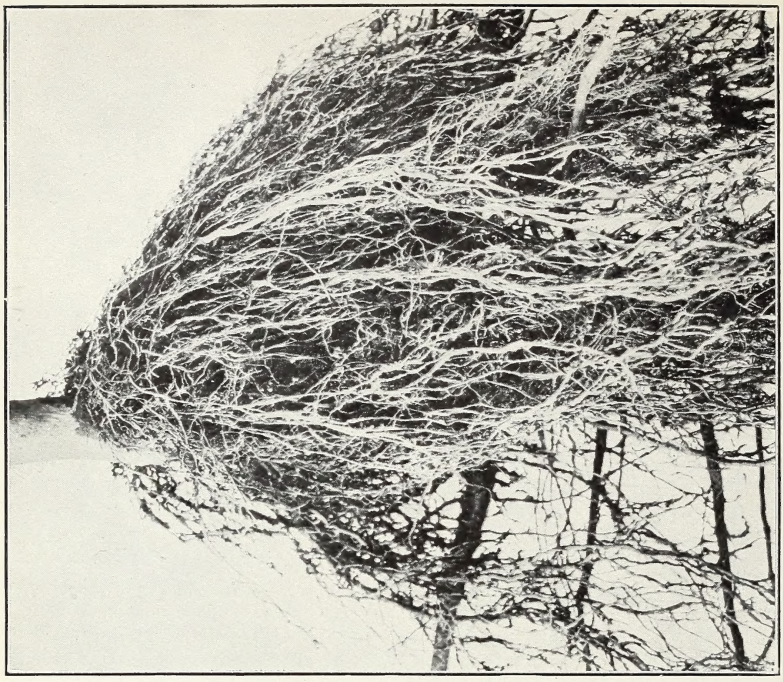

FIG. 2.—WOOLLY-KNOT FORM OF HAIRY-ROOT OF THE APPLE.

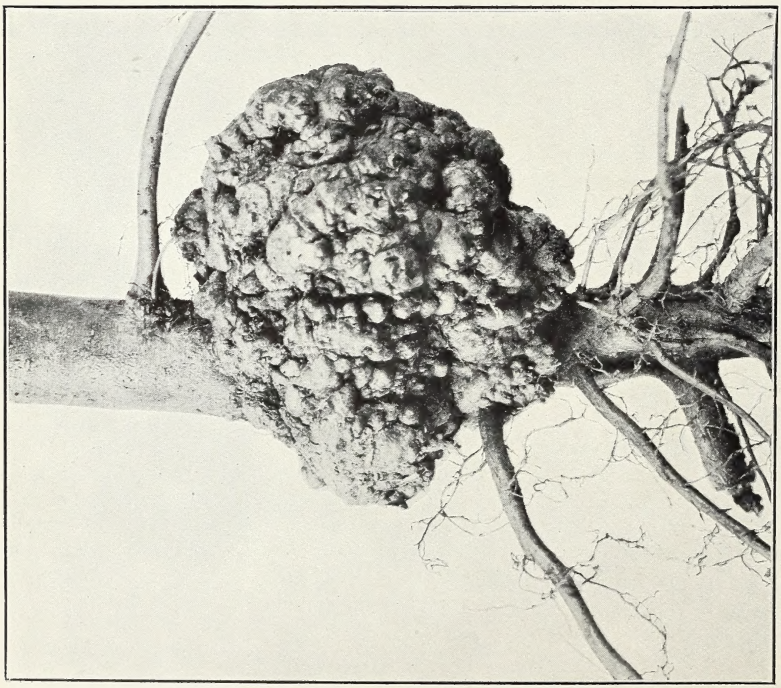

FIG. 1.—HARD FORM OF CROWN-GALL OF THE APPLE.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 186.

B. T. GALLOWAY, *Chief of Bureau.*

FIELD STUDIES OF THE CROWN-GALL AND HAIRY-ROOT OF THE APPLE TREE.

BY

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PATHOLOGIST, FRUIT-DISEASE INVESTIGATIONS.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., April 15, 1910.

Sir: I have the honor to transmit herewith a manuscript entitled "Field Studies of Crown-Gall and Hairy-Root of the Apple Tree," by Dr. George G. Hedgcock, at present Pathologist in Investigations in Forest Pathology.

This paper embodies the results of several years of investigation and experiment and covers the distribution of crown-gall and hairy-root, a description of their different forms, their probable relations, and their development; the effect of the diseases upon apple trees; the susceptibility of varieties; communicability in the nursery and orchard; and prevention and cure. The paper marks the completion of Doctor Hedgcock's work on this subject. The field study of these diseases will be continued by the Office of Fruit-Disease Investigations.

Studies of the etiology and interrelations of crown-gall have been made by Messrs. Smith and Townsend and by Miss Brown, of the Bureau of Plant Industry, and are still in progress.

I respectfully recommend that this manuscript be published as Bulletin No. 186 of the series of this Bureau.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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FIELD STUDIES OF THE CROWN-GALL AND HAIRY-ROOT OF THE APPLE TREE.

INTRODUCTION.

Growers of fruit trees have noted for many years a diseased condition of apple trees which usually manifests itself on young trees in the formation of galls and of clustered or fasciated roots at or near the surface of the ground, and on older trees in the form of knots or tumors occurring on the branches. These forms of disease have been variously designated as "galls," "crown-gall," "crown-knot," "hairy-root," "woolly-knot," "woolly-root," "broom-root," "root knots," "root galls," and "tumors."

In recent years these forms of the disease have been brought prominently before the public by a number of investigators. As a result of the consequent agitation, following statements alleging their dangerous nature, many States have enacted stringent laws for prevention and control. Although such laws, as a rule, should be enacted as a matter of precaution, in this case they have entailed great hardship and loss to nurserymen. An estimate of this loss, based upon reports received from leading wholesale nurserymen in various parts of the country, places the amount at not less than half a million dollars annually. The actual loss to orchardists is uncertain. In fact, data from exact and careful orchard experiments have not hitherto been available.

A very unsatisfactory condition has arisen from the widely divergent opinions of observers relative to the communicability of crown-gall and to its effect. State laws upon the control of these forms of disease vary as much as the opinions of those who have made observations upon their effect. Consequently, there has arisen an urgent demand from nurserymen and horticulturists for more exact data on their nature. In response to this demand, a series of studies and experiments, embracing the greater portion of the United States, has been conducted by the writer for a continuous period of seven years. This investigation has included the forms of disease ordinarily known as "crown-gall" and "hairy-root" attacking many kinds of trees, vines, and shrubs, embracing a study of the cause, communicability, effect, and extent of the various forms of disease.

This bulletin embodies the results of that portion of the investigation which relates to apple[a] trees. An endeavor is made to set forth clearly the nature of the disease and its effect upon trees in the nursery and the orchard, as well as to recommend methods for its control in the orchard. Of no less importance is the information for nurserymen resulting from a large number of experiments in nursery practice. Methods are given whereby loss caused by some forms of crown-gall and hairy-root may be either lessened or almost completely eliminated without greatly increasing the cost of growing trees in the nursery. Finally, it is shown by actual experiment that in the case of the milder and usual forms of the disease little or no injury is appreciable in young orchards. More intense forms, however, may be injurious, but in an orchard these rarely develop from the milder forms. No proof has been found that any of the forms are beneficial, as in case of the root tubercles of legumes.

The writer has briefly described in this and in previous publications a number of forms of crown-gall and hairy-root. There remain some points of doubt to be cleared up by other investigators, since this publication concludes the writer's work on this subject. In the discussion which follows, for reasons given later and in order not to confuse the reader, all forms of crown-gall and hairy-root will be considered as forms of the same disease.

The results of many experiments are given, some of which were conducted in Missouri, Illinois, Iowa, Nebraska, Kansas, and Arkansas, and others in the District of Columbia and Virginia. It is necessary, for brevity, to say in the beginning that all experiments were prepared and conducted under the personal supervision of the writer and that all portions of each experiment were equally well prepared and cared for under similar conditions. Where such is not the case mention is made of the fact.

In the index to literature, on pages 93 to 96 of this bulletin, are cited all of the principal publications on apple crown-gall and hairy-root published in the United States, as well as many of those in other countries. A number of American and foreign publications on the subject of crown-gall deal with the disease on other hosts than the apple, and these have not been cited.

Prior to July, 1907, the work of investigation was conducted in the Mississippi Valley Laboratory of the Department of Agriculture at St. Louis, Mo., under the supervision of Dr. Hermann von Schrenk.

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[a] Owing to the confusion in the nomenclature of many of the common varieties of apples, all of the names used in this bulletin are in accordance with the "Nomenclature of the Apple," by W. H. Ragan, Bulletin 56, Bureau of Plant Industry, issued January 25, 1905.

HISTORICAL NOTES ON CROWN-GALL AND HAIRY-ROOT.

The forms of the disease originally known as "crown-gall," consisting of fleshy outgrowths on the roots of fruit trees, have been known by nurserymen to occur in the United States for nearly half a century, although the first published mention of them is much later. In fact, about all the literature on the subject dates since 1890. No one can be certain as to the time of the first appearance of the disease in this country. In the opinion of the writer it was introduced with plants from Europe. The Europeans have known the disease, or a similar one, for many years. According to Sorauer (57 [a]) the Wurzelkropf, which may be considered the same disease, occurs on the apple and the pear in Germany.

Owing to its wide geographic distribution, crown-gall has attracted the attention of a number of investigators in this country. Bailey (5) and Stewart (62) in New York; Clinton (8) in Connecticut; Selby (49) in Ohio; Taft (65) in Michigan; Woodworth (79), Wickson (77), and W. E. Smith (56) in California; Toumey (68) in Arizona; Forbes (10) in Illinois; Alwood (1) and Phillips (40) in Virginia; and E. F. Smith (53), E. F. Smith and Townsend (54), von Schrenk (71), and Hedgcock (19) of this Department have published articles concerning the crown-gall forms of the disease. Others are cited later in this bulletin.

The forms of the disease known as hairy-root have been observed by some of the older nurserymen ever since they have grown apple trees, dating back nearly fifty years. Attention was first called to the disease in this country by Stewart, Rolfs, and Hall (64). In 1900 they described the simple form of hairy-root on apple seedlings in New York, giving it the name "hairy-root," which had already been applied to the disease by nurserymen. This form and three other forms of the disease have since been recognized and described by the writer (21).

In Europe at least two forms of the disease have been described by German investigators. That known in Germany as "Wurzelkropf" is apparently identical with crown-gall. Frank (14) and Sorauer (58) have described this disease on the apple and the pear. A second form of the disease in Germany, which is apparently identical with the aerial form of hairy-root, is called "Kropfmaser" by Frank (14) and Sorauer (61). Kissa (30) describes this disease on *Pirus malus sinensis*. Julie Jaeger (28) describes the same disease on the limbs of apple trees. Wakker (74) describes a similar disease on species of Ribes in Holland.

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[a] The numbers in parentheses used in this paper refer to the index to literature on pp. 93–96.

DISTRIBUTION OF THE DISEASE AND RELATED FORMS.

GEOGRAPHICAL DISTRIBUTION.

The hard and soft forms of crown-gall on the apple tree and on various other plants have either been observed by the writer or reported to him by others in practically every State in the Union. The writer has found both forms of the disease on apple trees in every locality where nurseries were inspected by him, and in many where no nurseries were located. The disease, in both forms, is most abundant in the more southern States of the apple-growing belt, from Virginia to Texas. The writer collected data in 31 States and Territories and received reports of occurrence from correspondents in all of the others except Nevada.

In Europe, as previously mentioned, crown-gall or a similar disease (Wurzelkropf) occurs on apple and pear trees in Germany. The writer finds it common on apple seedlings imported direct from Holland and France. W. S. Blair, in a letter, reports its occurrence in Ontario, Canada, on apple trees.

The forms of the disease known as hairy-root have been found as widely disseminated as crown-gall on apple trees in nurseries and orchards in the United States. In orchards hairy-root is more common than crown-gall.

In Europe the aerial form of hairy-root or a similar form (Kropfmaser) occurs on apple trees in Germany (60). W. S. Blair, by letter, reports the occurrence of hairy-root on the roots of apple trees in Ontario. Hairy-root of the simple and of the woolly-knot form has been found by the writer on trees imported into the United States from New Zealand.

DISTRIBUTION IN NURSERIES.

In seedling nurseries apple trees are grown for one season from seed, then dug and used for propagation in budding and root grafting. The writer inspected the stock at the time of digging in a number of the largest seedling nurseries in Kansas, Nebraska, Iowa, and Missouri. In one lot of 300,000 apple seedlings examined, sorted, and and counted under his supervision, less than one-half of 1 per cent was diseased with crown-gall, almost entirely of the soft form, and about 1 per cent with hairy-root, chiefly of the simple form. This percentage holds good for all of the nurseries examined.

In nurseries where trees are propagated by budding and root grafting, as compared with seedling nurseries, there is a much greater percentage of disease. On trees grown from root grafts there is more disease than on those propagated on seedlings by budding. The relative percentage of disease of each form found on budded and grafted trees in nursery experiments is shown on pages 18 and 19.

DESCRIPTION OF THE DIFFERENT FORMS OF THE DISEASE ON APPLE TREES.

FORMS OF CROWN-GALL.

The term "crown-gall" as used in this bulletin applies to the fleshy outgrowths, or galls, occurring rarely on the stems and frequently on the crown and the roots of apple trees. It is applied only to those galls that are not accompanied by an excessive formation of either roots or incipient roots and are not caused by insects. Two forms have been recognized by the writer—the soft and the hard (19).

Soft crown-gall.—The term "soft crown-gall" has been applied to the form most frequently found on young seedling, grafted, and budded apple trees (Pl. II, figs. 1 and 2). These galls consist at first of a soft, succulent growth of young cells thrust out from the cambial layer of roots or shoots. They commonly originate in wounds and their initial growth is quite similar to that of an enlarged callus (Pl. VIII, fig. 2), which they resemble in form, color, and structure. The surface of the galls, owing to an unequal growth of the elements in the tissues, soon becomes coarsely convoluted. Curled and distorted masses of wood cells and vessels are gradually formed throughout the softer tissues, often causing the galls to become hard and woody in the interior. At first the color of the surface is white, but later it either changes to the color of the adjacent healthy tissues or becomes brown or black from the decay of the surface cells, which at no time are protected by an epidermis.

In size these galls usually vary from that of a pea to that of a man's fist, but in exceptional cases they may grow to the size of a man's head. They do not develop roots from their surface, and under natural conditions in the nursery they generally decay at the end of the growing season. In general appearance and structure they resemble the crown galls of the almond, apricot, blackberry, cherry, chestnut, grape, peach, pear, plum, raspberry, rose, and walnut, to which they are related (22).

Hard crown-gall.—The term "hard crown-gall" has been applied to the form occurring more frequently on older trees in nurseries and orchards (Pl. II, figs. 3, 4, and 5). The earlier growth of these hard galls is similar to that of soft crown galls, but later they become covered with bark and develop a woody interior. They finally have a texture intermediate between that of healthy wood and that of soft crown galls. Roots often spring from their tissues and they thus develop into a form of hairy-root (see p. 57). Unlike the soft galls, they do not decay, but continue their growth the following season. The hard galls finally attain the same size as the soft galls, but are much slower in their development. They usually have a more finely convoluted surface and are of the same color as the adjacent healthy

tissues. During each period of new growth the bark of the hard galls is usually ruptured, only to be re-formed at the close of the growing season.

FORMS OF HAIRY-ROOT.

The term "hairy-root" as used in this bulletin is a general term applying to four closely related forms of the disease occurring on shoots and roots of apple trees. In these there is an increased and abnormal production of either roots or incipient roots. Four forms have been recognized: The simple, the woolly-knot, the broom-root, and the aerial.

Simple form.—The term "simple hairy-root" has been applied to the form of hairy-root originally described by Stewart, Rolfs, and Hall (64) (Pl. III, fig. 1). This form is the common one on apple seedlings, but occurs less frequently on grafted and budded apple trees in the nursery and the orchard. It consists of numerous small roots growing out at nearly right angles, either singly or in tufts, from an older root or stem (Pl. VI, figs. 2, 3, and 4). This root formation takes place from adventitious buds in the cambial layer, either directly from a root or stem or from swellings thereon. Such roots from the first are more succulent than normal ones. The cells of the parenchyma are hypertrophied and the formation of wood cells is retarded. On exposure to air such roots dry up and become hair-like in appearance.

Woolly-knot form.—A second form, which has been called "woolly-knot," is infrequent on young apple seedlings, but common on older seedlings and on grafted and budded trees in nurseries and orchards. This form originates as follows: A smooth, irregular swelling develops, usually in a larger root near the surface of the soil. This projects at first half an inch or so from the surface of the root. Meanwhile, in the interior of the swelling an incipient root formation takes place. In a few months this usually develops to such an extent that it breaks through the epidermis, producing a warty knot. Under favorable growing conditions, during either the same or succeeding years, there is thrown out from each root center on the surface of the knot a rapid-growing, succulent root, which resembles in development and structure those of the simple form. Many roots usually develop from a single knot. These are often fasciated, and through intricate branching develop into a great mass of fine roots (Pl. I, fig. 2). This form may develop from hard crown-galls. (See p. 57.)

