THE INFLUENCE OF NITROGEN AND POTASSIUM FERTILIZER RATES ON LEAF MINERAL CONTENT, TERMINAL SHOOT GROWTH, NUT ABORTION, YIELD, AND NUT QUALITY OF 25-YEAR-OLD 'WESTERN' PECAN TREES

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PECAN TREES

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CHAPTER I

INTRODUCTION

The pecan tree (Carya illinoensis [Wang.] K. Koch) is a very difficult subject for nutritional studies because of its large size and extensive root system that is very deep and occupies a large volume of soil. It, therefore, responds slowly to differential treatments, and is not easy to modify the physiological status of the tree by supplemental fertilization (10).

Every crop of nuts harvested removes some nitrogen (N), phosphorus (P), and potassium (K) from the orchard soil. Little is known as to the amount of nutrients that are actually removed in the production of a crop since the shucks and leaves are not removed from the land and a large portion of the plant nutrients utilized in production of the nuts are returned to the soil for reuse in succeeding years (20).

Information on precise fertilization programs for optimum results is generally not available. In some soils, certain elements in fertilizers are fixed, or become unavailable, so that the plants cannot absorb them. In such cases less growth or yield results. The conclusion must not be drawn, however, that the soil supplies all the nutrient elements in the amounts required until it has been found whether the element or elements supplied have been absorbed. This can be done by proper sampling of leaves from fertilized and unfertilized trees and chemical analysis of the samples (11). Tentative leaf levels, establishing a normal range for the essential elements, have been set for many pecan producing areas.

The purposes of this study were to determine: 1. the optimum concentration range of leaf N and K; 2. the amount of N and K fertilizer required to raise the nutrition level of the pecan leaf to the optimum concentration range. Tree response to the fertilizer treatments was determined by leaf analysis, visual deficiency symptoms, nutrient-element interactions, terminal shoot growth, nut abortion, yield, and nut quality.

CHAPTER II

LITERATURE REVIEW

Leaf Mineral Content

Leaf analysis as a means of diagnosing the nutritional status of perennial woody plants is based on the principle that for each nutrient element in the leaf there is an optimum concentration range of that nutrient associated with trees in good nutritional condition. However, the optimum concentration range will vary with geographical region due to changes in soil type, rainfall, and other factors. Within a geographical region optimum concentration ranges must be established based on cultivar and cultural practices.

Nitrogen nutrition can be more easily controlled through fertilization than can that of other elements, particularly that of P and K. The latter two elements are fixed by many soils with high clay content, and heavy soil applications may be necessary to bring their levels in the leaves into the optimum range (26). Jones (22) suggested the sufficiency range of N to be between 2.5 to 3.0%. If the concentration is 2.5% or less, trees may show deficiency symptoms. To determine an optimum leaf level for N, Sparks (32) grew 1-year-old pecan seedlings in sand culture with levels of 0 to 240 ppm N. Nitrogen deficiency symptoms were evident when leaf content ranged from 1.8 to 2.2%. Normal growth and foliage occurred when leaf N content was 2.2 to 2.6%. However, maximum growth was not reached until leaf N content reached 2.6 to 2.9%. Above 2.9% growth was suppressed due to excess N. Alben (1) applied N at a rate of 175.77 kg/m^2 of trunk cross section to 12-year-old 'Halbert' pecan trees. The data showed that the leaf samples from the fertilized treatments had a higher N content (2.42%) than those from the check trees (2.27%). Worley (43) applied N treatments to 4-year-old 'Desirable' pecan trees at the rate of 0, 56, and 112 kg/ha annually for five consecutive years. A significant increase in leaf N level between the 0 and 112 kg/ha rate over the five year period averaged approximately .14%. Houchin (19) applied N at the rate of 60 g/cm of trunk diameter to native pecan trees. It was concluded that the N treatments tended to reflect an increase in leaf N level (2.40%) compared to the check trees (2.20%).

Although many reports have shown that N fertilization increases the N level in the leaf, others have been unable to obtain this response with N fertilization. Worley, Harmon, and Carter (45) initiated a fertilizer experiment on approximately 40-year-old 'Stuart' pecan trees. Fertilizer treatments ranging from 0 to 134-59-111 (NPK) kg/ha were applied over a six year period. These fertilizer treatments had little effect on leaf N level. However, the average leaf N content every year was well within the 2.5 to 2.9% sufficiency range suggested for pecan leaf analysis. Ponder (24) applied N at 0, 179, and 258 kg/ha/year to black walnut (Juglans nigra L.). Over a four year period N content of the leaves were not significantly increased by the fertilization treatments. However, no trees had a N level below 2.5%, which is considered near the sufficiency level for walnut.

Jones (22) found the sufficiency range of leaf K to be between .75 to 1.25%. Upson and Sparks (38) grew 1-year-old 'Stuart' pecan seedlings in sand culture with 0 to 1740 ppm of K to determine the percent K in the leaf associated with optimum growth. The relationship of total dry weight of the tree to percent K in the leaves showed that concentrations of K below .85% were associated with rapidly diminishing growth. Between .85% and 3.0% K in the leaf normal growth occurred. However, growth did not increase with increasing percent K in the leaves. Leaves containing over 3.0% K, exhibited severe symptoms of toxicity and plant growth diminished rapidly. An experiment was set up by Gossard and Nevins (15) to study the effects of K applications on leaf K level. Soil applications of K at 3 and N at 1 kg/m^2 of cross section area of the tree trunks were applied to 28-32-year-old 'Moneymaker' and 'Stuart' pecan trees. The average K leaf level for the 'Moneymaker' trees was 1.17% compared to .97% for the check trees. There was no consistency in the K content of the 'Stuart' leaves associated with the fertilizer treatment. Worely (43) applied 0, 112, and 224 kg/ha/yr of K to 4-year-old 'Desirable' pecan trees from 1966-1970. Every year each increment of K caused a significant increase in K leaf content. Between the 0 and 224 kg/ha rate an average of .60% increase in leaf K content resulted. Between the 0 and 112 kg/ha rate an average of .26% difference was obtained. Between the 112 and 224 kg/ha rate an average of .33% increase was found. Alben (2) applied K at rates of 0, 205, 410, and 820 kg/ha to 20-25-year-old 'Stuart' pecan trees in 1945 and 1946. In 1945, the 205 and 410 kg/ha application rate resulted in a slight increase in the K content in the leaves over the check trees. However, the 820 kg/ha application did not increase the K content in the leaves over that from the 410 kg/ha application. In 1946 there was no increase over the check with the 205 kg/ha application, there was some increase with the 410 kg/ha application, and the 820 kg/ha application rate caused a leaf K level that was twice that of the check.

