Influence of Nitrate on Tomato Growth[1, 2]

B. E. Gomez-Lepe[3] and Albert Ulrich

Abstract. Tomato plants (*Lycopersicon esculentum* L. cv. VF 145-21-4) in the greenhouse developed over a 5-week period from seedling to early bloom stage, increased in fresh and dry weight of shoots and roots, in plant height, and internal NO_3-N concentration in relation to the NO_3 supply of the culture solution. Increases in NO_3-N varied among plant parts: roots < stem < petiole > blade. Growth of shoots was related to NO_3-N concentration in plant parts. A petiole from a young mature leaf, leaf 2, was the best indicator of N status of the plant. Its critical value for N deficiency was 275 ppm of NO_3-N (dry wt) when estimated at a 10% reduction in growth. A tentative critical value for use under field conditions was set at 500 ppm. Movement of NO_3 was primarily unidirectional from the petiole to the blade, with little return movement to the stem and upward to younger petioles.

Growth of the tomato and of other plants depends on an adequate supply of plant nutrients when all other growth requirements have been met. Meeting the nutrient requirements of the tomato is an urgent matter if large quantities of high quality fruit are to be produced effectively and efficiently year after year. Of the nutrient elements applied, N is often added in the largest amount over the largest acreage and most often during the growing season.

A highly efficient method of testing the N status of crops in the field is through the use of plant analysis, providing the appropriate background information has been developed (1, 3, 6, 7, 9, 10, 12). Consequently, we determined the influence of NO_3 supply on NO_3 concn in the plant, the relationship of internal NO_3 in various parts of the plant to growth, and estimated the critical NO_3-N concn of the plant relative to growth from the response curves.

Materials and Methods

Tomato seeds, *Lycopersicon esculentum* L., cv. VF 145-21-4, were planted on July 2 in trays containing vermiculite. The seeds and seedlings were watered daily with modified half-strength Hoagland's solution. Early in the 2-leaf stage the seedlings were transferred to tanks containing 20 l of nutrient solution. Individual seedlings were supported in one-hole varnished corks by Dacron batting. Five such seedlings were selected at random and placed into holes of covers provided for each tank.

Nitrate N, as $Ca(NO_3)_2$, was added to the nutrient solutions at 8 levels: 1, 2, 4, 8, 12, 16, 32, and 64 meq per liter. Calcium sulfate was substituted for $Ca(NO_3)_2$ as required to supply a minimum of 16 meq of Ca per 1 of nutrient solution. Calcium nitrate was added only once to the lower N treatments (1-4), and to avoid salt toxicity at the higher N treatments it was added in 2, 2, 3, or 4 equal portions in treatments 5, 6, 7, and 8, respectively. The initial nutrient solution also contained the following salts, expressed in millimoles per 1: 1.0 KH_2PO_4, 1.5 K_2SO_4, 1.0 $MgSO_4$, 0.5 NaCl, and 0.25 $NaSiO_3 \cdot 9\ H_2O$. Micronutrients were added (mg per 1): 0.025 Zn as $ZnSO_4 \cdot 7\ H_2O$, 0.01 Cu as $CuSO_4 \cdot 5\ H_2O$, 0.005 Mo as MoO_3, and 2.5 Fe as Fe EDTA. Three additions of these salts were made during growth, thus insuring an ample supply of all nutrients, except for N in the low N treatments.

The nutrient solutions were aerated continuously with air filtered through Dacron and activated carbon. Distilled water was added as needed and the pH of the nutrient solution was maintained at about 6.5 with either H_2SO_4 or *N* NaOH. All treatments were replicated 5 times in a randomized complete block design. The plants were cultured in a smog-free clear-glass greenhouse.

Plants were harvested August 17, at 30 and 46 days after transplanting and planting, respectively. At harvest, the plants were blooming and showed N-deficiency symptoms ranging from severe to mild in treatments 1-4 and none in treatments 5-8. The plants at harvest were separated into shoots and roots. Five leaves were selected for chemical analysis. Leaf 1, the oldest immature leaf, was at the "flat top;" the others were taken in order of increasing age (1). Stem material was taken from the apex to leaf 5. The remaining portion of the shoot, and the leaves older than leaf 5, were combined as residue. The leaves from 1-5 were further separated into 2 parts, the blade and the petiole plus rachis. We use the term petiole to include the petiole plus rachis, for simplicity. The roots were washed 3 times in distilled water and centrifuged at 40 x *g* for 5 min.

