ROOT COMPOSITION AND TOP DEVELOPMENT IN LARGE PECAN TREES HEADED TO VARIOUS DEGREES OF SEVERITY IN TOP WORKING[1]

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INTRODUCTION

An important phase of pecan (*Carya pecan* (Marsh.) Engl. and Graebn.) orchard development and management is the top working of native or undesirable trees to desirable varieties. Top working is practiced on trees of all sizes but is usually confined to trees having trunks less than 12 inches in diameter. Many different methods of top working pecan trees have been practiced, but not all successfully. In many instances the heading back of the top has been severe; the large wounds made have failed to heal and have become badly infected with wood-decaying fungi, with the result that the tops have been only partially rebuilt. The main incentive for severe topping is that it requires fewer buds or grafts and less time and expense to top-work a tree when it is cut back heavily than when it is cut back less severely. To be satisfactory, a method of top working must be biologically successful, i. e., the tree should be rebuilt to normal size and vigor; furthermore, the cost must be low.

The experiment herein reported was designed to determine the effects of different degrees of heading large pecan trees on their subsequent development after being top-worked to desired varieties.

MATERIAL AND METHODS

EXPERIMENTAL BLOCK

The experimental block, consisting of 9 rows of 32 trees each, excepting a few spaces where the trees had previously died, was located in the orchard of H. G. Lucas, in the valley of the Pecan Bayou, near Brownwood, Tex. The trees were 43 years old at the beginning of the experiment, having been grown from orchard-planted seeds and seedling trees planted in 1888. The trees were 40 feet apart on the square system. The average diameter of the tree trunks was about 12 inches in March 1931.

DEGREES OF SEVERITY OF HEADING

No heading.—One row of trees was left as checks without being cut back or top-worked (fig. 1, *A*).

Headed to stumps.—The trees in two rows were cut off approximately 3½ feet above the ground (fig. 1, *B*). Sloping wounds were made with the exposed surface facing the north so as to prevent drying out as much as possible. These wounds were from 12 to 18 inches in diameter except on a few small trees.

Headed to first forks.—The trees in two rows were cut off 8 to 10 inches above the first forks (fig. 1, *C*). The wounds were made at

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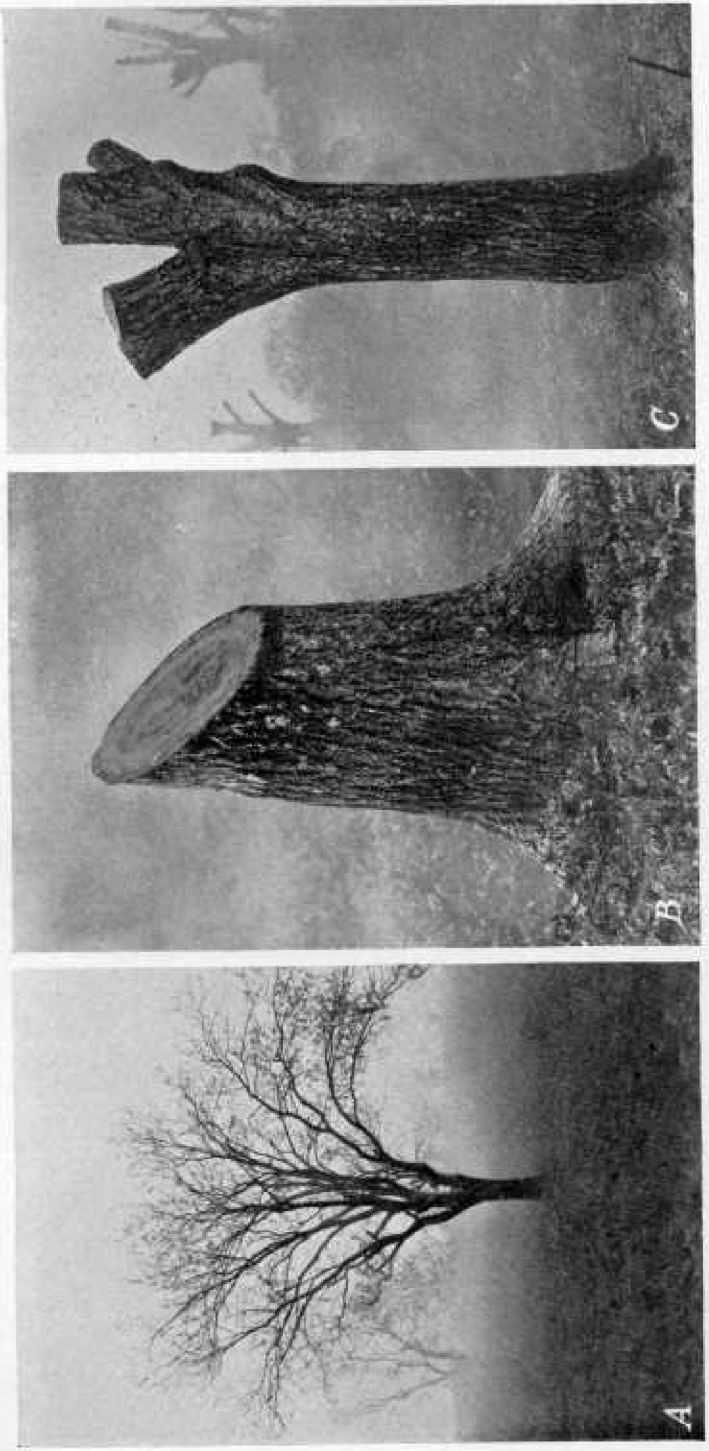

FIGURE 1.—Typical trees headed to different degrees of severity: *A*, Check tree, no heading; *B*, headed back to stump; *C*, headed to first forks. Note large wounds 6 to 8 inches in diameter.

right angles to the branches at first, and later cut to a slope after new shoot growth was sufficiently advanced. These wounds averaged 6 to 8 inches in diameter.

Headed to second forks.—Trees in two rows were cut off about 8 or 10 inches above the second forks (fig. 2, *A*). The wounds were made and treated in the same manner as in the trees headed to the first forks. These wounds averaged about 6 inches in diameter.

Headed to third forks.—Alternate trees in two rows were headed just above the third forks (fig. 2, *B*). The wounds averaged about 3 or 4 inches in diameter and were made and treated as in the trees headed to first forks.

Headed to fourth forks.—Alternate trees in two rows were headed just above the fourth forks (fig. 2, *C*). The diameter of the cuts averaged 2½ to 4 inches, most of them being not over 3 inches, and were made and treated as in the trees headed to first forks.

SUBSEQUENT PROCEDURE

The heading was all done in March 1931, and all wounds were protected by pruning paint. About one-half of the trees were grafted in the spring of 1931; the others were budded in late summer of that year. Trunk-circumference measurements and yield records of all trees were taken each year. A record of the cost of top working the trees in each treatment was also kept, as well as notes on the healing of wounds and infection by wood-rot fungi. However, this paper is concerned principally with the seasonal composition of the roots of trees and the growth responses following the different degrees of severity of heading.

Root samples were obtained from trees under each treatment at intervals from October 2, 1931, to January 23, 1934, and were analyzed for dry matter, sugars, starch, hemicellulose, and nitrogen. Three samples from check trees were taken after January 23, 1934. The data for the composition of roots of the check trees indicate the nutritional condition of normal trees under the conditions of the experiment.

ANALYTICAL METHODS

SAMPLING

Roots as uniform as possible but ranging between 5 and 20 mm in diameter were taken from trees in each treatment. The roots from each tree were washed free of adhering soil, wiped with a cloth towel, and allowed to dry in the air for 30 minutes. A composite sample of approximately 300 g was then made from the lots of roots. After the ends from each length of root had been clipped off, the remaining portion was cut into thin sections with pruning shears, placed in a covered soil-moisture can, and thoroughly mixed by shaking.

Two tared glass-stoppered weighing bottles were filled from this composite sample, weighed before any appreciable moisture loss occurred, and then saved for the determination of dry matter.