Some research has shown K fertilization not to be effective in raising leaf K levels. Worley (44) using 40-year-old 'Stuart' pecan trees applied fertilizer treatments of 45-20-37, 90-40-74, and 134-60-111 (NPK) kg/ha annually from 1962-1971. Leaf analysis taken four of the ten years did not reveal any significant response of K leaf level to the fertilization treatments. Worely (43) performed an additional K fertilizer study on younger trees. Fertilizer treatments of 18-8-15, 36-16-30, 45-16-59, and 89-16-59 (NPK) expressed as gm/cm of tree circumference were applied annually to 21-year-old 'Stuart' pecan trees from 1963-1970. The fertilizer treatments did not cause a significant increase in leaf K content over that of the check trees.

Nitrogen Deficiency Symptoms

Generally, the overall effect of inadequate N is a reduction in growth of all parts of the tree. Under severe shortage, N deficiency is characterized by a general yellowing of the leaves. Since the leaves are yellow, or chlorotic, photosynthetic efficiency is reduced with the net result being a loss in growth and yield. As the N supply is gradually increased, all parts of the tree increase in size up to an optimum concentration of N. However, except under conditions of severe N shortage, an inadequate supply of N will usually not be detectable by visual observation (32).

Sparks (32) grew 1-year-old 'Stuart' pecan seedlings in sand culture with levels of 0 to 240 ppm N. When leaf N content ranged between 1.8 and 2.2% obvious N deficiency symptoms occurred which indicated that these trees were suffering from lack of N. This range was designated as the region of "visible deficiency symptoms." From 2.2 to 2.6% leaf N content, leaf color appeared normal but growth continued as leaf N increased, this range was designated as the region of "hidden deficiency" since the leaf deficiency was not obviously visible. From 2.6 to 2.9% leaf N content, growth was at a maximum. Above 2.9%, growth was suppressed by excessive N. The second phase of Sparks' experiment was conducted on 7-year-old 'Desirable' pecan trees. In this experiment "visible deficiency symptoms" occurred below 2.2% N in the leaflets and "hidden deficiency" above this value.

In the spring of 1947, Alben (1) noticed severe leaf chlorosis in a 1-year-old pecan orchard. Nitrogen fertilizers were applied to the soil and in solution to the trees as a spray. Analysis of leaves from the trees, before treatment were made, confirmed the N deficiency diagnosis. The leaves that had the most severe chlorosis had a N content below 1.2%, whereas normal leaves had between 2.4 and 3.0% N. The trees recovered after receiving the N fertilizer and spray treatments. Alben (1) studied various cases in which orchards appeared to have different degrees of N deficiency symptoms. Leaves with the most severe deficiency symptoms had the lowest N content, less than half that of the normal leaves. The leaves with 1.17% had petioles, veins, and the entire younger leaflets with a pinkish tinge, and small dead areas between the veins. The leaflets with 1.30% N had petioles, veins and younger leaflets with a pinkish tinge, but no dead areas. The leaves with 1.54% N were yellow throughout with no pink on the petioles, veins, or young leaflets. The leaves with 1.84% had green basal leaflets and yellow apex leaflets on the same leaf. Practically normal leaves had 2.26% N, and dark green leaves 2.75 to 2.82% N. Smith and Hamilton (31) applied N at 0, 38, and 76 kg/ha/year to 12-year-old 'Burkett' pecan trees for three consecutive years. The applications of the N fertilizer caused the leaves to be greener than leaves on unfertilized trees. O'Barr (23) noted that the recommended level of leaf N content in pecan was 2.4 to 2.5% dry weight. Starting at 2.0 to 2.2% and below, the pecan leaf began to take on a yellow or pale chlorotic appearance. From 2.0 to 2.2 through 2.5%, the yield was limited due to low N but the trees looked normal and green.

Nutrient-Element Interactions

It should be emphasized that neither high intensity nor proper balance alone will result in maximum growth and yield. Though a high yield is dependent upon a sufficiently high intensity, a high level of nutritional intensity cannot result in maximum growth and yield unless a proper balance exists between all of the elements. It is because of this that it is possible to have completely normal appearing, yet low yielding trees. It is also true that the appearance of a symptom "typical" of the "deficiency" of a certain element does not indicate that a low level of that element in the plant is necessarily responsible for the symptom. It indicates that the element is low in relation to one or more other essential elements. It follows that only through complete leaf analysis is it possible to determine, for example, whether "Mg deficiency" symptoms are due to a low level of Mg nutrition, or too high a level of Ca, K, or N or a combination of the three (29).

Shear (26) emphasized the importance of a balance between elements, particularly the major cations. He found that a competitive relation existed between the major cations, K, Ca, and Mg. The effect of K was usually greater than the reciprocal effects of Mg or Ca on K. O'Barr (23) reported that high rates of N could induce deficiency of other elements. Two of particular concern were K and Zn. When these elements are near the deficiency range application additions of K and Zn may be necessary to avoid deficiency when N is applied. Other instances were reported in which one element effected the availability of another element. Potassium was competitive with Mg and Mg was antagonistic to Zn. Worley (40) analyzed leaf samples sent in by pecan growers throughout Georgia for N, P, K, Ca, Mg, Zn, Mn, and Fe. A correlation analysis was run for each of the elements analyzed in the leaves to see if the level of one element affected that of another. A negative correlation of leaf Mg and leaf K indicated competition between these two elements. Application of high K fertilizer over several years may have caused some of the Mg deficiencies in some of the groves. Nitrogen and Zn appeared competitive in the leaves as indicated by a negative correlation coefficient.

Gammon and Sharpe (13) applied different levels and combinations of N, P, and K to 35-year-old 'Curtis' pecan trees from 1954-1958. They found that by continuing different fertilizer treatments for several years, some secondary changes in the soil may be expected. When such changes take place, the crop responds to the nutrients of the fertilizer treatment plus the secondary effects the fertilizer may have had on the soil. Several conclusions were made as to the effects different fertilizer practices had on the soil and on the composition of pecan leaves. The N applications significantly reduced the soil retention of K and reduced the percentage of P and K, and, in 1957 and 1958, the Mg levels of the leaves. Nitrogen applications also tended to reduce the Ca levels in the leaves. Data for 1958 showed that increased N had a highly significant effect in reducing Zn in the leaves. These results suggest that N fertilization is likely to produce Zn deficiency symptoms (rosette). Potassium applications resulted in significant decreases in P in the leaves, even in the first year after application. The effect of the addition of both N and K had an additive effect in their depression of P and Mg in the leaves. Worley (43) applied 0, 56, and 112 kg/ha/year of N and 0, 112, 224 kg/ha/year of K to 4-year-old 'Desirable' pecan trees for five consecutive years. Increasing either the N or K treatment levels decreased leaf Mg. Differences became more pronounced with time. However, the N and K treatment levels had no effect on leaf Ca content.