Fresh wt of the shoots and other parts was recorded. Dry wt (70°C) was taken. Plant samples greater than 200 mg were ground in a Wiley mill to pass a 40-mesh sieve, those less than 200 mg in an oscillatory glass ball mill. The ground material was stored in plastic containers with plastic caps, until analyzed.

Plant material was tested qualitatively for NO_3 with diphenylamine reagent (5) and analyzed for NO_3-N by the phenoldisulphonic acid method (4). Statistical computations were done with a computer, using Duncan's multiple range test at the 5% level of significance for treatment mean separation.[4]

Results and Discussion

Visual Symptoms of N Deficiency

The first signs of N deficiency appeared on plants in treatment 1, two weeks after transplanting (2, 8, 11, 13). Thereafter, symptoms appeared progressively on higher N treatments through treatment 4. At harvest, symptoms in treatments 1 and 2 were severe; 3, moderate; 4, mild or trace; and 5 through 8, none.

Effects of Nitrate Supply on Growth

Plant height. Nitrogen supply had no significant effect on plant height 4 days after transplanting (Fig. 1). Seventeen days after transplanting, plant height increased slightly with the first three N additions but more N had no effect. Nitrogen, however, increased plant height greatly by 24 days after transplanting (Fig. 1).

Fresh and dry wts. The fresh and dry wt of shoots and roots, just as for plant height, increased progressively with NO_3-N supply and then remained relatively constant with non-limiting supplies of NO_3-N (Table 1 and Fig. 2). Again, it is the N supply *per se* and not its interaction with other nutrients in the culture

[1]Received for publication July 6, 1973.

[2]Department of Soils and Plant Nutrition, University of California, Berkeley.

[3]Present address: Department of Experimental Biology, National University, Mexico 20, D.F.

[4]BMD 07V, Multiple Range Tests Version of October 12, 1965, Health Sciences Computing Facility, UCLA, Los Angeles, California, and for regressions, G2 BC Regress, March 1966, Computer Center, UCB, Berkeley, California.

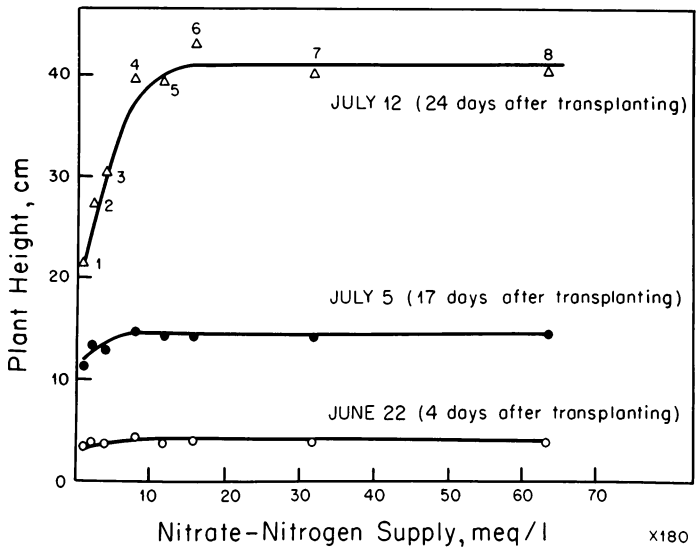

Fig. 1. Influence of nitrate supply on plant height at different time intervals.