Broom-root form.—A third form of hairy-root occurs frequently on budded and grafted trees in nurseries in States bordering on the Missouri River. It consists of a broom-like formation of fine roots, occurring usually at the end of a side root which otherwise appears

healthy (Pl. III, fig. 2). Frequently a broom-root springs from a root which has its origin in a hard crown-gall. Broom-roots resemble those of the woolly-knot in structure, and they develop in much the same way, except that they do not originate directly in swellings, but develop by the excessive branching of root ends. They usually grow upward from their point of origin toward the surface of the soil, in contrast with normal fibrous roots, which grow more nearly parallel to the surface.

Aerial form.—A fourth form of hairy-root, which also has been called "stem tumors" (22), occurs on the trunks and limbs of apple trees, more commonly on older trees in orchards. This form consists at first of smooth, fleshy swellings (Pl. IV, figs. 1, 2, and 3) in which the cambial layer is much thickened. These swellings are more or less rounded, but are often irregular in outline, vary in width from half an inch to 2 or 3 inches, and project from a half inch to an inch beyond the surface of the tree. They develop, internally, incipient adventitious roots, which as the disease progresses break forth, throwing off the outer bark and forming a warty knot (Pl. V, fig. 1). Cuttings containing the disease in its earlier stages readily throw out roots when placed in moist sand or soil in the springtime, developing directly into the woolly-knot form of the disease (Pl. V, fig. 2). On orchard trees as the knot grows older the incipient roots in the center of the knot die, and in some cases new ones are formed in the adjacent healthy tissues, increasing the diameter of the knots but not their projection.

RELATIONS OF THE FORMS OF THE DISEASE TO EACH OTHER.

RELATION OF SOFT CROWN-GALL TO HARD CROWN-GALL.

The work of Smith and Townsend (54) in discovering and demonstrating that *Bacterium tumefaciens* is the cause of the crown-galls of the Paris daisy, the peach, etc., and the work of Townsend with the same or a similar organism from the galls and hairy-root of apple trees indicate that all of the forms of the disease may be caused by the same species of bacterium or some of its forms.[a]

Since the soft and the hard forms of crown-gall are alike in their initial development and since the latter may develop from the former, the two thus differing only in the final form and in duration, it follows that they both may be due to the same cause. It may be that in the case of the hard form the apple tree partially resists the organism causing the disease by healing over the surface of the galls and confining the disease to limited areas, and the soft form may be a more virulent type of the disease.

[a] See also Smith, Erwin F., Science, n. s., vol. 30, no. 763, August 13, 1909, p. 223.

RELATION OF HAIRY-ROOT TO CROWN-GALL.

Smith, Townsend, and Brown have isolated from hairy-root a bacterium with which they have reproduced the disease on the sugar beet and on the apple. It has not yet been proved that the hairy-root forms of disease may be produced by inoculation of apple trees with *Bacterium tumefaciens*, unless the two organisms Smith, Townsend, and Brown have isolated are identical, but the production of these forms is not morphologically impossible. In the orchard experiments described on pages 38 and 57 it was noted that a considerable number of the trees diseased with hard crown-gall developed hairy-root from the galls.

RELATIONS OF THE FORMS OF HAIRY-ROOT TO EACH OTHER.

The forms of hairy-root are closely related to each other, the essential feature of each consisting of an excessive development of roots, evidently the result of the same sort of stimulus acting upon dormant root centers or buds in the twigs and the trunk of the tree in the case of the aerial form, upon root buds on the main roots in the case of the simple and woolly-knot forms, and upon the side roots in the case of the broom-root form. The woolly-knot form is directly related to the hard form of crown-gall (see p. 20).

European investigators of these forms of disease have always considered the crown-gall (Wurzelkropf, tuberculosis) a different disease from the aerial tumors or the aerial form of hairy-root (Kropfmaser, broussin). As the identity is not completely established, these forms will be treated separately in the experimental data recorded, and all data will be given under the separate forms as hairy-root and crown-gall.

DEVELOPMENT OF THE FORMS OF THE DISEASE.

NO DEVELOPMENT OF THE DISEASE ON SEEDLINGS WITHOUT WOUNDS.

Greenhouse experiments with uninjured seedlings.—In experiments conducted in pots and beds in the greenhouse with uninjured seedlings grown directly from seed (see p. 77), 102 apple seedlings kept free from wounds remained healthy, showing no traces of crown-gall or hairy-root. Of 48 apple seedlings grown under similar conditions, except that the surface layers of soil were mixed with finely chopped pieces of living hard and soft apple galls after the seed had germinated, none became diseased.

Greenhouse experiments with wounded seedlings.—In connection with the experiments mentioned in the preceding paragraph, 98 apple seedlings were grown under the same conditions as the first lot, without soil inoculation. When they were 2 months old each was

wounded on the root just below the surface of the soil with a sterile knife. In each case the cut extended upward and through the cambial layer. The blade of the knife was sterilized in a 1-to-1,000 solution of mercuric chlorid before each cut was made. Four seedlings became diseased with small, hard galls, which formed from outgrowths from the cambial layer on the upper edge of the wound. All other wounds healed normally. No formation of hairy-root occurred.

Nursery experiments with young seedlings.—In the nursery it is quite impossible to grow seedlings entirely free from injuries. To ascertain to what extent wounds favor the development of crown-gall and hairy-root, 100 consecutive trees in a nursery row were wounded by a knife cut in the cambial layer, just below the surface of the soil. These trees were about 2 months old when wounded. For a control, the same number of consecutive trees in an adjacent row were selected, in which no wounds were made. At the end of the growing season the trees in both rows were dug. Of the wounded trees, 3 died. Of the remaining wounded trees, 8 were diseased with soft crown-gall, 2 with the simple form of hairy-root, and 2 with the woolly-knot form. Of the control trees, 1 was diseased with soft crown-gall and 2 with the simple form of hairy-root. Thus, four times as many wounded as unwounded trees became diseased.

The percentage of diseased trees in apple-seedling nurseries is usually small. In exceptional cases only is it considerable, no doubt due to injuries received by the young trees during the first two or three months of their growth. This is certainly true in the case of the development of crown-gall, and may apply also in that of hairy-root.

In order to ascertain the relation of wounds to the various forms of crown-gall and hairy-root, 300 diseased yearling apple seedlings were selected, as follows: 100 with soft crown-gall, 50 with hard crown-gall, 100 with the simple form of hairy-root, and 50 with the woolly-knot form of hairy-root. These were dissected to ascertain the presence of wounds in the roots at the time that the disease attacked the seedlings. Such injuries are indicated by the presence of a small discolored rift, showing a break in the tissues near the heart of the tree beneath the outgrowth of the diseased portion. Certain indications of wounds were found under 90 of the soft galls, 47 of the hard galls, and 22 of the woolly-knots. In the case of most of the trees diseased with simple hairy-root, there were discolored areas which were not considered rifts or breaks in the tissues. On the whole, there was decided proof that the first three forms just named are quite closely connected with injuries to the young roots.

Nursery experiments with older seedlings.—In a field experiment at Louisiana, Mo., 350 apple seedlings were transplanted and grown

under ordinary nursery conditions. One-half of the trees, taking alternate trees in each row, were dug at the end of one year after transplanting, and the remaining trees at the end of two years. In transplanting, the taproot of each seedling was cut off. Table I, in the appendix to this bulletin, gives the results of the experiment.

Twenty trees died from the effects of transplanting. It will be noted in Table I that there was an increase of crown-gall amounting to 0.8 per cent the first year and 0.1 per cent the second year after transplanting. At the same time there was an increase of 8.6 per cent of hairy-root the first year, and a decrease of 2.3 per cent the second year.

No experiment was made with seedlings grown from seed in which the trees were allowed to grow in the original place of planting for longer than a year. Nurserymen assert that there is little or no increase of disease after the first year, and that where seedling trees have been pulled with a tree puller at the age of 10 years in the seedling nursery there is no greater percentage of disease present than during the first year.

RELATIVE DEVELOPMENT OF THE DISEASE ON BUDDED AND ROOT-GRAFTED TREES IN THE NURSERY.

Development on budded trees.—In the propagation of varieties of apple trees by budding, seedlings at the age of 1 year are tipped; that is, the taproot is cut off. Then they are planted in rows in the nursery. These are budded the following summer. The slit in the bark where the bud is inserted is just above the surface of the soil. Crown-gall of both forms usually develops, if at all, at the two points where wounds are made, i. e., at the place where the bud was inserted and at the tip of the root. As a rule, much less crown-gall develops on trees propagated by budding than on those propagated by root grafting. Hairy-root develops more frequently than crown-gall on budded apple trees. The simple and the woolly-knot forms are common, the former developing on portions of the root below the surface of the ground and the latter at or near the surface, often from the region of the wound made in budding.

Development on root-grafted trees.—In the propagation of apple trees by root grafting, whether by whole root or piece root, more extensive wounds are necessarily made than are usual in budding. Wounds occur at the point of union where the scion piece is spliced to the root piece—at the lower end of the scion piece and at the upper and lower ends of the root piece.

Crown-gall, both soft and hard, like callus, develops usually at two points in the root graft—the lower end or tip of the scion piece (Pl. VI, figs. 1 and 6) and the lower end of the root piece. More than 90

per cent of the galls ordinarily develop at the former point. An exception occurs with some varieties, like the Wealthy, which are susceptible to the hard form of crown-gall and woolly-knot. Such varieties often develop the disease from the scion above the union (Pl. II, fig. 3).

It was found in experiments where the seedlings used for root grafting were carefully selected and only smooth roots used that hairy-root of the simple form was nearly eliminated. Such was not the case with the woolly-knot form.

It is asserted by practically all of the nurserymen from whom data have been collected, and the list includes nearly all of the large growers of apples in the United States, that apple trees propagated by budding yearling transplanted seedlings are as a rule much freer from both crown-gall and hairy-root than root-grafted trees.

Reports have been received from a number of nurseries giving the number of diseased trees among budded and root-grafted trees grown under similar conditions. These are combined and given in Table II, in the appendix.

From Table II it will be noted that there is a decrease of 3 to 39 per cent of disease on budded trees as compared with root-grafted trees. This is representative of the reports received. Two exceptions not given in the table must be mentioned: One occurred in Utah, the other in Virginia. In these two instances budded trees were reported badly diseased with crown-gall.

Under the conditions that generally prevail in the Central and possibly in the Eastern States, propagation by budding is advised at least in the case of varieties susceptible to crown-gall and woolly-knot. Owing to the fact that it takes one season longer to propagate an apple tree by budding than by root grafting, it will be more profitable to use the latter method of propagation in such States as California, where an apple tree is easily grown for market from root grafts in one season.

RELATIVE DEVELOPMENT OF EACH FORM OF THE DISEASE IN THE NURSERY.

Development on root-grafted trees.—In all of the larger nursery experiments records were kept of the number of apple trees diseased with each form of crown-gall and hairy-root. In the set of experiments conducted on cooperative plats 1 to 8 (see p. 78), 50,472 trees were grown from root grafts made from healthy scions and seedlings. Of these trees, 77.2 per cent was healthy, while 0.6 per cent was diseased with the soft form and 13.3 per cent with the hard form of crown-gall; with 2.6 per cent diseased with the simple form, 3.5 per cent with the woolly-knot form, and 2.8 per cent with the broom-

root form of hairy-root. This result is considered representative of the relative proportion of each form of the disease occurring upon 1, 2, and 3 year old trees in the Mississippi Valley during 1905, 1906, and 1907.

Development on budded trees.—No experiments were conducted on budded trees in the nursery. Observation made at the time of digging indicated that although budded trees develop much less crown-gall than root-grafted trees, there is often a considerable development of the forms of hairy-root. This may in part be due to the poor grade of seedlings which are often planted for the purpose of budding.

RELATIVE DEVELOPMENT OF EACH FORM OF THE DISEASE IN THE ORCHARD.

Four orchards were planted and studied during the present investigation. In addition, observations were made of the trees in a number of orchards grown by others. The trees in experimental orchards 1 and 2 (for conditions of experiment see pp. 38 and 57 in the appendix) were dug at the close of the period of investigation, at which time they were 8 years old. Notes were taken on the condition of the roots of each tree in these orchards when it was planted in the orchard and again at the time of digging. Out of 234 apple trees that were healthy when transplanted into the orchards, 153, or 65.4 per cent, remained healthy; 23, or 9.8 per cent, died; 11, or 4.7 per cent, developed traces of the hard form of crown-gall; and 47, or 20.1 per cent, showed traces of the woolly-knot and aerial forms of hairy-root. Out of 235 apple trees diseased with crown-gall at the time of transplanting to the orchards, 73, or 31.1 per cent, entirely recovered from the disease; 30, or 12.8 per cent, died; 63, or 26.8 per cent, were diseased with the hard form of crown-gall; and 69, or 29.3 per cent, developed the woolly-knot form of hairy-root, chiefly from the surface of former hard galls.

The results of the experiment, briefly stated in another form, are these: Traces of the hard form of crown-gall developed on 4.7 per cent of the healthy trees, but none of the soft form was found. Traces of hairy-root, chiefly of the woolly-knot form, developed on 20.1 per cent of the healthy trees. Nearly a third of the trees (31.1 per cent) diseased with the hard form of crown-gall recovered; almost another third (29.3 per cent) developed the woolly-knot form of hairy-root from the hard form of crown-gall; and the remaining trees (31.1 per cent) were still diseased with the hard form of crown-gall, which had not developed as rapidly as the growth of the trees.

Orchard 1 contained both budded and root-grafted trees. Four rows of healthy trees grown by budding were planted near four rows

of healthy trees of the same varieties grown by root grafting. Of 27 budded trees planted, 5 became diseased, all with traces of the woolly-knot form of hairy-root. Of 31 grafted trees, 3 became diseased with traces of woolly-knot and 1 with the hard form of crown-gall.

In the results of these and other experiments in orchards 3 and 4, the following facts are prominent: That of the healthy trees transplanted, about the same proportion became diseased as is usual in the nursery, but only with traces of the disease, consisting mainly of hard crown-gall and woolly-knot; that nearly a third of the trees diseased with the hard form of crown-gall recovered; that the soft form of crown-gall may develop into the hard form; and that the hard form of crown-gall in many instances developed into the woolly-knot form of hairy-root.

A STUDY OF NURSERY METHODS IN ROOT GRAFTING AS RELATED TO THE DEVELOPMENT OF THE DISEASE.

The slight effect of varying the depth of planting the union in root grafts.—The effect of deep planting upon gall and hairy-root formation has been a matter of much discussion among nurserymen and others. Howard (24) concludes from experiments "that the gall develops least where the root is long, thus causing the point of union between the scion and stock to be near the surface of the ground. Especially is this true of clay soil."

A number of wholsesale nurserymen growing apple trees on a large scale assert that little benefit is gained by using short scions and long roots, and that a happy medium of length between the two is best. If a long scion is used, placing the union too deep in the soil, and at the same time using a short root piece, a poorer stand of trees and a slower growth takes place as compared with trees grown from equally long scions and root pieces or from short scions and long root pieces.

In order to test the influence of the depth of planting the union of grafts upon the occurrence of disease, two experiments were conducted in independent plat 1 (see pp. 77–78). In the first experiment root grafts were made with scions 6½ inches and roots 3½ inches in length, and these were planted with the union 6 inches beneath the surface of the soil. An equal number of grafts of each variety were made with the scions 3½ inches and the roots 6½ inches long and planted with the union 2½ inches below the surface of the soil. Sixty-four varieties of trees were used. Scions and roots from the same lot were used by the same workmen for making up each variety. They were planted in 1905. One-half of the trees were dug that year, taking every alternate tree, and the remainder in 1906, at the ages of 1 and 2 years, respectively, with the results shown in Table III, in the

appendix, in which all forms of disease, both crown-gall and hairy-root, are combined. A large increase of hairy-root, but not of crown-gall, was noted the second year.

The second experiment was made with five varieties, Northwestern Greening, Grimes, Duchess, Walbridge, and Ben Davis, grafted on seedling roots of the same stock. The same number of grafts of each variety was made in two equal sets, one with scions 6 inches and piece roots 4 inches in length, the other with scions 4 inches and roots 6 inches in length. The former were planted with the union 5 inches below the surface of the ground, and the latter with the union 3 inches below the surface. An equal number of each set and of each variety were planted in cooperative plats 1 to 8 (see p. 78). A definite proportion of the trees, selected in a numerical series in the rows, was dug each year for three years, at the ages of 1, 2, and 3 years, respectively. The results are shown in Table IV, in the appendix, in which the number of trees and the percentage diseased with crown-gall and hairy-root are given.

From the results of these two experiments (see Tables III and IV) it will be noted that there was an actual increase of the disease in the case of the shallower planting of the union, in the first experiment amounting to 6.5 per cent and in the second to 2.5 per cent. The greatest development of crown-gall took place the first year and of hairy-root the first and second years. If the results of the two experiments be combined by adding the number of healthy and diseased trees in each, the result is 19.2 per cent of diseased trees where the union was planted deeper and 22.2 per cent where planted shallower, or a difference of 3 per cent in favor of the deeper planting of the union. This, however, is much more than offset and the practical results of the experiment are reversed by the fact that 13.2 per cent more trees were raised when planted shallowly than when planted deeply, or, in other words, there was a gain of 10.2 per cent by planting the union 2½ to 3 inches below the surface of the soil as compared with planting it 5 to 6 inches deep.

