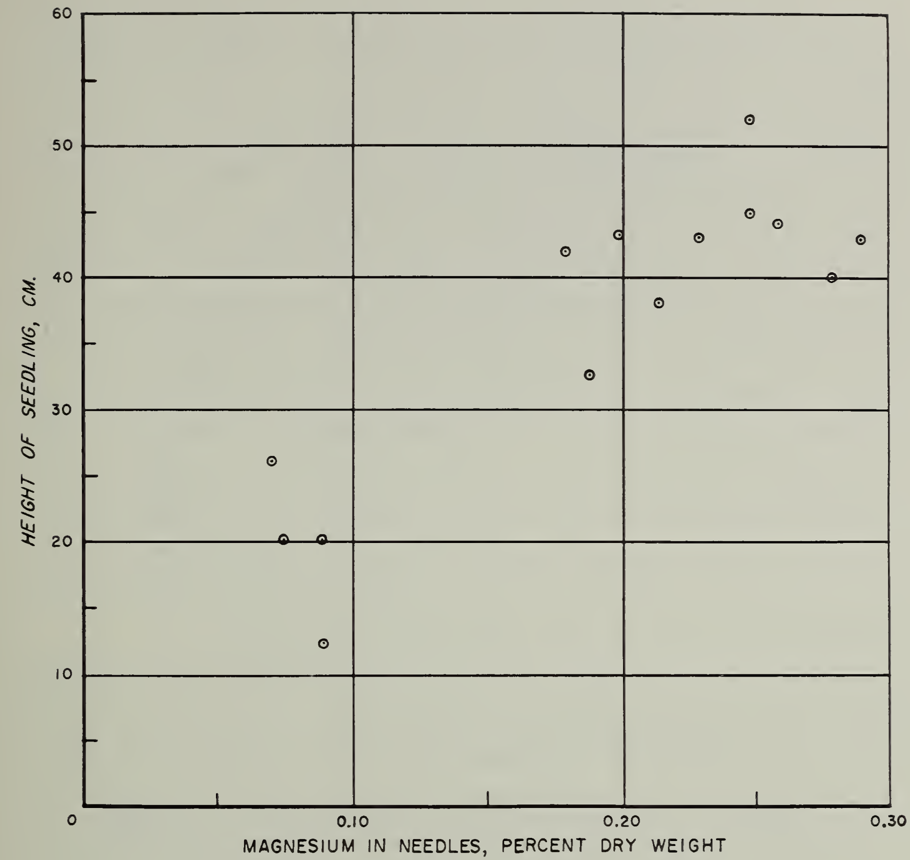

Figure 5.—Relationship between the height of the Virginia pine seedlings and the magnesium concentration in their needles. Each point is the mean for one container. Since all seedlings in the low-magnesium/high-calcium container died, only 14 points appear in the diagram.

Discussion

Three questions about the nutrient requirements of Virginia pine warrant special discussion: (1) What are the minimum concentrations of K, Mg, and Ca in the root environs that will support rapid growth? (2) How accurately can concentrations of these elements in the needles be related to growth? (3) Is there any evidence that Virginia pine has lower nutrient requirements than loblolly pine?

As to the first question: the minimum concentration of K apparently lies between 0.4 and 4 ppm.; at 0.4 ppm. growth was slow and at 4 ppm. it was nearly maximum (table 2). However, actual concentrations in the solutions were much lower most of the time than 0.4 or 4 ppm. These designated concentrations were only present just after the periodic change of solutions; after that they were quickly lowered through seedling absorption. Judged from a more recent experiment with loblolly pine,[3] both the 0.4- and the 4-ppm. solutions during the last 3 months of the Virginia pine experiment probably fell below 0.1 ppm. within a week after changing. Moreover, rapid absorption must have appreciably lowered ion concentrations around the roots between hourly irrigations. In short, the concentrations of K actually bathing the roots were unknown. One can say only that the minimum concentration of K for good seedling growth was something less than 4 ppm.

Attempts to determine the lowest concentrations of Mg and Ca that will support rapid growth were not very successful. The 0.15-ppm. level of Mg—at least when subjected to the depletion occurring under the experimental regimen—was too low. One can say only that the requisite level of Mg is something less than 24 ppm. For Ca, contamination of the solutions probably added more than the plants removed. Considering that this contamination amounted to as much as 3 ppm., and that no deficiency symptoms appeared at the designated 0.2-ppm. level, it was assumed that the minimum level of Ca for good growth is something less than 3 ppm.

As to the second question: the relationship between concentration of a limiting element and growth has been successfully represented for many crops (Ulrich, 1952; Goodall and Gregory, 1947), and for loblolly pine,[3] by means of a three-zone response curve (fig. 6). In zone I, growth increases sharply with very small increases in element concentration; these differences in concentration are too small to permit growth to be predicted from concentration. In zone II, growth increases occur only with

[3]Sucoff, Edward I. Potassium, magnesium, and calcium nutrition of *Pinus taeda* L. Doctoral dissertation, Univ. Maryland, 78 pp., 1960.