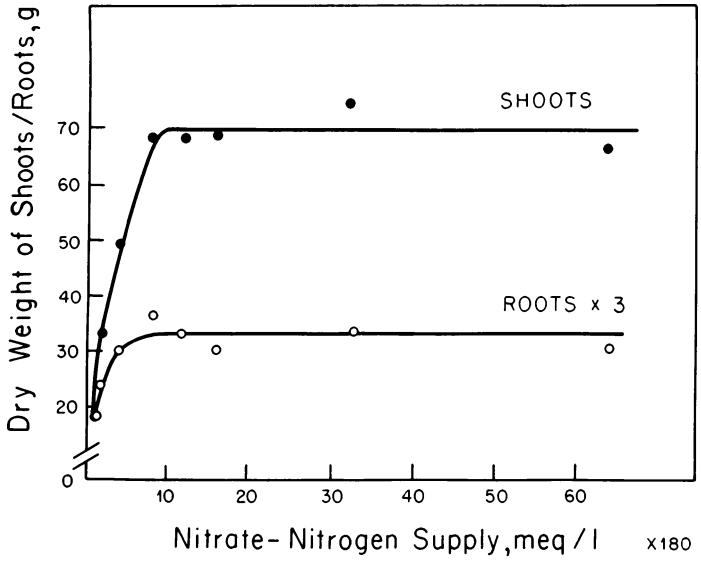

Fig. 2. Influence of nitrate supply on dry wt of shoots and roots.

solution or within the plant that determines root and shoot growth.

Shoot to root ratio. Nitrogen deficiency reduced shoot growth much more than root growth and this lowered the shoot to root ratio correspondingly (Table 1). Conversely, an abundance of N increased the shoot to root ratio, and this would induce wilting and nutrient deficiencies under field conditions sooner than when soil supplies are low. An abundance of N has also been found to increase the shoot to root ratio of grasses, such as *Lolium multiflorum* (3).

Dry wt percentage. An acute deficiency of N increased the dry wt percentage of the shoot from about 7.0% to about 15.0% (Table 1). This increase in percent dry wt may be due to an accumulation of carbohydrates in plant tissues or to an increase in dryness with N deficiency. Nitrogen deficiency also increased the dry wt percentage of the roots but the increase in percentage was only from about 5.5% to 7.7%.

Nitrate-N in Selected Plant Parts

Blades. The blade samples in treatments 1 through 4 ranged in NO_3-N from about 100 to 300 ppm, dry wt basis (Table 2). These values, determined by the phenoldisulfonic acid method, are essentially background readings and indicate that the samples are primarily devoid of NO_3. A negative test for NO_3 with diphenylamine reagent (5) confirmed this conclusion. When the supply of NO_3-N was increased from 12.0 to 16.0 meq per 1 (Table 2, treatments 5 and 6) then the blades increased in NO_3-N concn from 175 to 883 ppm in leaf 1 and from 1970 ppm to 4680 ppm in leaf 5, the oldest leaf. Additional supplies of NO_3 (treatments 7 and 8) produced further increases in NO_3-N concn of the blades. The youngest blades again contained the lowest concn of NO_3-N. This increase in NO_3 concn with leaf age is apparently consistent, except when N is extremely low all blades are essentially devoid

Table 1. Effects of nitrate supply on fresh and dry wt of shoot and root, shoot to root ratio, and percent dry wt.[z]

Treatment	NO_3-N supply me/l	Fresh wt Shoot g/pot	Fresh wt Root g/pot	Fresh wt S/R ratio	Dry wt Shoot g/pot	Dry wt Root g/pot	Dry wt S/R ratio	Dry wt Shoot %	Dry wt Root %
1	1.0	126_a	77_a	1.6	18.7_a	5.9_a	3.2	14.8	7.7
2	2.0	245_b	106_b	2.3	32.9_b	7.9_b	4.2	13.5	7.5
3	4.0	443_c	138_c	3.2	49.3_c	9.9_{cd}	5.0	11.1	7.7
4	8.0	771_d	178_d	4.3	68.6_d	12.0_c	5.7	8.9	7.2
5	12.0	951_e	181_d	5.2	68.7_d	11.0_{cd}	6.2	7.2	6.7
6	16.0	1050_e	174_d	6.0	68.4_d	9.6_d	7.1	6.5	6.1
7	32.0	1040_e	189_d	5.5	74.8_d	10.8_{cd}	7.0	7.2	5.5
8	64.0	950_e	180_d	5.3	65.7_d	10.7_{cd}	6.1	6.9	5.3
									6.0
F-value[y]	–	94.73	25.79	–	46.89	17.59	–	–	–

[z]Data are means of 5 replications. Means followed by a common letter within a column are homogeneous sub-sets at the 5% level of significance as shown by Duncan's multiple-range test.

[y]Required F value is 2.36 at a 5% level of significance.