The slight effect from using different portions of seedling roots in root grafting.—In making piece-root grafts the root of the seedling tree is cut into two or more pieces. The opinion has been expressed by nurserymen that when the upper or collar piece of the seedling root is joined to a scion in a root graft there will be a greater prevalence of disease than when the lower or middle piece is used. In order to test this assumption a series of experiments was conducted in which equal numbers of grafts were made on the collar or upper pieces of the seedling roots and on the tip or lower pieces of the roots. Scions from five varieties of apples—Northwestern Greening, Walbridge, Grimes, Duchess, and Ben Davis—were used. These were grown in

equal numbers in cooperative plats 1 to 8 (see p. 78). A definite proportion of these trees, selected in a numerical series,[a] was dug for each of three successive years—1905, 1906, and 1907—at the ages of 1, 2, and 3 years, respectively. The combined results from the eight plats are given in Table V, in the appendix.

The results of the experiments show an increase of hairy-root on trees grown from grafts made on the upper pieces of seedling roots. This is the portion of the seedling root that is most susceptible to the simple form. This increase of disease, 3.6 per cent, was more than offset by the greater stand of trees resulting from the use of the upper piece root, since an increase of 408 trees, or 15.9 per cent, was obtained. For practical purposes, then, the upper portion of the seedling root grows the greater number of healthy trees, in spite of the slight increase of disease. The tip pieces are smaller than the collar pieces, and root grafts made from them, being smaller, do not grow as vigorously as those made from collar pieces.

Increased development of the disease due to the use of seedlings diseased with hairy-root in making root grafts.—Two sets of experiments were conducted to determine to what extent the use of seedlings diseased with crown-gall and hairy-root would increase the development of the disease in root-grafted trees in the nursery.

Two series of eight experiments were conducted on cooperative plats 1 to 8. About three thousand apple seedlings diseased with the simple form of hairy-root (Pl. IX, fig. 2, Nos. *G* and *H*), but entirely free from galls, were selected for these experiments. Whip or tongue grafts were made, all of the pieces of the roots from these diseased seedlings being used. Some of these pieces from the root tips were apparently healthy. All of the pieces from the upper or collar pieces were diseased with hairy-root. As a control, an equal number of root grafts were similarly made on roots from healthy seedlings of the same diameter as the hairy-rooted seedlings selected from the same stock. These two sets of root grafts were made with scions from the following varieties of apple: Fameuse, Scott Winter, Wolf River, Jonathan, and Salome. A definite proportion of the trees grown from these root grafts was selected in a numerical series and dug at the ages of 1, 2, and 3 years. The results of the experiment are summarized in Table VI, in the appendix.

A second and smaller series of eight experiments was prepared and conducted the same as the first set, except that scions were used from the Yellow Belleflower apple. Two equal sets of grafts were prepared from the same stock of seedlings, one set made on

[a] In this bulletin the term "numerical series" means the selection of trees in sequence, as every second tree, every third tree, etc., depending on whether one-half, one-third, etc., of the trees were dug each year.

piece roots from seedlings with smooth roots and one on piece roots from seedlings with hairy roots of the simple form. These were grown also in cooperative plats 1 to 8. Table VII, in the appendix, gives the combined results of the experiments.

These experiments yielded three positive results:

(1) The use of root pieces from hairy-rooted seedlings did not increase the amount of crown-gall, since in the two sets of experiments 7.3 and 2.6 per cent of crown-gall developed on trees grown from hairy-root pieces, as compared with 12.6 and 7.3 per cent, respectively, on trees grown from smooth-root pieces.

(2) A greatly increased stand of trees resulted from the use of hairy-root pieces, since 4,956 trees were grown from grafts made on such pieces, as compared with 3,802 grown from the same number of grafts made with smooth-root pieces, an increase of 30.4 per cent.

(3) The use of hairy-root pieces resulted in an increased number of trees diseased with hairy-root, since 77 and 83.7 per cent of the trees grown from grafts made with such pieces were diseased with hairy-root as compared with 10.2 and 8.9 per cent from grafts made with smooth-root pieces.

The reason for the increased stand of trees from the root grafts on hairy-root pieces is as follows: Since the season was dry and unfavorable for the rooting of the grafts at the time of planting in the first experiments, the hairy-root grafts rooted more readily, and, as a results, fewer of them died and an increased stand resulted. The results of the following experiments are given in proof of this statement. It was found by a small experiment with cuttings from seedlings diseased with simple hairy-root that 25 per cent of such cuttings rooted (Pl. VII, fig. 1) and became trees in a bed in the greenhouse, whereas only 5 per cent of cuttings taken from smooth seedlings of the same lot and planted in the same bed with the former cuttings took root, and then feebly. This experiment was made with 100 cuttings of each kind on an ordinary greenhouse bench with 8 inches of soil, without bottom heat.

The trees grown from the different varieties of apples grafted on the hairy-root seedlings behaved differently in their root formation. Those varieties which rooted readily from the scion or stock—for example, the Fameuse and the Salome—sent out smooth roots, with very few exceptions, above the hairy-root piece (Pl. VII, fig. 3). Such trees very often formed a well-balanced root system from the stock, and there followed the second year an atrophy of the hairy-root pieces, which did not injure the tree. In the case of varieties that did not root readily from the scion—for example, the Jonathan and the Scott Winter—most of the roots were poorly balanced and sprang from near the union (Pl. VII, fig. 4). On the whole, nearly two-

thirds of the trees grown on the hairy-root pieces would be graded as culls, especially those grown from the Jonathan, the Scott Winter, and the Wolf River varieties, and the use of such seedlings for grafting must be condemned, the same as those diseased with crown-gall.

In these experiments a careful count was made by the writer of he number of trees diseased with each form of crown-gall and hairy-root. In the first series of experiments, of the 3,976 trees grown from grafts made from seedlings diseased with hairy-root of the simple form, 0.5 per cent was diseased with the soft form and 6.8 per cent with the hard form of crown-gall, while 69.1 per cent was diseased with the simple form, 5.2 per cent with the woolly-knot form, and 2.8 per cent with the broom-root form of hairy-root. Of the 2,864 trees grown from grafts made from seedlings with smooth roots, 0.7 per cent was diseased with the soft form and 11.9 per cent with the hard form of crown-gall; and 2.8 per cent was diseased with the simple form, 4.1 per cent with the woolly-knot form, and 3.3 per cent with the broom-root form of hairy-root.

Increased development of the disease due to the use of seedlings diseased with crown-gall in making root grafts.—In connection with the previous set of experiments (see Table VII, in the appendix), in addition to the two sets of root grafts prepared for that experiment, a third set was prepared in which the same stock of scions on root pieces cut from seedlings diseased with the soft form of crown-gall was used. Care was taken in each case to cut away the portion of the root containing the origin of the gall, so as to use the apparently healthy portions of the roots. These root grafts were made, planted, and grown with those in the previous experiment, the same set of root grafts being used for a control. The results of the experiment are given in Table VIII, in the appendix.

The results of this experiment prove that the use in making root grafts of apparently healthy root pieces from seedlings diseased with soft crown-gall increases the amount of the disease, the increase in this case amounting on an average to 12.9 per cent of crown-gall and 2.3 per cent of hairy-root or a total of 15.2 per cent.

In some nurseries workmen do not always discard seedlings diseased with crown-gall, but cut away the galls and use the remaining portion of the root, as was done in the experiment just given. Such a practice must be condemned, since it increases considerably the development of the disease in root-grafted trees.

The slight effect of using for root grafts scions from younger and older trees.—An experiment was conducted to determine the effect on the development of crown-gall and hairy-root of grafts made with scions taken from fruiting orchard trees as compared with those made with scions taken from yearling trees in the nursery. Two

sets of grafts were made on the same lot of seedling roots—one from scions selected from orchard trees 12 years old, the other from yearling nursery stock of the Northwestern Greening variety. These were grown in cooperative plats 1 to 8. Table IX, in the appendix, gives the results as tabulated each year for three years, a definite proportion of the trees being dug each year at the ages of 1, 2, and 3 years, the trees being selected in a fixed numerical series in the row.

It will be seen from Table IX that there was an increase of 2.4 per cent of crown-gall and of 3.1 per cent of hairy-root in the case of trees grown from scions taken from rapidly growing yearling trees in the nursery as compared with trees grown from scions of harder wood taken from fruiting orchard trees. The difference, however, is more than counterbalanced by the increased stand of trees, 7.8 per cent, obtained from the scions from yearling trees. It must be concluded that the difference, though small, is not in favor of the use of scions with softer wood from young and rapidly growing trees.

No effect from leaving a bud near the lower end of the scion in making root grafts.—It has been asserted by some of the older workers in nurseries that the increased amount of crown-gall on the union at the point or lower end of the scion is due to cutting the scions so that a bud is left near the lower end. This matter was tested in an experiment, with the result that the assertion was found to be without facts to support it.

In this experiment scions from the variety Jonathan were cut in two ways: One set was made without a bud at the lower end of the scion, another equal set with a bud in close proximity to it. These were grafted on healthy seedling roots of the same lot and planted in ordinary soil in independent plat 1 (see p. 77). Two lots of one hundred root grafts of each kind were planted. Of the trees grown from grafts with buds on the lower ends of the scions, 19.2 per cent were diseased, and of the trees grown from those without buds, 21.1 per cent were diseased, showing positively that the bud has no direct influence in increasing the amount of disease.

Experiments comparing American and foreign-grown apple seedlings.—There exists in many localities the opinion that seedlings grown from foreign seed are less apt to develop crown-gall and hairy-root than those grown from American seed. To test this theory, two equally large sets of grafts were prepared, scions from the following varieties of trees being used: Maiden Blush, Winesap, Baldwin, Yellow Transparent, and Missouri. One set was grafted on seedlings grown from apple seed imported from France, the other on seedlings of the same grade grown in the same field from American apple seed. The grafts were divided into eight equal lots and planted in cooperative plats 1 to 8. A definite proportion of the trees, selected in a

numerical series, was dug each year for three years. Table X, in the appendix, gives the combined results of the experiment.

The results of the experiment were in favor of the use of American seed for growing seedlings, since there was an increase of 4.9 per cent of crown-gall on the trees on roots grown from French seed, and, on the other hand, an increase of 1.3 per cent of hairy-root on trees grown from roots from American seed. If we combine the number of trees diseased both by crown-gall and hairy-root, there will be found an increase of 3.6 per cent of disease, due to the use of French seed. This difference is further accentuated by the number of trees grown from the same number of grafts on the roots from American seed, 2,255 as compared to 1,802 on roots from French seed, or a gain of 25.1 per cent in favor of the use of the former. The experiment proves that the assumption that the use of American seed in growing seedlings tends to increase the development of crown-gall is erroneous and it indicates a superiority in seedlings from American seed.

The use of seedlings from old nursery districts for making root grafts may not increase the development of the disease.—It has been asserted by some growers of nursery stock that seedlings purchased from regions where they had been grown year after year, and especially from Kansas, developed more crown-gall than those grown in new regions in soil where nursery stock had not been previously grown. To test the matter, two lots of grafts were made from the same stock of scions, including the following varieties: Yellow Transparent, Baldwin, Winesap, Maiden Blush, and Missouri. One set was made on seedling roots grown from French apple seed in the Kansas River valley, near Topeka, Kans., on soil subject to inundation from the river and overflow from neighboring nurseries and on which nursery stock had been previously grown; the other set was from another stock of seedlings grown from the same stock of seed by the same nursery company in a new locality near Lincoln, Nebr., on soil which had been cultivated in field crops for a number of years and on which nursery stock had never been grown. This set contained half as many root grafts as the former. The grafts were made, planted, and grown with the same care as in all of the experiments. They were grown on cooperative plats 1 to 8, and a definite proportion, selected in a numerical series in each row, was dug each year at the ages of 1, 2, and 3 years. Table XI, in the appendix, gives in a condensed form the results of the experiment.

In giving the results of this experiment it must be noted that the conditions under which the seedlings for the experiment were grown were not quite comparable for two reasons: The localities where they were grown (Kansas and Nebraska) varied in latitude, and the soil conditions were not quite the same, since these seedlings were grown

in different valleys. The trees from the two sets of grafts made from these seedlings, however, were grown under similar conditions, and the results of the experiment are of value, since they show what variation may be expected from seedlings grown in different localities and since they disprove the prevalent idea that Kansas seedlings are more apt to develop crown-gall than others. The results show a decrease of 3.4 per cent in crown-gall and of 1.1 per cent in hairy-root on trees from grafts on Kansas seedling roots. This is almost entirely offset by the increased stand of trees, 3.1 per cent, obtained from the trees grown from grafts on Nebraska seedling roots. The experiment, then, yields no positive proof of an increase of the disease where seedlings are purchased from localities where nursery stock has been grown for years.

Heavy wet soils favor the development of crown-gall in the nursery.—The consensus of opinion of nurserymen, based upon observation, has been that heavy wet soils underlaid with or composed largely of clay favor the development of crown-gall. No extensive set of experiments on this subject has been recorded. The most extensive experiment recorded in scientific publications is that of Howard regarding the increase of crown-gall due to clayey soil as compared with loess.

A large number of experiments have been conducted by the writer on different kinds of soils, only two sets of which were conducted in the same locality. These were on cooperative plats 1 and 2. Plat 1 consisted of a low wet tract of land, composed of a colluvial clay loam laid to a depth of 3 to 4 feet on a stratum of yellow clay. Plat 2 was an upland, well-drained, light clay loam of about equal depth, sloping gently to the south. The two plats were planted with an equal number of root grafts made from healthy stock and prepared in equal lots from twenty-four varieties of apples. The names of these varieties are given on page 85. One-third of the trees, selected in a numerical series, were dug each year for three successive years, at the ages of 1, 2, and 3 years. The results are given in Table XII, in the appendix.

Nearly the same amount of disease occurred in the two plats, 24.9 per cent in plat 1 and 24.1 in plat 2. There was a preponderance of 5.3 per cent of crown-gall on the heavier, wetter soil, and 4.5 per cent of hairy-root on the higher, drier soil. Without regard to the cause of the different forms of the disease, the usual rule with regard to the increased production of roots in drier soils holds good in these experiments. The well-drained upland soil in plat 2 yielded 20.2 per cent more good trees than the other plat. These, however, were at least a third smaller in size.

Six other cooperative plats, 3 to 8, were planted with experiments identical with those in plats 1 and 2, since the root grafts for each

experiment in these plats were all made at one time in the same nursery, divided into eight equal lots, and planted in each of the plats. The location of each plat and a description of the soil are given on page 78. It was noted that more diseased trees occurred on the plats with the wettest, heaviest soils. The results from the two plats with the heavier, wetter soils and from the two plats with the lighter, better-drained soils are given in Table XIII, in the appendix.

The wet, heavy soils gave from 8.1 to 11.1 per cent more diseased trees than the light, dry soils. The highest percentage of disease in a number of smaller experiments has invariably occurred on wet, heavy soils. It therefore appears that such soils are more favorable to the development of crown-gall.

Period for the maximum development of crown-gall and hairy-root in the nursery.—After compiling the data from a large number of experiments, involving many trees dug at different ages, certain regular variations were noted in the amount of crown-gall present at different ages on root-grafted trees in the nursery under the conditions of experimentation.

The results which follow are compiled from seven large sets of parallel experiments carried on in four of the cooperative plats—1, 2, 3, and 4 (see p. 78). The root grafts for each set were made from carefully selected healthy stocks of scions and seedlings at the same nursery, divided into four equal parts and planted in the four cooperative plats just named. Twenty-four varieties of apples were used, the same as are given in Table XXI, page 85, in the appendix. One-third of the trees in each plat, selected in a numerical series in each row, were dug each year, at the ages of 1, 2, and 3 years. The results are given in Table XIV, in the appendix.

The results in Table XIV indicate plainly that in the nursery and under the conditions given root-grafted trees developed crown-gall chiefly during the first year, and that during the next two years many of the trees threw off the disease, which decreased the second year from 26.7 per cent to 9.1 per cent, and the third year from 9.1 to 4.7 per cent. This table also shows that the development of hairy-root took place chiefly during the first year, but increased considerably the second year, 3.1 per cent, with little increase the third year, 0.1 per cent.

An objection to making such conclusions from average results may be offered for the reason that the average may be that of two widely differing extremes, either of which might include the results of a large number of the experiments, and that such extremes if taken separately would warrant the formation of entirely opposite conclusions. This objection can not hold here, since all of the sets of experiments gave approximately the same general results as the average,

and even the smaller units or variations combined in these sets, with very few exceptions, gave the same results. None of these exceptions varied widely from the general trend of the results. A reference to the tabular results of a number of other experiments given both earlier and later in this bulletin will lead to the same conclusions as are drawn from Table XIV.

EFFECT OF THE DISEASE UPON APPLE TREES.

OBSERVATIONS BY OTHERS ON CROWN-GALL.