Shear, Crane, and Myers (27) conducted an experiment to demonstrate nutrient-element balance by growing tung trees (Aleurites fordii Hermsl.) in sand culture with varying levels of nutrient elements. Results from this experiment demonstrated the depressing effect major bases, particularly K, had on heavy metals. Although Zn was not one of the heavy metals analyzed, growth data and leaf symptoms indicated a similar relationship may exist between K and Zn. It was also concluded that N accumulation probably takes place only when a functional imbalance exists between N and some other element. Analysis of leaves taken from tung trees grown in sand culture with nutrient solutions having N concentrations of 9, 27, 81, and 162 ppm showed a N content of 2.58, 2.53, 2.67, and 2.90%, respectively. In contrast to this slight effect on N content with wide differences in N supply, when N supplied was kept constant at 81 ppm, and P was supplied at levels of 0, 3, and 9 ppm, then dry matter percentage of N in the leaves was 1.91, 2.67, and 3.17%, respectively.

Pecan Nut Abortion

The factors that determine yield in pecan are: the number of pistillate (female) flowers that appear in the spring, the percentage of these flowers that are fertilized and mature into a nut, nut size, and nut filling. Sparks and Heath (35, 34) described drop of pistillate flowers and nuts of the 'Stuart' as a function of time and gave reasons for these drops. It was concluded that the first drop occurred at pollination time; the second drop or May drop occurred 10 to 20 days later, and the third drop or summer drop continued until the beginning of shell hardening. The first drop consisted primarily of weak or underdeveloped flowers. The second drop was apparently due largely to conditions preventing fertilization of the ovule. The third drop was attributed to embryo abortion.

Sparks and Heath (35, 34) tagged shoots bearing pistillate flowers on May 4, just past full bloom. The number of pistillate flowers or nuts per cluster were recorded at weekly intervals until shuck split began. Shoot length was divided into five classes at 5 cm intervals to study the relationship of pistillate flower and nut abscission to shoot length. Compared to the number of pistillate flowers present at full bloom, the flower or nut loss was about 54, 23, and 8% during the first, second, and third drop, respectively. The total loss was about 85% of the potential crop. The number of pistillate flowers and nuts lost decreased as shoot length increased. Relationships of the pistillate flower and nut loss to shoot length varied among individual drops. The first drop was inversely related to shoot length. As the vigor of the shoot increased the number of female blossoms dropped decreased. The second drop was not closely related to shoot length. The third drop was associated with a rapid increase in nut growth, placing an apparent stress for carbohydrates on the tree. Stress, due to insufficient leaf area per nut, was greater on the shorter shoots, resulting in more nut abscission from these shoots. The longer the shoots the more mature nuts per shoot were produced. Although considerable drop occurred on all shoots regardless of length, the percentage drop varied with length. As the length of the shoot increased from about 5 to 35 cm total drop decreased from approximately 100% to less than 70%. These relationships of vigor to number of blosssoms per shoot, nuts matured, and percent drop demonstrates the necessity for maintaining vigorous shoot growth.

Smith (30) stated that a greater number of nuts are produced and retained on strong shoots that are reasonably long. Alben et al. (4) found that trees in the check plots had a heavier drop of nuts than occurred on trees receiving 40 kg/ha of N. In a list given by Brinson on causes of nuts dropping before they are filled, a lack of sufficient nutrients was listed as one of the major causes.

O'Barr (23) listed several items that influenced premature blossom and nut drop. Low N was listed as the second major factor that influenced premature blossom and nut drop.

Terminal Growth

Taylor and Hinrichs (36) reported that terminal growth was an effective guide to monitor the nutritional condition of pecan trees. Crane (9) showed that N was the element having the greatest influence on pecan tree growth and that N increased the length and fruiting ability of the pecan shoots. Smith and Hamilton (31) in a study of factors associated with productiveness of pecan shoots found that weak shoots do not fruit, and that to improve the productiveness of a tree the vigor of the shoots must be improved. This, they concluded, could be done by the application of nitrogen fertilizers.

Sparks (32) grew 1-year-old 'Stuart' pecan seedlings in sand culture with levels of 0 to 240 ppm N. Results showed that shoot growth increased as N content of the leaflet increased from 1.8 to 2.9%. This increase was followed by growth suppression when the percent of N was too high (3.0 to 3.2%). The second phase of Sparks' study was conducted under field conditions on 7-year-old 'Desirable' pecan trees. Shoot growth increased linearly in response to increased percent N content in the leaflet. Results showed that shoot length increased from 35.6 to 40.6 cm as percent N in the leaflet increased from 1.9 to 2.7%. Crocker (12) indicated that if leaf N was brought up to a 3% level in older trees then 20.3 to 25.4 cm of shoot growth should result.

Skinner (29) applied 189 kg/ha of N, 83 kg/ha of P, and 15 kg/ha of K in all possible combinations to 12-year-old 'Schley', 'Alley', and 'Stuart' pecan trees for seven consecutive years. Shoot growth was greater where N was used singularly than with K or P. Mixtures of P and K produced less shoot growth than mixtures of N and P or N and K. Nitrogen effected tree growth more than the other fertilizer constituents. Alben et al. (4) utilized different cultural practices from 1935-1939 which resulted in soil N levels equivalent to applying 0 to 40 kg N/ha in plots of 5-year-old 'Schley', 'Stuart', and 'Success' pecan trees. Trees in the lowest N plots made less growth than made by trees in the highest soil N plots. Worley (42) conducted a fertilizer test in which three levels of N and K were used. Soil test levels of K were subtracted from treatment levels prior to application. The treatment levels were 0, 56, and 112 kg/ha of N, and 0, 112, and 224 kg/ha of K annually from 1966 to 1970. The N fertilizer applications increased shoot growth, but K treatments had no effect on shoot growth.

Yield

Many have shown that complete fertilizers furnishing N, P, and K increase growth and yield over unfertilized trees. Nitrogen was determined to be the single element that gave the largest yield response. Fertilizers containing high N and/or K were found to produce trees which grew better and had higher yields than those containing low levels of these elements (11).

Smith and Hamilton (31) applied N at 0, 38, and 76 kg/ha/year to 12-year-old 'Burkett' pecan trees from 1934-1936. The yield of nuts was increased by the applications of N in each of the three years. The 76 kg/ha application increased the yield to a much greater extent than the 38 kg/ha application; however, the amount of increase in each of the treatments was nearly proportional to the amount of fertilizer applied. Heaton et al. (17) in a nine year study on 40-year-old 'Stuart' pecan trees found that as N fertilization was increased yield was increased. Alben et al. (4) set up different cultural treatments from 1935-1939 which resulted in soil N levels equivalent to applying 0 to 40 kg N/ha in plots of 5-year-old 'Schley', 'Stuart', and 'Success' pecan trees. In 1937, 1938, and 1939 trees in the highest soil N plots produced three times as many kilograms of pecans as did trees in the lowest soil N plots.

Hinrichs (18) applied N at rates of 0, 19, and 38 kg/m^2 of cross sectional trunk area to large native pecan trees annually from 1962 to 1967. Over the six year period, higher yields were obtained from trees receiving the 38 kg rate of N than the 19 kg rate. Other research by Hinrichs (18) at the Oklahoma Pecan Research Station also showed that N fertilization increased pecan yields. Nitrogen applied at the rate of 133 kg/ha produced yields of 754.3 kg/ha compared to yields of 390.1 kg/ha from check trees. However, when N was applied at 266 kg/ha the yield of pecans increased only slightly to 777.9 kg/ha.