Two 50-g samples were weighed and transferred to pint fruit jars containing 250 ml of boiling 95-percent ethyl alcohol and a small amount of calcium carbonate. The covers were placed loosely on the jars and the boiling was continued for half an hour, after which the jars were removed from the water bath and sealed while hot. With this material this procedure is calculated to give a sample preserved in approximately 80-percent alcohol by weight.

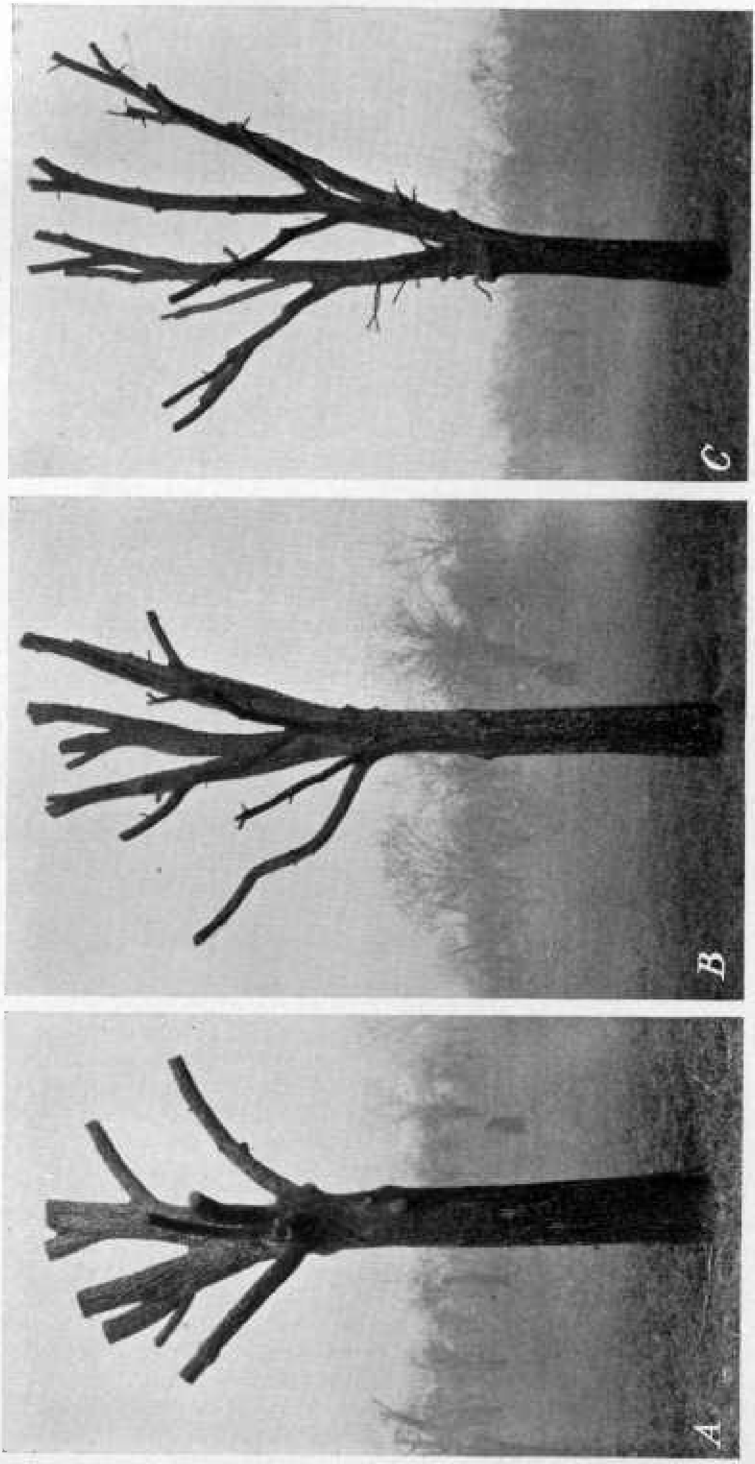

FIGURE 2.—Typical trees headed to (*A*) second forks, (*B*) third forks, (*C*) fourth forks. Note the small wounds, which heal easily, and the large framework for placing of buds and grafts.

Determination of Dry-Matter Content

The samples were dried in a vacuum oven at 80° C. and at a pressure of less than 1 inch of mercury. Since preliminary tests at 6, 12, 18, and 24 hours of drying showed that practically constant weight was attained in 6 hours, the samples were dried for two 6-hour periods and weighed at the end of each. The difference between these two weights was always well under 0.5 percent of the total moisture loss.

Determination of Sugars

Each alcohol-preserved sample was filtered and the solid portion transferred to an alundum extraction thimble 45 by 127 mm. It was then extracted for 24 hours in a large-size Soxhlet apparatus with the filtrate and alcoholic washings in the extraction flask. The residue was removed, dried in an air oven at 100° C. for 4 hours, and ground in a drug mill, care being taken that no significant loss of material occurred. The ground residue was again extracted for 24 hours with the same alcoholic solution. Preliminary tests had shown that the grinding and second extraction were necessary in order to insure complete extraction of sugars. The final residue was dried in an air oven at 100° for 4 hours, weighed, and saved for the determination of starch.

The alcoholic extract was concentrated in vacuo at a temperature below 55° C. to a volume of a few milliliters. This was taken up in water and filtered into a 250-ml volumetric flask. After adding 25 ml of saturated neutral lead acetate solution to the filtrate and washings, the mixture was made up to volume. The mixture was filtered through a dry filter, and the excess lead was precipitated from the clarified solution by means of anhydrous disodium phosphate. After being filtered through a dry filter, the solution was used for the determination of reducing and nonreducing sugars.

Reducing sugars were determined in 25-ml aliquots by the Munson-Walker method, the amount of reduced copper being determined by the volumetric permanganate method (*2, pp. 190–192* [*34–39*]).[2] Results were calculated as dextrose.

For nonreducing sugars, hydrolysis was effected with hydrochloric acid at room temperature by the procedure given in Official Methods (*2, p. 189* [*28*]). Results were calculated as sucrose.

Determination of Starch

The dried and weighed residue from the alcoholic extractions was ground once more in the drug mill, and samples were weighed from this for the individual starch determinations.

Starch was determined by direct acid hydrolysis as outlined in Official Methods (*2, p. 119* [*21*]) except that the preliminary washing with water was omitted since the material was already sugar-free and it was desired that any dextrin which might be present should be included in the result. The starch by the diastase method was subtracted from the starch by direct acid hydrolysis for corresponding samples, and the values thus obtained are referred to as hemicellulose. These values include the carbohydrate bodies that are not hydrolyzed

[2] Italic numbers in parentheses refer to Literature Cited, p. 841.

by diastase, such as dextrins and pentosans, but are hydrolyzed by dilute mineral acids.

Starch was also determined by the diastase method essentially as outlined in Official Methods (*2, p. 120* [*23*]). A freshly prepared 0.5-percent solution of takadiastase in water was used instead of the malt extract. The preliminary washing of the sample was again omitted for the same reasons as before.

In both cases the data for the starch content were finally calculated back to the original alcohol-preserved sample.

Determination of Total Nitrogen

The dried residue from the determination of dry matter was ground in a drug mill, and 2-g samples were weighed out for nitrogen determinations. Total organic nitrogen was determined by the Kjeldahl-Gunning-Arnold method as outlined in Official Methods (*2, p. 8* [*24*]). The analytical data are presented in figures 3 to 8.

EXPERIMENTAL RESULTS

CHEMICAL COMPOSITION OF ROOTS

Dry Matter

The percentage of dry matter in pecan roots fluctuated considerably during the course of the experiment (fig. 3). These fluctuations occurred at approximately the same time in roots of all trees but were less in roots of trees headed to stumps and first forks than in any of the others. The percentage of dry matter was apparently largely determined by the moisture supply in the soil and its absorption and storage in the roots, since in general the least dry matter was found in winter and spring when the soil moisture was relatively abundant. That the fluctuations were not due to a great extent to changes in amounts of the constituents of the dry matter is shown by the fact that starch increased at times when the percentage of dry matter was decreasing. The relatively high maximum concentration of starch and its wide fluctuation would have an appreciable effect on the dry-matter content, but not nearly so much as water absorption by the roots.