It has generally been held by pathologists that crown-gall is very destructive to trees. Frank (14), in discussing the Wurzelkropf on apple trees in Germany, notes that trees with very large galls show a weaker growth of the trunk and branches, probably due to the fact that the swellings absorb considerable nutritive substance. Wickson (77), in discussing the general subject of root knots on fruit trees, makes the following statement:

> Probably during the last twenty years hundreds of thousands of such trees (referring to trees with galls) have split and died in the best soil and with the best treatment. If disease has stunted the growth of a young tree, pluck it out and plant a new one. If the knots are found on larger trees which are making satisfactory growth in spite of them, remedial measures should be tried. The final result seems to depend upon whether the natural or the diseased growth secures ascendancy early in the life of the tree; but apricot trees have been taken up after thirty years of satisfactory growth and bearing and found to have roots badly affected with the knots.

In the same bulletin Woodworth makes this statement:

> The presence of a gall at the crown of the plant seems to effect an obstruction to the flow of the sap, and in this way a tree or vine becomes weakened and finally dies. The gall generally attacks small plants, but not always, and it often takes a number of years before the plant is killed.

Yates (80), in speaking of the crown-gall, does not consider the same a disease.

Selby (50), referring to apple crown-gall, says: "It seems unlikely that such affected trees will be worth planting, and all of them suffering with this trouble should be burned."

Stewart, Rolfs, and Hall (64), make the following statement: "We find crown-gall not uncommon on apple trees in the nurseries in western New York, but we know of no case where it has caused material loss. * * * We would recommend that all trees showing the least trace of the disease be rejected; for, although we have never seen any ill effects from the planting of affected apple trees, it appears probable that the disease may thus be spread." They refer to a nurseryman who writes that he planted a row of healthy apple trees and at the same time a row of trees affected with crown-gall, and who states that after two years the trees with the crown-gall had made just as good a growth as the healthy trees near by.

Garman (16), expresses an opinion to the effect that crown-gall trees can never be very profitable, since in their enfeebled condition they will not bear well.

Alwood (2), who made an extensive study of this disease, in his introduction, referring to the results of his experiments, states that these results "seem to point clearly to the conclusion that every planter must be prepared to detect this trouble, and exclude it from his orchard plantings." Commenting further on the results of his experiments, Alwood says: "Our observations in more recently planted orchards show that it is not usual for trees showing an attack of this trouble to form a normal root system; the root development is weak and confined to the surface. * * * We are also of the opinion that badly diseased trees, such as are now very commonly found in nursery stock, will not ordinarily come into fruiting." In a lecture before the Maryland State Horticultural Society Alwood (4) is quoted as saying, in speaking of orchard trees diseased with crown-gall, that "they have scarcely grown at all, although they have been cultivated for five years."

Butz (7), in speaking of eleven apple trees planted on the Pennsylvania Agricultural Experiment Station grounds, reports that after two years' growth the trees showed "immediate injury, due to the galls."

Norton (34) states that "trees affected with crown-gall set out in the college yard have never done well." In a later publication (37) he makes the following statements:

> The galls, when they occur on the main root, may interfere with the transfer of the sap in the tree, and thus weaken it. The constriction by the gall may cause the tree to fruit too young, or to overbear; they cause abnormal root development, and thus hinder the growth. They are often so well developed as to cut off and cause the death of the taproot, which is almost always killed when affected throughout by the hairy-root condition. The tissue of the gall may decay and form an entrance for wood-rotting fungi which will soon destroy the tree.

R. E. Smith (55) reports apple crown-gall to be very common in nurseries, but apparently it "does not result as seriously in orchard trees as with the similar disease on stone fruits."

Morris (33) makes the following assertion: "The trees affected with galls at the crown are doomed to death sooner or later. Sometimes the trees are completely girdled and starved to death, at other times the root of the tree is so weakened that it is easily broken by wind."

Sandsten (48), concerning crown-gall, says:

> Some kinds of fruit trees are less resistant than others. For example, it is well known that a young peach tree infested with the disease will live for a relatively short time, while apple trees may live for a number of years * * *. Perhaps the chief reason why fruit growers fear the disease is that just about the time when the trees

become profitable, or when the trees have attained the age of 8 or 10 years, they begin to rot off at the crown and die. This is especially true of apples. I have particularly in mind a thriving orchard in the Southeast of 25 acres of apple trees, 11 years old, which bore a few crops, then all at once about half of them began to fall. Upon examination it was found that the trees had been killed by crown-gall.

Van Deman (70), in a discussion on fungous diseases, is quoted as follows, in a Virginia Horticultural Society Report, in answer to a question concerning an apple tree diseased with crown-gall: "Yes, sir; it lives right along until it begins to bear, and then it begins to dwindle, and you wonder why. * * * It doesn't attain the size of other trees, though sometimes it is fairly vigorous. The gall will, however, keep on growing for years and years."

Popenoe (44) reports the following experiment: A lot of Ben Davis trees, 2 years old, one half having visible galls on the roots and the other half being similar trees without galls, were planted a few years ago on rich, second-bottom, level, black land on the station grounds at Manhattan. At the time the report was made, in 1903, Popenoe says: "There is practically no difference in the growth above ground of the trees of the two lots, and of the trees originally clean of galls, ome are now affected."

OBSERVATIONS BY OTHERS ON HAIRY-ROOT.

In the various citations as to the effect of crown-gall on trees there is little or no reference to hairy-root. Stewart, Rolfs, and Hall (64), referring to the hairy-root of seedlings, which we have designated as the simple type, state that "affected trees are worthless for planting."

Garman (16), discussing a knot disease of apple trees which is evidently the aerial form of hairy-root of the woolly-knot type, makes the following statement:

> It undoubtedly weakens the trees attacked, but does not keep them from bearing in all cases, and when but few knots are present the trees show no other outward evidence of disease.

In a letter dated September, 1907, Garman writes as follows concerning the disease: "I am satisfied it is not spreading, and I do not regard it as particularly destructive, although I have no doubt it affects the health of the tree when a great many of the knotty growths are present."

The gist of the foregoing quotations, which include a summary of nearly everything that has been published on the effects of crown-gall and hairy-root in this country, is that in the opinion of a majority of those observers who have investigated these forms of disease, they are to be considered dangerous and likely to weaken or kill affected trees. This general opinion concerning the nature and effect of crown-gall of apple trees seems to have gained ground largely as a

result of the opinion expressed by Toumey (68) concerning crown-gall of the almond, who proved that it may be highly contagious and extremely destructive.

Beginning with the date of Toumey's paper on crown-gall of the almond, without waiting for further proof, the general assumption has been that the effect of crown-gall upon the apple tree is identical with that of this disease upon the almond. With the general opinion prevalent in most parts of the country, vigorous methods have been advocated very generally by pathologists, entomologists, nursery inspectors, and others. Stringent laws have been enacted for stamping out the disease, with the assumption that the disease of the apple is as injurious as that of the stone fruits.

In summing up the few opinions which were given from actual experiments, it may be well to suggest that in all probability the effect of root-rot has been confused with that of crown-gall. It is well known that root-rot attacks orchards in many portions of the apple-growing belt, especially in the South and the Southwest. In collecting accurate data on the effect of crown-gall and hairy-root it is absolutely necessary that each individual tree be examined and the condition of the roots noted before drawing any conclusions as to the cause of the death. A study of the connection between root-rot and crown-gall is also necessary. All of the trees in the orchard experiments of the writer have been free from root-rot, but borers were present in orchards 1 and 2 and killed all of the trees that died after the first year, but attacked healthy and diseased trees alike. In forming conclusions as to the cause of the death of an apple tree, not only root-rot but also these borers should be taken into account, since they apparently attack smooth-rooted trees as often as those diseased with crown-gall and hairy-root. These insects bore beneath the bark into the wood of the tree and allow root-rot fungi to enter the wounds made by them. Quite often death results in a couple of years from the first attack.

Wherever an orchard has been reported as dying in a short time from crown-gall it will be well to look deeply into the causes of the death of the trees before accepting the report as a scientific fact. In the writer's opinion, which is based upon exact orchard experiments, crown-gall never kills an apple tree suddenly, and where no other disturbing factor enters, it may not be able to kill it at all. The wounding of a projecting hard or soft gall may enable wood-rotting organisms to enter the tree and kill it. Again, the presence of gall tissues may the better enable insects to attack the tree, but in the writer's experiments he found no proof that diseased trees were more subject than healthy trees to the attacks of insects and wood-rotting fungi.

EXPERIMENTS ON THE EFFECT OF THE DISEASE ON APPLE TREES.

EFFECT ON SEEDLINGS NOT UNIFORM.

No extended experiments have been made to determine the effect of crown-gall and hairy-root on seedlings. From small experiments and from observation the following conclusions have been reached: On yearling seedlings with relatively large galls encircling the root (Pl. II, fig. 2) or with a very abundant formation of fine side roots (Pl. III, fig. 1), such as accompany extreme forms of hairy-root, there is a perceptible stunting of the growth of the tree. Where the galls are small and the hairy-root formation is not extensive, no apparent effect on the growth is noted. In the latter case, as the trees grow older, they may outgrow the effects of the disease.

The aerial form of hairy-root (stem tumors) was found in the autumn of 1908 on 40 trees in a block of 500 8-year-old seedling apple trees in a pedigree orchard near Mitchell, Ind., belonging to the Indiana Agricultural Experiment Station. These were first reported in a letter by Prof. C. G. Woodbury, of that station. Six of these trees bore from 8 to 25 large, rough knots (Pl. V, fig. 1), in some cases encircling the tree. None of these trees was quite as large as the neighboring trees. No difference in size was noted in the other 34 diseased trees.

One striking effect of hairy-root of the simple form should again be noted. Seedlings diseased with this form are enabled to root more readily than healthy seedlings. Cuttings taken from such seedlings root more readily than those from healthy seedlings (see p. 24). Such cuttings usually develop into trees (Pl. VII, fig. 1), affording to some extent a method of propagation not ordinarily used and not to be recommended.

SLIGHT EFFECT ON GRAFTED TREES IN THE NURSERY.

The same observations made on the effect of crown-gall and hairy-root on seedling trees apply to young grafted trees, except that the stunting, as a rule, is not nearly so marked. A great variation in effect is shown, since some diseased trees exhibit as great or even a greater vigor of growth than healthy ones. On the average, however, trees in the nursery rows that are diseased with the simple form of hairy-root are not quite so tall as smooth-rooted trees, and those with the woolly-knot form may be taller. Those affected with forms of crown-gall are somewhat shorter than those with hairy-root.

In order to determine the effect of the disease on the height of trees in the nursery rows, measurements were taken of 18,042 1 and 2 year old root-grafted trees grown in a number of the experiments mentioned earlier in this bulletin. These trees were grown in coop-

erative plats 1 and 2, in southwestern Iowa; plat 3, in eastern Nebraska; plat 4, in western Illinois; and plat 6, in eastern Kansas. In five of these sets of experiments, the results of which are given in Tables XV and XVI, in the appendix, a definite proportion of the trees, selected in a numerical series in the row, was dug at the age of 1 year, and the remainder at the end of the following season.

From Tables XV and XVI it will be seen that the average height of healthy trees in the experiments at the age of 1 and 2 years was 37.2 and 56.4 inches, respectively, as compared with 33.5 and 51.3 inches for trees diseased with crown-gall and 34 and 53 inches for trees affected with hairy-root. In other words, galled trees were only ninety hundredths and ninety-one hundredths and hairy-rooted trees ninety-one hundredths and ninety-four hundredths as tall as healthy ones. A few measurements of root-grafted trees made at the end of three years indicate that approximately the same rate for each still held at the end of the third year's growth. A few measurements were made of the diameter of healthy and diseased trees of some of the rows in each experiment, but time would not permit of the measurement of all. It was found that the ratio of the diameters was approximately the same as that of the heights, viz, almost 10 to 9.5 for healthy and diseased root-grafted trees in the nursery.

In conclusion it must be said that taken collectively the forms of crown-gall and of hairy-root do have a slightly stunting effect on root-grafted trees in the nursery during the first three years, and for that reason, at least, such trees are not equal to healthy ones for planting in orchards. This conclusion as to hairy-root is given with the following modifying statements:

(1) The effect of the simple form of hairy-root in stimulating root production in root grafts is described on a previous page. When cuttings are taken from trees diseased with the knots or the aerial form of hairy-root and planted or used as scions, root formation is more abundant than with healthy cuttings. Roots are thrown out readily, especially from the young knots, producing the woolly-knot form (Pl. V, fig. 2, and Pl. VII, figs. 1 and 2). Such trees are sometimes more vigorous growers for a time than healthy trees. The final effect is not yet known.

(2) The abnormal root production of the woolly-knot form often stimulates the growth of grafted trees, and, as a result, such trees frequently become the largest in the row. This stimulation often continues after the trees are planted in the orchard. The largest tree in experimental orchard 1 was diseased with woolly-knot (Pl. IX, fig. 1).

LITTLE OR NO EFFECT ON ORCHARD TREES SHOWN IN EXPERIMENTS.

Experiments by others.—Orchardists and nurserymen, as well as investigators, differ in their opinions as to the effect of crown-gall and

hairy-root on the apple tree. It would be interesting to cite the statements of a number of nurserymen and orchardists, but it will be better to give data from orchards grown by them with diseased trees.

The owners of one orchard, Marshall Brothers, at Arlington, Nebr., reported in a letter dated January 25, 1909, as follows:

> We have 29 Wealthy apple trees that we planted thirteen years ago. All of them were more or less galled, some galls being nearly as large as a hen's egg. These trees have grown well and have done splendidly. We have noticed no difference between these and other Wealthy trees of the same age in growth and bearing. They have given almost annual crops the last five or six years, and two or three very heavy crops.

The owners of a second orchard, of 10 acres, at Troy, Ohio, reported May 16, 1907, as follows:

> The orchard you ask about was planted five years ago this spring and consisted of Yellow Transparent apples which were badly infested with crown-gall and aphis. Inasmuch as the authorities in this State are opposed to the use of trees thus infested, we have discontinued the growing of apples at this place, and therefore did away with the orchard this spring. However, we wish to say the trees were thrifty and in good growing condition, and we do not believe there could be any objection to the showing they made. There was some fruit on this orchard last season.

A third orchard is reported upon by Charles C. Bell, of Boonville, Mo., January 4, 1908. He states that an orchard of about 20 acres was planted in 1900 with 2-year-old trees diseased with crown-gall, after samples of the trees had been condemned by experts, as unfit for planting. He says: "To-day these trees which were condemned * * * are a beauty to behold; they are healthy and strong and ready to bear fruit."

A fourth orchard was planted and grown in 1902 near Mountain Grove, Mo., by F. A. Faurot, a collaborator of the Bureau of Plant Industry. This experiment was in cooperation with the Missouri Fruit Experiment Station at that place. By permission of the director of the station, Paul Evans, Mr. Faurot furnished the data for publication. The orchard is planted in two plats, one sloping gently to the east, the other to the north. The soil is a clay loam. In the first plat 275 apple trees were planted, one-fifth of which were diseased with crown-gall. The diseased trees were in a separate row, but were of the same varieties and of the same stock as the healthy ones. The second plat consisted of 96 apple trees, one-third of which were plainly diseased with crown-gall. In company with Mr. Faurot, the writer visited the orchard in the autumn of 1908. No difference could be detected in the growth and appearance of the trees in the diseased rows of trees when compared with those in the healthy ones. Relatively, in number, no greater proportion of the diseased trees had died in six years of growth. No evidences of premature development, such as early bearing, stunted growth, etc., were noticed in any of the diseased trees.

A fifth orchard, belonging to the Arkansas Agricultural Experiment Station, located at Fayetteville, Ark., has been under the observation of the writer for five years. This orchard is 15 years old and was planted as an experiment to test varieties of apples from a horticultural standpoint. Twelve out of a hundred trees in this orchard, mostly Russian varieties, have developed the aerial form of hairy-root, with no apparent effect as yet upon the growth or the fruiting of the trees.

A sixth diseased orchard is situated near Mitchell, Ind., on the farm of the Burton Fruit Company. Among other older trees there are planted over two hundred Benoni apple trees now 8 years old. This orchard was visited by the writer in the autumn of 1908. More than half of the Benoni trees are diseased with the aerial form of hairy-root, with little or no apparent effect, as yet, on their growth. Mr. Joseph A. Burton, superintendent of the orchard, asserts that many of the knots disappear as the trees grow older, but that their immediate effect is to make the trees bear younger. In an older orchard belonging to Mr. Burton there is a thrifty 25-year-old Chenango apple tree that has been diseased with the aerial form of hairy-root for years, with no effect upon its fruitfulness.

In summing up the data from these orchards, the results show that crown-gall and hairy-root have but little immediate effect on the growth of trees in the orchard. Orchards that were reported dying from disease have been examined by the writer, but the immediate causes on examination have proved to be heart-rot and root-rot, usually accompanied in unfavorable soil conditions by poor drainage, neglect of cultivation, etc. These diseases apparently attack and kill the trees originally healthy, without regard to the presence of crown-gall or hairy-root.