Table 2. Effects of nitrate supply on nitrate-N concn of blades.[z]

Treatment No.	NO_3-N supply meq/1	Blades 1	2	3	4	5
1	1.0	116_a	165_a	266_a	220_a	305_a
2	2.0	131_a	154_a	217_a	174_a	246_a
3	4.0	122_a	159_a	290_a	135_a	222_a
4	8.0	150_a	200_a	237_a	233_a	270_a
5	12.0	175_a	353_a	1350_a	1760_a	1970_b
6	16.0	883_a	1350_a	3150_b	3860_b	4680_c
7	32.0	2550_b	3140_b	3570_b	6790_c	6350_d
8	64.0	3340_b	3140_b	6090_c	6770_c	8150_e
F-value[y]		7.50	18.31	10.16	29.42	35.28

[z]Nitrate-N concn in plant parts are expressed in ppm on the dry wt basis. Data are means of five replications. Means followed by a common letter within a column are homogeneous sub-sets at the 5% level of significance as shown by Duncan's multiple-range test.

[y]Required F value is 2.36 at a 5% level.

Table 3. Effects of nitrate supply on nitrate-N concn of roots, stem and petioles and on spot test for nitrate in culture solution at harvest.[z]

Treatment No.	Nitrate-N Supply meq/l	Spot test	Roots	Stem	Petioles 1	2	3	4	5
1	1.0	–	77_a	183_a	194_a	274_a	140_a	229_a	150_a
2	2.0	–	108_a	308_a	125_a	299_a	221_a	156_a	122_a
3	4.0	–	158_a	449_a	166_a	267_a	215_a	406_a	795_a
4	8.0	–	241_a	1900_a	133_a	409_a	1170_a	4320_a	8710_b
5	12.0	+	3470_b	17000_b	6970_a	11500_b	14900_b	19940_b	27000_c
6	16.0	+	11200_c	20800_{bc}	22700_b	26700_c	32800_c	32300_c	33800_d
7	32.0	+	13100_{cd}	20800_{bc}	27000_b	31500_c	30300_c	34500_{cd}	33600_d
8	64.0	+	13800_d	23500_c	28100_b	32900_c	34400_c	38500_d	38700_d
F-value[y]			64.87	39.42	28.02	53.45	43.69	141.69	103.57

[z]See Table 2.

[y]Required F-value is 2.36 at a 5% level.

of NO_3 (treatments 1-4).

Petioles. The NO_3-N pattern of the petioles was similar to the one for the blades. The values increased with NO_3 supply and with leaf age (Table 3). Once the readings for NO_3-N were above background, as in treatment 3, petioles 4 and 5, the NO_3 values rose much faster with NO_3 supply than in the corresponding blades (Table 2). In treatment 3, the petioles also started to increase rapidly in NO_3-N concn with leaf age (leaves 4 and 5). In treatment 4, all petiole values for NO_3-N increased with leaf age, with only 133 ppm for petiole 1 and increasing rapidly to 8710 ppm for petiole 5. In treatment 5, the increase in NO_3-N supply again increased the NO_3-N concn of the petioles greatly. Here, the N supply met the N needs of the plant fully (Table 1), and this fact was reflected in the very high NO_3-N values of the petioles. Smaller increases in petiole NO_3-N took place with more N in treatments 6, 7, and 8. In these instances the petioles of older leaves were also higher in NO_3-N concn than those of younger leaves.

Stem. The NO_3-N concns of the stem approximate those of the petiole in leaf 1 and reflected the NO_3 supply to the plant at the moment. In one respect the NO_3-N concn of the stem can be viewed as a weighted average of the petioles from 1 through 5, since the stem sample consists of material from the growing point to leaf 5. A brief inspection of the NO_3-N values for petioles and stems in Table 3 indicates that a treatment stem value could represent an average petiole value in treatments 1-5, but not in treatments 6-8, where all stem values are lower than those of the petioles, regardless of leaf age. Alternatively, stem values may be unique and do not necessarily reflect those of other tissues.

Culture solutions and roots. The diphenylamine test for NO_3 showed that the culture solutions at harvest were negative in treatments 1-4 and were rather low positive in treatment 5 (Table 3). The roots in treatments 1-4 were also NO_3 negative, although they were strongly NO_3 positive in treatment 5. NO_3-N concns of the roots (Table 3) increased greatly from treatment 4 to 5 and again from treatment 5 to 6, followed by smaller increases in treatments 7 and 8. The highest NO_3-N values were distinctly lower than those of the stems or petioles but were much higher than those of the blades (Table 2).

