lene levels as high as 20,000 ppm was found on either oranges or tangerines in these studies.

The studies indicate that the maximum response of citrus fruits to ethylene is reached at between 5 and 10 ppm, confirming some published results (1, 5, 6). The responses recorded for high O_2 were not impressive although in some cases, as with tangerines, these may be useful. Further work is needed, but it is apparent that the response to oxygen was not comparable to that previously reported on Navel oranges (4, 14). Possibly variety, fruit maturity, or climatic differences may have had an effect although some of our work also was on Navel oranges.

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Growth Response of One-Year-Old Pecan Seedlings, *Carya illinoensis*, Koch, in Sand Culture to Various Levels of Potassium[1,2,3]

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Abstract. The growth response of 1-year-old pecan seedlings in sand culture to various levels (0, 60, 120, 240, 615, 990, 1365, and 1740 ppm) of K was determined.

Leaves of the plants receiving no K exhibited deficiency symptoms; and those receiving 1740 ppm K exhibited toxicity symptoms. In both cases, plant dry weight was suppressed when compared to plants grown with intermediate levels of K (60 to 1365 ppm). Growth response (weight of roots, stems, and leaves) to intermediate treatments of K was normal and did not vary significantly.

In all tissues, increase in per cent K was a diminishing response to the increasing supply of K in the nutrient solution. Per cent K in the leaf or leaflet was a better indicator of K availability than K in the roots or stems. Potassium in the leaf or leaflets was equally reliable indicator of K availability, but the percentages of K associated with a given availability varied with the tissue sampled and the time of sampling. Under the conditions of this study, the data indicate that K deficiency will probably occur when K, on a leaf dry weight basis, falls to some value below 1.0%.

Introduction

LEAF analysis is rapidly becoming the accepted method for diagnosing the mineral nutritional status of pecan groves. Nutritional standards, i.e. mineral composition values of the leaf considered to be associated with good yields, have been proposed (2). However, as yet, standard leaf composition values for most of the essential mineral elements apparently have not been determined experimentally for the pecan. One-year-old pecan seedlings were grown with various levels of K in sand culture to determine the per cent K in the leaf tissue associated with optimum growth and with symptoms of deficiency and toxicity, and to study changes in per cent K as a function of K supply.

Materials and Methods

One-year-old dormant seedlings grown from seed of the 'Stuart' cultivar, were planted February 2, 1966, in 2 gal glazed crocks filled with sand. Two seedlings, paired according to stem length, were planted per crock. The plants were maintained in the greenhouse and watered daily with distilled water until the terminal buds began to break. The experimental design was a randomized complete block replicated 6 times. As previous observations had indicated differences in time to bud break among seedling pecans, the replications were differentiated on the basis of time to bud break. In this study, bud break occurred over a 3 week period (March 19 – April 8).

Upon completion of each replication, differential application of K was begun. A modified Hoagland's solution (5) was used with K being the only variable at concentrations of 0, 60, 120, 240, 615, 990, 1365, 1740 ppm. Sodium nitrate ($NaNO_3$) and $NH_4H_2PO_4$ were used to complete the N requirements in solutions of 120 ppm or lower of K. For K concentrations above 240 ppm, the additional K was supplemented as K_2SO_4. The pH did not vary appreciably with K concentration in the solutions.

The plants were watered on alternate days with 400 ml of nutrient solution or 400 ml of distilled water. Iron (5 ppm solution), as Fe chelate (ethlenediamine tetraacetic acid) was added weekly. In mid-April the procedure was altered to the application of 600 ml of nutrient solution daily and leaching weekly with 3 liters of distilled water. To remedy incipient Fe

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deficiency symptoms, addition of Fe was made twice weekly.

Three times during the growing period, June 29, and July 13 and 30, samples of leaflets were collected for K determination. At the first sampling date, one leaflet of the fourth pair was removed from alternate leaves; at the second sampling date, one leaflet of the fourth pair was removed from leaves not previously sampled; at the last sampling date the remaining leaflet of the fourth pair was removed from all leaves.

By July 30, shoot extension had ceased and the lower leaves on trees receiving 0 or 1740 ppm K were deteriorating. On this date the experiment was harvested. The leaves (leaflets and rachises), stems (current and previous season's growth), and washed roots were separated, air-dried for 2 weeks, and oven dried for 72 hr at 70 C. The dried tissues were ground to pass through a 20-mesh screen, soaked for 2 hr in a 0.04% acetic acid solution, filtered and atomized in a Coleman model 21 flame photometer.