The manner in which yield increases with increasing N in the leaflet was demonstrated by Sparks (32) on 7-year-old 'Desirable' pecan trees. Over the range of percent N observed (2.0 to 2.6%) yield consistently increased. As N increased from 2.0 to 2.6%, yield increased 2.7 times. Seventy percent of the total increase in yield occured in the region of "hidden deficiency". From 1944 to 1948, Alben and Harris (3) used different cultural practices with and without N fertilization to cause differences in the amount of N supplied to 'Stuart', 'Success', and 'Schley' pecan trees. In 1948, leaf samples were taken from the various plots and analyzed for N content. The leaf N varied from 1.90 to 2.85% for the 'Stuart' variety; 1.72 to 2.52% for the 'Schley' variety; and 1.82 to 2.67% for the 'Success' variety. Trees of the 'Stuart' and 'Schley' cultivars which had the highest N content in their leaves produced the highest yield of nuts per hectare. 'Success' trees with the highest concentration of N in their leaves produced the second highest yield of nuts per hectare, while those with the second highest N content in their leaves produced the highest yield of nuts. Trees of all three varieties with the lowest content of N in their leaves produced the lowest yield of nuts. 'Schley' and 'Stuart' trees with the highest N content in their leaves produced approximately three times as many nuts as the same cultivar with the lowest N content in their leaves. 'Success' trees with the second highest N content in their leaves produced almost twice as many nuts as those with the lowest N content in their leaves.

Hagler and Johnson (16) collected leaf samples from 176 pecan orchards and analyzed the samples for N and K to determine the relation of foliar analysis to yield. There were seven yield classes according to the average yield per tree. The highest yield class produced 25.4 kg/tree or more and those in the lowest class produced 2.3 kg/tree or less. Data from the foliar analysis showed that N increased in the leaves as the average yield of nuts per tree increased. The K content of the foliage was not significantly different in any of the yield classes.

The influence of K on yield of 'Moneymaker' and 'Moore' pecans was studied by Blackmon and Ruprecht (7). Fertilizer treatments at rates of 57-22-0, 57-22-39, and 57-22-78 (NPK) kg/ha were applied annually from 1924-1931. When data from the 'Moore' trees was considered, it appeared that K influenced the yield, because when it was included, yield was greater than when N and P were applied alone. The fertilized trees showed an average annual increase in yield over the checks in kg/ha of 104.1 for the 57-22-0 rate, 267.3 for the 57-22-39 rate, and 219.4 for the 57.22-78 rate. The differences in yield of the 'Moneymaker' trees were not in the same order as in the 'Moore' trees. The highest yielding plot was the one which received 57-22-78, the second highest was 57-22-0, the third highest was 57-22-39, and the unfertilized plot produced the lowest yield. Sharpe, Blackmon, and Gammon (25) applied K at rates of 25, 50, and 100 kg/ha/year to 23-year-old 'Stuart' pecan trees from 1942-1945. The average K leaf mineral content was grouped by yield classes. There was a consistent increase in K with increasing yields. An apparent contradiction was observed, in that the better yielding trees had a higher average leaf K content, but heavy K fertilization did not produce appreciable yield increases. Worley (43) applied annual applications of K at 0, 112, and 224 kg/ha to 4-year-old 'Desirable' pecan trees for five consecutive years. Yield response to K treatments were not significant.

A five year study was conducted by Gossard and Hammer (14) on 14- and 15-year-old 'Moneymaker' and 'Success' pecan trees to compare the effects of a "good" rate and a "very high" rate of K application on cultivated land. Fertilization consisted of N as a cover crop and

0-24-45 and 0-24-134 (NPK) kg/ha. The highest average annual yields per tree (85.1 kg and 73.9 kg) of both cultivars were produced in the 0-24-134 plots and the lowest average yields per tree (67.6 kg and 68.4 kg) of both cultivars were produced in the 0-24-45 plots. Ponder (24) studied the effects of fertilization on 28-year-old pole-sized black walnut trees. Nitrogen at 0, 179, and 358 kg/ha and K at rates of 0, 156, and 312 kg/ha were applied in various combinations in 1972 and again in 1974. After four years the fertilized trees produced more nuts than the control trees. The N treatments yielded 16% more kilograms of nuts than the controls. Nitrogen plus K treatments yielded 16% more kilograms of nuts than the controls and 27% over the N treatments. Because there was no K only treatments it could be suggested that the increase came from the addition of K and/or a K/N interaction.

Pecan Nut Quality

Perhaps there is no one factor directly responsible for poor pecan nut quality (nut length, nut diameter, and percent kernel); but if there is one it would be logical to expect it to be the nutritional condition of the trees. It has been found that during their filling period pecan nuts accumulate fairly large quantities of N, P, and K at the expense of the leaves and shoots (21). Whitehead (39) concluded that nut size was determined largely by the health and vigor of the pecan tree during June, July, and August.

The effects of N fertilizer on pecan nut quality were indicated in a study by Smith and Hamilton (31). Nitrogen at the rates of 0, 38, and 76 kg/ha/year were applied to 12-year-old 'Burkett' pecan trees from 1934-1936. The pecans produced by the fertilized trees were larger in size than those produced by unfertilized trees, and except in 1936, the nuts from trees receiving 76 kg/ha of fertilizer were larger than those receiving 38 kg/ha. The percentage of kernels in nuts from check trees was higher on the average than in nuts from fertilized trees. Alben et al. (4) utilized different cultural treatments from 1935-1939 which resulted in soil N levels equivalent to applying 0 to 40 kg N/ha in plots of 5-year-old 'Schley', 'Stuart', and 'Success' pecan trees. As a result nuts from trees in the lowest N plots were smaller than pecans from trees in the highest N plots.

Taylor (37) conducted an experiment to determine the effects of certain fertilizer treatments on the quality of nuts produced. Fertilizer treatments consisted of annual applications of 49 kg/ha of N, 39 kg/ha of P, and 38 kg/ha of K applied in combinations of P-K, N-P-K, 2N-2P-2K to 16-year-old 'Stuart' pecan trees from 1926-1929. In 1929, nuts from trees receiving heavy annual applications of complete fertilizer were smaller in size and more were required to weigh a kilogram than those in trees receiving moderate applications. The nuts from the heavy fertilized trees contained a smaller kernel percentage than those from trees receiving moderate applications of only P and K. These differences in size, weight, and kernel percentage from the different plots in 1929 were thought to be largely due to differences in the amount of water available to the nuts during critical periods. It was noted that the increased transpiration of trees with large leaf areas due to heavier fertilization may have lessened the amount of available water in comparison with other plots and thus adversely influenced the size of the nuts.

