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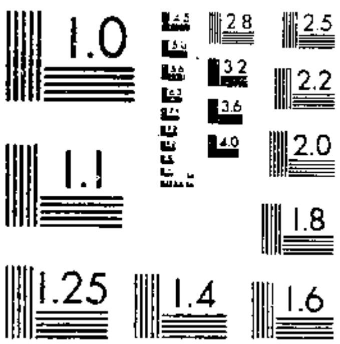

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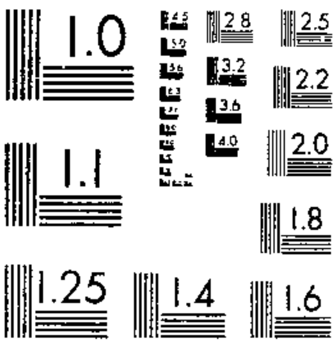

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE RELATION OF SEASON OF WOUNDING AND SHELLACKING TO CALLUS FORMATION IN TREE WOUNDS[1]

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INTRODUCTION

The decorative and esthetic value of beautiful shade trees has ever been appreciated by civilized man, and the question how best to protect such trees from the ravages of time undoubtedly dates back to very early days. In the past few years, the public has apparently become more interested in matters relating to the care of shade trees than formerly. Commendable effort has been directed toward the improvement of existing practices and the development of better ones.

Among the many practices in which improvement has been sought are those relating to pruning, since upon pruning depends in large measure the degree of success with which trees may be adapted to habits and sites that are foreign to them in nature. It plays a rôle in treatment of their damage by weather, insects, and fungi. Since the usefulness, beauty, or health of the shade tree often depends in part upon the skill with which it is pruned, numerous problems arise

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[2] The writer acknowledges great indebtedness to G. P. Clinton, of Yale University, under whose direction the present investigation has been conducted, and to Carl Hartley, of the Bureau of Plant Industry, for helpful suggestions and advice regarding the mathematical handling of the data presented.

regarding the best performance of the task. The present work has been undertaken in an effort to shed light on that question so frequently asked, "When is the best time to prune shade trees?"

The idea underlying the present investigation first suggested itself in the course of some preliminary experiments in the use of wound dressings. This is a phase of the pruning problem which has occasioned much controversy, since a review of the literature shows not only frequent disagreement among different writers but even in the results of the same writer as to the merit of the various materials employed in treating tree wounds. The author's observations suggested the likelihood that some of these apparent discrepancies might be due to differences in the seasons at which the pruning was done and the dressings applied. In this possibility lies the basis of the present investigation, in which are considered the area and shape of callus produced by both treated and untreated wounds on forest trees, with the purpose of applying the results to practical pruning and cavity work of shade trees.

REVIEW OF LITERATURE

The literature of pruning in general contains voluminous references in regard to the best time to prune. There are, however, conflicting opinions. At one extreme there are adherents of Long (*10*),[3] who said, "As to the time [of pruning], the advice of the successful old gardener, to prune when your knife is sharp, would be hard to improve upon"; and at the other extreme are those who stipulate some definite season as the only one suitable for cutting. In the main, investigators and general practice alike tend to favor pruning during the dormant period, but even the results of such outstanding work as that of Bedford and Pickering (*2, p. 37–38*) in England, of Chandler (*4, p. 41–43*) in New York, and of Brierly (*3*) in Minnesota do not point to appreciable advantage in pruning at any particular time during this dormant period.

Somewhat different are the conclusions of Rose (*13*), based on his study of pruning wounds of apple trees in Missouri. He writes:

> The poorest time to make large pruning wounds, in Missouri orchards, is in winter. Wounds made then heal slowly and are very likely to become infected with cankers. The best time to do such pruning is some time during the period from March to June, inclusive, preferably in May or June on account of the lessened danger then from canker infection and bark injury around the wound.

Wiltshire (*16, p. 190*), in his study of wound dressings discovered somewhat the same condition existing in England, as evidenced by his statement:

> On June 8 the wounds made on April 20 were found to be much further advanced in healing than those made on February 10, a somewhat astonishing result.

Corbett (*6, p. 19*) states:

> Convenience and climatic conditions must be taken into consideration in determining the period for pruning. In the removal of large branches, however, the work should be done at a season when growth is at its height, in order that the healing process may begin at once and continue as long as possible during the season in which the cut is made.

[3] Italic numbers in parentheses refer to Literature Cited, p. 28.

Bailey (*1, v. 5, p. 2821*) has summed up the situation, both from the standpoint of the healing of the wound and from the practical aspect of its making, by saying:

> So far as the healing of the wound is concerned, it is perhaps best to prune when the vegetative activities begin in spring so that the wound is quickly covered or "healed." For the purpose of checking growth and producing other definite results, it may be necessary to prune at other times of the year. As a general rule, however, the best time to prune is late autumn or early spring, when labor can be had and before the rush of spring work comes on. In practice, it resolves itself largely into a question of the convenience of the operator.

The pruning problem in this country is stressed chiefly in connection with ornamental and horticultural trees.

In Europe matters relating to pruning have been given considerable study by European foresters. Zederbauer (*17*) experimented with *Fagus sylvatica*, *Quercus pedunculata*, *Q. sessiliflora*, *Pseudotsuga douglasii*, and *Picea excelsa*. As a result of a study in which he measured the callus produced following the removal of branches, he concluded that pruning of forest trees is least injurious when carried on in early spring.

Swarbrick (*15*), an English investigator, has studied histological changes that take place during the healing process. His work does not treat of callus formation, but relates to the blocking of the wood vessels by the deposition of gum in the region of the wound. Working with sycamore, rhododendron, plum, and apple, his method consisted in clipping off the ends of branches at a point where they were approximately three-quarters of an inch in diameter, the cut surface being smoothed with a knife and left exposed. For each species a series of such wounds was made each month for a year, and subsequent to each treatment branches were cut off for study at monthly intervals. Microscopic examination showed that during the growing season the tracheae became plugged with a deposit of viscous substance of an unknown chemical nature, referred to as "wound gum," whereas during the dormant season no complete blocking took place. Swarbrick stated. therefore, that "the experimental results would appear to favor the practice of spring and summer pruning so far as the natural closure of the cut surface against disease is concerned." Priestley (*12*), under whose direction Swarbrick's research was performed, has given a brief, less technical account of the study.

EXPERIMENTAL METHODS AND PROCEDURE

The study was conducted at the Yale Forest Preserve, Woodbridge, Conn., in an open, mixed hardwood stand (fig. 1), on a tract slightly sloping to the south. The soil is a stony clay loam overlying a bed rock of chlorite schist. Because of competition for soil moisture and for light, the environment of the trees in this area seemed less favorable than that of well-planted specimen shade trees, but more favorable than the adverse environment of many trees planted for street and park purposes.

A total of 30 trees, exclusive of check trees, was used in the experiment proper, 5 trees being selected of each of the following six species:[4] Red maple (*Acer rubrum* L.), black oak (*Quercus velutina* Lamarck), chestnut oak (*Q. montana* Willd.), red oak (*Q. borealis*

[4] Nomenclature from Sudworth (*14*).

maxima (Marshall) Ashe), white oak (*Q. alba* L.), and yellow poplar (*Liriodendron tulipifera* L.).

These species were used because they were well represented in the particular stand and because the trees of these species often receive treatment. Individuals within the species were not selected for vigor but were taken as they grew on the site in order that both vigorous and weak specimens might be included in the study.

At the time the experiment was laid out the smallest tree was 5.6 inches in diameter at breast height, the largest 12.7 inches, and the average of all 30 trees 9.1 inches. (Table 1.)

FIGURE 1.—General view of the site used

TABLE 1.—*Trees used in the experiment*

Species and tree No.	Vigor of trees	Diameter breast high	Species and tree No.	Vigor of trees	Diameter breast high
		Inches			*Inches*
Acer rubrum:			Quercus borealis maxima:		
1	Fair	8.1	1	Good	9.5
2	do	10.2	2	do	7.6
3	do	10.6	3	do	12.7
4	do	8.4	4	do	7.6
5	do	11.4	5	do	9.1
Average		9.7	Average		9.3
Liriodendron tulipifera:			Quercus montana:		
1	Good	11.4	1	Good	10.0
2	do	10.0	2	do	9.4
3	do	9.4	3	do	8.6
4	do	11.8	4	do	7.6
5	Fair	9.4	5	do	8.6
Average		10.4	Average		8.8
Quercus alba:			Quercus velutina:		
1	Good	6.3	1	Good	10.0
2	Fair	9.5	2	Poor	5.6
3	Poor	9.5	3	Good	9.4
4	Very poor	5.9	4	Poor	7.3
5	Poor	7.6	5	Fair	9.4
Average		7.8	Average		8.3

The wounds were made with an auger in order to have them as nearly uniform as possible. They thus differed from wounds made by the removal of branches in that they presented cuts that were parallel with the grain of the wood rather than cut across the grain. The holes, 1½ inches in diameter, were bored through the bark and about one-half inch into the wood, care being taken to see that they were sufficiently deep to remove all the cambium tissue.

On each of the trees studied auger wounds were made on the 15th day of each month in the year. The work was begun on October 15, 1926. The holes were bored in pairs, the members of the pair being side by side with their centers approximately 3 inches apart. For each pair of holes, the left received no treatment, and the right was painted with shellac. Ridged or depressed areas were avoided, since growth at such locations sometimes varies much from the normal growth of the trunk as a whole.

The first pair of wounds were made near the base of the tree from 1 foot to 18 inches above the root collar. They were not placed at the same points of the compass for the several trees, but were varied on each tree so that any possible favorable growth effect of a particular aspect of facing might be disregarded. Each pair of wounds made in succeeding months was bored from 2 to 5 inches above, and to the right of the pair of the preceding month, so that the pairs spiraled upward about the trunk. At the completion of the work each of the 30 trees bore 12 pairs of wounds.

The nature of the experiment was such that each tree of a given species provided something of a check against the four other trees of the same species, and, to a lesser degree, a check against the trees as a whole. Comparison was also aided by the fact that paired wounds were used, although one of each pair had been coated with shellac and the other left untreated.