Experimental orchards.—The orchard experiments conducted for the study of the disease were four in number. The location of these orchards, designated as orchards 1, 2, 3, and 4, and a description of the soil in each, with the methods of experimentation, are given on page 79.

Orchard 1 was planted with trees of the following varieties: Ingram, Gano, Collins, and York Imperial, grown in a nursery in eastern Missouri. It was planted with 112 healthy apple trees (Pl. III, fig. 3) and 96 diseased with the hard form of crown-gall, the galls being near the crowns of the trees, just below the surface of the soil as they grew in the nursery (Pl. I, fig. 1). This orchard was on well-drained soil, and the healthy and diseased trees were planted in alternate rows.

Orchard 2 was planted in a soil similar to that of orchard 1, except that it was situated at a lower elevation and was subject to seepage.

It was planted with the same varieties, but the healthy trees, 122 in number, were planted in blocks of several rows, rows of healthy trees alternating with rows consisting of 139 diseased trees. Both orchards were cultivated across rows, from diseased to healthy trees, to facilitate the spread of disease by cultivation. One block of 36 diseased trees of the Collins variety in this orchard was composed of trees diseased with the soft form of crown-gall, the other varieties being diseased with the hard form. Most of the galls were from 1½ to 2 inches in diameter.

Orchards 1 and 2 were cultivated with ordinary care, receiving no special attention. The trees were planted thickly and stood 8 by 9 feet apart. The soil was not the best, owing to the fact that it had been cultivated to grain crops without fertilization for many years. No fertilizer was used, natural soil conditions being preferred. The growth of the healthy and the diseased rows was so nearly uniform that on repeated tests trained pathologists could not pick out the rows of diseased trees. Photographs of representative rows of trees were taken at the age of 6 years (see Pl. X).

Owing to a fire which killed many of the trees in orchards 1 and 2, the experiments had to be discontinued, and the trees were taken up when they were 8 years old: that is, after they had grown for six seasons in the orchards. Just before the trees were taken out, the trunk of each was carefully measured at a height of 6 inches above the surface of the ground. At the time of removal careful notes were taken of the condition of the roots as to increase of disease, recovery therefrom, forms of disease, etc. The results of the experiment are given in a condensed form on pages 20 and 57 and in Tables XVII, XVIII, and XIX, in the appendix. Table XVII gives the average diameter of the healthy and the diseased trees at the time they were dug.

It will be seen from Table XVII that the effect of crown-gall and hairy-root on the trees in the experiment was to diminish very slightly the diameter of the trunks. The trees with healthy roots had developed in six years an increase in diameter of six one-hundredths of an inch greater than those diseased with hairy-root, and of twenty-nine one-hundredths of an inch greater than those diseased with crown-gall. These diseases are thus shown to be very slightly detrimental to the growth of orchard trees during the first few years, and the assertions of many to the contrary are disproved.

In orchards 1 and 2, during the six seasons of growth the number of healthy trees that died was 23 out of 234, or 9.8 per cent, and of diseased trees it was 30 out of 235, or 12.8 per cent, indicating that the presence of the disease may have slightly increased the death rate. During the first four years 9 healthy and 9 diseased trees died.

Of these 5 healthy and 7 diseased ones died from the effect of transplanting to the orchard. During the fifth year 10 healthy and 12 diseased trees died, and during the sixth year 4 healthy and 9 diseased trees died. It should be noted, however, that all of the trees that died during the fifth and sixth years and 3 trees during the first four years were killed by borers encircling the trunk near the surface of the ground. In no case could their death be directly attributed to crown-gall or hairy-root, nor can it be said that borers prefer the diseased trees to any marked extent.

Tables XVIII and XIX, in the appendix, show the number of healthy and diseased trees of each variety planted in orchards 1 and 2, as well as the number of each that died during six seasons of growth. The diseased trees of the variety Collins in orchard 2 had soft galls on the roots. All of the other galls were of the hard form.

A third orchard, designated as "orchard 3," was planted in the latter part of April, 1907, with 1,108 well-rooted apple trees of a number of varieties selected from trees grown in experiments in the nursery. Of these 572 were healthy, 354 diseased with hairy-root (Pl. I, fig. 2), and 117 diseased with crown-gall of both the hard and the soft forms. The trees were transplanted after the buds were greatly swollen, and a month of dry weather ensued just after the planting. As a result, the loss from transplanting was heavy. A fire in the autumn of 1908 killed many of the trees and ruined the experiment. The trees were then dug, no notes being taken at the time of digging as to the condition of the roots. The trees that died in 1907 and 1908 are enumerated in Table XX, in the appendix.

By combining the data for 1907 and 1908 in Table XX, it is found that in two years 33.4 per cent of the healthy trees died, and at the same time 37.3 per cent of those diseased with crown-gall and 25.1 per cent of those diseased with hairy-root. Again it must be said that the reason for the increased vitality of the trees diseased with hairy-root is the greater tendency to throw out roots. This has already been mentioned in the case of seedlings affected with hairy-foot (see pp. 24 and 34). On the other hand, the trees diseased with crown-gall had slightly less vitality, since a somewhat greater number died.

A fourth experimental orchard, partly described on page 79, was planted on the Potomac Flats, near Washington, D. C., in 1907 and transplanted to the experimental farm at Arlington, Va., in 1908. Trees of the following varieties, grown in a nursery in eastern Missouri, were planted: Jonathan, Grimes, and Gano. The trees diseased with crown-gall and hairy-root were selected on account of their having intense forms of disease, in addition to possessing as abundant roots as the healthy trees. During the two years that have elapsed

since planting only 8 trees have died, in spite of the fact that the trees have been twice transplanted. Out of 225 healthy trees, 3 have died; of 82 trees diseased with hairy-root, 2 have died; and of 193 trees diseased with crown-gall, 3 have died, the percentage being but slightly in favor of the healthy trees. This difference is so small as to depend entirely on chance.

The experiments mentioned, as well as observations made in other orchards, indicate that the mere presence of the forms of crown-gall or of hairy-root at or near the crown of an apple tree, in the orchard has very little effect on the subsequent growth of the tree, provided it has a well-developed root system.

Observations made on badly diseased trees growing elsewhere under poor soil conditions indicate that where either hard or soft galls extend entirely around the main root of a tree, unless it is able to throw out roots above such growths, a marked stunting effect may follow. A grafted tree of this character can not develop into a good tree unless it can form roots on the scion portion above the union.

It is inadvisable on general principles to plant any trees affected by a contagious disease like crown-gall, and particularly so with varieties that do not root well from the scion. Trees of the following varieties are more likely to overcome a mild attack of crown-gall, as they are better able to root from the scion: Ben Davis, Wolf River, Northern Spy, Grimes, Gano, Northwestern Greening, Missouri, Wealthy, Walbridge, Fameuse, and Salome.

The following statement made by Wickson (77) fully meets the views of the writer and applies to hairy-root as well as to crown-gall:

> If the diseased growth is so extensive during the early period of the life of the tree as to stunt the development of the root system, no favorable results can be expected during the later period of development of such a tree. It is fortunate that nursery trees are generally dug and sold at a period when the stunting effect of these diseases is most marked.

The same statement might be made of many poorly rooted trees which have not formed a perfect union between scion and root piece in the root graft and as a result have a defective root system, irrespective of these diseases. These constitute a considerable loss to the nurseryman where poorly fitted root grafts are used.

These statements apply to both hard and soft crown-gall and to all of the forms of hairy-root found in the nursery. The results of the investigation indicate very clearly that apple trees are able to resist the effects of these forms of disease in the orchard, and their importance has been greatly overrated.

It must not be understood, however, that trees diseased with even the milder forms of crown-gall and hairy-root are fully as valuable for planting as healthy trees. They can certainly not be rated as

first grade in the markets, and if a purchaser buys trees guaranteed to be free from disease and of first grade, trees with distinct forms of disease should not be supplied. Orchardists should plant healthy trees and be willing to pay more for them if necessary. Since the initial cost of an orchard is only a small item in the entire outlay for its maintenance, it will certainly pay to plant the best grade of trees that can be bought.

SUSCEPTIBILITY OF VARIETIES OF APPLE TREES TO THE DISEASE.

DATA UPON A NUMBER OF COMMON VARIETIES USED IN EXPERIMENTS.

The susceptibility of the different varieties of apple trees to crown-gall and hairy-root has not been discussed by others in any previous publication on the subject. Nurserymen have asserted for a number of years that certain varieties are extremely susceptible to the disease. Since the same varieties are not grown in all localities, sometimes one variety has been named as more susceptible and sometimes others. A request for a list of the varieties considered to be ordinarily most badly diseased with crown-gall and hairy-root was sent to fifty of the leading nurseries in various parts of the country to ascertain if there was any uniformity of opinion in this matter. Each was requested to have the field superintendent send in the names of the six worst diseased varieties. In a compilation of thirty-two replies the following varieties were found to be the most badly diseased, those named oftenest being given first: Ben Davis, Early Harvest, Yellow Transparent, Wealthy, Grimes, Oldenburg, Wolf River, Red June, Gano, and Rome Beauty. All of these varieties except the last named have been included in the experiments of the Bureau of Plant Industry, from which data will be given later.

Since obtaining these opinions reports have been received for three successive years from twelve nurseries, the number of diseased trees being given in the case of a large number of varieties. The reports are from nurseries in Utah, Iowa, Nebraska, Kansas, North Carolina, Missouri, Illinois, Indiana, Ohio, and Virginia, and many of them were based upon careful counts made at the time of digging. These corroborate quite generally the opinions of the nursery superintendents as given in the preceding paragraph. They show, however, as would be expected, a variation year by year with the same varieties in the same locality. For instance, one nursery reports for the Gano the following percentage of disease during successive years: 1904, 15; 1905, 46; 1906, 28. Another reports as follows for the Ben Davis: 1904, 15; 1905, 40; 1906, 30.

In order to obtain some idea as to whether in certain varieties there was a susceptibility to either crown-gall or hairy-root, or both, experi-

ments with twenty-four of the more valuable commercial varieties of apple trees were conducted in connection with the other lines of investigation. The data from the trees that were grown in these experiments from ordinary whip grafts have been carefully recorded and compiled for five years. A larger number of grafts were planted and dug during the last three years than during the first two of the period of experimentation. During the first two years, 1903 and 1904, the work of experimentation was confined to one locality. During the last three years each stock of root grafts was made at a single nursery and divided into eight equal lots and planted in cooperative plats 1 to 8, thus getting the combined results of the effect of growing a variety under as many different conditions. The results from these series of experiments for five years are combined and given in Table XXI, in the appendix.

The conclusion from this series of experiments is that the different varieties of apple trees show a wide variability in their susceptibility to the disease: that some varieties are more apt to develop forms of crown-gall and others forms of hairy-root; and that none of the varieties were free from either type of the disease.

It will be noted that the varieties Wealthy, Yellow Transparent, and Wolf River developed a high percentage of crown-gall, and the Ben Davis, Wolf River, and Northern Spy varieties a high percentage of hairy-root. In both cases the forms of disease occurred chiefly on the scion portions of the trees. (See Pl. II, fig. 3.) It follows that the disease must be considered more with reference to the scion than to the seedling or root portions of the root graft; also that in root-grafted trees, susceptibility or resistance is inherent in the variety of scion, and methods for the prevention of the disease must be directed primarily to the selection of varieties resistant to the disease, and secondarily to the selection of resistant seedling stocks.

The tendency toward the development of the disease appears to be in no way related to the character of the growth of any particular variety. Certain of the varieties experimented with are vigorous growers, such as Wealthy, Walbridge, Wolf River, Minkler, Ben Davis, Northwestern Greening, Northern Spy, and Baldwin, while others, like Yellow Transparent, Whitney, Red June, Maiden Blush, and Jonathan, are much slower growers. It will be seen from Table XXVI, in the appendix, that some of the more vigorous varieties showed a high percentage of disease, as, for example, the Wolf River, with an average of 46.4; the Wealthy, with 43.3 per cent; and the Ben Davis, with 36.1 per cent. On the other hand, equally vigorous growers were the Baldwin, with only 16.6 per cent; the Minkler, with 16.8 per cent; the Walbridge, with 14.1 per cent; and the Martha, with only 10.7 per cent. It must be added, however, that there was

a doubt as to whether the variety called "Martha" used in the experiment was true to name. Of the slow-growing varieties, the Yellow Transparent showed an average of 34 per cent of diseased trees, the Maiden Blush 26.4 per cent, and the Whitney 20.4 per cent. It must be concluded that susceptibility is not directly related to vigor of growth.

It was found that those varieties that throw out roots more readily from the scion are the ones that are most susceptible to hairy-root. The forms of hairy-root apparently originate only in tissue centers capable of producing adventitious roots.

SUSCEPTIBILITY OF SCIONS GROWN IN DIFFERENT LOCALITIES.

The collection of data on the susceptibility of different varieties of apple trees to crown-gall and hairy-root brought out the fact that while certain varieties were found to be more susceptible than others, the same variety during the same season or several seasons was diseased more in one locality than in others. This could probably be due to a number of facts, one of which might be a varying susceptibility in stocks of the same variety grown in different localities.

To ascertain whether there was any difference in susceptibility of stocks in different sections of the country, scions of three different varieties of trees were obtained from a number of nurseries from Ohio to California. These varieties were Wealthy, Wolf River, and Yellow Transparent. Each variety was made into root grafts, the same stock of seedlings being used. They were planted in 1906, each variety in a different plat, and grown three years before digging. The names of the nurseries furnishing the scions are not given, numbers being substituted, but the State in which each nursery is located is given. Table XXII, in the appendix, gives the number of trees grown from each lot and the percentage diseased.

From the results given in the table it will be seen that there was a great variation in the amount of disease present in scions taken from different localities, but it will not be safe to ascribe this wholly to greater susceptibility, since the health of the trees from which the scions were selected in each locality could not be ascertained, and it has already been shown that this is a factor in the problem.

The difference in the percentage of disease in the case of the Wolf River variety, as shown by the two extremes in the results from the experiment, is 14.7 per cent. In the experiment with the Wealthy it is 17.5 per cent, and with the Yellow Transparent 12.8 per cent. This is quite a wide range, but since the results can not be considered as strictly comparative they may be taken as tentative, paving the way for further inquiry along this line.

COMMUNICABILITY OF THE DISEASE IN THE NURSERY AND THE ORCHARD.

PREVIOUS PUBLICATIONS ON THE COMMUNICABILITY OF APPLE CROWN-GALL.

Ever since crown-gall and hairy-root have been brought to the attention of plant pathologists one of the chief problems under discussion was related to the question of whether these forms of disease are communicable, especially under nursery and orchard conditions. As a matter of precaution, growers have been generally advised to refrain from planting diseased trees, and their destruction, both in the nursery and the orchard, has been recommended. In some cases trees to the extent of a carload at a time have been condemned by zealous nursery inspectors and destroyed on account of the presence of diseased trees.[a]

The earlier accounts of the disease by W. E. Smith (56), Yates (80), Bailey (5), and others, are based upon the idea that the disease is probably not communicable, but later researches have overthrown this theory.

Woodworth (78) recommends rejecting all affected stock, purchasing from nurseries known to be entierely free from crown-gall, burning diseased trees, and devoting fields in which the galls have appeared to some other crop for a number of years.

Toumey (68), in his work on the crown-gall of the almond, records an experiment in which he attempted to transfer the disease from the almond to the apple, both by soil inoculation and by graft insertion, but was unable to communicate the disease.[b]

Selby (52) recommends the destruction of all affected stock, and says:

> Soil which causes this sort of growth upon peach trees in the nursery has been known to produce the same upon the apple, and conversely.

Garman (15) makes the following statement, without citing proofs:

> It has been demonstrated that crown-gall is a contagious disease, to be conveyed to seedling trees by crushing the galls and putting them in soil in which seeds are planted. Trees grown with others that are galled are therefore not above suspicion, even when they show no outward evidence of the disease.

Guilford (17), speaking of apple crown-gall, says:

> For the past three years I have been trying to inoculate the Virginia crab roots with this gall. Conditions were made favorable by wounding the roots and covering them

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[a] Paddock, Wendell. Crown-gall. Bulletin 86, Colorado Agricultural Experiment Station, 1903, p. 5.

[b] Dr. Erwin F. Smith has shown the writer large, hard crown-galls on apple stems produced by him in 1908 by pure-culture inoculations of *Bacterium tumefaciens* obtained from the soft crown-gall of the peach.

with galls. I have failed to get a catch; but I have no trouble in making the inoculation on our common seedlings. They usually take hold on the seedlings at the graft union.

This would seem to indicate immunity of the Virginia crab.

Howard (24) made a number of experiments to test the contagious nature of different galls, using apple grafts, and found that apple trees inoculated with apple galls were affected to the extent of 30 per cent; apple trees inoculated with raspberry galls, 16⅔ per cent; and apple trees inoculated with peach galls, 22 per cent. He, however, gives no comparative results with apple trees which had not been inoculated; hence, it is not certain that his results are due to inoculation.

Alwood (2) states:

Apparently crown-gall can be readily inoculated from a diseased plant into healthy ones; hence, diseased plants should not be allowed to remain among healthy ones in the orchard.