Distribution of nitrate. The increases in NO_3 concn of the roots paralleled those of the stem, petioles, and blades. When the tomato roots accumulated NO_3 from the nutrient solution, there were further large increases in NO_3-N concn in the stem and again in the petiole (Table 3), followed by a steep decline in the blade (Table 2). This indicates that NO_3 was reduced and metabolized in the blade and that its rate of movement from petiole to blade was the rate-limiting step. A further implication is that NO_3 moved primarily from the petiole to the blade and not in the reverse direction. Failure of NO_3 to return rapidly to the stem is shown by a retention of NO_3 by the older petioles of the plant at the onset on N deficiency (Table 3, treatment 4). Apparently, once NO_3 has moved from the stem into the petiole it is more or less trapped until it is either reduced in the petiole or moves into the blade. Strangely enough, the concn of NO_3 within the blade does not seem to depend greatly on that of the petiole. Consequently, large changes in NO_3 concn of the petiole produce only small changes in NO_3 concn of the blades. Conversely, a low concn of NO_3 in the blade does not necessarily mean a low concn of NO_3 in the petiole.

In essence the rate of NO_3 reduction and its metabolism in the blade largely determines the NO_3 concn of the blade. Thus, when the rate of NO_3 utilization is high under full sunlight, as in blades 1 and 2, any slight impairment in NO_3 supply, as in treatment 5 (Table 2), results in a decrease in NO_3 concn of the blades. This could account for the large decrease in NO_3 concn of blades 1 and 2 to the point of N deficiency even though the petioles of these leaves were still relatively high in NO_3 (treatment 5, Table 3). In this instance, the NO_3 supply of the nutrient solution at harvest was on the verge of depletion and as a result the movement of NO_3 up the stem to the petioles was most likely decreased. The older leaves with less sunlight and lower NO_3 utilization were affected to a lesser extent. Nevertheless, all leaf blades, including blades 1 and 2, were still green in color and the fresh and dry wts of the shoots were still at a maximum (Table 1, treatment 5).

These observations also imply that new NO_3 moves primarily from the nutrient solution to the young leaves, and that when the NO_3 supply becomes depleted, the young leaves are the first ones affected, since they are on the main shoot in full sunlight and are much more active metabolically than older, less exposed leaves.

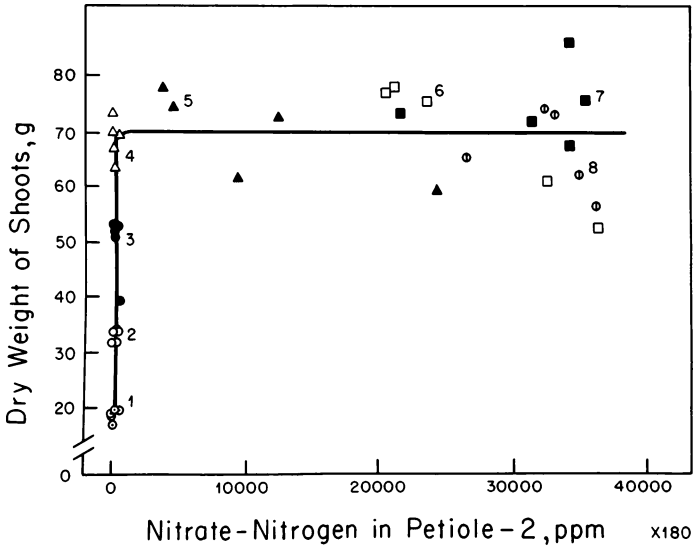

Fig. 3. Relationship of dry wt of shoots to nitrate-N concn (dry basis) in petiole-2. Petiole-2 is from a "young mature leaf," also referred to as a "recently matured leaf." The numbers adjacent to each symbol refer to treatment number, Tables 1-3.