It appeared advisable to distribute the wounds of corresponding months so that any possible directional effect in their location around the trunk might be minimized. It might perhaps seem equally desirable to have distributed them more or less definitely with reference to height on the trunk. This was not done, however, partly because of the complexity that such arrangement would have introduced, and partly because there appeared to be little reason for suspecting marked variance in the callusing of wounds that differed only slightly in their vertical placement.

The correction of this latter assumption was demonstrated by check trees, one of which was used for each of the species in the experiment proper. On each of these check trees (fig. 2) six paired wounds were made with the auger precisely as described except for the fact that the wounds were all made on the same date (July 15, 1927), and that they were in line up and down the trunk rather than spiraled. Wounds of the check trees failed to show any material difference in rate of healing due to their location on the bole.

The first field notes were taken on July 15, 1927. Subsequent records were made on or within two days of the 15th of each month during the growing seasons of 1927 and 1928. Field records were taken on mimeographed forms. The circles on these sheets were 1½ inches in diameter, representing the full-sized outlines of wounds made by the bit. Two sheets were required for each inspection of each tree. They were filled in with the number of the tree, its species, and the date of examination. Then, by means of numerous measurements, the outline of the callus of each wound was carefully sketched into its particular diagram. The wound and its diagram were next compared side by side, and the diagram corrected when necessary. In filling in these sketches the longer edge of the sheet was held parallel with the axis of the bole of the tree, the bottom of the sheet being toward the ground.

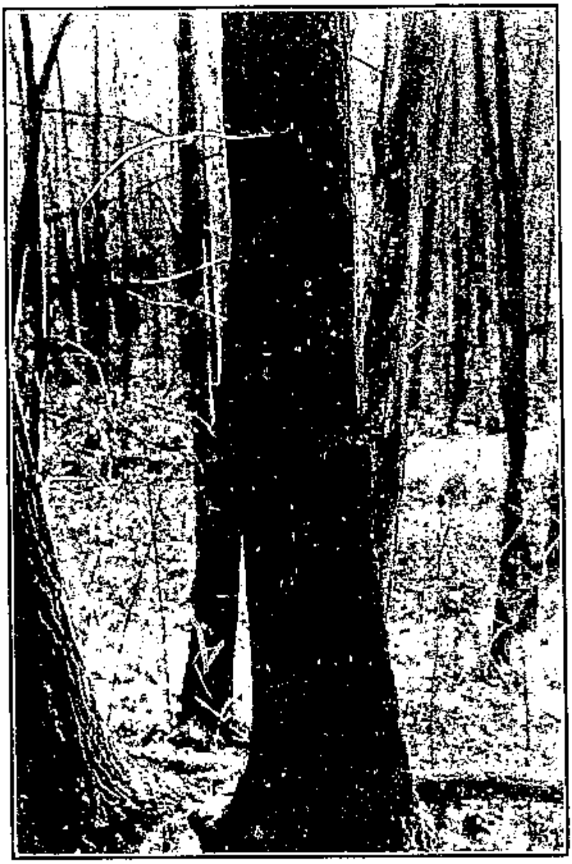

FIGURE 2.—A check tree of chestnut oak showing that the height at which the wounds were located on the boles did not affect the rate of healing

The field notes thus traced diagrammatically the closing in of the callus growth until the wound was completely healed (fig. 3) or until the experiment was terminated.

REASON FOR TESTING SHELLAC

In general practice, shellac has long been famed as a dressing for tree wounds. In Lindley's Theory of Horticulture (*9, f. n. p. 233*), which appeared in 1841, the following statement is made:

> A solution of Gum Shellac in alcohol, of the consistence of thin paste (put on with a brush), is an admirable application to wounds of stone-fruit trees, and others which are disposed to bleed profusely. It is readily applied, adheres closely, excludes the air completely, and is less offensive to the eye than large plasters of clay, composition, etc.

Durand (*7, p. 370*) in 1853 says:

> It will be well to have large wounds covered by a composition of gum shellac, dissolved in alcohol to the consistency of paint, and put on with a brush. This, I think, is as cheap and as good composition as can be had for closing pores of the wood—also protecting it from weather.

Howe (*8, p. 83*) in more recent studies used white lead, white zinc, yellow ocher, coal tar, shellac, and avenarius carbolineum on wounds of apple and peach trees. In summing up their effects on healing he stated:

Shellac seemed, the first season, to exert a stimulating influence upon the wounds used but the second season this effect disappeared. Of all the materials used shellac was least injurious. On the other hand it adheres to the wounded surfaces least well of all.

Collins (*5*), in his bulletin on tree surgery, recommends shellac as a dressing for scars less than one-half of an inch in width. On larger wounds he suggests its use as a protection to the cambium tissues against any drying out which might take place before the application of some more permanent dressing, such as tar or creosote, and to prevent possible chemical injury to the same tissues following the application of these substances. In a statement that healing of wounds by means of new callus growth at the sides is often more rapid if neither paint nor other generally used waterproof covering is applied, shellac alone is excepted.

Peets (*11, p. 31–32*), in his book on tree repair, says of shellac:

Of the paint group, recent experiments indicate that shellac has great value. It is not a durable dressing but it seems to be entirely harmless to the cambium and to the young callus, which is not even true of white lead paint. Shellac has the further great advantages of drying very quickly and of being cheap and convenient. It ought to be in constant use when cavity work is being done in hot dry weather. A coat of shellac over the edges of an excision will often prevent the cambium from being killed back and the bark from separating from the wood, thus enlarging the wound.

FIGURE 3.—A completely callused wound of white oak

In some unpublished experiments the writer has tried some 90 different materials as applications for wound dressings. Of these materials shellac seemed the most logical choice for this particular work. Beeswax, paraffin, "parapine wax," and grafting wax are also substances that could have been used. Dressings made with any of these latter materials are thicker and less transparent than applications of shellac. They were avoided because they would have masked results. In brief, shellac, despite its short life and consequent failure to afford adequate protection against the invasion of insect or fungus pests, is generally recognized as a material noninjurious to the development of callus.

The shellac used in these experiments was made by cutting dry orange shellac with alcohol denatured according to United States Internal Revenue Formula No. 1. The mixture was of the consistency of paint. A single coat was applied with a brush immediately after the wounds were made.

RESULTS EXPRESSED IN DIAGRAMS OF CALLUS GROWTH

To present diagrammatically the successive stages of callus development, the data for each individual tree were assembled upon a chart. Blank forms for this chart were drawn on tracing paper. The circles representing the outlines of the wounds were natural size. The several circles of the field notes were placed beneath their designated circles on the chart, and the outlines of the callus growth traced through the paper. In order to emphasize the areas of callus formation they were shaded. Where no shading occurs in the circle there had been no growth of callus; where the circle is completely shaded, callus had completely filled the wound. Several circles are

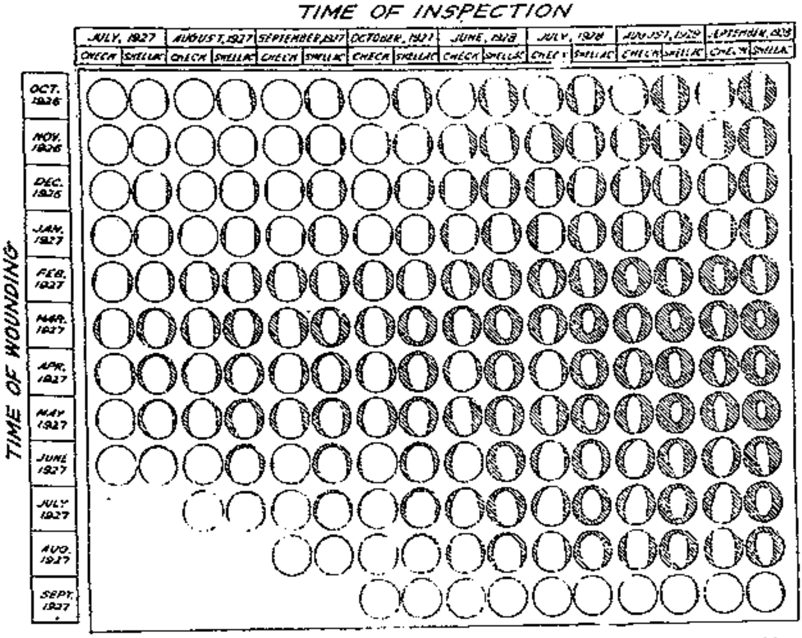

FIGURE 4.—Successive stages of callus growth for each wound on *Acer rubrum* No. 1

wanting in the lower left-hand corner of the chart, these wounds not yet having been made at the time the records were taken.

The completed individual diagrams of two trees of each species appear as shown in Figures 4 to 15, inclusive.

The tree worker is frequently more concerned with the shape of the callus than with the area of its growth. He has, in general, little difficulty in obtaining its satisfactory development at the sides of the wounds made by the removal of branches, through accidents to the bark, or in the cutting of cavities. The top and the bottom of the wound are slow to heal and prone to give trouble. This is especially true of the bottom of the wound, where healing is accomplished with difficulty, particularly if the wound is of considerable width. Dying back of the cambium at the top, and even to a greater degree at the bottom, is a frequent result. Even where considerable

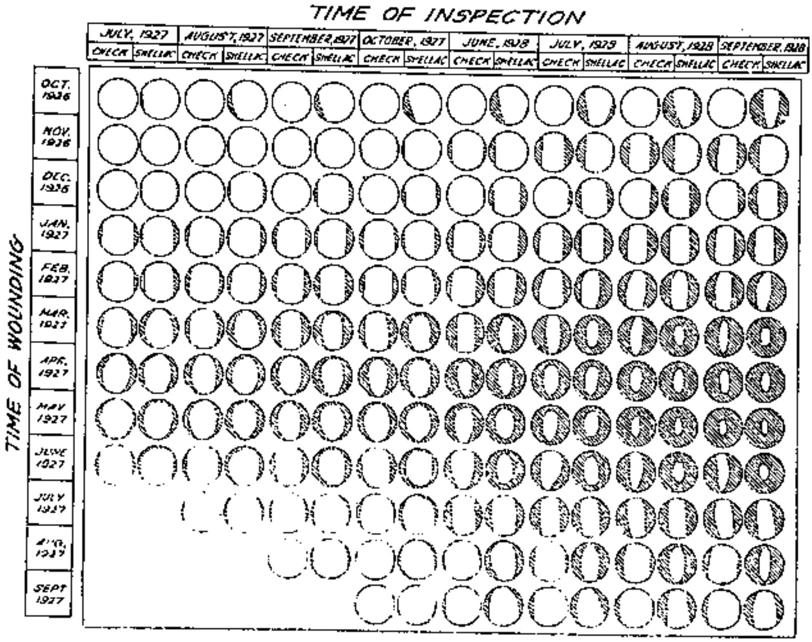

FIGURE 5.—Successive stages of callus growth for each wound on *Acer rubrum* No. 4