Hunter and Hammer (21) applied treatments of 38 kg/ha of N alone and 38-33-32 (NPK) kg/ha to 14- and 15-year-old 'Moore' pecan trees from 1939-1945. Each of the fertilizers used increased yields over the trees which received no fertilizer; but the nuts that filled to the highest degree were produced by trees which received N-P-K. The N levels in the leaves of the trees were found to be approximately the same and bore no direct relationship as to the degree to which the nuts were filled. Worley (43) conducted two experiments at different locations to determine the effects that fertilization had on nut quality. In one grove, 45-20-37, 90-40-74, and 135-60-111 (NPK) kg/ha were applied annually to 40-year-old 'Stuart' pecan trees from 1962-1971. In another grove, 18-8-15, 36-16-59, and 45-16-59 (NPK) expressed as g/cm of trunk circumference were applied annually to 21-year-old 'Stuart' pecan trees from 1963-1970. In these groves nuts/kg count and percentage kernel behaved erratically over the years, but in some of the years increasing the fertilizer rate lowered kernel percentage. Worley (41) applied 45-29-37, 90-40-74, and 135-60-111 (NPK) kg/ha annually to 35-40-year-old 'Stuart' pecan trees from 1962-1967. The treatments had no significant effect on nut quality in 1967 as measured by percent kernel, percentage of No. 1 kernels, or nuts/kg. There was not a trend toward a lower percentage of No. 1 nuts as the fertilizer rate increased.

CHAPTER III

MATERIALS AND METHODS

A factorial treatment combination of four levels of N and three levels of K were applied to 25-year-old 'Western' pecan trees (Carya illinoensis [Wang] K. Koch) in 1978 and 1979. Nitrogen rates were 0, 56, 112, and 224 kg/ha. Potassium rates were 0, 112, and 224 kg/ha. Urea (45%) and potassium chloride (60%) were used as N and K sources, respectively. Fertilizer treatments were broadcast within the drip line March 15, 1978, and March 18, 1979. Fertilizer treatments were not incorporated until discing was required for weed control approximately eight weeks later. A randomized complete block design was used with four replications and two-tree plots. Analysis was by Fisher's F-test and regression analysis.

The study was conducted on a Port silty clay loam soil with 0-1% slope. Trees were spaced 15 x 15 m. During the study, the orchard floor was maintained by summer cultivation as required, with a winter cover crop of native grasses. Three applications of zinc, as a foliar spray of zinc sulfate, were made in 1978 and 1979.

Leaf samples were collected July 15 in 1978 and 1979. The index tissue used was the middle pair of leaflets from the middle leaf on current season growth. One hundred leaflets were collected at a height of 3 to 6 m around the tree. Samples were washed with water for one minute in 1979 to remove possible contaminates. The samples were then dried in a forced air oven at 80°C for 12 hours. Following drying, leaves were ground using a Wiley mill with a 1 mm mesh screen, and stored in 50 ml vials until used for analysis.

Each sample was analyzed for N, P, K, Ca, Mg, and Zn. Nitrogen determinations were made by the Macro Kjeldahl analysis as stipulated by the Association of Agriculture Chemists (6). One gram samples were used. For analysis of the other elements the samples were first digested using a nitricperchloric acid digestion procedure. Twenty mg of plant tissue was placed in 50 ml test tubes. Five ml of 69% nitric acid and 5 ml of 70% perchloric acid were added to each test tube. The samples were heated at 100°C in a block digestor until they turned a straw yellow color. The temperature was then raised to 175°C until they became pale yellow in color, then increased to 230-270°C and heated until 0.5 ml or less of the digested sample remained in the test tubes. The samples were transfered with deionized water to a 50 ml volumetric flask, and diluted to volume with deionized water.

Phosphorus concentrations were measured by a sodium molybdate-hydrazine sulfate procedure (28). Ten ml aliquats of digested plant samples were pipetted and placed in 200 ml graduated beakers. Volume was made to 50 ml with deionized water. Five drops of 2, 4-dinitrophenol was added to each beaker and the samples were titrated to a yellow tint with ammonium hydroxide. Five ml of sodium molybdate and, after five minutes, 5 ml of hydrazine sulfate was added to each beaker. The samples were boiled for one minute on a hot plate, then cooled and brought to an 100 ml volume with deionized water. The samples were then read on a B & L spectrophotometer 20 colorimeter at 700 nm using a red filter.

The other elements, K, Ca, Mg, and Zn, were determined using a Perkin-Elmer Model 403 atomic absorption unit. The samples were prepared by pipetting 16 ml of nitroicperchloric acid digested sample and 4 ml of a 5% lanthanum chloride solution into 50 ml vials.

Leaf chlorosis ratings were taken on Ocotber 5, 1978. Three people rated each tree individually on a scale of 1 to 5, with 1 = no chlorosis and 5 = severe chlorosis.

Nut abortion was studied as a response to fertilizer treatment. One subsample from each plot was randomly selected on May 25, 1978. Fifty nuts from clusters of two, three, or four nuts were randomly selected around the periphery of each tree. A tag was placed around each nut cluster and the number of nuts present were recorded on the tags. On July 1 and September 23, 1978, abortion counts were taken.

Shoot growth was measured December 19, 1978 and August 21, 1979. Fifty randomly selected terminal shoots were measured on each tree at a height of 3 to 6 m. Total yield was taken in 1978. Yield was estimated in 1979 on August 21 by counting the number of nuts of 50 randomly selected shoots at height of 3 to 6 m. Twenty nuts were randomly selected from each test plot (unless yield was zero) and analyzed for nut length, nut diameter, and percent kernel.

CHAPTER IV

RESULTS AND DISCUSSION

Pecan Tree Response to Nitrogen Fertilization

The effect of N fertilizer treatments on leaf N content in 1978 and 1979 is presented in Table I. Leaf analysis for N shows that as N application rates increased the percent N in the leaves increased significantly in 1978 and 1979. Leaf samples taken from the orchard in 1977 had an average N content of 2.1%. In the check plots the leaf N remained constant over the three years. Data shows that N applications in 1978 increased the leaf N content of each treatment over the average 2.1% leaf N obtained in 1977. Leaf analysis shows that after the N applications were repeated in 1979, the average percent leaf N from each treatment increased over the percent N content obtained from each treatment in 1978. However, after application of 224 kg N/ha for two consecutive years, leaf N content was 2.40%, still below the N sufficiency range (2.5%-3.0%) suggested by Jones (22).