Sugars

The reducing-sugar content of roots of the trees in all treatments was relatively low throughout the experiment, but after May 1932 roots of the stumps contained less than any others. At the end of the experiment there was little difference in the amount of reducing sugars in any of the other treatments (fig. 4).

The nonreducing sugars behaved in a manner similar to the starch. There was a larger amount and greater fluctuation in the roots of the trees least severely headed (fig. 4). The fluctuations of nonreducing sugars were, in general, somewhat parallel to those of starch after May 1932. In the roots of trees headed to stumps the nonreducing sugars were low throughout the experiment, while in those headed to first and second forks there was an increase beginning about the middle of 1933 and continuing to late fall. In general, the nonreducing-sugar content in roots of trees headed to third and fourth forks was lower than in roots of check trees until near the end of the experi-

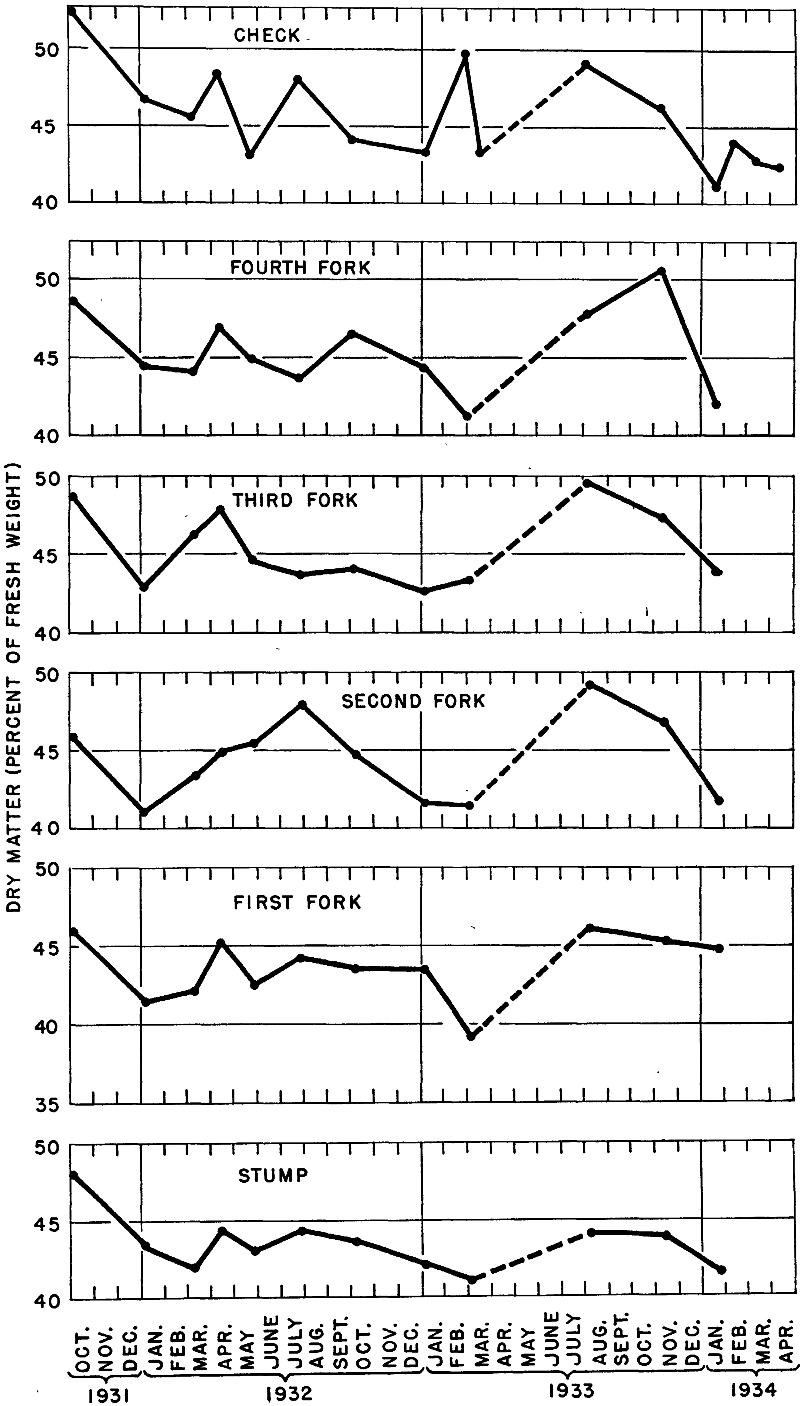

FIGURE 3.—Percentage of dry matter in roots of normal (check) trees and those headed to different degrees of severity in top working.

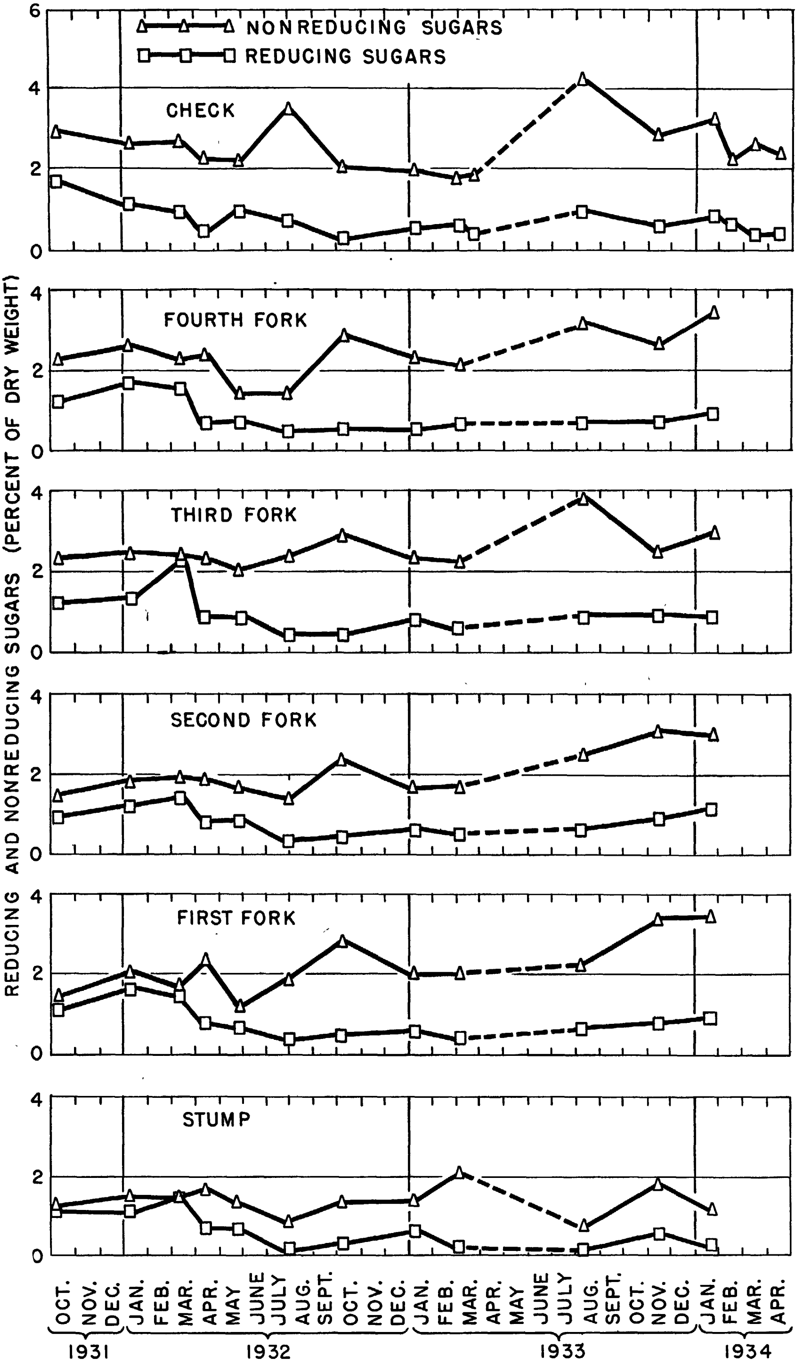

FIGURE 4.—Percentage of reducing and nonreducing sugars in roots of normal (check) trees and those headed to different degrees of severity in top working.