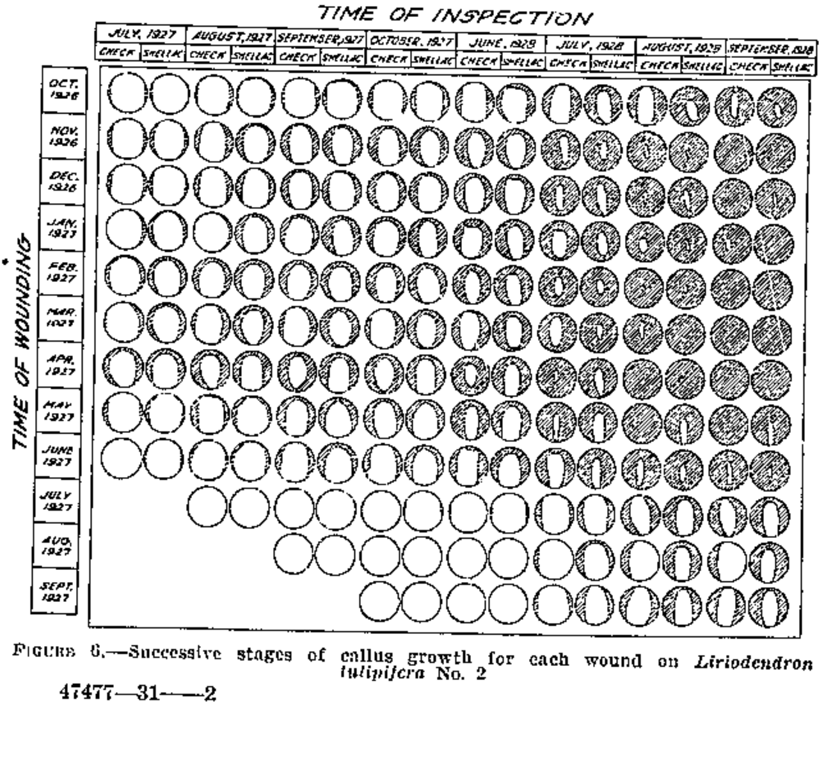

FIGURE 6.—Successive stages of callus growth for each wound on *Liriodendron tulipifera* No. 2

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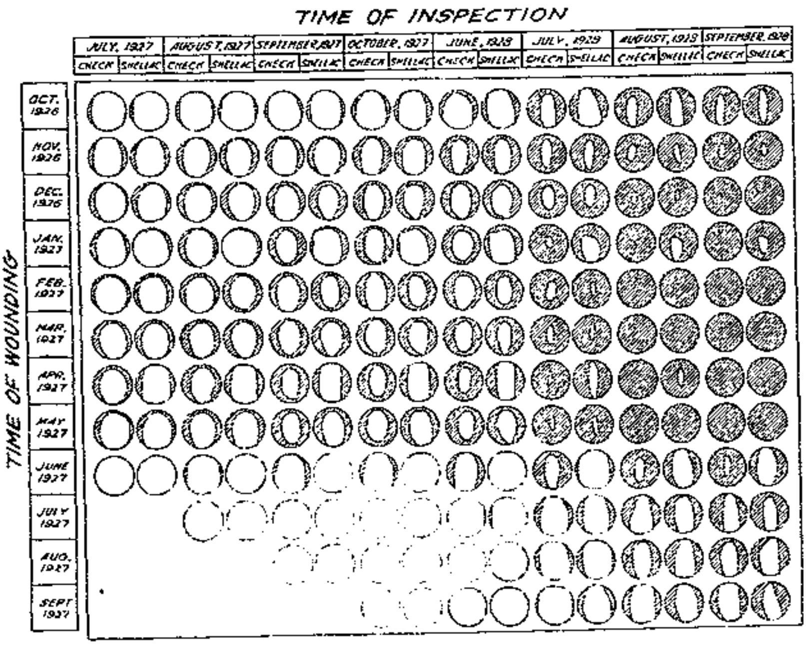

FIGURE 7.—Successive stages of callus growth for each wound on *Liriodendron tulipifera* No. 3

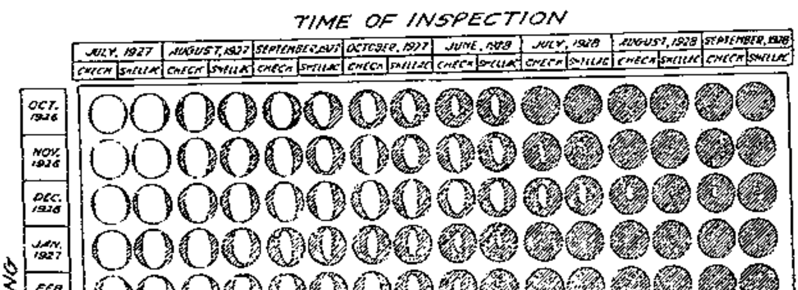

FIGURE 8.—Successive stages of callus growth for each wound on *Quercus alba* No. 2

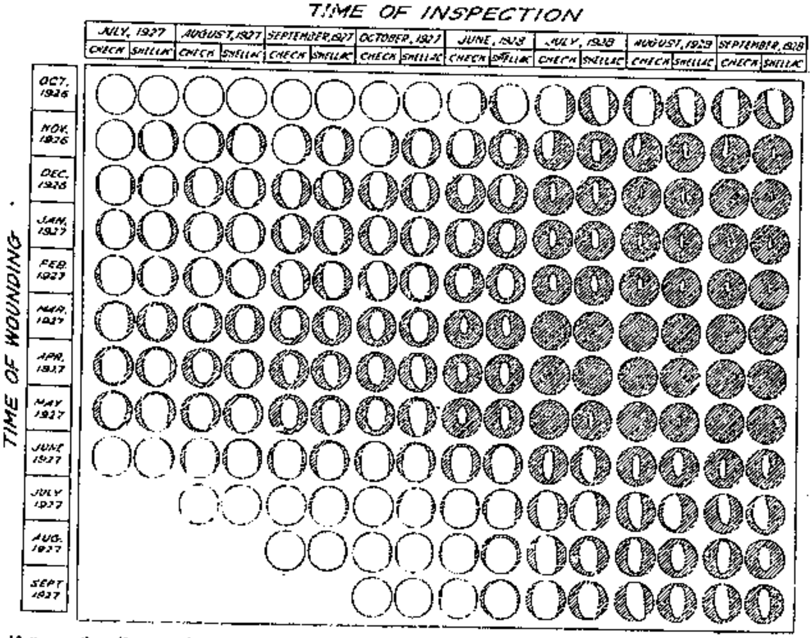

FIGURE 9.—Successive stages of callus growth for each wound on *Quercus alba* No. 3

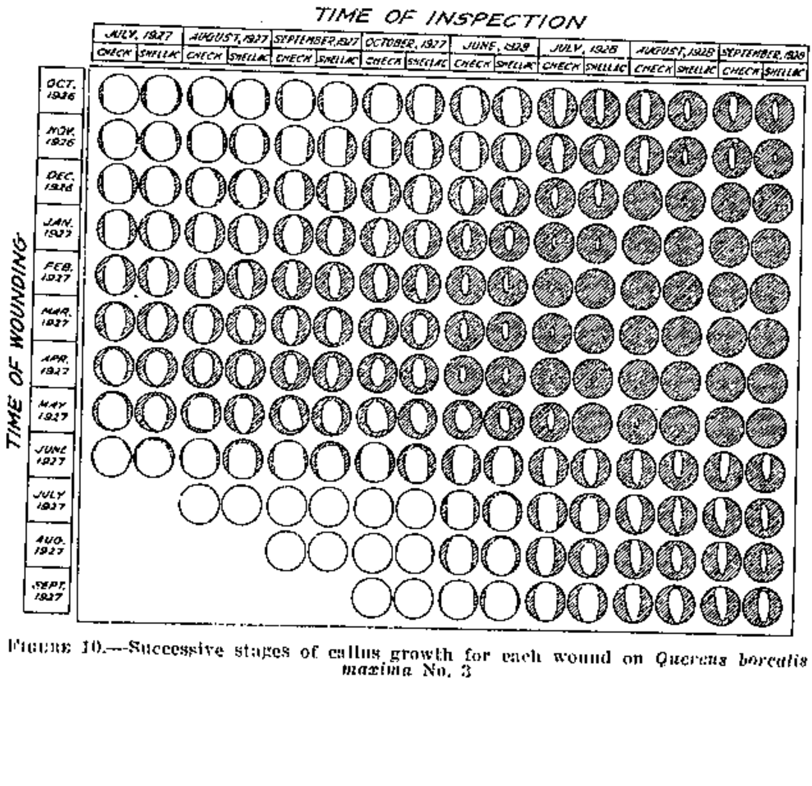

FIGURE 10.—Successive stages of callus growth for each wound on *Quercus borealis maxima* No. 3