Data from visual deficiency symptom ratings taken on October 5, 1978 are presented in Table 1. Results show that as N applications increased visual deficiency symptoms decreased significantly. Figure 1 illustrates the basis on which these ratings were made. Figure 2 shows the leaf N content corresponding to the visual deficiency ratings. Visual deficiency symptoms were not evident when leaf N

TABLE I

THE INFLUENCE OF NITROGEN FERTILIZER APPLICATIONS ON LEAF MINERAL CONTENT OF PECAN[Z]

N kg/ha	N (%)		K (%)		P (%)		Ca (%)		Mg (%)		Zn (ppm)		Visual[X] Ratings
	1978	1979	1978	1979	1978	1979	1978	1979	1978	1979	1978	1979	1978
0	2.15	2.20	0.78	0.59	0.16	0.14	1.37	1.28	0.75	0.66	128	72	3.0
56	2.23	2.31	0.73	0.57	0.15	0.13	1.43	1.30	0.73	0.66	121	72	2.6
112	2.27	2.32	0.66	0.52	0.13	0.12	1.35	1.35	0.73	0.68	109	68	2.5
224	2.39	2.40	0.71	0.54	0.14	0.12	1.32	1.27	0.74	0.68	111	63	2.0
Linear	**	**	*	*	**	NS	NS	NS	NS	NS	NS	NS	**
Quadratic	NS[Y]	*	**	NS	*	NS	NS	NS	NS	NS	NS	NS	NS

[Z]All levels of potassium are pooled.
[Y]Non Significant (NS); significant at 5%(*), significant at 1%(**).
[X]Rating 1-5; 1=Normal Appearing Foliage, 5=Severe Chlorotic Foliage.

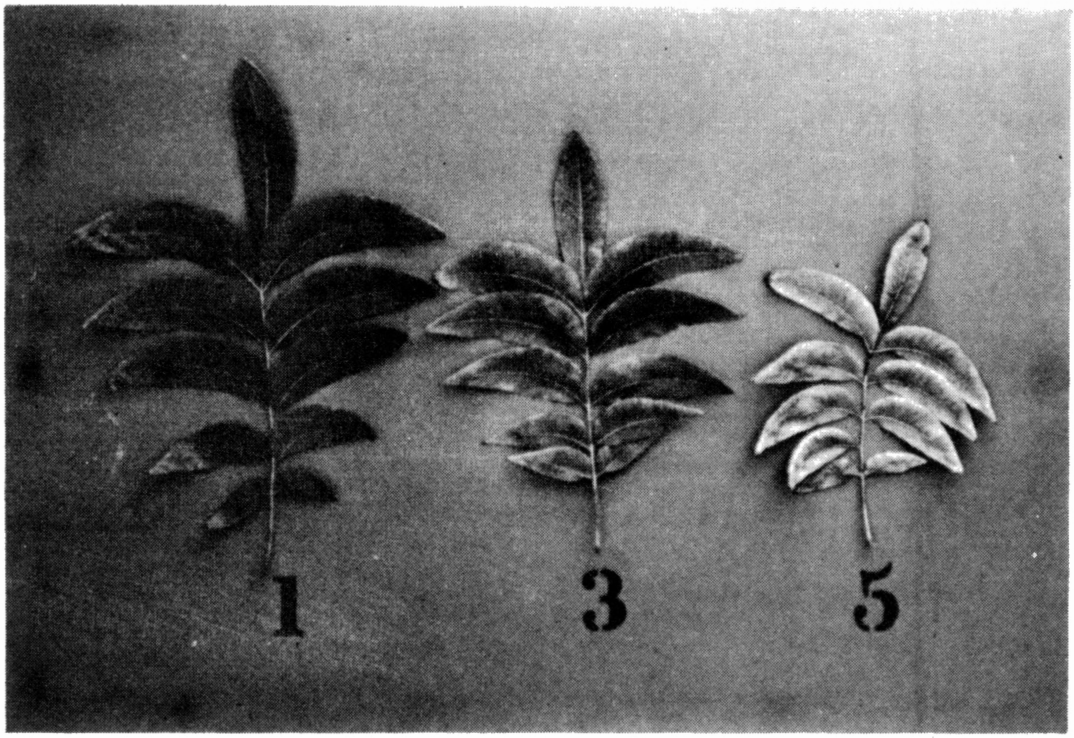
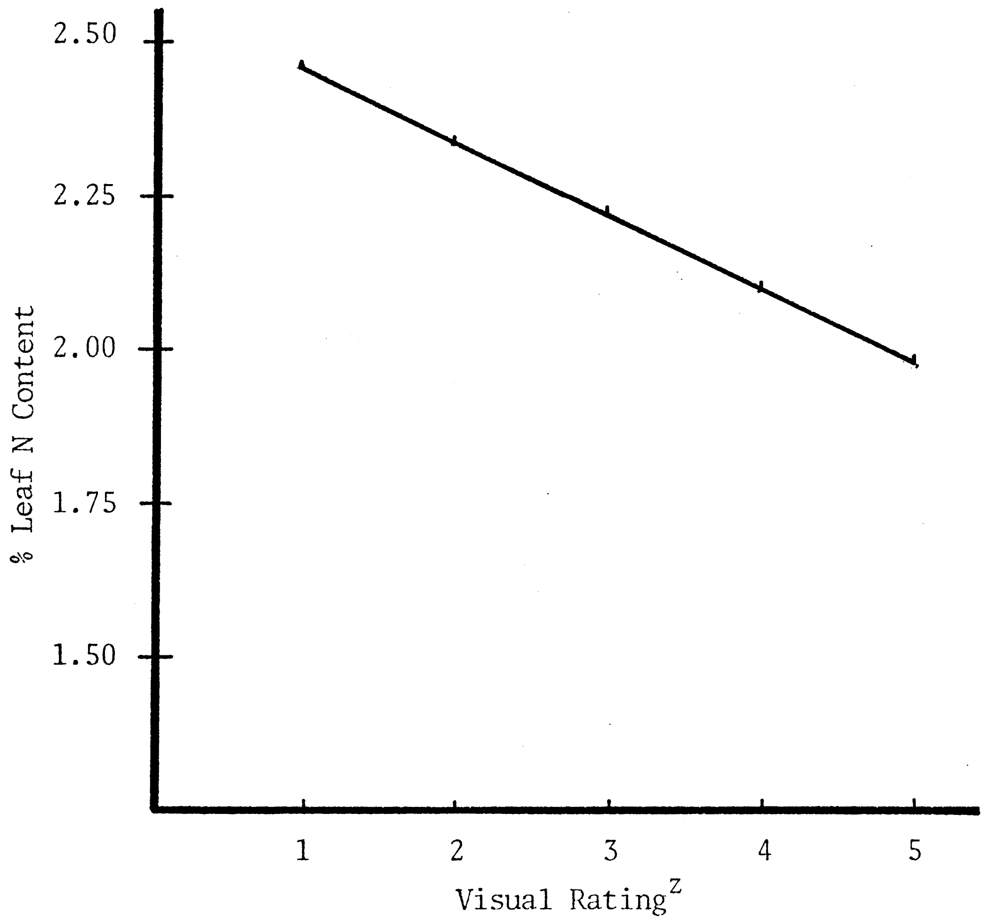


Figure 1. Visual Leaf Deficiency Symptom Ratings on a Scale of 1-5; With 1 = Normal Appearing Foliage, 3 = Chlorotic Foliage, and 5 = Severe Chlorotic Foliage.



[z]Rating 1-5; 1 = Normal Appearing Foliage, 5 = Severe Chlorotic Foliage.