Table 4. Critical nitrate-N and transition zone values for selected parts of tomato determined from response curves.[z]

Plant part	Critical values: At the mid-point of transition zone	At 10% reduction growth	Range of transition zone
Blades			
1	250[z]	150	150- 500
2	350	250	250- 750
3	300	250	250- 750
4	350	250	250- 750
5	350	300	250- 750
Petioles			
1	250	250	100- 500
2	450	275	250- 800
3	1200	600	1000-3000
4	1600	1000	1000-4000
5	2400	1500	600-6000
Stem			
	950	450	250-2000
Root			
	250	250	100- 500

[z]Nitrate-N values are expressed in ppm on the dry wt basis.

Growth as a Function of Internal NO_3-N Concn

Calibration curve. Within limits, increases in NO_3 supply increased the growth of tomato plants (Table 1) and the NO_3 concn of various plant parts: blades, petioles, stems, and fibrous roots (Tables 2 and 3). As expected, an increase in supply of N increased growth dramatically at first and then by smaller increments with each addition of N until adding more N failed to increase growth (Table 1 and Figs. 1-3).

In contrast to growth the first 4 additions of NO_3 did not increase the NO_3-N concns of the second leaf petioles at harvest (Table 3 and Fig. 3). But with another increase in N supply (treatment 5) there was a large increase in NO_3-N concn. At this point there was no further increase in dry wt of shoots over those plants with a lesser amount of N (treatment 4). Further increases in N increased the NO_3-N concns of the petioles, but not the yields (treatments 6, 7, and 8). The end-point for this calibration curve, the critical concn (Fig. 3) is about 250 ppm with respect to N deficiency. Such a low value is essentially trivial when compared with the large range of NO_3-N values, starting from a low of about 100 ppm to a high of nearly 40,000 ppm, dry wt. Thus it matters little from the diagnostic viewpoint if we set the critical value at 250, 500, or even as high as 1,000 ppm as long as the values for petiole 2, for example, remain well above 1,000 ppm of NO_3-N. Adding more N will not increase plant growth immediately. However, having more NO_3-N in the plant will be important if the supply of NO_3 is cut off, as when the plants are moved to a nutrient solution deficient in NO_3 or when soil N has become depleted. Naturally, those plants with the highest NO_3 concn will make the most growth thereafter. It is thus better to have plants well above the critical concn to make sure that growth is not impaired by an N deficiency arising shortly after taking the plant samples.

Differing calibrations. Calibration curves differ for each plant part analyzed and yet generally are predictable depending on the element and form of element determined, the plant part analyzed, and its relative age. The detailed plotting of the dry wts of the shoots versus the petiole NO_3-N values for leaf 2 are given in Fig. 3. The values for treatments 1 and 2 in Fig. 3 are closely clustered as well as those for treatment 3 except for one point represented by a low dry wt but with an identical NO_3-N concn. The unusually low yield for a single pot in treatment 3 indicates that there was either an error in adding N or in weighing.

The greater scattering of points in the vertical direction for treatments 5 through 8 is due to yield differences associated primarily with greenhouse variation in light and temp rather than in N addition. The variations in NO_3 plotted in the horizontal direction for treatments 5-8 reflect sampling variation, the inherent variation of plant material from pot to pot, and yield differences. Pots with higher yields for the same treatment tend to be lower in NO_3-N simply because of the dilution effect associated with growth. But regardless of these variations the results in Fig. 3 can be reproduced in other trials or in the same experiment with leaves of increasing age from the same plants. In general, both the range of values for NO_3-N in petioles (Table 3) and the transition zones (Table 4) tend to broaden considerably as leaf age increases, although the transition zones for petioles 1 and 2 are narrow and nearly the same (Table 4). A similar pattern may be seen for NO_3-N values for the corresponding blades of these leaves except here the transition zones are much narrower than the corresponding petioles of the older leaves.

Critical concentration. A value of 500 ppm NO_3-N can be set tentatively as the critical concn for the vegetative growth of the tomato plant. This value is higher than the 275 ppm determined at a 10% reduction in growth and is about equal to that established by inspection as the mid-point of the transition zone (Table 4). These differences in critical concn are large in terms of percentage change but are trivial in terms of the range of values (100 to 40,000 ppm dry wt) often observed in tomato petioles.