ment. There was also somewhat less fluctuation of the nonreducing sugars in roots of these trees than in the check trees. When the values for nonreducing sugars are calculated on a fresh-weight basis and then plotted, they form a curve that parallels somewhat the curve for dry matter (fig. 5). This shows that the concentration of these sugars varies to some extent with the variation in dry matter; however, calculations show that the change in the amount of dry matter was usually not proportional to the change in amount of nonreducing sugars. Therefore, a part of the variation in nonreducing sugars was due to actual increases or decreases of the total amount in the roots. The data are given for check trees only, since those for headed trees show similar variations.

Starch

The data for starch analyses are given in figure 6. The starch content in the roots of check trees showed pronounced fluctuations that seemed to be more or less seasonal in character. The root samples were not taken at sufficiently frequent intervals to determine the exact seasonal trends, but the data indicate that in general starch increases from a minimum in summer to a maximum in autumn, and then decreases to a minimum in summer again. This is in line with what LeClerc du Sablon (*7*), Murneek (*9*), and Davis (*4*) have found in various deciduous trees.

In 1931 the starch in the roots of check trees did not reach a maximum in the autumn but continued to increase through the winter to a maximum in March. In each of the other two seasons the starch concentration attained a maximum in autumn and then decreased during the winter. The only known differences in the conditions during 1931 as compared with 1932 and 1933 are that the nut crop of 1931 was much smaller and the leaves remained on the trees later in the fall.

With the initiation of growth in the spring of 1932 there was a rapid disappearance of starch from the roots; the starch was probably used in growth and blossom development. From the last of May to October 5 there was a gradual increase in the starch. This increase is probably due to storage of the excess assimilated from photosynthesis by the leaves. Little vegetative growth was being made at this time, and the nut crop had not begun to fill; the leaves were full-grown and probably capable of maximum photosynthesis.

The starch decreased during the nut-filling period, which was completed about the middle of November, and continued to decrease until the following March. The nut crop was large and made a heavy demand for carbohydrates for oil formation in the kernels (*11*), and the starch reserve was probably used to supplement the carbohydrates produced by photosynthesis. Defoliation occurred shortly after the nuts were harvested, and therefore the starch reserve could not be built up again by photosynthetic activity. It will be noted that there was also a rapid decrease in starch after leaf fall in 1933, which seems to corroborate the view that there is usually a winter decrease of starch in roots of deciduous trees caused by its translocation, in the form of simpler carbohydrates, from the roots to the aerial portions of the trees.

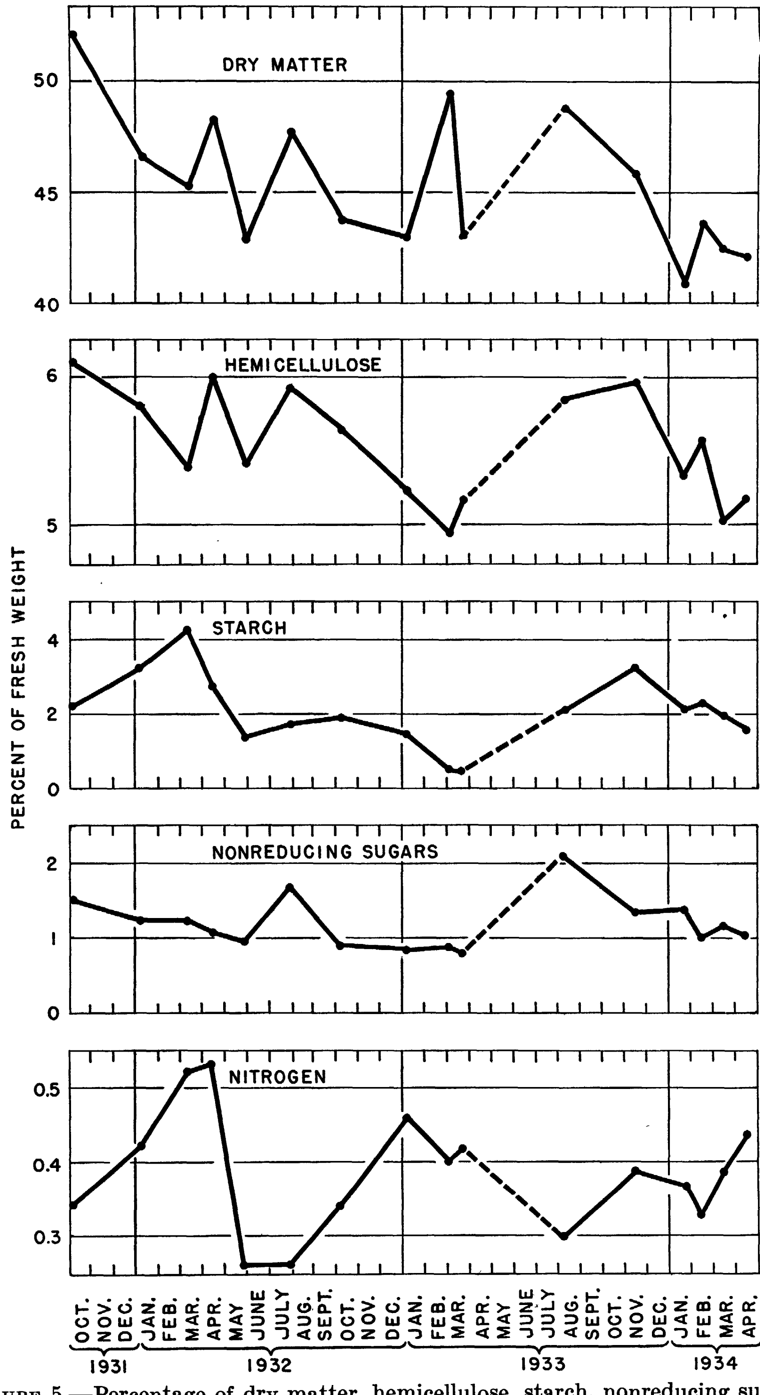

FIGURE 5.—Percentage of dry matter, hemicellulose, starch, nonreducing sugars, and nitrogen on a fresh-weight basis in roots of normal (check) trees. Note that the concentration of hemicellulose and nonreducing sugars varies to a considerable extent with the variation in dry matter.

From March to November 1933, when the nut crop was light and the conditions in late summer and fall were poor for vegetative growth, the starch content increased to a relatively high level and then decreased as in the season of 1932.