In another publication Alwood says:

Cultivating the orchard may possibly serve to spread the disease by carrying disease germs from one tree to another. It is very probable that infection occurs without assistance wherever parts of the diseased tissues remain in the ground occupied by apple trees.

Alwood bases his conclusions in the first instance upon experiments containing a small number of trees.

Norton (37) regards crown-gall as a communicable disease on the apple, and says that "in grafting, the disease may be communicated from diseased to healthy trees by means of knives, etc." He does not, however, give experiments or cite authority for the statement.

Butz (7) states that healthy trees set in infected land develop the disease within a year or more.

The author (19) stated in a bulletin in 1905, concerning the hard form of crown-gall on apple trees, that "the results of extensive inoculations with this type have failed to prove that this disease is of a contagious nature." And again, concerning the soft form of crown-gall: "Nor is there proof yet that they are of a contagious nature." Similar statements were published in 1905 in Science (18) and in the National Nurseryman (18). These opinions were based upon a failure to secure positive results from inoculations of apple trees with pieces of hard galls in earlier experiments, disease occurring both in control and in inoculated plants.

Later experiments by the author (22) in 1906 and 1907 and published in 1908 established the fact that crown-gall of the soft form on apple trees was contagious and that it was identical with crown-gall of the almond, apricot, blackberry, cherry, peach, plum, prune, chestnut, and walnut. These experiments also indicated that the disease in the hard form was either slightly or not at all contagious.

From the preceding citations, which are representative, it is apparent that the opinions of plant pathologists, with few exceptions, have been as follows:

(1) Apple crown-gall spreads rapidly in the nursery and the orchard from tree to tree.

(2) It may be communicated from diseased to healthy trees by contact, in bundles, etc.

A review of the literature on the subject reveals that little has been done previously in the way of experimentation to substantiate these views as to the degree and the rapidity of the spread of the disease in the nursery and the orchard.

PREVIOUS PUBLICATIONS ON THE COMMUNICABILITY OF HAIRY-ROOT.

The previous citations bore upon the communicability of crown-gall, but in most cases the statements made no separation of crown-gall from hairy-root, both types of disease being included under the term "crown-gall."

Stewart, Rolfs, and Hall (64), who first described hairy-root of the apple, did not express their opinion as to the communicability of the disease, but regarded it as separate and distinct from crown-gall.

EXPERIMENTS ON THE COMMUNICABILITY OF THE DISEASE.

Studies on the formation of callus as related to crown-gall.—In order to study the relation of callus to wounds an experiment was prepared with a number of sets of apple cuttings, seedlings, and root grafts. Some of the cuttings were made with blunt or square ends, others with slanting or pointed ends. Some were cut with longitudinal incisions, some with spiral incisions, and some with cross incisions through the bark and cambial layer; others lacked such incisions. The seedlings were washed clean, sterilized for five minutes in a one-tenth per cent water solution of corrosive sublimate, and again washed in boiled water. They were cut off at both ends, roots and shoots, to the length of 9 inches. The root grafts were made of the tongue or whip-graft pattern, some closely fitted, some poorly fitted, others with the upper end of the root cut off bluntly, and others with the lower end of the scion cut off in the same manner.

The materials were prepared for the experiment the 1st of February, the usual time for root grafting at the larger nurseries in the Mississippi Valley. The cuttings, seedlings, and root grafts of each pattern were tied for storage in bundles in the same manner as root grafts are tied for storage at nurseries. They were divided into two equal series, one of which was stored in a cool cellar at a temperature

of 50° to 60° F. and the other in a greenhouse at a temperature of 65° to 90° F.

Both series were packed in sterilized jars in a number of different kinds of packing. The jars and substances used in packing were sterilized in an autoclave at a temperature of 239° F. for three hours. The sets were placed under the following conditions of moisture in the cellar and the greenhouse: (1) Moist sphagnum moss; (2) moist sand; (3) moist sawdust; (4) moist soil; (5) moist chopped excelsior; (6) moist air over water, surrounded by wet blotting paper; (7) all but the tips of the upper ends in water.

In nursery practice root grafts are made and either planted out immediately or stored in moist conditions until the wounds are filled with callus. Of the two sets of root grafts in the experiment those placed under the cooler conditions formed callus about one-half as rapidly as those in the warmer conditions. Those in the warmer conditions, had they been in the nursery, should either have been planted at the end of ten to fourteen days or placed in cold storage to inhibit further development of callus. Those in cooler conditions were ready to plant in three to four weeks, and at the end of six weeks the formation of callus had become excessive, especially in moist moss, earth, sawdust, and chopped excelsior. Sand was found to be much the best for packing root grafts, since only a moderate formation of callus took place. In this substance there was no excessive formation of callus except in a few cases when the period of time in the cellar was extended to two months. The grafts, however, after two months in the cellar or one month on the benches had begun to form shoots and roots, and for this reason were not in good condition for planting.

The experiment gave the following general results:

(1) On apple cuttings callus formed readily but not excessively in spiral and cross incisions, and less readily in longitudinal incisions, filling the cuts with new tissue, and in the former often projecting from the surfaces in small outgrowths.

(2) Usually no callus developed from the upper cut of cuttings, seedlings, and scions, whether cut off slanting or square. If any was formed, it barely showed above the surface of the cambial layer.

(3) Under moist air conditions, either in moss, sand, sawdust, soil, or in the open air, callus formed readily on the lower cut ends of cuttings, seedlings, and scions. In time it formed excessively developing outgrowths half an inch or even more in diameter.

(4) In root grafts in time callus formed excessively under the conditions mentioned in the preceding paragraph at the lower pointed end of all the scions and at the lower cut ends of some of the roots in the grafts (Pl. VIII, fig. 2). The graft union was closed with callus

in a short time, but, except as mentioned, the callus was usually confined to the wounds and did not project beyond.

(5) Under very wet conditions, as in water, the formation of callus was almost entirely inhibited in wounds, but lenticellular proliferations were abundant from other parts of the surface of shoots and roots.

(6) The two regions where the formation of callus in root grafts was most abundant, the lower point of the scion piece and the lower end of the root piece coincide exactly with the position of more than 90 per cent of the galls occurring on root-grafted trees, indicating a close relation between the formation of callus and the development of the disease.

Fifty root grafts with large outgrowths of callus (Pl. VIII, fig. 2) were selected from those in the experiment and the same number with no excessive development of callus were selected. These were planted in separate benches in a greenhouse in ordinary soil, not sterilized. They all grew. Of the set with excessive callus 32.2 per cent developed galls of the hard form. All of the other set grew into healthy trees. This indicates that excessive callus formation either is incipient crown-gall or may develop into it. Storage conditions should be such as to hinder the excessive development of callus. Moist sand is the best medium of those tested for packing root grafts.

Studies on root formation as related to hairy-root.—In connection with the study of the formation of callus and under the same conditions, an experiment was conducted for the study of root production on healthy seedlings as compared with that on those diseased with hairy-root and the woolly aphis. Seedlings of these three types were prepared as in the former experiment and placed under the same conditions of moisture.

It was found that as a rule no roots were produced from cuttings or scions from the limbs of healthy apple trees under the conditions of the experiment. Such was not the case with cuttings taken from the tops of a number of apple seedlings badly diseased with the simple form of hairy-root. Roots were produced freely from all of these under moist conditions. Where healthy apple seedlings in which the stem and root tip had not been cut off were kept in a cool condition for two months and in a warm condition for one month, a few scattered new side roots developed on most of the roots, but only shoots or leaves developed from the stems. In the case of the seedlings diseased with hairy-root which were placed under similar conditions, abundant root formation, usually in clusters or tufts, took place from tissues in or adjacent to the diseased parts, not only from the roots but often from the stems, and at the same time shoots were thrown out from the root tips below diseased areas. This is a reversal of the natural order of root and shoot formation in apple seedlings.

A third set of apple seedlings was also placed at the same time under the conditions of the experiment. This consisted of a number of bunches of apple trees badly affected with aphis galls but showing no hairy-root formation. It was thought that these seedlings with galls might develop hairy-root, but they behaved in their rooting no different from the set of healthy seedlings.

The relation existing between the woolly aphis, however, and the aerial form (stem tumors) of hairy-root (Pl. V, fig. 2) is a subject for future investigation. The following observation gives the reason: In a seedling nursery in Indiana, mentioned on page 37, about forty trees were found diseased with this form of hairy-root, and they were also infested with the woolly aphis. It was noted that the trees adjacent to the badly affected trees were contracting the disease, indicating that this aphis may assist in the spread of the disease by carrying the organism causing it.

No communication of the disease to healthy uninjured seedlings.—In an experiment with healthy apple seedlings, described on page 16, it was shown that healthy seedlings, uninjured as far as could be determined, failed to become diseased even when the soil about their roots was mixed with finely chopped pieces of living soft and hard crown-galls from apple trees. Thus, without wounds, there was no communication of these forms of disease to apple seedlings. Where wounds were made, other conditions being the same as before mentioned, 4 per cent of the trees became diseased with the hard form of crown-gall.

The disease is communicable to wounded seedlings.—A number of experiments have been conducted with healthy apple seedlings grown in the nursery and carefully washed and the tips of the roots cut off. They were then divided into lots of approximately equal numbers and prepared for the experiment as follows: The plants in one lot were prepared for a control by making a slanting incision into the root and then wrapping the wound with a thread in the same manner that grafts were wrapped. A second control set was similarly treated, except that a cross section of clean, healthy apple roots was inserted in the wound before wrapping. A third set was prepared like the first, except that a piece from the outside of a living apple crown-gall of the soft form was inserted in the wound. A fourth set was prepared similarly, except that a piece from the outside of a living apple crown-gall of the hard form was inserted. A fifth set, consisting of a smaller number of seedlings, was similarly prepared, except that a cross section of a piece of living apple seedling diseased with the simple form of hairy-root was inserted. After growing one season the results were as given in Table XXIII, in the appendix.

These experiments prove that soft crown-gall of the apple is communicable to some extent in wounds by inoculating with pieces of living galls, but that pieces of hard crown-galls and the simple hairy-root may not readily communicate the disease under similar conditions.

Increase of the disease in root-grafted trees due to the inoculation of grafts.—In order to test the communicability of the soft form of apple crown-gall, a set of nursery experiments was conducted. The grafts were prepared from healthy scions from the varieties Red June, Rambo, York Imperial, and Minkler, grafted on the roots of healthy selected seedlings from trees grown from the same seed in the same field. The grafts were prepared in three lots: The first as ordinary tongue or whip grafts; the second lot had a piece of clean cross section of healthy apple seedling root inserted beneath the lower end or tongue of the scion before wrapping each graft; the third had a piece of living apple crown-gall of the soft form taken from the outside of the gall and inserted under the lower end of the scion in each graft before wrapping it. Each of the three lots of grafts was separated into eight equal sets, which were planted and grown in three experiments (1, 2, and 3) in the same localities and which were dug in the same manner as the grafts in the experiments whose results are given on page 62. The results of the experiment are given in Table XXIV, in the appendix.

Briefly summarized, the results from the experiments are as follows: Where a piece of living healthy root chip had been inserted in the graft union it caused an increase of crown-gall amounting to from 1 to 14.2 per cent and where a piece of living apple crown-gall had been inserted there was an increase of crown-gall amounting to from 2 to 33.8 per cent as compared with the amount of crown-gall present in trees grown under similar conditions from ordinary root grafts. In the former case the average increase was 4.7 per cent and in the latter 12.6 per cent. The resulting disturbance did not vary the amount of hairy-root present in either case.

On the whole, this set of experiments shows that crown-gall is communicable in root grafts if they have an opportunity to become infected at the time the healing processes are taking place in the union; or, in other words, at the time callus is formed abundantly in the wounds.

The data in experiment 1 indicate not only that there is no further spread of crown-gall in the nursery rows the second and third years, but that there is an actual decrease of the disease due to the recovery of many trees. This must have taken place, since in experiment 1 every third tree was dug with spades the first year, the second year one-half of those remaining also with spades, and the balance of the

trees the third year, with a tree digger. In digging the trees with spades those remaining were often wounded, and this alone should have led to an increase of disease. In this and in all of the other experiments mentioned in this bulletin conducted by the author he personally examined the root grafts when made, directed the planting and cultivation, saw every tree as it was dug, and noted in each case the condition of the roots.

Increase of the disease due to poorly fitted root grafts.—In order to determine the relation of defective grafting to the increase of crown-gall in the nursery a number of experiments were conducted. Two series of whip or tongue root grafts were prepared from the same lots of scions and seedling roots. The varieties Gano, Wealthy, Red June, Martha, and Whitney were used. The root grafts of one series were carefully made, root and scion pieces of equal diameter being selected and smoothly fitted at the union (Pl. IX, fig. 2, *A*). The second series consisted of similar grafts very poorly fitted in which either root and scion piece were of different diameters or the end of the one projected beyond the surface of the other (Pl. IX, fig. 2, *C* and *D*).

These root grafts were planted in eight equal lots in experiments 1, 2, and 3 in cooperative plats 1 to 8 (for description see p. 78). In experiment 1, four lots of grafts planted in cooperative plats 1 to 4, every third tree was dug at the end of one season, every second at the end of two years, and the remaining trees at the end of the third year. In experiment 2, two lots planted in cooperative plats 5 and 6, every other tree was dug at the end of the first season, and the remaining trees at the end of the second year. In experiment 3, two lots planted in cooperative plats 7 and 8, all of the trees were dug at the age of 2 years. Table XXV, in the appendix, gives the results from each of the experiments.

A smaller experiment, similarly prepared, in which a number of poorly fitted root grafts and twice as many carefully fitted grafts from the same stock of scions and seedlings were made, was conducted in eastern Missouri. The results of the experiment are as follows: Out of a total of 357 trees grown from the smoothly fitted root grafts, 7.8 per cent was diseased with crown-gall and 5.1 per cent with hairy-root; and out of a total of 217 trees grown from the poorly fitted root grafts, 17.5 per cent was diseased with crown-gall and 11.1 per cent with hairy-root, or a saving of 15.7 per cent on trees of a marketable size due to smooth fitting.

Briefly summarized, the results of these experiments are as follows:

(1) Poorly fitted root grafts, as compared with carefully fitted ones, yielded an increased percentage of diseased trees both with crown-gall and with hairy-root. The increase of crown-gall in both

experiments varied from 1.2 to 41.7 per cent and of hairy-root from 1.8 to 6 per cent.

(2) The use of carefully fitted root grafts, as compared to poorly fitted ones in both experiments, yielded an increased stand of trees. This increase amounted to 21.6 per cent in the first experiment and to 26.7 per cent in the second experiment. This was due to the death of many more of the poorly fitted grafts just after planting, before they struck roots.

In the case of the smoothly fitted grafts the superior stand of trees is due to the more perfect union formed by the callus quickly establishing a circulation in the graft when it is planted in moist soil. This brings about a more rapid healing and results in a higher vitality and an increased stand of trees.

A poor fitting of root grafts also causes an increase of abnormal callus, permitting a greater communicability of crown-gall during the first year's growth. This increase takes place chiefly at the time the wounds of the graft union are healing. The same does not apply so well to forms of hairy-root, which, as a rule, are not necessarily connected with the graft union, but occur as often on other portions of the roots of grafted trees.

What does this loss from poorly fitted root grafts mean to the nurseryman? On the basis of 15,000 trees to the acre, a low estimate, it means the loss of 2,355 marketable trees for every acre of apple trees. If trees are valued at 8 cents apiece, it means the loss of $188.40 per acre.

The use of scions from diseased trees increases the amount of disease.—It has been the custom of some growers of grafted apple trees in the central United States to grow their stock three years before marketing it. The yearling trees are cut back to near the ground, and the tops are used for scions in making root grafts for the next season's planting. A portion of such scions must, of course, come from trees with diseased roots. Some growers cut scions directly from cull trees in the nursery bins, many of which are diseased with crown-gall and hairy-root. Others plant these culls in their scion orchards and later cut scions from them. These three methods of selecting scions must be condemned, since they tend to increase the number of diseased trees grown from orchard grafts.

In order to test the effect of taking scions from trees with diseased roots, a series of experiments has been conducted, in which scions were taken from trees with both healthy and diseased roots.

The grafts in the first and largest experiment were planted in 1905. The trees were dug in 1906, at the age of 2 years. In this experiment the trees used were grown from root grafts made in equal number from scions taken from healthy trees and from those diseased with

crown-gall. The varieties used were Collins, Wealthy, York Imperial, Gano, and Jonathan, planted and grown in independent plat 2 (see p. 78). The results from this experiment are given in Table XXVI, in the appendix.

The second experiment, in which the trees were dug in 1907, at the age of 1 year, was made in independent plat 3 (see p. 78). The root grafts were made with scions from both healthy trees and those diseased with crown-gall and hairy-root. The results are given in Tables XXVII and XXVIII.

The grafts of the last experiment were planted on the clayey soil in independent plat 4 (see p. 78). The sets of root grafts were made from scions taken from healthy trees and from those diseased with crown-gall and hairy-root. The results of this experiment are given in Tables XXIX and XXX.