The selection of the petioles of leaf 2 as the material to sample and the setting of the critical value at 500 ppm of NO_3-N was done somewhat objectively and partly subjectively (1, 9). In Table 4, for example, the critical values determined from analysis of blade material differ little with leaf age or with method of calibration. At first glance this appears to be an ideal plant part to sample, except that the range of values is about 10% of that of petiole 2 (Tables 2 and 3). An increase in range from 20% to 50% can be obtained by using blades 3 to 5, but here sampling in the greenhouse and especially in the field becomes more difficult, although not impossible.

A much better part of the plant to sample is the petiole of the second leaf, a young mature leaf, which is just below the flat top. This leaf is easy to recognize and to sample. Also, it has a narrow transition between the zones of deficiency and adequacy, and a broad range of values in the adequacy zone from 1,000 ppm to 40,000 ppm. Furthermore, since it is a young mature leaf, it can be sampled at the same physiological age for most of the growing season. The selection of 500 ppm of NO_3-N as the critical value is justified mainly because it represents a true reading for NO_3-N and is the point at which growth decreases. Such low values are undesirable in commercial practice, especially early in the growing season when subsequent growth and fruit losses could be large.

Literature Cited

1. Fong, K. H., and A. Ulrich. 1969. Leaf analysis as a guide for potassium nutrition of potato. *J. Amer. Soc. Hort. Sci.* 94:341-344.
2. Hewitt, E. J. 1963. The essential nutrient elements: Requirements and interactions in plants. *In* Plant Physiology, a Treatise. F. C. Steward, pp. 140-143. Academic Press, New York.
3. Hylton, L. O. Jr., A. Ulrich, and D. R. Cornelius. 1965. Comparison of nitrogen constituents as indicators of the nitrogen status of Italian Ryegrass, and relation of top to root growth. *Crop Science* 5:21-22.
4. Johnson, C. M., and A. Ulrich. 1950. Determination of nitrate in plant material. *Anal. Chem.* 22:1526-1529.
5. _____, and _____. 1959. Analytical methods for use in plant analysis. *Calif. Agr. Expt. Sta.* Bul. 766, pp. 25-78.
6. Lorenz, O. A. 1972. Plant analysis as a guide for fertilizing vegetables. *Agrichemical Age* 15: October, 12, 14.
7. _____, B. L. Weir, and J. C. Bishop. 1972. Effect of controlled-release nitrogen fertilizers on yield and nitrogen absorption by potatoes, cantaloupes, and tomatoes. *J. Amer. Soc. Hort. Sci.* 97:334-337.

8. Lundegardh, H. 1966. Plant Physiology, p. 325. N. Y. Amer. Elsevier Publishing Co., Inc.
9. Ulrich, A., and W. L. Berry. 1961. Critical phosphorus levels for lima bean growth. *Plant Physiol.* 36:626-632.
10. ———, and F. J. Hills. 1967. Principles and practices of plant analysis. *In*: Soil testing and plant analysis. Part II. Plant Analysis. SSSA Special Publication No. 2, Soil Sci. Soc. of Amer., Inc., Madison, Wisc.
11. Wallace, T. 1961. The diagnosis of mineral deficiencies in plants by visual symptoms. Chem. Publish. Co., Inc. N.Y.
12. Winston, W. J. 1966. Nitrogen in diagnostic criteria for plants and soils. Chapman, H. D. (ed.), pp. 310-323. University of California, Division of Agricultural Sciences.
13. Woolley, J. T., and T. C. Broyer. 1957. Foliar symptoms of inorganic elements in tomato. *Plant Physiol.* 32:148-151.

Effect of N, P, K, and Lime on Yield, Nut Quality, Tree Growth, and Leaf Analysis of Pecan (*Carya illinoensis* W.)[1]

Ray E. Worley
University of Georgia
Coastal Plain Experiment Station, Tifton

Abstract. Mature 'Stuart' pecan trees in good condition on Tifton loamy sand did not respond to fertilizer [10-4.4-8.3 (N-P-K)] at rates from 0-1344 kg/ha annually over a 10-year period, but color and vigor of trees receiving no fertilizer were reduced near the end of the study. Highest yields were obtained with 448 kg/ha. Fertilizer effects on shoot growth and nut quality were inconsistent, but quality tended to be poorer for heavily fertilized than lightly fertilized trees near the end of the study. Fertilizer and limestone effects on yield and shoot growth were also inconsistent for mature 'Stuart' trees on Leefield sand at Waycross, Ga. over a 10-year period. Leaf analysis responded very slowly to nutrient application with leaf N and K being first increased by fertilizer application in the 6th and 9th years, respectively. Fertilizer P had little effect on leaf P. Liming to pH 6.0 with calcite increased leaf Ca and decreased leaf Mg and Al.