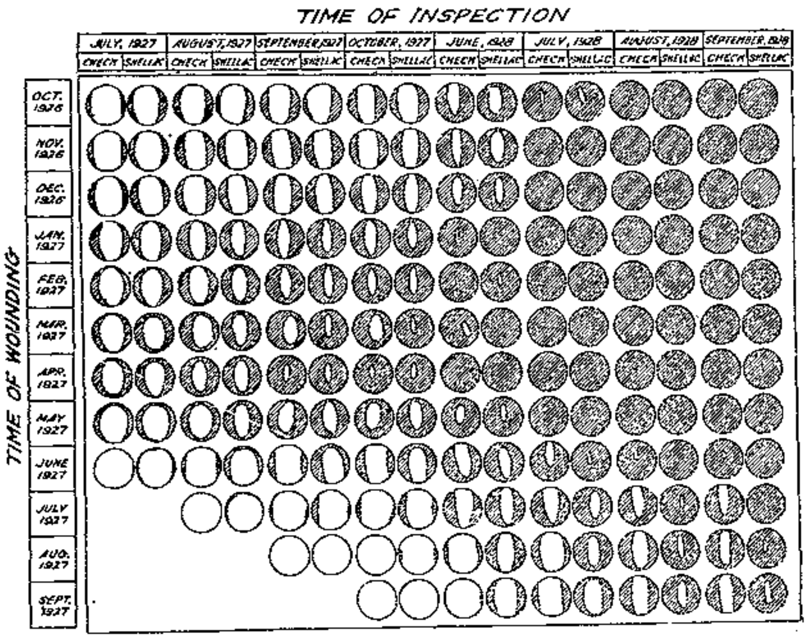

FIGURE 11. Successive stages of callus growth for each wound on *Quercus borealis maxima* No. 3

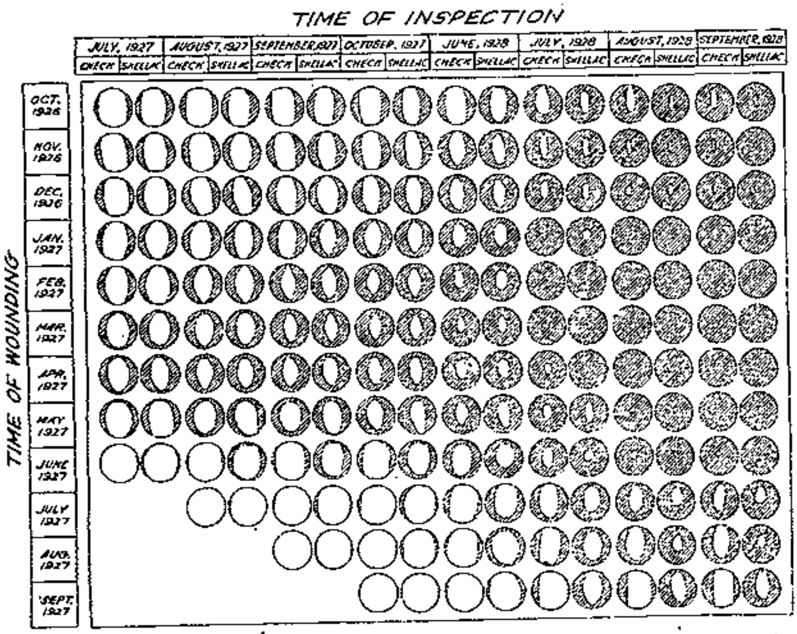

FIGURE 12.—Successive stages of callus growth for each wound on *Quercus montana* No. 3

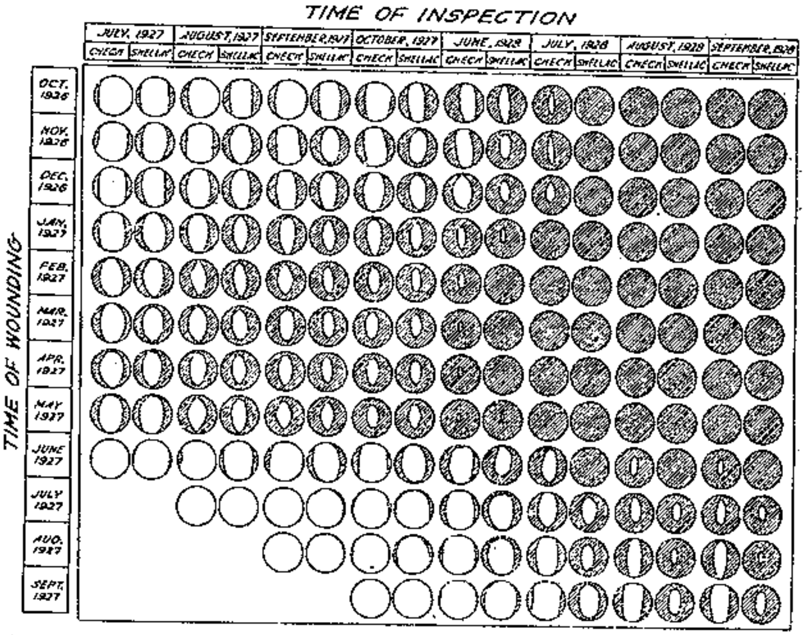

FIGURE 13.—Successive stages of callus growth for each wound on *Quercus montana* No. 4

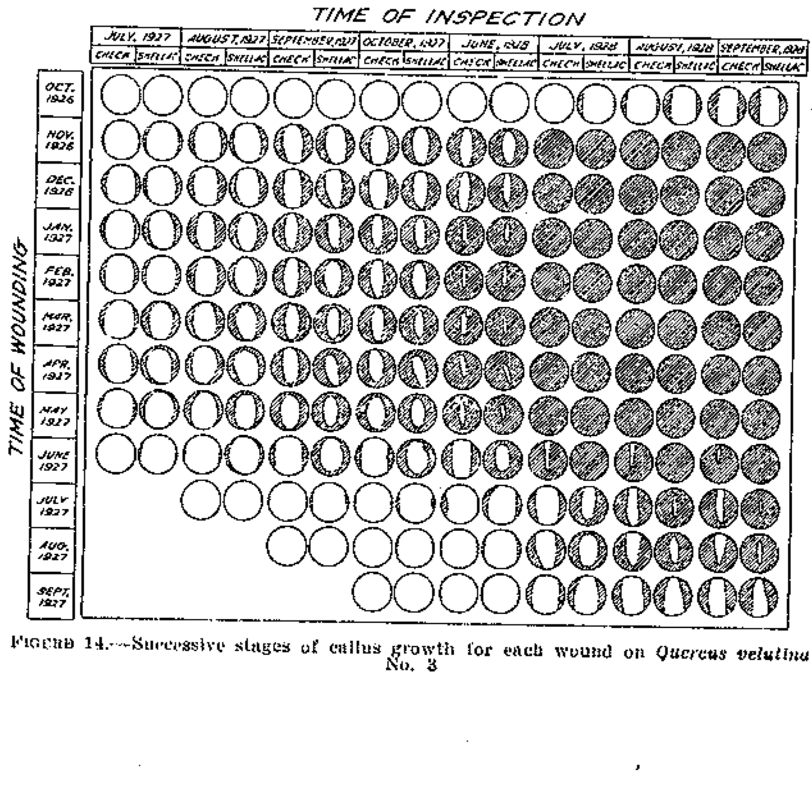

FIGURE 14.—Successive stages of callus growth for each wound on *Quercus velutina* No. 3

shaping is done, the difficulty of healing the base of the cut still presents a problem that requires the most careful handling.

The relatively slower growth and the tendency to kill back are not the only factors that play a rôle in making the healing of the bottom of the wound of importance to the tree worker. Fungus spores that collect on the face of the wound sometimes tend to be washed downward by rains and heavy dews and to lodge in any cracks or irregularities that may be present. Moisture collecting at such points aids the spores in germination and infection and assists the resulting mycelium in at least its initial attack on the outer wood.

From a diagrammatic presentation of the shape of the callus the tree worker is often able to interpret something of what took place

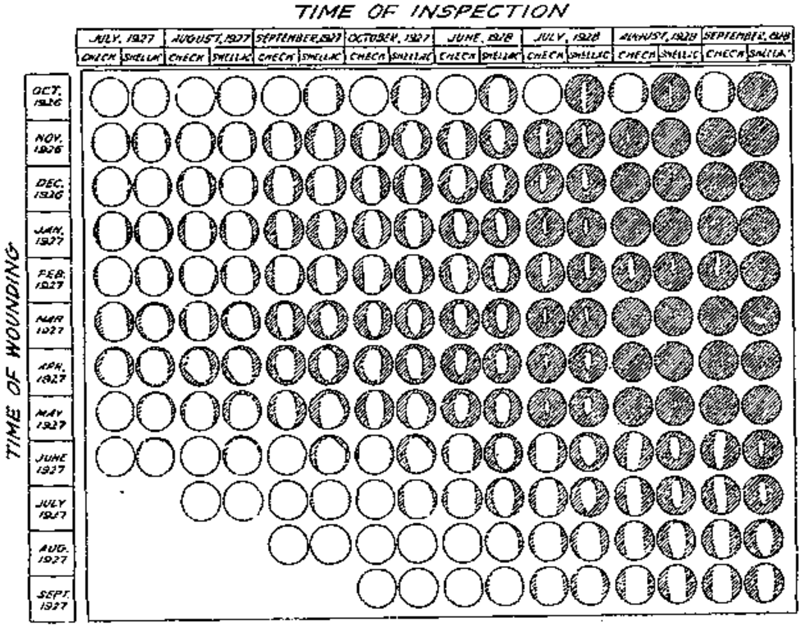

FIGURE 15.—Successive stages of callus growth for each wound on *Quercus velutina* No. 5

in the formation of the callus. This can not be interpreted from a mere statement of the area that this growth may have covered. If the growth has taken place along the sides of the wound and is wanting at the top and bottom he at once realizes that killing back (fig. 16) has taken place above and below the wound. The distance of separation between two such lateral areas of callus, together with the straightness or degree of curve of their inner edges, at once furnishes a clue as to the relative severity of the killing.

In making the field measurements of the present study it would have been possible to cut back the overlying bark from areas which had been killed back and to present both the actual degree of killing and the shape of the killed area. This procedure was avoided for two reasons: (1) It seemed highly probable that the cutting back of the bark would have changed the results of the experiments by producing further injury, followed by further dying back of the delicate cambium tissues; and (2) even had it not endangered the results, the diagrammatic presentation would have required many times the already extensive space needed for giving the results pictured by the present method.