These experiments show a decided increase of disease in root-grafted trees grown from grafts made from scions from apple trees diseased with crown-gall and hairy-root as compared with those grown from scions selected from healthy trees. This increase in the different experiments is as follows:

An increase of crown-gall in the first experiment of 2.2 per cent, in the second of 7.4 per cent, and in the third of 7.2 per cent. An increase of hairy-root in the first experiment of 7.1 per cent, in the second of 12.5 per cent, and in the third of 16.3 per cent.

Although this increase is not very great, it is cumulative where the process is repeated year after year, and is of sufficient importance to deserve the careful attention of every nurseryman. All scions should be selected from healthy trees, and the same observation will no doubt apply to the selection of buds for budding where the twigs are kept dormant in cold storage. To accomplish this means that the scion orchard must be grown from healthy trees, and all diseased trees should be removed from the scion orchard as soon as detected.

The spread of the disease from tree to tree in nursery rows is almost negligible after the first year.—In experimenting along the various lines of the problem, a number of experiments were conducted so that all conditions would be equalized as nearly as possible, and a definite proportion of the trees grown in nursery rows was dug each year for the purpose of noting the spread of the disease in the rows from tree to tree. Three sets of such experiments, designated as experimental sets 1, 2, and 3, were conducted in cooperative plats 1 to 6.

In experimental set 1 seven duplicate experiments, each using grafts from the same stocks of healthy scions and seedling roots, were planted in four equal lots in cooperative plats 1 to 4. One-third of the trees grown from these root grafts were dug at the end of one year,

digging every third tree; one-half of the remainder, or each alternate tree, were dug at the end of the second year, and the remaining trees were dug the third year. The combined results from these experiments are given in Table XXXI, in the appendix.

In experimental set 2 the conditions in set 1 were duplicated and the grafts planted in cooperative plat 6 in 1905. One-third of the trees, as before, were dug at the end of the first year, but at the end of the second year it became necessary to dig the remainder on account of the more rapid growth of the trees in this locality. The results from this experiment are given in Table XXXII.

In experimental set 3 the conditions of set 1 were duplicated and the grafts planted in cooperative plat 5 in 1905. One-half of the trees, selecting each alternate tree in the row, were dug at the age of 2 years and the remainder at the age of 3 years. The results from this experiment are given in Table XXXIII.

The results from the three sets of experiments are summarized as follows:

(1) They show a decrease of crown-gall in trees in nursery rows after the first year: in set 1 a decrease from 26.7 per cent the first year to 9.1 per cent the second and to 4.7 per cent the third; in set 2 from 20 per cent the first year to 12.8 per cent the second; in set 3 from 11.7 per cent the second year to 2.6 per cent the third.

(2) They show a general and decided increase of hairy-root the second year, with a slight or no increase the third. In set 1 there was an increase from 5.5 per cent the first year to 8.6 per cent the second and 8.7 per cent the third; in set 2 from 7.9 per cent the first year to 10.3 per cent the second; in set 3 from 6.4 per cent the second to 10.2 per cent the third year.

(3) The increase in hairy-root does not nearly offset the decrease in crown-gall and some of the trees must throw off the disease and recover. In set 1 crown-gall decreased 22 per cent, while hairy-root increased but 3.2 per cent. In other words, the number of diseased trees decreased 18.8 per cent. In set 2 crown-gall decreased 7.2 per cent, while hairy-root increased 2.4 per cent, and of diseased trees there was 3.8 per cent less. In set 2 the percentage of crown-gall decreased 9.1, while that of hairy root increased 3.8, and of diseased trees there was a decrease of 5.3 per cent.

In conclusion, the time when the disease is communicated to the trees is during the first year. In the light of experiments already described the communicable period must be during the time of the formation of callus for closing the wounds in the union of scion and root.

These experiments show that crown-gall as a rule does not spread from tree to tree in the nursery after the first year and that hairy-root

increases considerably from the first to the second year, and but slightly the third year.

The disappearance of crown-gall is considered to be due to two causes: (1) Some of the hard galls throw out roots and develop into woolly-knot, while (2) a much larger number of galls gradually disappear as the tree increases in size, and such trees must recover from the disease.

In closing the discussion of this subject it should be noted that the results given here are from seven parallel sets of experiments in six localities, or forty-two parallel experiments in five States, and include data on 31,886 trees. The results might not have been the same in all localities in the United States, but certainly fairly represent typical nursery conditions in the heart of the apple-growing belt in the central States of the Mississippi Valley.

Pruning and grafting knives are not responsible for much of the disease.—In view of the fact that it has been asserted that crown-gall is largely communicated by the use of pruning and grafting knives, 100 carefully selected seedlings from the nursery were washed, thoroughly dried, and planted in sterilized soil in a greenhouse (p. 77). Before being planted a downward cut on the root near the ground line was made with a grafting knife which had in each instance just been used in making a cut in a live soft apple gall. The greatest care was exercised to see that the knife used in making the cuts in the seedlings was in each case passed back and forth through a fresh crown-gall before the cut was made. For comparison, 100 healthy seedlings from the same stock were planted after being carefully washed and dried. Before planting, a cut was made in each of these seedlings as before, except that in each instance the knife blade was dipped in a one-tenth per cent corrosive-sublimate solution before making the cut. At the end of the growing season 4 per cent of the control seedlings had developed crown-gall and only 2 per cent of those that had been wounded with the gall-infected knife were similarly diseased. This experiment fails to confirm the belief that the grafting knife is responsible for much of the crown-gall present in root-grafted stock in the nursery.

Crown-gall not readily communicated to dormant trees stored in bundles.—The communicability of crown-gall by contact of healthy trees with diseased ones while tied in the same bundle has been the subject of much dispute, especially between nurserymen and nursery inspectors.

The experiments conducted in cooperative plat 6 in 1905 may throw some light on this subject. Two sets of seedling apple trees, 100 in each, were inoculated with chips of living soft galls from

apple trees inserted into slanting incisions in the roots and tied with grafting thread. One set was prepared about six weeks before planting and kept dormant by being stored in moist excelsior in a cool place; the other was prepared in the same way as the first and planted out immediately. For each set an additional set of an equal number was wounded and wrapped with thread without inoculating. All were grown one year. Of the inoculated stored seedlings, 7.4 per cent became diseased with crown-gall; of the control, 4.3 per cent, chiefly of the hard form; of the inoculated set planted immediately, 34.1 per cent became diseased with crown-gall, chiefly of the soft form; and of the control, 2.9 per cent, chiefly of the hard form.

In a second experiment, 500 root grafts were prepared from healthy scions of Wealthy grafted healthy seedling roots as a control set. A similar set of 500 grafts was prepared by rubbing the tongued end of both the scion and the root pieces on the freshly cut surface of a living soft gall from an apple tree before joining together the cut, a number of galls being used. These were planted in the nursery after being stored for six weeks in separate boxes in a cool cellar. At the end of one season's growth there was approximately the same amount of disease in the control as in the inoculated sets, the control containing about 19.5 per cent of trees diseased with crown-gall, and, the inoculated set 21 per cent, both chiefly of the hard form.

The results of the these experiments indicate that the communication of crown-gall to wounds in apple trees is a variable factor and that the contact of wounded living galls with wounded surfaces when dormant may result in little or no infection, but that under growing conditions, where callus is formed abundantly, such as resulted at once where the seedlings were inoculated with pieces of living apple galls and planted immediately, the disease was communicated readily. In these seedlings growth, with the formation of callus, took place at once, favoring the entrance of the organism. In the case of the stored seedlings and grafts, owing to the low temperature, the formation of callus was retarded at least one month before it became warm enough for its development.

In the writer's opinion, given in the light of the results of these and other experiments recorded in this bulletin, crown-gall is communicable by contact only in wounds where fresh callus is being formed. Where trees are dormant there is little danger of communication.

The disease only slightly communicable in orchards.—Reference will again be made to orchards 1 and 2, already described. A statement of the condition of the trees in these orchards at the beginning of the

experiment and six years later, when the trees were dug, is given in Tables XXXIV and XXXV, in the appendix.

The results from the experiments, as shown in Tables XXXIV and XXXV, are as follows: The orchards were planted with trees 50.1 per cent of which were diseased with crown-gall. At the close of six years 40.5 per cent of the original number of trees was diseased, of which 15.8 per cent was diseased with crown-gall and 24.7 per cent with hairy-root.

Of 416 trees alive at the end of six years, 226, or 54.3 per cent, were healthy, as compared with 49.9 per cent of the original number.

In order to further analyze the results of the experiment, Tables XXXVI and XXXVII are given, with the separate record of the healthy and diseased trees in each plat.

From these tables it will be seen that, after deducting the dead trees, 1 out of the 83 healthy ones in orchard 1 had become diseased with crown-gall and 18 with hairy-root; and out of the 70 healthy trees in orchard 2, 10 had become diseased with crown-gall and 29 with hairy-root; but it was noted at the time of digging that in every case the amount of disease on the newly infected trees was slight, the badly diseased trees in the plat after six years being few in number and among those that were originally diseased. In comparison with this increase of disease it must be noted that, after deducting the number of dead trees, out of 96 diseased trees planted in orchard 1, 32 fully recovered and out of 139 diseased trees planted in orchard 2, 41 recovered entirely. In other words, where 58 trees became slightly diseased, 11 with crown-gall and 47 with hairy-root, 73 trees recovered from crown-gall during the same period without any treatment whatever.

This slight communicability shown by traces of disease is certainly almost negligible from the standpoint of the orchardist and must have occurred during the first growing season, since great care was taken not to wound the trees by cultivation. The experiment certainly indicates that apple trees when they are once established are not in danger of becoming seriously diseased on the roots if cultivated carefully and without incurring wounds, even when every tree 9 feet away in the adjacent rows is diseased, as in the experiment. There appears, then, no need of removing diseased trees from orchards, except when they are not doing well; that is, when they show every indication of becoming unprofitable or when there is danger of communicating the disease to valuable small fruits. The matter of communicability as it applies to other apple trees in the orchard need hardly he considered when the question of removal is being taken into account.

PREVENTION AND CURE.

PROBABLE FUTILITY OF ATTEMPTS AT PREVENTION.

Numerous recommendations have been made from time to time by plant pathologists and others looking toward the prevention of crown-gall by the removal of supposed sources of infection. These recommendations were made not specifically for the apple disease but for crown-gall in general. Advice has generally been given to obtain nursery trees as far as possible from nurseries free from disease. It has generally been considered that the planting of trees affected with crown-gall and hairy-root is liable to give rise to diseased trees throughout the orchard. In spite of the most vigorous nursery inspection for a number of years in many States the disease on apple trees is quite generally disseminated throughout the United States, and the writer knows of no apple-growing nursery that is entirely free from the forms of disease described in this bulletin.

Although much advice has been given for the prevention of the disease, little in the way of successful experimentation along this line has been done hitherto. Butz (7) planted healthy trees in infected land to which finely powdered sulphate of copper had been added. On account of the death of most of the trees, attributed to a serious drought, he was unable to make any generalization regarding the efficiency of this treatment. Sulphur used by him in the same way had no effect in retarding the disease.

Popenoe (45), in speaking of attempts made by growers in Kansas to prevent loss by apple crown-gall, says:

> It has been the hope of some nurserymen to prevent the large percentage of loss from diseased stock by planting their apple grafts in localities and soil not before in apple trees, but in some notable cases coming under my observation within the last few years this endeavor has failed signally of the object.

The writer personally knows of similar experiences by nurserymen in a number of localities in Kansas, Nebraska, Missouri, and Iowa.

The writer has conducted a number of experiments along the line of prevention and cure. Some of these have resulted in materially lessening the amount of disease present in nursery stock. The results will be given, in the hope that they will effect a great saving not only to nurseymen but to orchardists as well.

As a result of many observations in nearly three-fourths of the States in the Union the writer is of the opinion that the crown-gall organism is so widely disseminated that any system of eradication must fail.

In discussing methods to control and limit the formation of crown-gall and hairy-root on apple trees in nurseries and orchards, the the subject-matter will be brought under two general headings, one

dealing with methods for the control of the disease in the nursery, and the other with methods for its control in the orchard.

METHODS FOR THE CONTROL OF THE DISEASE IN NURSERY BINS.

Since it has been found that apple crown-gall is communicable, and can be transferred from the apple to the stone fruits, the raspberry, the blackberry, the rose, the grape, etc., and vice versa, nurserymen should at the time of digging pick out and remove all plants diseased with crown-gall. They should not be tied in bundles with other plants, owing to the slight possibility of transferring the disease to healthy wounded plants. In the case of apple-root grafts it has been shown that they are most susceptible at the time the graft is forming callus and is uniting. Care should be taken to keep the nursery bins, especially where material for root grafts is kept, free from diseased plants. It is best to clean all nursery bins and thoroughly spray them with a strong solution of copper sulphate each year before the time for storing trees for the winter.

PROPAGATION OF SUSCEPTIBLE VARIETIES OF APPLE TREES BY BUDDING.

It has been shown elsewhere in this bulletin that in most sections of the country where apple trees are propagated, both by budding and by root grafting, budded trees are freest from disease. For this reason it is advisable to propagate those trees most subject to crown-gall and woolly-knot by budding. There is an objection offered to budding on account of the necessity for growing the trees a year longer. The additional cost for this extra year may be more than offset by the increased number of healthy trees obtained by this method. The additional loss from woolly aphis during the last year of growth in the nursery is asserted by many nurserymen to be so great in some localities as to preclude budding. If such nurserymen will consult with the Bureau of Entomology of this Department as to the proper method of combating and controlling this troublesome insect pest by fumigation, etc., means will be found by which this loss may be greatly diminished, and propagation by budding in the case of varieties susceptible to crown-gall will become profitable.

IMPROVEMENT IN METHODS OF ROOT GRAFTING.

SELECTION OF HEALTHY SCIONS NECESSARY.

In the control of any disease that might be transmitted through root grafts it is perfectly logical to demand that the pieces, both scion and root, that are built into the root grafts should be healthy. It has been shown on page 23 that there is an increase in disease due to taking apparently healthy scions from trees whose roots are dis-

eased. Growers of root-grafted trees will make no mistake if they insist on getting scions from strictly healthy trees, and they should grow their own healthy scions if possible.

SELECTION OF HEALTHY SEEDLING ROOTS NECESSARY.

The selection of healthy seedling trees from which roots are to be taken for root grafts is of prime importance to the grower. It has already been shown by experiment that the selection of roots from seedling trees diseased with hairy-root often results in the growth of a tree with diseased and deformed roots (Pl. VII, figs. 3 and 4), one which is unmarketable, even though in many cases it would no doubt develop into a profitable tree in the orchard. It is not profitable to grow diseased trees or to be the distributor of diseased stock.

It has also been shown by experiment that it is not best to use the apparently healthy portion of a seedling root which bears a soft gall. The use of such stock will certainly result in an increase of this form of disease and can not be profitable.

Finally, it must be said to growers of seedling apple trees that when the seedlings are dug, all rough, warty, hairy, or tufted seedlings should be rejected and destroyed (Pl. III, fig. 1, and Pl. IX, fig. 2, *G* and *H*). As a matter of precaution, they should not be tied up with healthy seedlings. Nurserymen purchasing seedlings for making root grafts should insist on this.

CAREFUL FITTING OF ROOT GRAFTS NECESSARY.

The influence of a projecting scion in the formation of excessive callus and the liability of such callus through infection to develop into crown-gall has already been discussed. It will pay nurserymen to put a premium on neat, close-fitting tongue grafts made at a reasonably rapid rate rather than to encourage the rapid manufacture of a poorly-fitted graft with the scion projecting at the union or with one made too blunt at the lower end, such as are shown in Plate IX, figure 2, *C* and *D*. The best results with the least amount of disease will be secured by the use of No. 1 unbranched seedling roots upon which there have been closely and smoothly fitted scions of equal diameter, properly wrapped. The stress of competition in recent years has led to increased carelessness in the manner in which root grafts have been put together and to the use too often of inferior roots and scions.

EXPERIMENTS ON THE BEST METHODS OF WRAPPING ROOT GRAFTS.

Mention has been made of the tendency of root grafts to form excessive callus at the lower tip of the scion when stored under moist conditions in sawdust, excelsior, moss, and other similar materials. Where the two pieces of the graft are snugly fitted, there is little

tendency for the callus to form anywhere except in the intervening spaces. When the pieces are more or less imperfectly fitted and are not firmly held together, especially at the lower end of the scion, there is a tendency for the callus to grow out into the air, forming thick cushions (Pl. VIII, fig. 2) or gall-like outgrowths. The wrappings were planned to confine this formation of callous and to hasten the union between scion and root pieces.

In order to find a method of controlling the formation of callus, 25,200 root grafts were wrapped with various materials (Pl. VIII, fig. 1) during the winter of 1904–5. The idea of wrapping root grafts is not a new one, since nurserymen used both waxed cloth and waxed paper for many years before the present method of thread wrapping came into vogue.

All of the grafts made for the experiment were of the type known as "whip" or "tongue" grafts. They were especially well made from No. 1 Kansas roots, fitted with a selected lot of scions from each of the following varieties: Winesap, York Imperial, Wealthy, Missouri, and Northern Spy. They were made in February, packed in moist, chopped excelsior, and stored in a cool place for about six weeks.