Although the data shown in figure 6 were calculated on a dry-weight basis, the same type of curve is obtained by plotting the amounts of starch in roots of the check trees calculated on the fresh-weight basis (fig. 5). A comparison of this curve with the one for dry matter

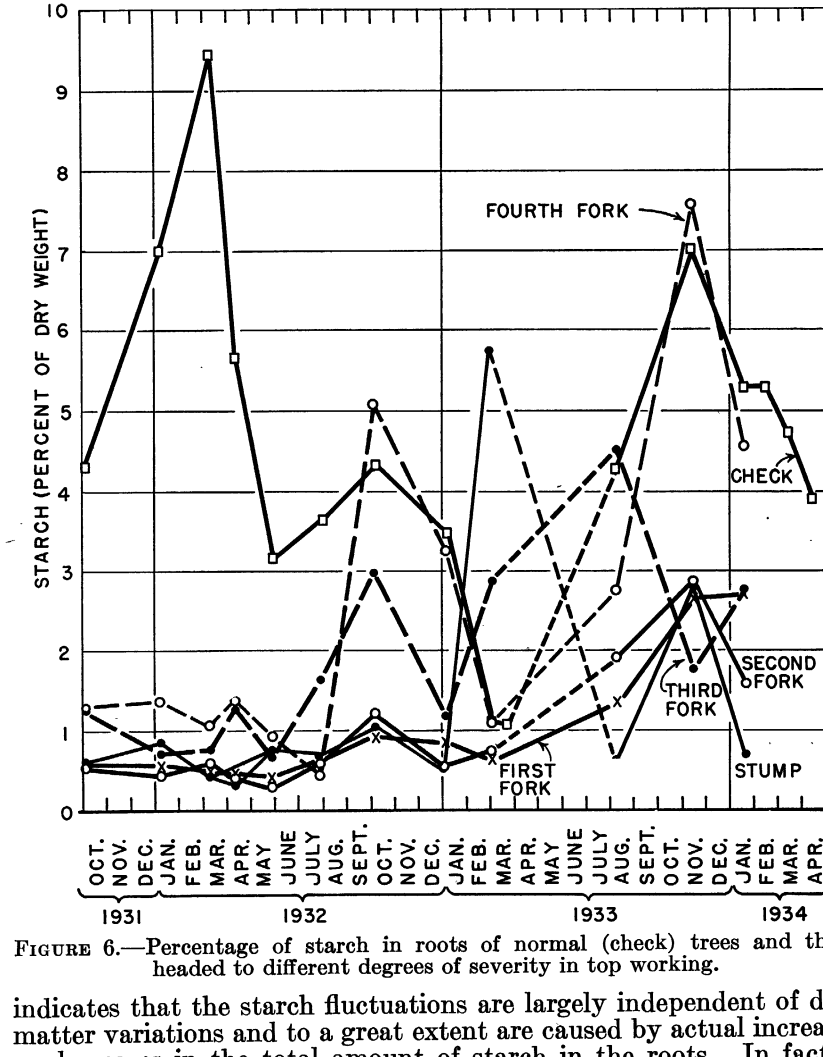

FIGURE 6.—Percentage of starch in roots of normal (check) trees and those headed to different degrees of severity in top working.

indicates that the starch fluctuations are largely independent of dry-matter variations and to a great extent are caused by actual increases or decreases in the total amount of starch in the roots. In fact it would be impossible for the changes in amount of dry matter to cause the starch fluctuations in most cases because the starch content on a fresh-weight basis increases with decreases in dry matter. The reverse is also true, and the proportionate variations in the two constituents are not the same.

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The starch content in the roots of all the cut-back trees was very low from October 1931 to the middle of the summer of 1932, and showed relatively little fluctuation regardless of the degree to which the trees were cut back. Subsequent to August 1932, however, there was a progressive increase in the amount of starch in the roots of trees under the third- and fourth-fork treatments. In the roots of trees headed to third forks the starch began to increase during the summer of 1932, and it fluctuated in the same manner as that in check trees but to a lesser degree. The starch content in roots of fourth-fork trees started to increase at the same time and during the latter part of the experiment was as high as that in roots of the check trees. Its fluctuation was also very similar to that in the roots of check trees, in both manner and degree, during this period.

The amount of starch and its fluctuations in roots of first- and second-fork trees were very similar throughout the experiment. There was no progressive increase in starch content until the summer of 1933, and at the end of the experiment it was still relatively low. The starch content of the roots of trees cut to stumps was low throughout the experiment, except for one abnormally high concentration on March 3, 1933. The reason for this large value is not known.

Hemicellulose

The average amount of hemicellulose in roots of the trees under the different treatments was about 12 percent on a dry-weight basis and showed no consistent seasonal variations (fig. 7). However, on a fresh-weight basis the hemicellulose varied with the dry matter (fig. 5), indicating that the changes in the hemicellulose values are due largely to changes in dry matter rather than to changes in the total amount in the roots. Therefore, it is apparent that the hemicellulose was not utilized as a reserve carbohydrate to any appreciable extent.

Nitrogen

The amount of nitrogen in the roots of trees headed to stumps was, in general, somewhat larger than in the roots of the trees under any other treatment, but it showed practically no seasonal fluctuation (fig. 8). In roots of trees headed to first and second forks the nitrogen content showed somewhat greater fluctuations, which appeared to be seasonal except that there was a continued decrease in the amount of nitrogen after March 3, 1933, to the end of the experiment. In the roots of trees headed to third forks the amount of nitrogen was as low as or lower than that in roots of second-fork trees, but it showed more definite seasonal fluctuations. The nitrogen increased from October 1931 to April 12, 1932, after which it decreased to July 27. Then there was a gradual increase to March 3, 1933, followed by a decrease to August 9, and then an increase again to January 23, 1934.

The nitrogen content in roots of trees headed to fourth forks was a little higher as a rule than in roots of third-fork trees and showed greater seasonal fluctuations, which coincided with those in the trees under third-fork treatment. In roots of the check trees was found the greatest seasonal variation in nitrogen. The fluctuations occurred at the same time as those in the third- and fourth-fork trees but were wider over the period of the experiment.

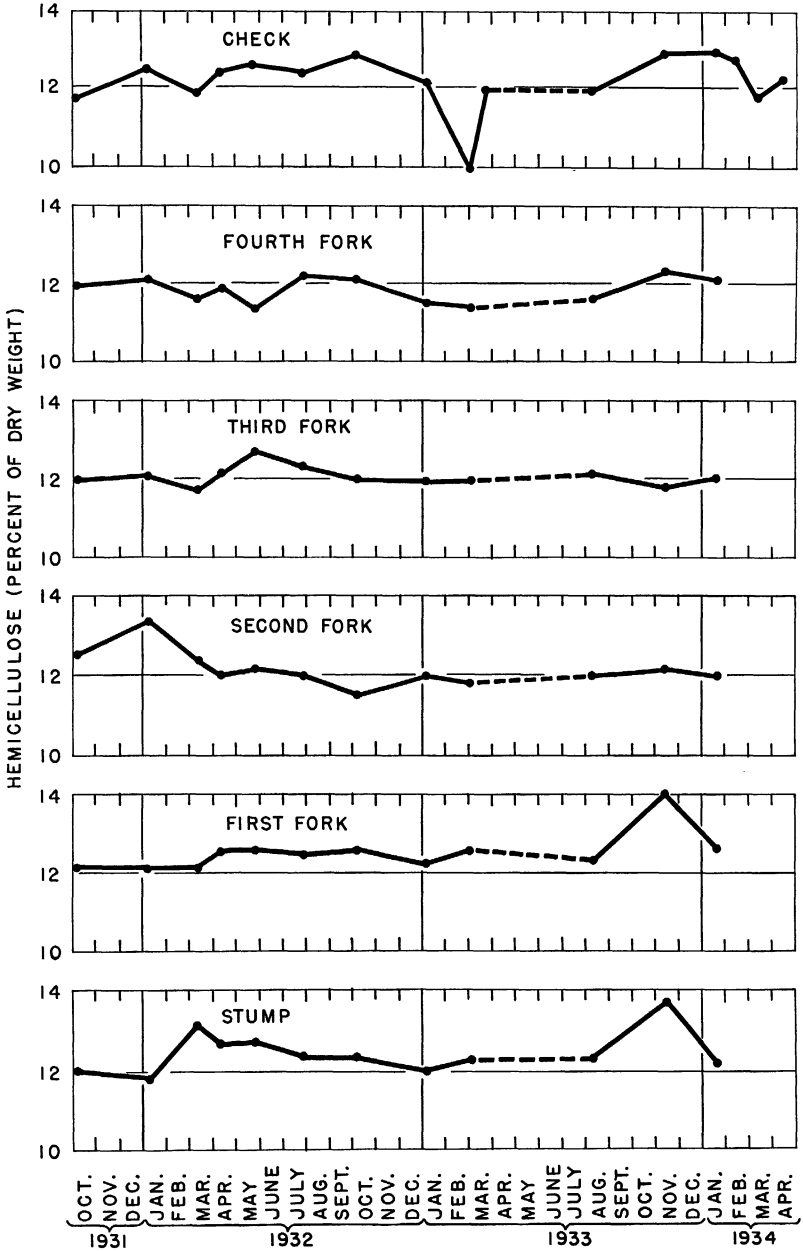

FIGURE 7.—Percentage of hemicellulose in roots of normal (check) trees and those headed to different degrees of severity in top working.