FIGURE 16.—Killing back on red maple

RESULTS EXPRESSED AS AVERAGE AREA OF CALLUS GROWTH

For convenience in averaging results, the callus growth was expressed in terms of the square inches of area that it covered. Such a practice, however, introduces a certain degree of error. For example, in Figure 17, the outlines of two wounds might be represented by the circles, growth of callus by the shaded areas, and a possible killing back in B by the dotted lines. Measuring shows that the areas of callus produced by A and B are equal, yet the healing represented by A is more desirable than that of B.

In calculating the numerical results all areas of callus were measured with a planimeter (fig. 18) from the full-sized charts. They were expressed to the nearest tenth of a square inch. Since the area of the 1½-inch wound used is approximately 1.8 square inches, measurements of the areas of callus ranging from no healing to complete healing read from 0 to 1.8 square inches.

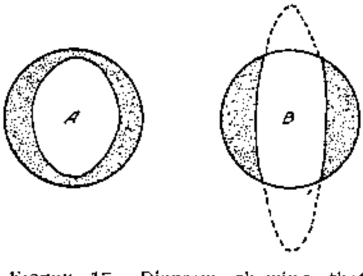

FIGURE 17.—Diagram showing that wounds with equal areas of callus do not always have equally desirable healing. The areas of callus of A and B are equal, but A represents more desirable healing than does B

After measurement, areas of callus of corresponding wounds were averaged. In each case the average represents five trees of the same species. These average figures appear in Table 2. Their arrangement corresponds to that of the diagram charts.

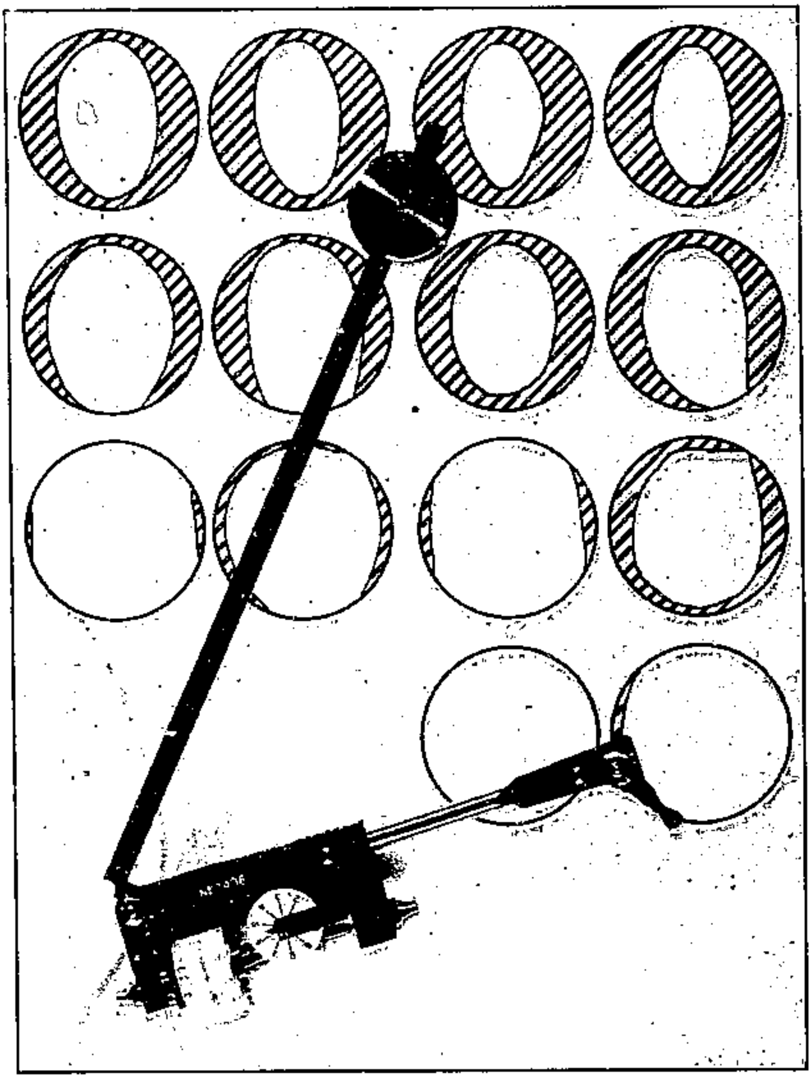

FIGURE 18.—Method of measuring the areas of callus with a planimeter

TABLE 2.—*Average areas of callus for five trees of each species*

[C=check wound; S=shellacked wound]

Species	Date wound was made	Square inches of callus on indicated dates: July, 1927 C.	July, 1927 S.	Aug., 1927 C.	Aug., 1927 S.	Sept., 1927 C.	Sept., 1927 S.	Oct., 1927 C.	Oct., 1927 S.	June, 1928 C.	June, 1928 S.	July, 1928 C.	July, 1928 S.	Aug., 1928 C.	Aug., 1928 S.	Sept., 1928 C.	Sept., 1928 S.
	Oct., 1926	0.0	0.1	0.0	0.2	0.0	0.3	0.0	0.4	0.1	0.6	0.2	0.8	0.3	1.0	0.3	1.1
	Nov., 1926	.0	.1	.1	.2	.2	.4	.2	.3	.3	.5	.6	.6	.7	.8	.8	.9
	Dec., 1926	.1	.2	.1	.2	.2	.3	.2	.2	.3	.4	.6	.5	.7	.7	.6	.8
	Jan., 1927	.2	.2	.2	.3	.3	.4	.3	.4	.5	.6	.6	.7	.8	.9	.8	1.0
	Feb., 1927	.2	.2	.3	.4	.4	.5	.4	.4	.7	.7	.8	.9	1.1	1.0	1.0	1.1
Acer rubrum	Mar., 1927	.3	.5	.4	.7	.6	.8	.6	.8	.8	1.2	1.1	1.3	1.3	1.5	1.4	1.6
	Apr., 1927	.3	.6	.4	.7	.6	.8	.6	.9	.9	1.1	1.1	1.4	1.4	1.5	1.5	1.6
	May, 1927	.2	.4	.4	.7	.5	.7	.5	.8	.9	1.1	1.1	1.3	1.4	1.4	1.5	1.5
	June, 1927	.0	.2	.1	.4	.2	.6	.2	.6	.4	1.0	.6	1.0	1.2	1.3	1.0	1.4
	July, 1927	----	----	.0	.1	.1	.2	.1	.2	.3	.6	.5	.8	.8	1.0	.9	1.0
	Aug., 1927	----	----	----	----	.0	.1	.0	.1	.1	.4	.2	.7	.4	.9	.4	1.0
	Sept., 1927	----	----	----	----	----	----	.0	.0	.0	.2	.1	.2	.1	.3	.2	.4
	Oct., 1926	.1	.2	.2	.3	.3	.4	.3	.6	.4	.6	.7	1.1	1.1	1.6	1.2	1.6
	Nov., 1926	.3	.4	.5	.6	.6	.7	.7	.7	.9	.9	1.3	1.4	1.6	1.6	1.7	1.7
	Dec., 1926	.3	.3	.5	.6	.6	.6	.7	1.0	.8	.9	1.3	1.3	1.6	1.6	1.7	1.7
	Jan., 1927	.3	.4	.5	.6	.7	.8	.8	.8	.9	.9	1.4	1.4	1.6	1.6	1.7	1.7
	Feb., 1927	.3	.4	.6	.7	.8	.8	.8	.8	1.1	1.0	1.5	1.4	1.7	1.6	1.7	1.7
Liriodendron tulipifera	Mar., 1927	.5	.5	.8	.7	.9	.9	1.0	.9	1.2	1.1	1.6	1.6	1.8	1.7	1.8	1.7
	Apr., 1927	.7	.5	.9	.7	1.1	.8	1.1	.9	1.3	1.1	1.7	1.5	1.8	1.7	1.8	1.8
	May, 1927	.4	.4	.7	.6	.9	.8	.9	.8	1.2	1.0	1.6	1.5	1.8	1.7	1.8	1.7
	June, 1927	.0	.0	.2	.1	.4	.2	.4	.2	.6	.2	1.1	.6	1.4	1.1	1.6	1.2
	July, 1927	----	----	.0	.0	.0	.0	.1	.1	.1	.1	.5	.6	.9	1.0	1.1	1.1
	Aug., 1927	----	----	----	----	.0	.0	.0	.0	.0	.0	.2	.4	.6	.9	.7	1.0
	Sept., 1927	----	----	----	----	----	----	.0	.0	.0	.0	.2	.4	.6	.7	.8	.9
	Oct., 1926	.0	.3	.2	.6	.3	.7	.4	.8	.6	.9	.9	1.1	1.0	1.4	1.1	1.4
	Nov., 1926	.3	.3	.5	.7	.6	1.0	.7	1.0	.9	1.1	1.2	1.4	1.4	1.5	1.4	1.6
	Dec., 1926	[illegible]	.4	.6	.8	.9	.9	.9	.9	1.1	1.1	1.4	1.4	1.5	1.5	1.5	1.5
	Jan., 1927	.4	.6	.6	.8	.8	1.0	1.0	1.1	1.2	1.3	1.5	1.5	1.5	1.6	1.6	1.6
	Feb., 1927	.4	.6	.7	.7	.9	1.0	.9	1.1	1.2	1.2	1.5	1.3	1.7	1.5	1.6	1.6
Quercus alba	Mar., 1927	.5	.7	.8	.9	1.1	1.2	1.2	1.2	1.4	1.4	1.6	1.5	1.6	1.6	1.6	1.6
	Apr., 1927	.7	.7	.9	.9	1.2	1.2	1.2	1.2	1.4	1.4	1.6	1.6	1.7	1.7	1.7	1.7
	May, 1927	.6	.5	.8	.8	1.1	1.1	1.1	1.1	1.3	1.4	1.6	1.6	1.6	1.6	1.7	1.7
	June, 1927	.0	.1	.2	.3	.3	.6	.5	.6	.7	.9	1.1	1.2	1.2	1.4	1.3	1.5
	July, 1927	----	----	.0	.0	.1	.2	.1	.3	.4	.6	.9	1.0	1.2	1.2	1.2	1.3
	Aug., 1927	----	----	----	----	.0	.1	.0	.2	.4	.5	.8	1.0	1.1	1.3	1.2	1.4
	Sept., 1927	----	----	----	----	----	----	.0	.0	.1	.3	.4	.8	.9	1.0	1.0	1.1
	Oct., 1926	.2	.4	.3	.4	.4	.7	.6	.8	.9	1.2	1.4	1.6	1.5	1.8	1.6	1.7
	Nov., 1926	.3	.4	.4	.6	.7	.8	1.0	1.0	1.1	1.3	1.5	1.7	1.5	1.8	1.7	1.8
	Dec., 1926	.4	.5	.6	.9	.6	.9	.9	1.0	1.3	1.4	1.6	1.8	1.8	1.8	1.8	1.8
	Jan., 1927	.4	.6	.8	.8	1.0	1.1	1.1	1.2	1.5	1.6	1.7	1.8	1.8	1.8	1.8	1.8
	Feb., 1927	.5	.6	.6	1.0	1.1	1.2	1.2	1.3	1.6	1.7	1.8	1.8	1.8	1.8	1.8	1.8
Q. borealis maxima	Mar., 1927	.7	.8	.8	1.0	1.1	1.3	1.1	1.4	1.6	1.7	1.8	1.8	1.8	1.8	1.8	1.8
	Apr., 1927	.7	.7	.9	1.0	1.2	1.3	1.3	1.5	1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.8
	May, 1927	.5	.6	.8	.7	1.1	1.1	1.2	1.2	1.6	1.6	1.7	1.8	1.8	1.8	1.8	1.8
	June, 1927	.0	.1	.1	.3	.3	.5	.4	.6	.7	.8	1.1	1.2	1.4	1.4	1.5	1.5
	July, 1927	----	----	.0	.0	.0	.1	.1	.2	.5	.8	.8	1.2	1.1	1.6	1.4	1.6
	Aug., 1927	----	----	----	----	.0	.0	.0	.1	.3	.5	.6	1.1	.8	1.3	1.3	1.6
	Sept., 1927	----	----	----	----	----	----	.0	.0	.1	.3	.4	.8	.8	1.1	1.0	1.3
	Oct., 1926	.1	.4	.2	.7	.3	.7	.4	.9	.6	1.2	1.1	1.6	1.4	1.8	1.4	1.8
	Nov., 1926	.4	.5	.5	.8	.7	.9	.8	.9	1.1	1.4	1.6	1.6	1.7	1.8	1.8	1.8
	Dec., 1926	.4	.6	.7	.9	.9	1.1	1.0	1.2	1.3	1.5	1.6	1.7	1.8	1.8	1.8	1.8
	Jan., 1927	.5	.7	.7	1.0	1.0	1.2	1.2	1.3	1.5	1.6	1.7	1.8	1.8	1.8	1.8	1.8
	Feb., 1927	.7	.7	1.0	1.1	1.3	1.3	1.4	1.5	1.6	1.6	1.8	1.8	1.8	1.8	1.8	1.8
Q. montana	Mar., 1927	.8	.9	1.0	1.0	1.3	1.4	1.4	1.4	1.6	1.7	1.8	1.8	1.8	1.8	1.8	1.8
	Apr., 1927	1.0	.9	1.1	1.2	1.2	1.4	1.3	1.5	1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.8
	May, 1927	.9	.7	1.0	1.0	1.2	1.2	1.3	1.3	1.6	1.6	1.8	1.8	1.8	1.8	1.8	1.8
	June, 1927	.0	.2	.2	.3	.3	.6	.5	.6	.8	1.1	1.2	1.5	1.6	1.7	1.7	1.8
	July, 1927	----	----	.0	.0	.0	.2	.1	.3	.4	.8	.8	1.1	1.4	1.6	1.5	1.7
	Aug., 1927	----	----	----	----	.0	.1	.1	.2	.3	.6	.7	1.2	1.1	1.5	1.3	1.6
	Sept. 1927	----	----	----	----	----	----	.0	.0	.2	.4	.4	1.0	.8	1.3	.9	1.4
	Oct., 1926	.0	.1	.0	.1	.1	.2	.1	.3	.2	.4	.4	.8	.6	.9	.7	1.4
	Nov., 1926	.1	.2	.2	.4	.5	.6	.6	.8	.7	.9	1.2	1.5	1.6	1.7	1.6	1.7
	Dec., 1926	.2	.3	.4	.4	.5	.6	.7	.8	.8	.9	1.3	1.3	1.6	1.5	1.6	1.6
	Jan., 1927	.2	.4	.5	.6	.7	.8	.8	.9	1.0	1.2	1.4	1.5	1.6	1.7	1.6	1.7
	Feb., 1927	.3	.3	.6	.6	.7	.9	.8	.8	1.1	1.4	1.4	1.6	1.7	1.7	1.7	1.8
Q. velutina	Mar., 1927	.3	.5	.6	.7	.8	1.1	.9	1.1	1.1	1.3	1.5	1.6	1.7	1.7	1.8	1.8
	Apr., 1927	.4	.6	.8	.8	.9	1.1	.9	.9	1.1	1.3	1.4	1.6	1.7	1.5	1.8	1.8
	May, 1927	.2	.4	.5	.6	.8	.9	.9	.8	1.0	1.3	1.6	1.6	1.7	1.8	1.8	1.8
	June, 1927	.0	.2	.1	.4	.2	.6	.3	.7	.6	.9	.9	1.3	1.2	1.6	1.3	1.6
	July, 1927	----	----	.0	.0	.0	.1	.1	.2	.2	.5	.6	.9	.9	1.2	1.1	1.1
	Aug., 1927	----	----	----	----	.0	.0	.0	.1	.1	.2	.4	.7	.7	1.0	.8	1.2
	Sept., 1927	----	----	----	----	----	----	.0	.0	.1	.2	.3	.5	.6	.7	.7	.8