Yield and shoot growth of young 'Desirable' trees increased with the first 56 kg/ha increment of N, but further increases due to the second increment were seldom significant. Phosphorus and K additions had little effect on yield and shoot growth, but increasing K reduced nut size. Increasing N rates to 112 kg/ha improved vigor and color of trees. Leaf N and K for young trees increased from increasing application levels the first year, and leaf K was maintained in the desired range when soil test plus applied K equaled 112 kg/ha annually. Increasing N and K applications reduced leaf Mg, and increasing K applications increased leaf Mn, Fe, Al, and Na in young trees.

Problems of disease, weather, poor cultivars, etc. often make pecan returns from fertilizer application questionable (6, 7), but a recent survey (43) indicated that the highest yielding groves received over 1120 kg/ha of complete fertilizer annually. Whether such high applications are needed is questionable. Most of the nutritional work on pecans was done prior to the development of efficient pest control practices; hence, additional data are needed for trees under intensive care. Early studies indicated that yield or growth responses were obtained from complete fertilizer or N (10, 13, 30, 32-36). Pecan trees vary a great deal and are influenced by previous treatment (16); therefore, our tests were long-term studies.

Effects of fertilizer on kernel quality and nut size have been erratic. Complete fertilizer or N has been reported to increase (20, 21, 31), to have little effect (8, 17), and to lower (11, 18, 22, 23, 40) nut quality. Applications of complete fertilizer have increased nuts/lb count over applications of N alone (20). Complete fertilizer application has also increased (31), lowered (40), or had an erratic effect on (11) nut size. Oil content has been increased by N (12) and K (19) applications.

The relationship between leaf nutritional levels with application levels, soil test levels, yield, and growth is complex under field conditions. The increase in leaf levels from application of an element that is usually noted in annual crops is not always found for tree crops (3, 21), but surveys have shown that high yielding groves have higher leaf N than low yielding ones (14). Applications of fertilizer P have increased leaf P (2, 4, 21), but leaf P has been reported to be inversely correlated (28, 37), not correlated (3), and positively correlated (21) with yield. The influence of K application on leaf K and yield has also been erratic (3, 4, 21, 28, 29). Leaf Ca has been reported to be lower for unfertilized than for fertilized trees (21), not affected by cultural treatment (37), and not correlated with yield (3). Magnesium applications have increased leaf Mg, but .34% in leaves appeared sufficient (28). Leaf Mg was reduced as K application increased (29), and leaf Mg was not correlated with yield over the range of .46-.63% (3).

Some studies have attempted to establish deficiency and optimum ranges for various elements in pecan trees. In greenhouse sand culture experiments, trees grown without N, P, K, Ca, and Mg, leaf levels reached 1.20, 0.10, 0.12, 0.43, and 0.08%, respectively (1). Leaf N was optimum between 2.6-2.9% for 1-year-old seedlings (38), and K deficiency symptoms were found on leaves that had levels of 0.3% in similar greenhouse studies (42). These may or may not apply to old trees under field conditions. In one of Hunter and Hammar's tests (21) a dying tree contained 0.29% leaf K while a normal tree contained 0.53% leaf K.

Pecan leaf analysis has now become an accepted tool used by growers to maintain good nutrition of their groves and to determine which nutrients to apply (5, 45). Normal ranges for many of the nutritional elements in pecan leaves have been suggested (5, 38, 42, 45), but more research was needed to

[1]Received for publication December 21, 1972.

[2]Associate Professor of Horticulture.

[3]Thanks are expressed to Dr. J. B. Jones of the Soil Testing and Plant Analysis Laboratory, University of Georgia Cooperative Extension Service, for assistance with leaf analysis, to Dr. Ed Warren of the University of Georgia Computer Center for assistance with statistical analysis, to Dale Sherman, Vivian Mizelle, and H. M. Moore of the Abraham Baldwin College Center for Automation for providing computer service, and to Fred and Harold Voigt for use of their groves.