A comparison of the dry-matter and nitrogen curves in figure 5 shows that the nitrogen fluctuation was independent of the variations in dry-matter content. In general, nitrogen increased on both the fresh-weight and dry-weight bases as the dry matter decreased, and vice versa. It is probable that this was only coincidental, however, and that neither factor was the cause of the other.

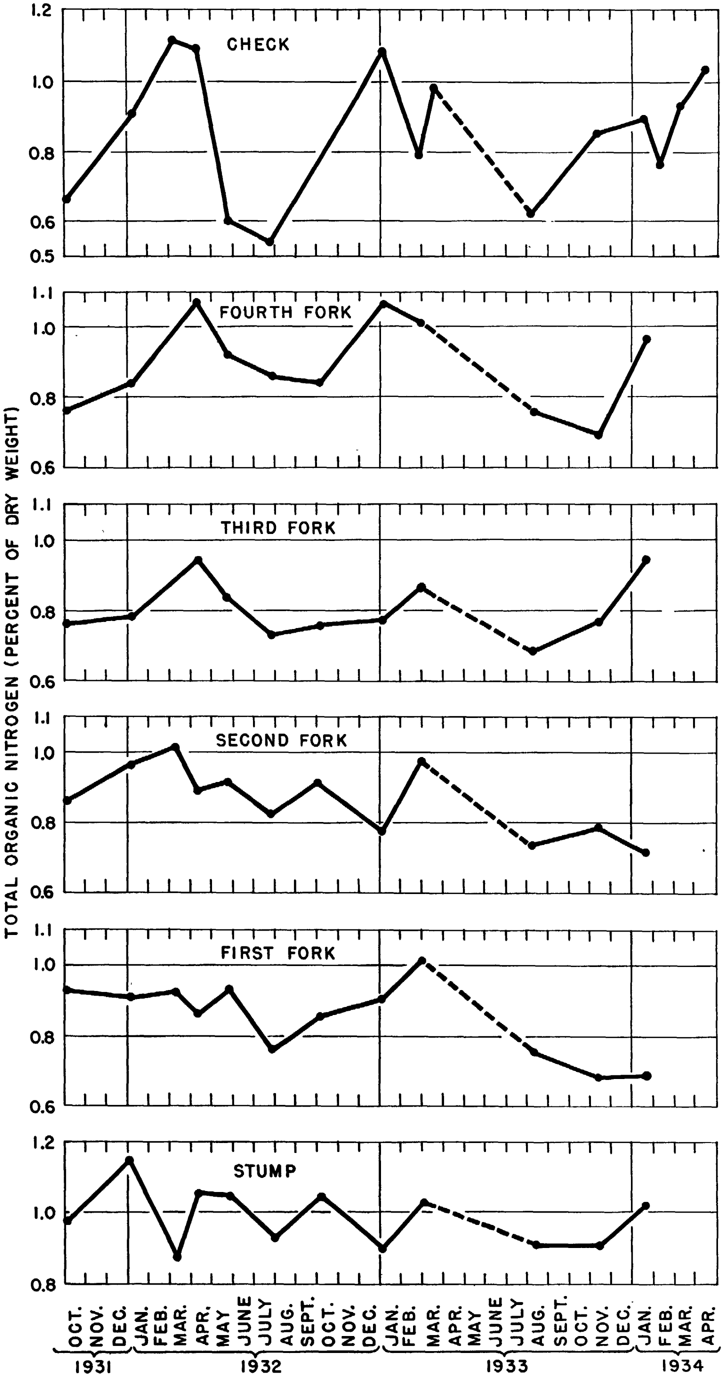

FIGURE 8.—Percentage of total organic nitrogen in roots of normal (check) trees and those headed to different degrees of severity in top working.

TREE GROWTH

Gain in Cross-Sectional Area

The following data show the average increase from March 1931 to December 1933 in cross-sectional areas of the trunks of normal (check) trees and trees headed to different degrees of severity in top working.

Treatment:	*Square inches* [1]
Normal (check) trees	22.60
Fourth-fork trees	5.61
Third-fork trees	6.34
Second-fork trees	3.98
First-fork trees	3.53

[1] Average increase in cross-sectional area of trunks.

This increase is greater the less severe the heading treatment, except that the third-fork trees made somewhat more trunk growth than fourth-fork trees. The check trees show an increase in trunk growth more than three times as great as any of those cut back. No measurements are recorded for trees given the stump treatment, since most of these died to the ground before the end of the experiment.

Top Growth and Healing of Wounds

It is believed that the amount of top growth of cut-back trees is a much more accurate measure of their actual growth than the increase in cross-sectional area of the trunks. No measurements were made of the top growth of trees under the different treatments, but the relative

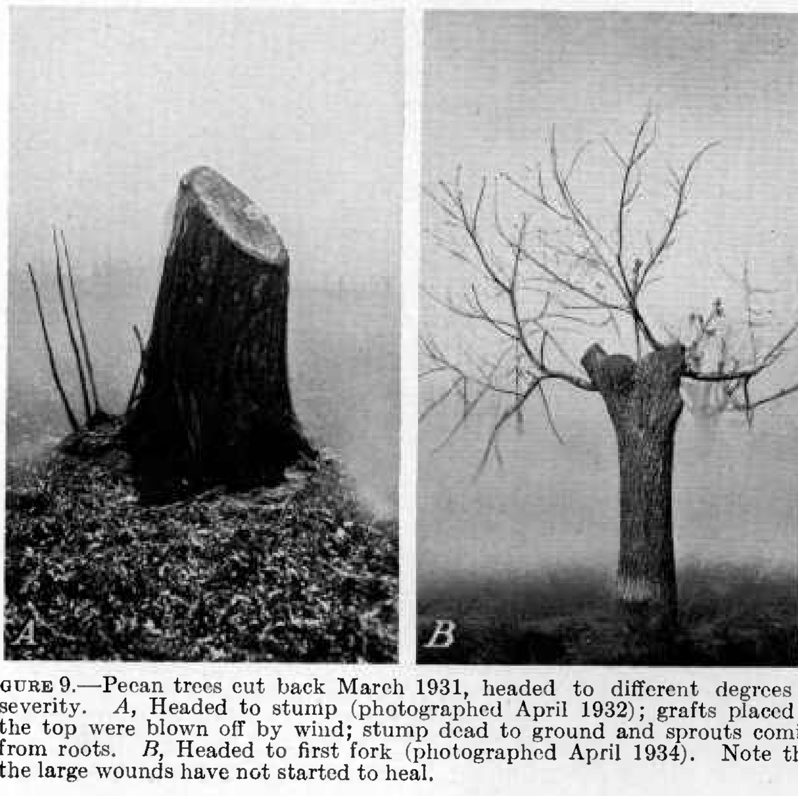

Figure 9.—Pecan trees cut back March 1931, headed to different degrees of severity. *A*, Headed to stump (photographed April 1932); grafts placed at the top were blown off by wind; stump dead to ground and sprouts coming from roots. *B*, Headed to first fork (photographed April 1934). Note that the large wounds have not started to heal.

amounts of this growth and the degree of healing of wounds are shown by photographs of typical trees near the end of the experiment (figs. 9 and 10).

All the large trees that were cut back to the stumps died to the ground, and sprouts came up from the roots (fig. 9, *A*). A few of the smaller stumps lived, but the wounds have made little progress in healing, and much difficulty has been experienced in preventing grafts and buds from being blown off by winds.