DISCUSSION OF RESULTS

EFFECT OF SEASON OF WOUNDING AS SHOWN BY AREA OF CALLUS

As there are 5,400 measurements included in the diagrams of callus growth, graphs are introduced to facilitate the interpretation of the diagrams and the averaged areas.

Figure 19 is a graphic presentation of the effect which the season of wounding exerted on the amount of callus produced by the healing of the wounds. (Table 2.) The average areas of callus during the two growing seasons were figured by averaging the areas of the inspections made each season.

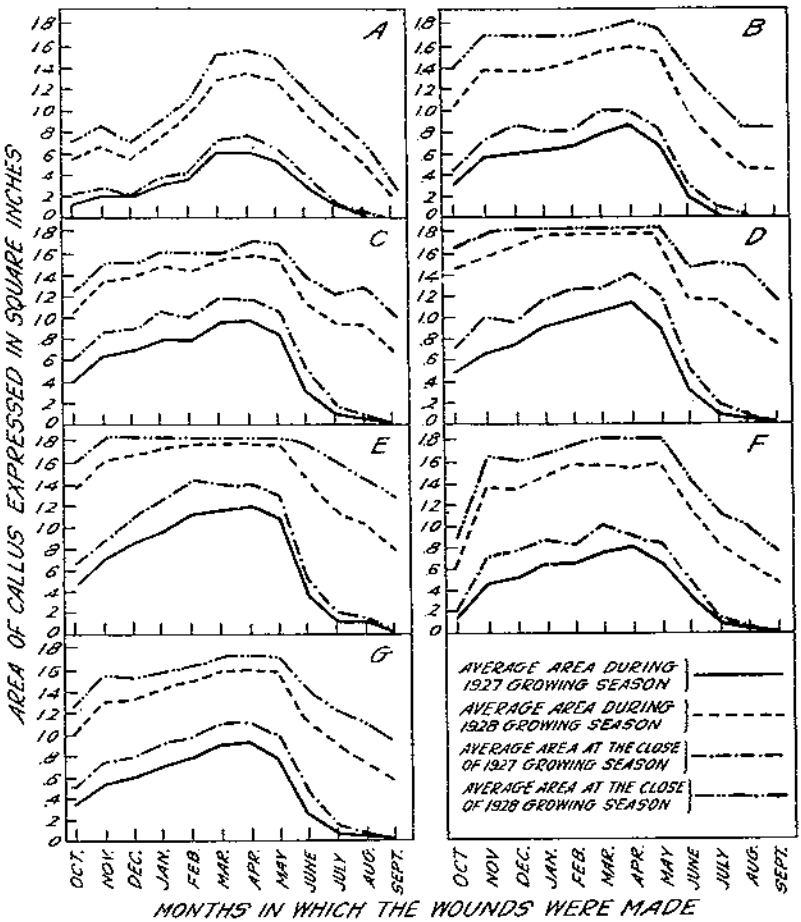

FIGURE 19.—Effect of season of wounding as shown by average area of callus growth produced by the wounds. These averages are for five trees of each species. A, *Acer rubrum*; B, *Liriodendron tulipifera*; C, *Quercus alba*; D, *Q. borealis maxima*; E, *Q. montana*; F, *Q. velutina*; G, average of the six species

In interpreting these graphs it is to be remembered that the area of the completely callused wound is 1.8 square inches. For this reason a flat line must finally be obtained when the wounds have become completely healed. This feature is illustrated by the upper lines D and E of Figure 19 where the curves have become so much flattened by growth that they fail to peak. Aside from this feature, all four curves in all six graphs (A to F) seem to agree in exhibiting a more or less gradual rise from October to peaking in the period between February and May. In June the curves drop sharply.

From these graphs it is evident that, judged from the area of callus growth, the period from February 15 to May 15 represented, for the trees studied, the most favorable season of wounding. The 15th of the month is specified, since that date was selected as a time of wounding, in preference to the 1st of the month. Should it be desired to shorten still further the season of wounding, February should be omitted, since its results seemed less satisfactory than those of March, April, or May.

EFFECT OF SEASON OF WOUNDING AS SHOWN BY SHAPE OF CALLUS

An attempt has been made to select for each of the 30 trees the three pairs of wounds that show the most satisfactory shape of callus growth. This was judged by their several appearances at the eight examinations. These are tallied in Figure 20, where the large bars (A) represent the result for all 30 trees and the smaller bars (B) the scatter of the curves through the six species of trees studied.