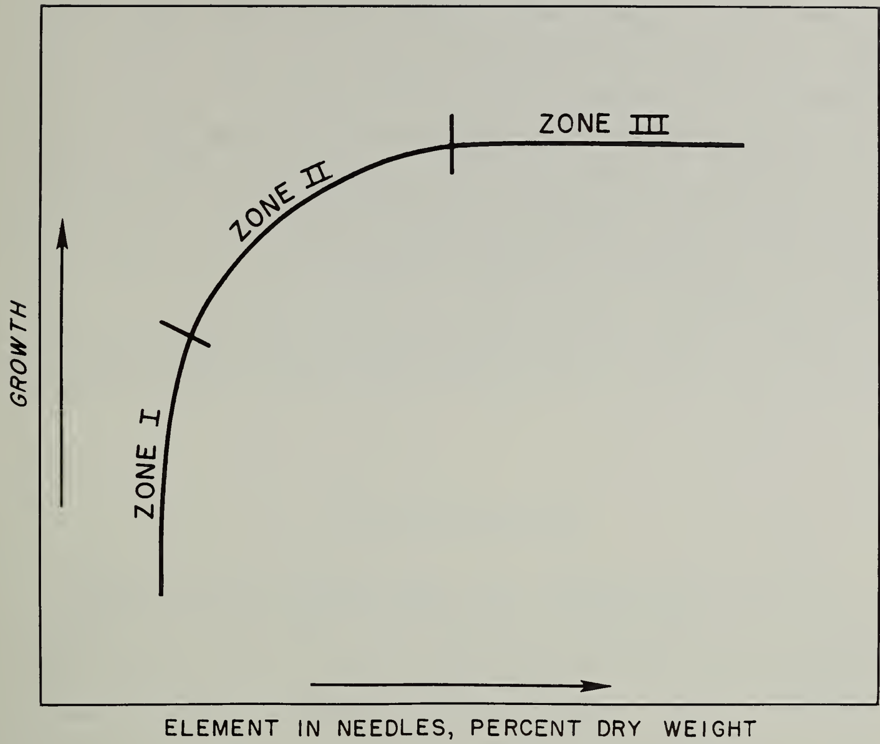

Figure 6.—The idealized relationship between the growth of a seedling and the concentration of the limiting nutrient element in its needles. In zone I growth increases sharply but the nutrient concentration does not. In zone II growth increases are associated only with sizable increases in the concentration. In zone III growth no longer increases with further increases in nutrient concentration.

sizable increases in concentration, and growth can be readily predicted from concentration. In zone III, growth no longer increases as concentration increases.

In this study, the data were insufficient for defining a continuous three-zoned response curve. However, there were enough data for conjecturing in what zones different concentrations belonged. With potassium, a concentration of 0.28 percent fell in zone I or in the left portion of zone II; 0.75 percent fell in zone III. With magnesium, a concentration of 0.08 percent fell in zone II and 0.18 percent in zone III. With calcium, concentrations of 0.10 to 0.44 percent fell in zone III.

Now for the ecologically significant question of the comparative nutrient requirements of Virginia pine and loblolly pine. Virginia pine has been rather widely believed to have lower requirements. The locally common name "poverty pine", attests to this belief. Foresters often have interpreted the local distribution patterns of Virginia pine and loblolly pine in the mid-southern Piedmont as being controlled in part by differences in soil fertility.

Results of this study of Virginia pine were compared with results of an almost identical and simultaneous study of loblolly

Table 7.—*Concentrations of five elements in the needles of Virginia and loblolly pine seedlings deficient in the elements*

Deficient element	Species	Concentration	Age of needles	Reference
		% dry wt.		
N	Virginia	<1.2	Just mature	Fowells & Krauss (1959)
	Loblolly	<1.2	Just mature	Fowells & Krauss (1959)
P	Virginia	<0.10	Just mature	Fowells & Krauss (1959)
	Loblolly	<0.10	Just mature	Fowells & Krauss (1959)
K	Virginia	0.28	All ages grouped	Present study
	Loblolly	0.26	All ages grouped	Sucoff (1960) [2]
	Loblolly	0.16—0.62 [3]	Immature [1]	Sucoff (1960) [2]
Mg	Virginia	0.08	All ages grouped	Present study
	Loblolly	0.07	Any age	Sucoff (1960) [2]
Ca	Virginia	[4]	All ages grouped	Present study
	Loblolly	<0.033	Immature	Sucoff (1960) [2]

[1]All 10 cm. long.
[2]Sucoff, Edward I. Potassium, magnesium, and calcium nutrition of *Pinus taeda* L. Doctoral dissertation, Univ. Maryland, 78 pp., 1960.
[3]Deficiency begins somewhere within this range of concentrations.
[4]No deficiency observed.

pine.[3] As far as can be determined from the data, the two species have similar requirements for external supplies of K, Mg, and Ca. And, according to the parallel study by Fowells and Krauss (1959), they have similar requirements for nitrogen (N) and phosphorus (P). The comparisons also showed that the two species have practically identical deficiency thresholds for K, Mg, N, and P—on the basis of dry-weight percents of the elements in the needles (table 7). The notion that Virginia pine has lower nutrient requirements than loblolly pine is not supported by these studies.

Summary

The potassium, magnesium, and calcium requirements of Virginia pine seedlings were studied in automatically irrigated sand cultures. The seedlings were grown with various levels of the three elements. It was learned that:

- The minimum concentrations needed to support rapid growth are below 4 ppm. potassium, 24 ppm. magnesium, and 3 ppm. calcium.
- Within limits, the uptake of the three elements is positively related to the external supply.
- The growth of the seedlings can be related to the concentrations of potassium and magnesium found in their needles.
- Virginia pine seedlings exhibit definite deficiency symptoms for potassium and magnesium.

When the results of this experiment were compared with those of an identical experiment with loblolly pine, no major differences in nutrient requirements of the two species were detected.

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