Figure 2. Percent Leaf Nitrogen Content Correlated to Visual Deficiency Symptom Ratings.

content was approximately 2.45%. Visual deficiency symptoms occurred when leaf N content was approximately 2.33%. Obvious visual N deficiency symptoms occurred between 2.21% and 2.10%. Severe visual N deficiency symptoms were detected when leaf N content was approximately 1.97%. This data is in agreement with work done by Sparks (32). He concluded that obvious deficiency symptoms occurred from 1.8% to 2.2% leaf N content and when leaf N content was above 2.2% foliage appeared normal. Alben (2) also found that pecan tree foliage appeared normal when leaf N content was from 2.4% to 3.0%. Alben (1), in another experiment, also found that leaves with 1.84% N had obvious deficiency symptoms, practically normal leaves appeared at 2.26%, and dark green leaves appeared when leaf N content was 2.75%.

The effects of N fertilizer treatments on leaf content of K, Ca, Mg, and Zn are presented in Table I. Data shows that as N applications in 1978 increased from 0 to 112 kg/ha leaf K content significantly decreased. In 1979, leaf K content decreased significantly as N applications increased from 0 to 224 kg/ha. Leaf P content also significantly decreased in 1978 as N applications increased from 0 to 112 kg/ha. Increase in tree growth from N fertilization could have induced the decrease in percent leaf K and P content. Nitrogen applications did not significantly effect the leaf content of Ca, Mg, or Zn. These interactions may not have occurred because the leaf levels of these three elements were well above their sufficiency range suggested by Jones (22) in both years (Ca .70-1.50%; Mg .30-.60%; Zn 50-100 ppm). Whereas decrease in leaf K and P content due to N applications may have occurred because the leaf levels of these elements were on the border line of their sufficiency range (P .12-.30%; K .75-1.25%) as given by Jones (22).

The large decrease noted in leaf Zn content between 1978 and 1979 was probably due to excess Zn foliar spray remaining on the leaves in 1978 and not due to fertilizer treatments. High amounts and large variability in leaf Zn content was noted in 1978. In 1979, the leaves were rinsed with water to remove excess Zn foliar spray that may have remained on the leaves.

The response of terminal shoot growth, yield, and nut quality to N fertilizer treatments in 1978 and 1979 are shown in Table II. Terminal shoot growth in 1978 did not increase with increasing rates of N fertilizer. This may have been due to the low fertility of the trees prior to this study and the age of the trees. Growth responses under these conditions could be expected not to occur the first year. In 1979, terminal shoot growth did significantly increase as N application rate increased. This increase in shoot growth was small with the greatest difference in terminal shoot growth being between 0 and 224 kg N/ha which totaled 2.17 cm. However, since mature pecan trees respond slowly to fertilization the higher N fertilizer treatments may increase terminal shoot growth more in future years.

Yield was estimated in 1979 by counting the total number of nuts on 50 randomly selected shoots on August 21. Data shows that as N application rates increased nuts/shoot increased significantly. An increase of .37 nuts/shoot was obtained from the 224 kg N/ha over the check trees. Nitrogen applications did not significantly alter percent kernel when compared to the check trees. Nut size (length and diameter) increased significantly as the N application rates increased.

TABLE II

THE INFLUENCE OF NITROGEN FERTILIZER APPLICATIONS
ON SHOOT GROWTH, YIELD, NUT QUALITY, AND
NUT ABORTION OF PECAN[Z]

N kg/ha	Shoot Growth (cm) 1978	Shoot Growth (cm) 1979	Nuts Per Shoot 1979	Percent Kernel 1978	Length (mm) 1978	Diameter (mm) 1978	Nut Abortion 5/24-7/1 (%) 1978	Nut Abortion 7/1-9/24 (%) 1978	Nut Abortion 5/24-9/24 (%) 1978
0	6.2	8.2	1.97	58.19	38.8	18.8	16.7	17.8	32.2
56	5.5	8.3	2.10	57.57	39.9	19.1	16.4	18.6	30.2
112	5.7	8.8	2.22	57.46	39.6	19.1	18.8	13.0	30.4
224	6.5	10.3	2.34	57.71	40.6	19.3	18.1	15.4	31.2
Linear	NS[Y]	**	**	NS	**	**	NS	NS	NS
Quadratic	*	NS	NS	NS	NS	NS	NS	NS	NS

[Z]All levels of potassium are pooled.
[Y]Non Significant (NS); significant at 5%(*), significant at 1%(**).

The influence of N fertilizer applications on nut abortion in 1978 is presented in Table II. Data shows that the N applications did not significantly reduce the percentage of nuts aborted May 24 to July 1, July 1 to September 24, or May 24 to September 24.

Pecan Tree Response to Potassium Fertilization

The effects of K fertilizer treatments on K leaf content in 1978 and 1979 are shown in Table III. Data shows that K applications did not significantly effect leaf K content in 1978 or 1979. Results in 1978 showed that average leaf K content was approximately .72% regardless of the amount of K applied. The same results were obtained in 1979, except average leaf K content decreased to .55%. This decrease in leaf K content in all treatments may have been due to the increase in crop size in 1979. Sparks (33) has found that the shuck contains 5 to 7% K and the kernel and shell contains about .33% K. Therefore, in heavy crop years when adequate amounts of K are not absorbed from the soil, K is translocated from the leaves to the maturing nuts. The failure to get an increase in leaf K content with rates as high as 244 kg/ha for two consecutive years may be accounted for in several ways. Since it is known that the pecan nut requires a large amount of K, it may be assumed that the trees are utilizing all the available K in the soil and the amount of K in the soil has not yet been enough to satisfy both that of the foliage and the pecan nut. Potassium may have been converted to unavailable forms in the soil, due to the soil's high fixing capacity or soil pH. However, random soil samples were taken approximately two months after fertilizer applications in both years and results showed

TABLE III

THE INFLUENCE OF POTASSIUM FERTILIZER APPLICATIONS ON LEAF MINERAL CONTENT OF PECAN[z]

K kg/ha	N (%) 1978	N (%) 1979	K (%) 1978	K (%) 1979	P (%) 1978	P (%) 1979	Ca (%) 1978	Ca (%) 1979	Mg (%) 1978	Mg (%) 1979	Zn (ppm) 1978	Zn (ppm) 1979	Visual Ratings[x] 1978
0	2.26	2.31	0.72	0.55	0.15	0.13	1.34	1.25	0.75	0.67	112	71	2.6
112	2.28	2.32	0.72	0.55	0.14	0.13	1.38	1.33	0.71	0.66	114	65	2.4
224	2.24	2.29	0.72	0.56	0.14	0.12	1.39	1.31	0.74	0.68	115	70	2.7
Linear	NS[y]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]All levels of nitrogen are pooled.
[y]Non Significant (NS); significant at 5%(*), significant at 1%(**).
[x]Rating 1-5; 1=Normal Appearing Foliage, 5=Severe Chlorotic Foliage.

the pH of all samples to be approximately 6.5. Potassium applications to trees of initial low fertility and of this age may require several years before K fertilizer responses can be detected in leaf analysis.