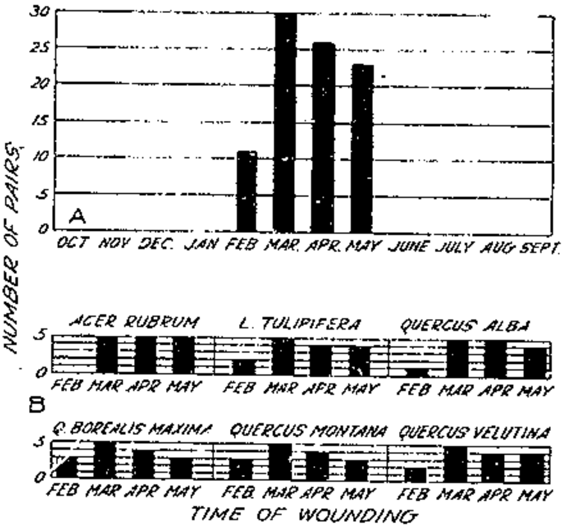

FIGURE 20.—Effect of season of wounding as shown by the shape of callus growth. A, Made by tallying the three pairs of wounds that showed the most satisfactory shape of callus growth; B, scatter of A within the several species

This graph indicates that, judged by the shape of the resulting callus growth, the season between February 15 and May 15 was the most favorab'e time for wounding the particular tree species studied. Wounds made during February produced somewhat less satisfactory callus than did those made during March, April, or May.

EFFECT OF SHELLAC AS SHOWN BY AREA OF CALLUS

At the time the wounds were made the right-hand wound of each pair was given a single coat of orange shellac. In order to obtain an index of the effect that this dressing exerted upon subsequent healing, the areas of callus produced by the treated and untreated wounds of several pairs may be plotted against each other. Using the average areas given in Table 2, such a plotting may be made by averaging the average figures either down or across the table.

If the figures are averaged downward so as to include an average of all wounds examined at any given inspection, subsequent stages of the closing in of callus growth from no growth toward complete healing are traced. Averaging the wounds made for each month in the year offsets the effect of season. Such a plotting has been made in Figure 21.

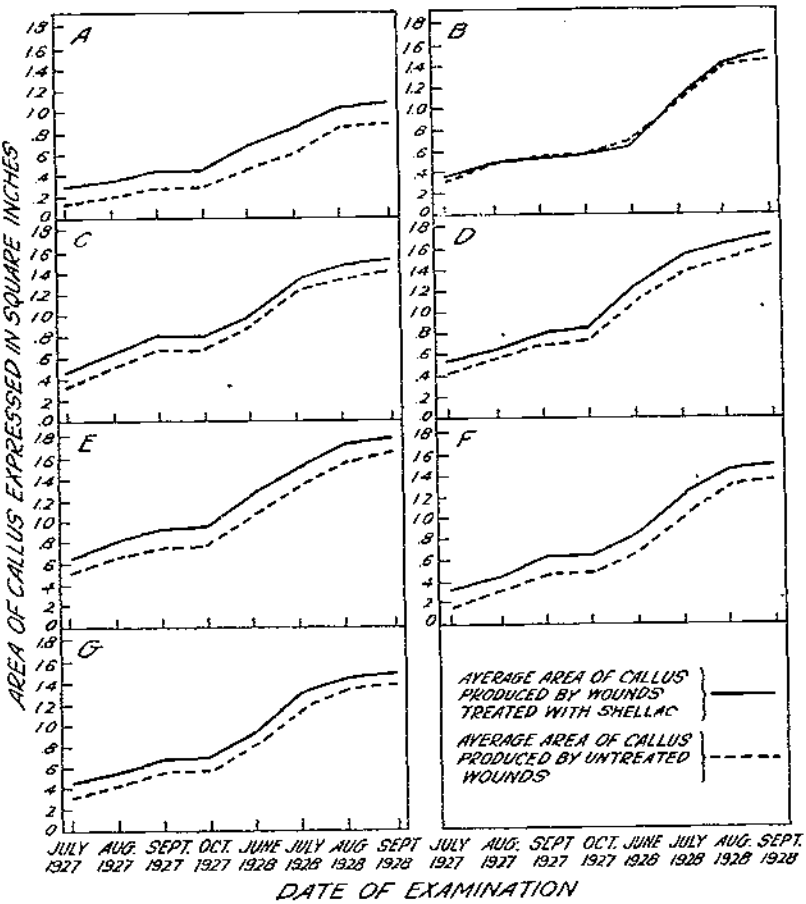

FIGURE 21.—Effect of shellac as shown by area of callus produced. These curves are drawn from averages of five trees of each species. A, *Acer rubrum*; B, *Liriodendron tulipifera*; C, *Quercus alba*; D, *Q. borealis maxima*; E, *Q. montana*; F, *Q. velutina*; G, average of the six species

Examination of the curves shows that they follow each other closely and are practically parallel. No continuous effect is demonstrated in the application of shellac as a wound dressing, since these lines of average growth are neither divergent nor convergent. The effect of the treatment has been immediate, the initial rate of healing having been stimulated. This effect has been carried over into subsequent examinations without becoming evidently greater or less.

In five of the six species of trees the use of shellac as a wound dressing is indicated to be of value, as evidenced by the fact that the curve of the average growth of wounds to which shellac was applied is above the curve of the untreated wounds. In one case, that of *Liriodendron tulipifera*, there is no evidence that the use of shellac hastened the healing of the wounds. Here the average curves are not only nearly parallel, but they are practically coincident.

The writer is unable to explain definitely why shellac should have proved beneficial as a wound dressing for five species of trees and of no value to a sixth, although there was one feature of difference in the wounds of this tree compared with those of the other species. For the most part the wounds of *Liriodendron tulipifera* showed a slime-flux condition. This trouble was not observed in any wound of any of the other species under experiment. The slime flux formed a more or less profuse, thick, black ooze which ran down the trunk. (Figs. 22 and 23.) Neither its chemical nature nor its flora was investigated. Slime flux appeared to be equally severe on both shellacked and untreated wounds, and for this reason it could not of itself account for the failure of the treatment. The cause of the slime flux may, however, furnish a possible explanation of the difference in reaction of this species and that of the five species in which the trouble was not observed. Slime flux probably developed primarily because of a continued flow of sap from the wounds of the tree. If, as is generally supposed, the value of shellac as a wound dressing lies in its protection of the otherwise exposed growing layer from drying, it seems possible that a continual flow of sap from the wound might also prevent the drying out of the exposed cambium tissue and so effect the benefit otherwise to be derived from the application of shellac.

FIGURE 22.—Yellow poplar showing flow of slime flux as thick black ooze from most of the wounds

In order to show the relative effect obtained by applying shellac at various seasons, the average areas of callus growth have been averaged across the chart for each of the two seasons as in Figure

19, with the exception that the check and shellac wounds have been plotted against each other rather than together. The *resulting* curves, given in Figure 24, show *that in* general the application of shellac is least beneficial when applied to wounds made in the spring. The seasonal variation of benefit derived from shellac is slight in *Quercus velutina* and in *Acer rubrum*. The seasonal effect is most marked in the case of *Liriodendron tulipifera*. Here the curves cross markedly, showing that the application of shellac stimulated callus formation when applied to wounds made between July and January, but retarded callus formation when applied to wounds made between February and June.

FIGURE 23.—Close view of one of the wounds shown in Figure 22

EFFECT OF SHELLAC AS SHOWN BY SHAPE OF CALLUS

To determine whether the application of shellac exerted a favorable influence on the shape of the callus ultimately produced, the results in the diagrams of callus growth were tallied. Looking across the sheet, the appearances of series of paired wounds were considered for the entire period of two seasons. An attempt was made to determine whether the check wound or the shellacked wound of each pair presented the more desirable outline of healing during these two years. If the callus produced by the check wound seemed the more favorable, it received a tally. If the shellacked wound were the better, it was tallied. If the healing was approximately of equal desirability, neither check nor shellac was tallied.

The results of the tally are assembled in Table 3. Since five trees of each species were included, the individual number combinations shown in the body of the table are based upon 5 cases, the totals at the bottom of the table upon 60 cases, and the totals at the right upon 30 cases.

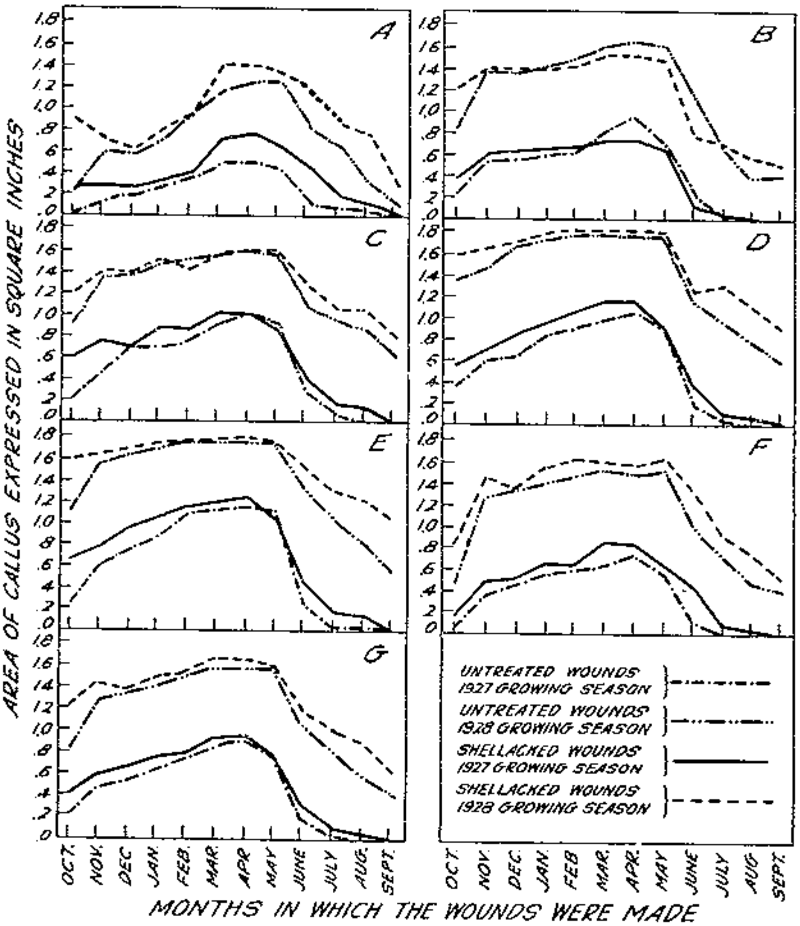

FIGURE 24.—Relative effect of applying shellac at various seasons as shown by the average area of callus for the growing season. These curves are drawn from averages of five trees for each species. A, *Acer rubrum*; B, *Liriodendron tulipifera*; C, *Quercus alba*; D, *Q. borealis maxima*; E, *Q. montana*; F, *Q. velutina*; G, average of the six species