The individual percentages of K were transformed to logarithms before calculating the analysis of variance. This was necessary since the standard deviations of the 40 means varied directly with the means (r=.729**), indicating that the experimental errors followed a distribution that was decidedly skewed and not normal as required for analysis of variance (3, 9).

Results and Discussion

Symptoms of K deficiency on the trees receiving no K began to appear about 1 month followed bud break. A slight loss of green color along the leaflet margins and interveinal areas, with the appearance of very minute necrotic spots occurred on the surface of some of the mature leaves. At harvest, the upper "immature" leaves of these trees were bowed downward with the leaflet blades cupped downward. At the same time the two sides of the blades of the older, more mature leaflets were curved upward and exhibited rust-like reddish necrotic spots over a yellow-green surface. Both upper and lower leaves were glossy in appearance. Alben et al. (1) described similar K deficiency symptoms for the pecan.

Toxicity symptoms, exhibited as pronounced leaf scorch followed by rapid deterioration and early partial defoliation, occurred on plants receiving 1740 ppm K. Foliage on plants receiving 60 to 1365 ppm K was a normal deep green color.

As the supply of K was increased in the nutrient solution, per cent K was highest in the leaves, intermediate in the roots, and lowest in the stem (Fig. 1). Calculations from data of Forshey (4) indicate a similar distribution of K in the apple. The differences among these tissues continued to augment as long as the concentration within the individual tissues increased in response to increasing supply of K. At the level of K associated with toxicity, 1740 ppm, per cent K appeared to have decreased slightly in the roots and stem and to be near a maximum in the leaves.

In all tissues, increase in K concentration was a diminishing response to the increasing supply of K in the nutrient solution (Fig. 1). The diminishing effect was most striking in the stem, intermediate in the root and least pronounced in the leaves. This relationship indicates that under field conditions, the magnitude of plant response to a given application of K, with respect to changes in per cent K, will be an inverse curvilinear function of the initial level of available K in the soil. This further suggests that field research involving applications of K should be conducted on sites with the lowest possible levels of available K if increases in K concentration and growth are to be obtained in the shortest time interval possible. Similarly in short-term nutrient culture studies, the initial concentration of K within the plant would be expected to effect the magnitude of response to a given application of K.

Since K concentration in the leaves, as contrasted to the roots or stems, increased at a greater rate with increasing supply of K (Fig. 1), K in the leaf was a better indicator of K availability than K in the roots or stem. Based on relatively rate of change, K in the leaves or leaflets (Table 1) was an equally reliable indicator. This is evidenced by the high and similar correlation coefficients (r) between per cent K in the leaves on July 30, and in the leaflets on June 29 (r=.994**), July 13 (r=.993**) and 30 (r=.998**).

Although the K concentration of the leaf tissues was an equally reliable indicator of K availability, the actual percentages of K in these tissues varied both with sampling date and with the tissue sampled (Table 1). This was the case at any given level of K in the nutrient solution. Some of the statis-

Table 1. Percentage K in the leaves, leaflets, roots, and stems of 1-year-old pecan seedlings as a function of ppm K in the nutrient solution.

Tissue sampled	Date sampled	ppm K in nutrient solution[x]							
		0	60	120	240	615	990	1365	1740
Leaflets	6/29	.26 b	1.01 e	1.26 c	1.56 d	2.03 bc	2.70 c	3.22 c	3.25 d
Leaflets	7/13	.30 c	.93 c	1.15 b	1.51 c	2.07 c	2.73 c	3.42 d	3.21 c
Leaflets	7/30	.27 b	.99 de	1.25 c	1.67 e	2.41 d	2.96 d	3.58 e	3.54 e
Leaves	7/30	.30 c	.98 d	1.28 c	1.80 f	2.64 e	3.06 e	3.75 f	3.91 f
Roots	7/30	.34 d	.86 b	1.15 b	1.41 b	1.98 b	2.01 b	2.35 b	2.16 b
Stems	7/30	.17 a	.44 a	.59 a	.83 a	1.19 a	1.15 a	1.39 a	1.37 a

[x]Means having the same letter in common in a given column are not significantly different, 5% level. Duncan's multiple range test.