The first-fork trees have made relatively little top growth, and the large wounds have not begun to heal (fig. 9, *B*). Many of the new branches that grew on these trees were blown off by winds, since the unions with the large limbs were not strong.

Trees in the second-fork treatment made considerably more top growth than first-fork trees, but the wounds have made little progress in healing (fig. 10, *A*). Some of the new branches on these trees were also blown off by winds.

The top growth in third-fork trees was much greater than in second-fork trees, and the wounds are partially healed (fig. 10, *B*).

The fourth-fork trees made more top growth than any other cut-back trees, and the wounds are practically healed (fig. 10, *C*). The tops are now reestablished to such an extent that the trees can bear large crops of nuts. No loss of buds or grafts from windstorms occurred in these trees or in those cut back to third forks.

DISCUSSION

The data show certain definite differences in the composition of roots of check trees as compared with those of trees that were cut back in top working. These differences were nearly the same for all cut-back trees during the first season but tended to disappear as the tops were reestablished.

Starch and nitrogen were the largest variables of the constituents determined, and their fluctuations seemed to be more or less seasonal. The data for starch seem to indicate a summer minimum and a fall maximum, with a small winter decrease following leaf fall and a rapid decrease during spring growth and blossoming. In the fall of 1931, however, the starch in the roots of check trees increased from October until the following March, while in 1932 and 1933 it reached a maximum in the autumn and then decreased during the winter. The nut crop of 1931 was very small, the conditions were poor for vegetative growth, and the foliage remained on the trees until late in the fall. Under these conditions the excess carbohydrates produced by photosynthesis were probably translocated to the roots and stored as starch. There may also have been some weather conditions prevalent during the period that were favorable for the continued translocation of carbohydrates from the aerial portions of the trees to the roots, whereas in the other two seasons such conditions were absent. Murneek and Logan (*10*), in a study of autumnal migration of nitrogen and carbohydrates in the apple tree, concluded that since starch and possibly other more complex carbohydrates are hydrolyzed to sugars with the onset of cold weather, or vice versa, modifications induced by weather often are of greater amplitude than possible seasonal trends.

The starch in the roots of check trees reached its lowest concentration in the spring following the large nut crop of 1932. The starch

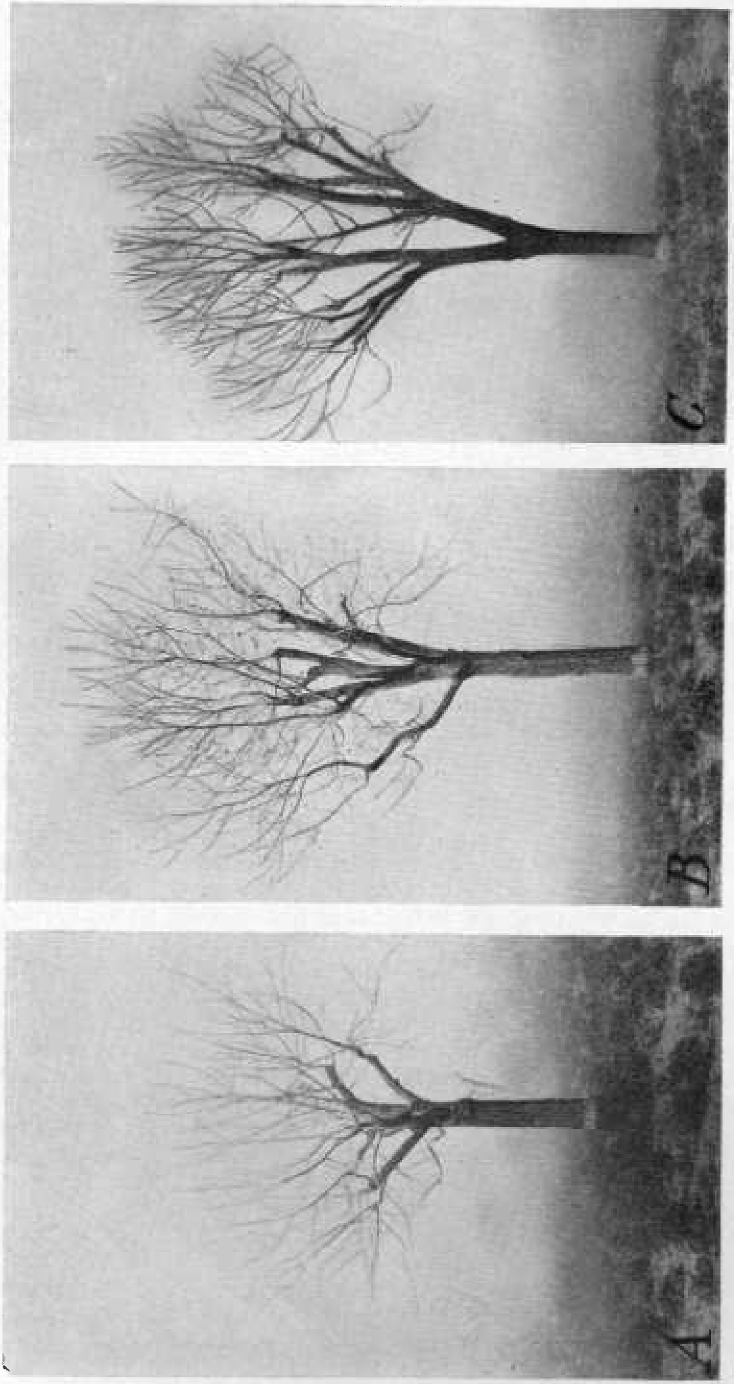

FIGURE 10.—Pecan trees cut back March 1931 (photographed April 1934), headed to different degrees of severity. *A*, Headed to second forks; large wounds have made little progress in healing. *B*, Headed to third forks; note that the wounds are relatively small and are partially healed. *C*, Headed to fourth forks; the wounds are small and practically healed; the tops are large enough to bear good crops of nuts.

decreased rapidly during the nut-filling period and, no doubt, was used in oil formation in the kernels. Thor and Smith (*11*) have shown that there is a heavy demand for carbohydrates during the period of oil formation in the pecan nut in the early fall, and that most of this carbohydrate material is translocated to the nut during this period. On the basis of microscopic studies, Finch and Van Horn (*5*) concluded that starch storage in fruit-bearing shoots of the pecan was initiated in early summer, reached a maximum shortly before nut filling began, and then decreased rapidly during this period. A comparable decrease did not occur in nonfruiting shoots. Davis (*4*) found that the starch content in the roots of nonbearing sugar-prune trees was much higher than in roots of bearing trees. He also observed a very rapid decrease of starch in the bark, spurs, and wood of bearing trees during the period of ripening of the fruit, while during the same period there was not a comparable decrease in nonbearing trees. With the beginning of growth in the spring, there was a decrease in starch content of both bearing and nonbearing trees, which attained a minimum at blossoming, but the minimum in the bearing trees was much lower than in those not bearing. This probably explains the very low concentration of starch in the spring of 1933 following the large nut crop of 1932. The starch content of the roots was depleted during the nut-filling period; and, since the foliage dropped soon after the nuts were harvested, the starch was not built up again by photosynthesis. Consequently, with the normal winter decrease of starch and the initiation of growth in the spring, the starch had reached a very low level on March 3. No analyses were made during the period of shoot growth and blossoming in the spring of 1933, but it is likely that the starch continued to decrease during this period since the data for 1932 and 1934 show decided decreases in the starch during similar periods.