TABLE 3.—*Effect of shellac upon shape of callus*

[In this table the shellacked and untreated wounds of paired wounds have been tallied against each other the better wound receiving a tally. The tallies of shellacked wounds are above the dashes and the tallies of the untreated are below]

Month wound was made	Acer rubrum	Liriodendron tulipifera	Quercus alba	Q. borealis maxima	Q. montana	Q. velutina	Total
October	5	3	4	4	5	2	23
	0	0	0	0	0	1	1
November	4	1	4	3	3	2	17
	1	1	0	0	0	0	2
December	3	2	0	2	3	1	11
	0	1	1	0	0	1	3
January	2	1	1	2	2	1	9
	0	1	0	0	0	0	1
February	1	1	1	1	2	3	9
	2	2	0	0	1	0	5
March	4	1	1	4	2	2	14
	1	3	1	0	1	0	6
April	3	0	0	2	4	1	10
	0	5	0	0	0	0	5
May	2	0	1	2	1	3	9
	1	4	2	2	3	0	12
June	5	1	3	2	3	5	19
	0	4	0	1	0	0	5
July	3	3	3	4	4	3	20
	0	2	1	0	0	1	4
August	4	2	4	5	4	4	23
	0	1	0	0	1	0	2
September	4	3	4	4	5	2	22
	1	0	0	0	0	0	1
Total	40	18	26	35	38	29	186
	6	24	5	3	6	3	47

An examination of the row of totals in the lower line of the table shows that there is no significant difference between the shellacked wounds and the check wounds of *Liriodendron tulipifera*. If minor differences are sought, they are against rather than in favor of treatment. In the case of the five other species of trees the differences are significant in favor of the shellac.

Examining the totals to the right in order to determine the effect of the applications of shellac during the several months, it is noted that the figures are not significant for the month of May and that they become increasingly significant in favor of the shellac as the months of September and October are approached.

EFFECT OF VIGOR ON HEALING

The vigor of the tree wounded has always been recognized as of prime importance to callus formation. The effect of this factor was best illustrated in the present experiment in the case of *Quercus alba*, where the unusual ability of the species to heal rapidly was felt to warrant the inclusion of individuals lacking vigor. In fact, the poorest tree used in the experiment was barely alive. The average areas of callus growth of the first four trees of this species are plotted in Figure 25. The fifth tree was not plotted because both its vigor and its growth curve were practically identical with that of tree No. 3. The relative vigor of the trees was judged by averaging the growth of .0 seasons, 1917 to 1926, from increment borings.

The areas of callus growth of all wounds, both treated and untreated, have here been averaged for each of the eight examinations.

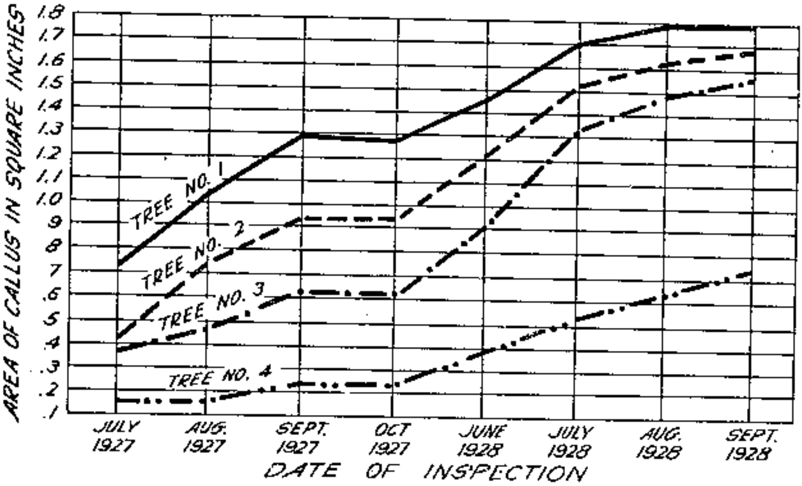

FIGURE 25.—Effect of vigor on healing as shown by the area of callus growth produced by four trees of *Quercus alba*. Average yearly diameter growth: Tree No. 1, 0.15 inch—vigorous tree; No. 2, 0.12 inch—fairly vigorous tree; No. 3, 0.10 inch—weak tree; No. 4, 0.06 inch—very weak tree

The resulting curves of average growth registered for the successive examinations differ markedly. So great is the effect of vigor that the most vigorous tree is seen to have formed as much average callus growth at the first examination of the first growing season as had the poorest tree at the time of the last examination of the second growing season. The effect of the relative vigor of the four individuals is best illustrated by their growth during the first year, for in the second year curves converge toward 1.8 square-inch line as the callusing over of the wounds becomes complete.

FUNGUS GROWTH ON THE WOUNDS

Aside from the usual occurrence of the lower forms of fungi, the most evident of which were various sap-stain organisms, a single form of basidiomycete was observed fruiting on the experimental wounds. This fungus was *Panus stipticus* Fr. The sporophores were well formed though small because of their crowded condition in the wounds. Only two wounds showed these mature fruiting structures. In both cases they were first observed at the September, 1928, examination on *Quercus borealis maxima* Nos. 3 and 4 in the check wounds made in August, 1927. Since the sapwood about these wounds was sound, the organism had presumably infected through the auger holes.

APPLICATION OF RESULTS

The results of the experiment indicate that callus development of wounds made between February 15 and May 15 was, in the case of the species studied, better both in the shape that it assumed and in the area that it covered, than was that of wounds made at any other period. It is then probable that pruning and cavity work that can be conducted in the spring of the year will have advantage in callus production over similar work performed during the summer, fall, or winter.

On the other hand, it may not always be practicable to perform a major part of the pruning during the spring season. Weather conditions are not especially favorable for pruning during February; in March high winds frequently increase the difficulty of operating on tall trees; while during April and May the task of spraying frequently causes any but the most pressing duties to be set aside. But even in this event the advantageous effect of spring wounding should prove to be of much value in dealing with (1) tree species that have delicate bark or that tend to form but little callus growth, (2) the individual that is lacking in vigor, and (3) the particularly valuable tree.

Possibly a principal application of this seasonal effect is to the treatment of such fungus diseases as affect twigs and small branches. While the life histories of the particular forms for which control is sought are highly important, it is to be remembered that some fungi, especially those that belong to the Ascomycetes, tend to fruit very early in the season. Theoretically, thorough pruning in February would therefore seem to be advantageous from a number of angles:

(1) It should remove the diseased parts before the fruiting of the causal pathogene and so lessen the spread of infection.

(2) Pruning at this season would permit the use of reasonably strong fungicides as dormant sprays immediately following the removal of the diseased wood.

(3) It is impossible to apply wound dressing to the numerous small cuts resulting from twig pruning, and yet the same spray which affords temporary protection against the infection of other parts must also afford temporary protection to such cuts. This is a point which the orchardist has long recognized but which the commercial tree expert has often overlooked.

(4) Such a season of pruning would be in accord both with discussed favorable season of wounding from the standpoint of callus formation and with the time determined by Swarbrick (*15*) as most favorable to rapid blocking of the wood vessels with wound gum and the consequent formation of barrier against infection through the cut surface ultimately left exposed by the weathering of the protecting cover of spray material.

Although the use of shellac as a wound dressing failed to give results with the yellow poplar, its effect was favorable with the remaining five species. It therefore seems probable that, in general, such an application may be of considerable value in temporarily protecting the otherwise exposed cambium tissue. For this reason it is recommended, where practicable, that all cut surfaces of the cambium be given an immediate application of some protective dressing that is known to be noninjurious to this tissue. If shellac or any similar product is used for this purpose it is not to be interpreted from the present investigation as of value for the protection or preservation of the wound itself against weather, insect, or decay. This substance has been tested merely for its effect on the growth of the callus.

Vigor is a prime factor in healing. When a tree is to receive cavity work or considerable pruning, particularly that which involves the removal of large branches, its general vigor should be carefully considered. If it is in a condition of low vigor, the rectification of any known unfavorable condition may be of great advantage in aiding the rapid healing of the cuts. Such unfavorable conditions may arise from numerous causes, common among which are lack of sufficient soil moisture at some time during the year, insufficient drainage, the exhaustion of the available forms of certain chemical elements in the soil which are important to plant growth, improper mechanical condition of the soil, lack of soil aeration, the presence of toxic substance in the soil or air, and the presence of fungus or insect pests.

SUMMARY

Five trees each of *Acer rubrum*, *Liriodendron tulipifera*, *Quercus alba*, *Q. borealis maxima*, *Q. montana*, and *Q. velutina* were wounded by boring holes with a 1½-inch auger. One pair of wounds was made on each of the 30 trees on the 15th day of each month during the course of a year. One wound of each pair was shellacked; the other was left untreated.

Developments were followed through two growing seasons. Diagrams of the growth of callus in these wounds were drawn on the 15th day of the month. At the end of this period there were 5,400 individual diagrams representing the appearance of the callus growth at the several inspections.

Wounds made between February 15 and May 15 developed callus growth of more desirable shape and greater area in all six species of trees than did wounds made at any other time.

A single coat of orange shellac applied immediately following wounding was an aid to callus formation in five of the species. In the sixth (*Liriodendron tulipifera*) its application had no appreciable effect. Where the application of shellac was beneficial the result of its use was evident at the first examination. This advantage carried over into subsequent examinations without becoming appreciably greater or less. The effect of shellac on the formation of callus may vary with the season at which the shellac is applied.

The vigor of the individual tree was found to be of prime importance to healing, callus formation being much more rapid in vigorous trees than in weak trees.

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