The effects of K fertilizer treatments on N, P, Ca, Mg, and Zn leaf content in 1978 and 1979 are shown in Table III. Potassium applications did not significantly affect the levels of the other elements in 1978 or 1979. However, the effect of K on Ca, Mg, and Zn may have not occurred since these elements were well above their suggested sufficiency ranges during both years. Potassium applications did not significantly affect the leaf content of K or P, even with both elements on the border of their suggested sufficiency ranges both years.

Potassium fertilizer applications did not significantly decrease nut abortion over the 1978 season as shown in Table IV. However, data showed that 17.5% of the nuts aborted from May 24 to July 1, and 13.5% of nuts aborted from July 1 to September 24. A total of 31% of the nuts present May 24 were aborted by September 24. Sparks and Heath (35) also reported a 31% nut abortion from May through early October.

Data in Table IV shows that K fertilizer applications did not significantly influence terminal shoot growth in 1978 and 1979, or nuts per shoot in 1979. Percent kernel, nut length, and nut diameter were not significantly affected by K fertilizer applications.

TABLE IV

THE INFLUENCE OF NITROGEN FERTILIZER APPLICATIONS ON SHOOT GROWTH, YIELD, NUT QUALITY, AND NUT ABORTION OF PECAN[z]

K kg/ha	Shoot Growth (cm) 1978	Shoot Growth (cm) 1979	Nuts Per Shoot 1979	Percent Kernel 1978	Length (mm) 1978	Diameter (mm) 1978	Nut Abortion 5/24-7/1 (%) 1978	Nut Abortion 7/1-9/24 (%) 1978	Nut Abortion 5/24-9/24 (%) 1978
0	6.1	8.9	2.15	57.73	40.0	19.2	22.0	15.6	33.7
112	6.3	8.6	2.12	57.06	39.8	19.0	12.8	18.8	29.9
224	5.5	9.2	2.20	58.44	39.4	19.0	17.8	14.2	29.9
Linear	NS[Y]	NS	NS	NS	NS	NS	NS	NS	NS

[z]All levels of nitrogen are pooled.
[Y]Non Significant (NS); significant at 5%(*), significant at 1%(**).

CHAPTER V

SUMMARY AND CONCLUSIONS

Leaf N content increased significantly as the N application rates increased in 1978 and 1979, with percent leaf N being higher in 1979. However, after applications of 224 kg N/ha for two consecutive years, leaf N content reached only 2.4% which was still below the sufficiency range given by Jones (23). Visual leaf deficiency symptoms decreased significantly as N application rates increased. Leaf deficiency symptoms occurred from approximately 1.97 to 2.33% leaf N and when leaf N content was approximately 2.45% foliage appeared normal. As N fertilizer rates increased leaf K and P tended to decrease over the two year period. After two years of N fertilizer applications, terminal shoot growth and nuts/shoot increased significantly as N application rates increased. Nitrogen fertilizer applications significantly increased nut size without decreasing percent kernel.

Leaf K content was approximately .72% in 1978 and .55% in 1979 regardless of the amount of K applied. Results indicate that leaf K level is decreased in a heavy crop year compared to a light crop year. Potassium fertilizer treatments did not significantly affect leaf levels of N, P, Ca, Mg, or Zn. Potassium fertilizer treatments did not influence terminal shoot growth, nut/shoot, nut quality, or nut abortion in either of the two years. It was found that 17.5% of the nuts aborted from May 24 to July 1 and 13.5% of the nuts aborted from July 1 to September 24. A total of 31% of the nuts present May 24 were aborted by September 24.

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APPENDIXES

TABLE V

RAINFALL AT OKLAHOMA PECAN RESEARCH STATION NEAR SPARKS, OKLAHOMA DURING 1978 AND 1979

1978		1979	
Date	Rainfall (cm)	Date	Rainfall (cm)
January 1	0.79	January 1	0.13
		January 11	0.20
		January 21	0.15
		January 26	3.45
February 13	7.11	February 21	1.42
February 15	0.23		
February 20	0.69		
February 28	0.61		
March 8	0.24	March 5	2.03
March 23	0.74	March 19	3.53
March 24	0.08	March 20	0.97
		March 22	1.80
		March 30	0.13
April 4	0.25	April 2	0.86
April 10	1.76	April 4	0.38
		April 11	4.24
		April 18	1.14
		April 23	0.51
		April 30	1.07
May 1	0.90	May 3	3.91
May 3	3.45	May 4	4.60
May 4	0.30	May 7	1.32
May 8	0.76	May 21	5.21
May 17	1.04	May 22	4.88
May 18	0.94	May 23	0.25
May 22	5.13	May 29	0.13
May 30	5.49		
June 2	0.18	June 6	0.74
June 5	0.69	June 7	4.11
June 6	1.04	June 11	9.88
June 19	2.49	June 21	2.24
June 22	2.39	June 25	6.73
		June 26	0.46

TABLE V. (Continued)

1978		1979	
Date	Rainfall (cm)	Date	Rainfall (cm)
July 24	1.47	July 6	3.25
July 31	0.53	July 9	0.23
		July 17	0.51
		July 18	0.43
		July 30	0.23
		July 31	1.93
August 4	0.91	August 11	1.22
August 28	0.13	August 20	2.03
		August 21	0.25
		August 22	2.79
		August 27	0.38
		August 31	2.16
September 6	0.23	September 1	2.41
September 21	0.48	September 6	0.30
September 25	0.89	September 21	0.28
October 9	3.33	October 22	1.25
October 23	0.48	October 30	3.61
November 6	0.89		
November 14	0.31		
November 15	2.03		
November 16	0.84		
November 17	1.73		
November 22	2.26		
November 27	2.18		

TABLE VI

THE INFLUENCE OF FERTILIZER APPLICATIONS ON SOIL pH IN 1979

Rate kg/ha N	K	Soil pH Reading
0	0	6.8
0	224	6.5
56	0	6.6
224	0	5.9
224	224	6.1

TABLE VII

COMPARISON OF LEAF MINERAL CONTENT IN RINSED AND NONRINSED LEAF SAMPLES IN 1979

Sample	K (%)	P (%)	Ca (%)	Mg (%)	Zn (ppm)
1 R[z]	0.64	0.13	1.42	0.72	62
1 NR	0.63	0.13	1.40	0.72	81
2 R	0.55	0.12	1.37	0.66	65
2 NR	0.56	0.12	1.35	0.65	87
3 R	0.58	0.15	1.29	0.71	70
3 NR	0.58	0.14	1.30	0.72	94

[z]R = samples rinsed in water for one minute, NR = samples not rinsed in water.

VITA

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Masters of Science

Thesis: THE INFLUENCE OF NITROGEN AND POTASSIUM FERTILIZER RATES ON LEAF MINERAL CONTENT, TERMINAL SHOOT GROWTH, NUT ABORTION, YIELD, AND NUT QUALITY OF 25-YEAR-OLD 'WESTERN' PECAN TREES

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