The starch was relatively very low in the roots of all headed trees and showed little fluctuation during the first part of the experiment, but there was a progressive increase in its amount and fluctuation during the latter part of the experiment. Therefore, it seems evident that the quantity of starch is controlled largely by the growth and fruiting of the tree. In a study of the relation of leaf area and position to quality of fruit and to bud differentiation in apples, Haller and Magness (*6*) found an increase in blossom-bud formation and in size of fruit with an increase in leaf area on ringed branches, thus indicating that sufficient synthesis of food materials for blossom-bud differentiation and fruit development is obtained only with a relatively large leaf area. No doubt a similar condition prevails in the pecan tree, since the data seem to corroborate this view. During the first season after the trees were cut back the leaf area per tree was small under all treatments. The amount of leaf area was practically inversely proportional to the degree of severity of heading, but in no case was it adequate to synthesize sufficient carbohydrates to support growth, heal the wounds, and have much excess for storage in the roots. A considerable number of the leaves that grew on the new branches during the first season were removed when the top working was done in order to force out the buds and grafts. Thus there was actually less difference in the leaf area of trees in the different treatments during this period than if no leaves had been removed, and consequently there was very little difference in the amount and fluctuation of starch.

During the latter part of the experiment much of the leaf area of trees under the stump, first-fork, and second-fork treatments was lost because the branches that grew from buds or grafts were blown off by wind. The loss of these branches also necessitated rebudding the trees and removing still more leaf area to force the buds. This partly accounts for the low starch values in the trees under these treatments at the end of the experiment as compared with those in the check trees, or those under the third- and fourth-fork treatments. The trees headed to third and fourth forks bore more branches and leaves than the severely cut-back trees, and practically none were blown off by winds. Therefore, toward the latter part of the experiment the tops of these trees had been reestablished to such an extent that the amounts of starch and its fluctuation in the roots were very similar to those in the check trees.

The data indicate that the sugars in pecan roots are not storage but labile forms into which other more complex carbohydrates may be converted for use or translocation. The amount of reducing sugars was relatively low in the roots of trees under all treatments, but after May 1932 the roots of stumps contained less than any others. The concentration and fluctuation of nonreducing sugars were greater in the roots of check trees and those least severely headed, the fluctuations being somewhat parallel to that of starch during the latter part of the experiment. The larger amount of sugars in roots of the check trees and those not severely headed, as compared with those that were, no doubt is a direct result of the greater supply from the larger leaf area, and the wider fluctuations may be due to the usage during growth and fruiting activities.

The concentration of nitrogen in the pecan roots was about the same for check trees and those cut back except that it was slightly higher in the roots of stumps. However, the extent of the seasonal fluctuations of the nitrogen was somewhat inversely proportional to the degree of severity of heading.

The nitrogen increased during the fall and winter and decreased during the spring, which indicates that it is used mainly in growth and blossom development. During late summer and fall when the vegetative growth has practically ceased it is assumed that the nitrogen continues to be absorbed and is stored. Weinberger and Cullinan (*12*) found that nitrogen was absorbed in large amounts by the roots of peach trees in late fall. They state (*12, p. 67*): "The roots of fertilized trees, however, practically doubled in nitrogen content in the same period [October 19 to December 22], compared to only a 15 per cent increase in check roots." Aldrich (*1*) obtained similar results with fall and winter applications of nitrogenous fertilizers to apple trees. Crane (*3*) has shown that fall applications of nitrogenous fertilizer are about as effective in increasing the growth and yield of pecan trees as are similar applications made in the spring. Loomis (*8*) presents data which indicate that nitrogen is rapidly synthesized to organic forms upon absorption by the roots. His data indicate that nitrogen is normally translocated in organic forms through the phloem, and that the process of digestion and translocation may be very rapid. In the bark of 3-year-old poplar trees one-half the nitrogen was digested and moved from the trunks in the first 4 weeks of the growing season. Murneek and Logan (*10*) found that there was an autumnal migration of nitrogen from the leaves to the stems prior to leaf fall in the apple. A part of the increase in nitrogen in the pecan roots occurring in the fall may have been due to the nitrogen that was translocated from the leaves prior to their abscission.

In the spring there is a large demand for nitrogen for the production of vegetative growth and blossoms, which probably cannot be met by absorption at that time. The nitrogen stored in the roots is probably translocated to other portions of the tree for these purposes, and the root content is thereby decreased. The fact that there was greater seasonal fluctuation in the amount of nitrogen in roots of the check trees and in those with less severe heading, where more growth and fruiting occurred, than in trees severely cut back, where little growth and fruiting took place, is further evidence that the explanation given above is valid.

According to the data the actual amount of nitrogen present at any one time could not be used as a measure of the physiological activity of the tree, since in the roots of trees headed to stumps the nitrogen present was generally as high as or higher than in the check trees. There was so little growth activity in the stumps that the root system was able to absorb nitrogen rapidly enough to supply this demand, and consequently the nitrogen remained nearly constant.

SUMMARY AND CONCLUSIONS

Pecan trees of an average diameter of about 12 inches were headed back in March 1931 to stumps, first forks, second forks, third forks, and fourth forks prior to being top-worked to improved varieties. Analyses of roots of these trees and of similar untreated ones were made at intervals from October 1931 to January 1934 for dry matter, reducing and nonreducing sugars, starch, hemicellulose, and organic nitrogen.

The dry-matter content of roots of pecan trees was higher in the summer and autumn than in the winter and spring, and apparently these fluctuations were controlled largely by transpiration and the moisture supply in the soil. The dry matter fluctuated less in roots of trees headed to stumps and first forks than in roots of check trees or those headed to second, third, and fourth forks.

Although the root samples were not taken at sufficiently frequent intervals to determine exact trends, the data indicate that starch increases from a minimum in summer to a maximum in fall or early winter, and then decreases again to a minimum in summer; also, that the fall maximum may be prevented in a heavy crop year because of the demand for carbohydrates for oil formation in the kernels of the nuts during filling.

The amount and fluctuation of starch in pecan roots appear to be largely dependent upon the amount of leaf area and the growth and fruiting of the trees. During the first year after the trees were cut back, the leaf area on all headed trees was relatively small, and the starch content was low and showed no seasonal variation. After this time, however, the amount of foliage showed an inverse relationship roughly proportional to the severity of heading back, and the amount of starch and its fluctuation were about proportional to the leaf area.

In the roots of check trees the starch content fluctuated widely, and its concentration was relatively high except in the winter and spring following the large nut crop of 1932.

The reducing-sugar content in the roots of all the trees was low and about equal throughout the experiment except in the stumps, where it was lowest during the last half of the experiment. The nonreducing sugars behaved in a manner similar to starch. The amounts were higher and there was more fluctuation as the leaf area per tree was increased. In general, the seasonal fluctuations of nonreducing sugars were nearly parallel to the starch variations but apparently these fluctuations were partly due to changes in the dry-matter content of the roots. The indications are that sugars in pecan roots are not storage but labile forms into which other more complex carbohydrates are converted for use or translocation.

There were only moderate fluctuations in the hemicellulose content in the roots of trees under the different treatments, and these variations were caused largely by changes in the dry-matter content of the roots.

The amount of nitrogen was somewhat higher in the roots of trees headed to stumps and fluctuated less than in those under any other treatment. In the roots of the check and of the third- and fourth-fork trees the amount of nitrogen fluctuated widely, increasing from late summer to early spring and then decreasing again, indicating that its main function is in growth and blossoming. In roots of first- and second-fork trees this same seasonal fluctuation occurred during the first 2 years of the experiment, but during the last year the nitrogen continued to decrease from March to January. The seasonal fluctuations in nitrogen concentration were independent of changes in dry-matter content of the roots.

For comparing the growth made by pecan trees during the first few years after they had been cut back in top working, the amount of top growth appears to be a better measure than the increase in the cross-sectional area of the trunk.

The rate of healing of wounds occasioned by the heading of trees was approximately proportional to the amount of leaf area per tree.

The data, together with observations made on the rate and facility of healing of wounds in the different treatments, indicate that, in heading pecan trees preparatory to top working, cuts more than 4 inches in diameter should be avoided. Larger cuts are hard to heal and, in heading trees severely enough to make wounds larger than 4 inches in diameter, the potential leaf area is automatically so reduced that it will probably be inadequate to synthesize sufficient foods for the normal recovery of the tree.

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