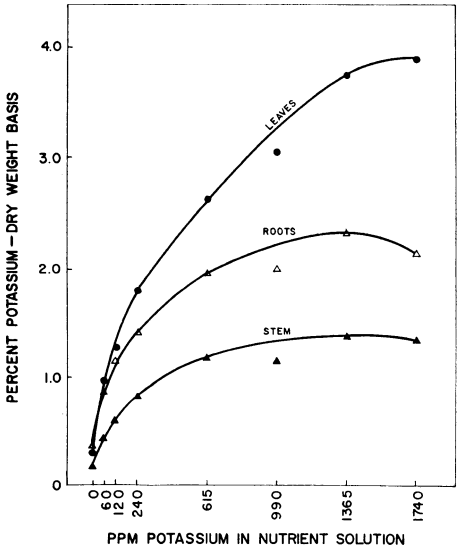

Fig. 1. Percentage K in the roots, stem, and leaves of 1-year-old pecan seedlings as a function of ppm of K in the nutrient solution.

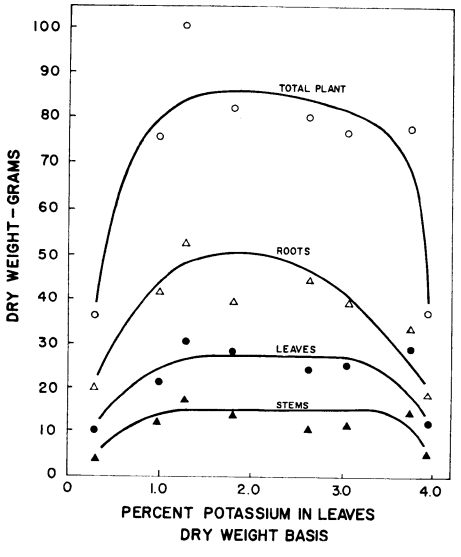

Fig. 2. Dry weight of the roots, stems, leaves, and total plant of 1-year-old pecan seedlings as a function of percentage K in the leaves.

tically significant differences are of doubtful physiological significance. Other differences, especially at the higher concentrations in the tissues, are judged to be of sufficient magnitude to be physiologically important. These latter differences indicate that the relationship of per cent K to the developmental stage or physiological age must be elucidated and the tissue to be sampled must be prescribed before young seedling pecans can be validly compared among diagnostic greenhouse studies or possibly compared with field studies. This is not to say that they could not be used in studies involving relative comparisons.

The relationship of the dry weight of the roots, stems, leaves, and total plant to the per cent K in the leaves is depicted in Fig. 2. The K values are those induced by the respective ppm of K in the nutrient solution. Significantly less growth of all portions of the plants occurred at the 2 extremes of K (0.30% and 3.91%). Growth of plants with intermediate concentrations of K in the leaves did not vary significantly with increasing K.

As there was no intermediate growth response between plants showing deficiency symptoms and plants exhibiting optimum growth, the data in Fig. 2 do not allow the establishment of a critical percentage of K in the leaves above and below which growth could be expected to be at a maximum or decrease, respectively. This may have been due to lack of an intermediate treatment between 0 and 60 ppm or a critical concentration may have existed but was obscured by the variation in growth within a given treatment. This variation is evident from the data in Fig. 2 and may have resulted, in part, from differences in root size that existed at the initiation of the study. The pecan has a fleshy taproot which apparently serves as a storage organ for carbohydrates (8), and as the root may constitute as much as 76%[5] of the dry weight of a 1-year-old pecan tree, differences in initial growth the following season could be considerable. Also, variation may have been introduced by planting 2 trees per pot; however, the data did not allow unequivocal proof of this since variation inherent to the pecan could not be separated from variation due to competition.

These considerations suggest that in similar studies with seedling pecans only one tree should be planted per pot, replication should perhaps be differentiated on a fresh weight basis, and, probably, the number of replications increased. However, the economical feasibility of increasing accuracy by replication alone may be questionable; since to halve a given standard error of a treatment mean requires increasing the degree of replication 4 times (6).

Regardless of the limitations of these data, the minimal value of K associated with normal growth, when compared to the total range obtained, indicates that the K requirement for vegetative growth of pecans is low, and probably is under 1% K on a leaf dry weight basis. The optimum concentration proposed by Amling (2) for cv. 'Stuart' (0.75 to 0.95% K) and data of Sharpe et al. (7) also suggest the critical concentration is less than 1%. In addition, the wide range of per cent K encountered indicates that "luxury consumption" of K can be extensive in seedling pecans. However, the probability of such magnitude of luxury consumption and eventual toxicity occurring under field conditions is small since both the conditions for growth and availability of K are not expected to be as adequate under field conditions as was the case of this study.

[5]Based on 17 plants.

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