The manner in which the wrapping was made and the material used may be briefly described as follows:

Wrapping with cloth.—The cloth used was a cheap black calico of the poorest grade obtainable in the market. (See Pl. VIII, fig. 1, *C.*) This was torn into strips 1 inch wide and 4 or 5 inches long. After the graft was made one end of the cloth was dipped for one-half inch into hot, melted grafting wax. Starting with the other end, the cloth was then wrapped tightly around the scion and the free waxed end pressed down. This completed the operation.

Wrapping with rubber.—The rubber used was of a quality similar to dental rubber, which is also frequently used for insulating wires. (See Pl. VIII, fig. 1, *E.*) It was bought in rolls 1 inch wide and was cut off in such lengths as were necessary to completely envelop the union. The rubber was usually wrapped so as to encircle the union twice, and the free end was fastened with rubber cement applied with a brush.

Wrapping with waxed paper.—Sheets of ordinary unglazed printers' paper were waxed on one side by coating them with hot grafting wax applied with a paint brush. (See Pl. VIII, fig. 1, *G.*) They were then cut into 1-inch strips, ten to twenty sheets being cut at one time, and these again into strips about 4 or 5 inches long. One paper strip was then wrapped around the union, the waxed side toward the graft, the free end being stuck down by pressing on it.

Wrapping with plain thread.—The thread used for the ordinary grafts was machine cotton No. 9. (See Pl. VIII, fig. 1, *A.*)

Wrapping with waxed thread.—The waxed thread used was machine cotton No. 28. This was soaked in hot grafting wax until thoroughly penetrated and was then allowed to drain while hot. (See Pl. VIII, fig. 1, *D.*)

Waxing the union.—Ordinary grafts were made with plain thread, wrapped as previously described, and then the union of scion and root was coated with melted grafting wax nearly at the point of hardening. (See Pl. VIII, fig. 1, *B.*)

Unwrapped grafts.—The grafts left without wrapping of any kind were made with special care, so that when the roots and scions were joined they remained quite firmly united. (See Pl. VIII, fig. 1, *F.*)

Results of experiments.—As these root grafts were made they were divided into eight equal duplicate sets. One set was planted in April, 1905, in each of the cooperative plats 1 to 8. (For description see p. 78.) All plats showed a fair stand in November, 1905. The trees grown from these grafts made with No. 1 seedlings and scions corresponding in diameter were from the beginning larger and more vigorous than any other lot of trees planted at the same time in other parallel experiments in which No. 2 seedling roots were used. This was the case even where scions of the same varieties were used. This proves that No. 1 seedlings are the best for root grafting.

In cooperative plats 1 to 4, one-third of the trees were dug at the end of one year, taking every third tree in each row; one-third at the end of the second year, taking each alternate tree in the row; and the remaining trees at the end of the third year. The results from these plats, designated as experiment 1, are given in Table XXXVIII, in the appendix.

Of the trees in cooperative plat 6, one-third were dug at the end of one year, taking every third tree in each row, and the remaining trees at the end of two years. The results from this plat, designated as experiment 2, are given in Table XXXIX.

Of the trees in cooperative plat 5, one-half, taking each alternate tree in the row, were dug at the end of the second year and the remaining trees at the end of the third year. The results from this experiment, which is designated as experiment 3, are given in Table XL.

All of the trees in cooperative plats 7 and 8 were dug at the age of 2 years. The results from these plats, designated as experiment 4, are given in Table XLI.

In order to show the general results from each kind of wrapping on 1-year-old, 2-year-old, and 3-year-old trees, the results from the four experiments are combined in Table XLII.

Finally, the results of the four wrapping experiments in cooperative plats 1 to 8 are summarized in Table XLIII for convenience in comparison and in summing up the results.

There were planted 3,600 root grafts with each kind of wrapping. The percentage of healthy trees grown from each set, given in order from the highest to the lowest, is as follows: Cloth, 78.2; rubber, 71.4; waxed paper, 62.5; waxed thread, 60.5; plain thread, 60.3; no wrapping, 49.6; and wax covered, 28.5.

The results from this series of experiments are comparable, considering the varying physical conditions of the plats in which the trees were grown, since other conditions were similar. There is but a slight variation in the experiments in the percentage of trees diseased in the case of each kind of wrapping. It is for this reason that the results from each experiment are given separately.

The conclusions taken from the experiment as a whole are these: Cloth is the best wrapping to use. Rubber is almost equal to cloth, but its cost is prohibitive. Waxed paper is a little better than ordinary thread wrapping, which is again better than waxed thread. The other two methods are not worth considering.

The percentage of trees in each set lost by disease, considering each diseased tree as a cull, is as follows: Cloth, 12.1; rubber, 15.7; waxed paper, 22; plain thread, 25; waxed thread, 28.6; no wrapping, 31.5; and wax covered, 38.2. These percentages do not include the root grafts that died.

The best way to consider the results of the experiment from the nurseryman's standpoint is to estimate the number of healthy trees to the acre that would be obtained by each method of wrapping. Not nearly all root grafts that are planted grow. Many die before they strike root, owing to various causes, such as the breaking of the callus in the union by careless bundling, poor soil, and conditions at the time of planting, etc. If 15,000 root grafts are required to plant an acre, the number of healthy trees to be obtained from each kind of wrapping, on the basis of the results from this experiment, is as follows: Cloth, 11,730; rubber, 10,610; waxed paper, 9,375; waxed thread, 9,075; plain thread, 9,045; no wrapping, 7,440; and wax covered, 4,275.

If apple trees are worth 8 cents each wholesale, the gain from the use of cloth wrapping as compared to the ordinary plain thread wrapping is 2,685 trees, or $214.80 per acre.

Attention is called to the fact that to get the best results any wrapping must hold the parts firmly together and that the union should be entirely covered, especially the lower end of the scion piece. It should also be noted that the cloth used was not waxed cloth, but ordinary cloth, a cheap calico without wax, except to fasten down the end. Waxed cloth may serve its purpose in preventing excessive formation of callus and in keeping out germs, but often does not rot

away soon enough to prevent a constriction of the tree at the point of wrapping.

It is suggested where cloth or cheap calico is used for wrapping that sections of the proper width be cut from the end of a bolt of cloth, using an ordinary lever paper trimmer, such as is found in printing shops. This will give narrow strips of cloth which can be placed on a reel in front of the wrapper. In nursery practice it has been found best and quickest to secure the end of the cloth after the graft has been wrapped by tying it with a half hitch instead of waxing it down. In no case should the cloth or any other wrapping be secured by drawing it under the end of the scion tongue, because anything placed at this point will act as a disturbing element and tend to increase the formation of callus and to permit the development of crown-gall.

LATER EXPERIMENTS IN WRAPPING ROOT GRAFTS.

A number of nurseries tried wrapping with cloth in 1908, and all that have reported to this office obtained good results. Some also report good results with waxed cloth and waxed paper.

Some nurserymen use raffia in place of thread for wrapping root grafts with good success. The method they use in wrapping is shown by Plate VIII, figure 1, *I*. In a small experiment in a greenhouse in 1906 raffia was found to be equally as good a wrapping as cloth when used as shown in Plate VIII, figure 1, *H*. There are two objections to the use of either cloth or raffia. The first is the increased expense of wrapping; the second is that neither is applied by the ordinary wrapper, who is usually a boy, in an effective manner. The lower end of the scion is often not bound down closely, allowing the formation of abundant callus and defeating the very purpose for which the cloth and raffia are intended.

As to what constitutes an ideal wrapping for root grafts the writer has repeatedly put himself on record in these words:

> An ideal wrapping should hold the root and scion pieces together firmly till the root graft has been planted in the nursery row. It should then rot quickly away.

The superiority of cloth as a wrapping has resulted in the invention by two different persons, one in Missouri and one in Alabama, of a continuous thread wrapping for grafts, which is applied evenly and closely over the surface of the union, just as thread is wound on a spool, and which is apparently superior to either cloth or raffia. (See Pl. IX, fig. 2, *B*.) In 1908 a test was made of this continuous thread wrapping for root grafts in comparison with the ordinary thread wrapping. (See Pl. IX, fig. 2, *A*.) Five hundred apple grafts were prepared in each manner, using scions from the Wealthy apple, a variety very susceptible to crown-gall and hairy-root. The grafts

were planted on the Arlington Experimental Farm of this Department and grown for one season in a moist, stiff, heavy, clayey soil. The results were as follows:

Of a total of 470 trees grown from grafts with continuous fine thread wrapping, 38.1 per cent was diseased with crown-gall and 16.8 per cent with hairy-root. Of a total of 419 trees grown from grafts with ordinary fine-thread wrapping, 48.7 per cent was diseased with crown-gall and 25.2 per cent with hairy-root. This is a difference of 19 per cent in favor of the new thread wrapping, aside from an increase in the stand of 10.2 per cent, indicating that it will probably prove to be as good as cloth, if not better. The new thread wrapping when applied with a machine made for the purpose can be used with far greater rapidity than any wrapping hitherto in use, and as it holds the union more firmly together it is destined, for this reason alone, to supersede the ordinary wrapping.

None of the forms of wrapping mentioned will prevent the formation of galls and of woolly-knot on the scion of a root graft above the union, since these occur above the wrapping, especially in such varieties as the Wealthy (Pl. II, fig. 3). In the case of Wealthy trees, such occurrence of disease on the scion often equals, or even exceeds, that at the union, as was noted in the foregoing experiment. To reduce this loss, budding or top-grafting must be resorted to, since wrapping reduces only the disease occurring on the union. In the nursery top-grafting is not practicable, owing to the amount of time that it consumes. The additional labor adds to the expense, so as to make the process unprofitable for the grower; not so with the orchardist who grows a few trees and who wishes to take the time. The Walbridge is a good, vigorous-growing tree, quite free from crown-gall, and is recommended as a good stock for top-grafting with the Wealthy in an orchard. The Walbridge and the Wealthy are hardy with reference to cold, and such a combination of scion and rootstalk should do well in the northern apple-growing States in the Mississippi Valley, such as Nebraska, Iowa, and other States in the same latitude.

THE USE OF WEAK ANTISEPTICS FOR THE PREVENTION OF DISEASE IN ROOT GRAFTS OF DOUBTFUL VALUE.

At various times a number of nurserymen have tried dipping scions and seedling roots in weak solutions of copper sulphate, either before or after making them into root grafts. Those who have experimented have reported little or no results in the prevention of disease.

In order to test the use of copper sulphate, an experiment was conducted with two equal sets of root grafts, planted, prepared, and

grown under the personal supervision of the writer. Both the scions and the seedling roots were grown in Virginia. The reason the stock was obtained from Virginia is that certain writers have insisted that most of the crown-gall comes from the West, especially from Kansas. Scions were taken of the following varieties: Wealthy, Gano, and Northern Spy. Before cutting it up into pieces for the root grafts two-fifths of the stock, both scions and seedlings, were dipped and thoroughly washed in a 2 per cent solution of copper sulphate in water. The grafts were made in the ordinary manner of making commercial whip grafts, except that care was used in fitting the scion and root pieces together. The results of the experiment are given in Table XLIV, in the appendix.

The results show a considerable decrease of crown-gall and hairy-root (13.8 per cent) in the case of the trees grown from disinfected stock, but this is more than offset by the decreased stand, which was less than one-half of that of the untreated trees. It is quite probable that there was enough copper sulphate present to interfere with the formation of the union in the graft, and it may yet be found that the use of a more dilute solution will prove beneficial. The experiment at least paves the way for further experimentation along this line with less concentrated solutions. Many of the scion pieces treated in the experiment died, while the seedling roots lived, thus indicating an imperfect formation of callus in the union, probably due to the action of the poison.

PACKING AND STORING ROOT GRAFTS.

There can be no question but that the packing and storing of root grafts before planting are of vital importance in the prevention of disease. Care should be taken to use fresh new packing for this purpose, avoiding the use of material or boxes which have been used for packing trees that may have been diseased. The time of formation of callus in the root graft is the most critical in the growth of the tree, and for this reason the grafts should be cared for with the greatest solicitude.

In order to prevent the excessive formation of callus, which predisposes the grafts to attacks of the disease, it will be necessary to follow one of two procedures. The best method is to pack the grafts in clean moist sand, and after a few days' favorable growing temperature store them in cold storage but slightly above freezing, keeping them there until planting time. Good results may be obtained by a second method, in which a cool cellar is used for the immediate storage of root grafts as fast as they are made. This method answers well if the temperature of the cellar can be kept at about 40° to 45° F., so that callus will form very slowly and the growth of shoots and roots will be held back.

For the proper development of callus in apple grafts, as already mentioned, it was found that sand was the best material for packing. The materials used in the experiment were steam sterilized. It will not be easy to thoroughly sterilize sand in the nursery unless improved machinery is invented, but with a little ingenuity in the arrangement of perforated steam pipes through the sand container, whether it be a box or a bin, most of the sand in use can be sterilized. Moss or excelsior can easily be sterilized more or less thoroughly by putting it in a barrel or box and passing through it live steam from a pipe. This will rid the packing material of fungi, a number of which are found attacking grafts improperly stored. Two such fungi are certainly species of Botrytis and Fusarium.

TIME OF PLANTING ROOT GRAFTS.

If root grafts are put in cold storage they can be held in good condition till the proper time for planting in the spring. If the facilities for holding back growth in root grafts are poor, then early planting is necessary. Do not allow the root grafts to form excessive callus and start to grow (Pl. VIII, fig. 2). In the writer's experiments the highest percentage of crown-gall occurred under such conditions.

CARE IN THE CULTIVATION OF TREES IN THE NURSERY.

It has been shown that root grafts acquire crown-gall chiefly during the first season's growth and that much of the crown-gall (Pl. II, fig. 3) and woolly-knot (Pl. VI, fig. 5) on certain varieties, such as the Wealthy, occurs on the scion portion of grafted trees near the surface of the soil. An examination of such galls usually shows the presence of a wound in the tissues at the base of each. This wound was evidently made with a hoe in cutting out weeds in the row while the trees were young. For this reason care should be taken to avoid wounding trees in cultivation.

When apple seedlings have been budded care should be taken not to ridge the dirt about the trees until the bud wounds have at least partially healed. If the trees are cultivated immediately after budding, crown-gall is often communicated to the callus forming in the fresh wound. It is better to cultivate a short time before budding rather than just after.

SELECTION OF HEALTHY TREES FOR THE SCION ORCHARD NECESSARY.

The matter of securing healthy scions for root grafting is important, as has been shown by the experiments with apparently healthy scions taken from trees with the roots diseased with crown-gall and hairy-root. It was shown that the use of such scions increased the amount of disease present in root-grafted trees (see pp. 23 and 25).

The planting of cull trees in the scion orchard can not be too strongly condemned, since the greater number of such trees are diseased with forms of crown-gall and hairy-root. Only healthy, vigorous trees should be planted in the scion orchard. Any tree in such orchards that shows even a trace of disease should be removed. A scion orchard should be used only as long as it is healthy and vigorous; then it should be replaced by a new orchard.

SELECTION OF THE BEST KINDS OF SOIL FOR GROWING TREES.

It is well known to experienced nurserymen that only certain tracts of land in any locality are suitable for growing trees. It has been strongly indicated by the results of the writer's experiments that heavy, wet, clayey soils increase the amount of crown-gall present, and that trees on many well-drained soils show the least disease. In general the light, loamy, well-drained soils, where fertile, are the best for growing apple trees with a minimum of disease.

CURE OF DISEASED TREES IN THE ORCHARD.

Experiments by others.—When an apple tree has become diseased with crown-gall and hairy-root it is a question as to whether any curative method can be used to insure a healthy growth. Some writers, notably the following, have advocated cutting off the tumors:

Howard (24), of Missouri, carried out the most extensive experiment in an attempt to cure crown-gall. He studied the subject for two years, employing many different remedies and combinations and experimenting with nearly 3,000 trees. He used the following: Copper sulphate (bluestone), iron sulphate (copperas), sodium chlorid (common salt), lime, sulphur, formalin, ammonia water, bichlorid of mercury (corrosive sublimate), copper carbonate, carbolic acid, hydrocyanic acid, potassium dichromate, mercuric cyanid, silver nitrate, gas tar, kerosene oil, Bordeaux mixture, and hot water.

The remedies were used in three ways: By dipping the roots in the materials; by sprinkling the soil with the solutions until the surface was wet just as trees were being planted; and by cutting away the galls and covering over the wounds with the materials to prevent their growing again. Howard's results show that some of the compounds did prevent the growth of the galls, but not without injury to the tree. He says that "copperas, bluestone, and lime mixed together and applied to the wound was the best remedy of all for preventing a new growth of galls, although this was not entirely efficacious." He mentions no control in which the galls were removed without treatment with fungicides.

Butz (7), in Pennsylvania, took 60 apple trees and cut off the galls from 40, one-half of which he dipped in Bordeaux mixture before

planting; the other 20 were planted without removing the galls, after dipping in Bordeaux mixture. After two seasons of growth, in which none of the trees died, no result from the treatment was obtained, as all of the trees still showed the disease.

Clinton (8) reports as follows from Connecticut:

> In 1899 Doctor Sturgis set out on the station grounds ten young trees affected with knots; part of these had the knots cut off, others had knots cut off and roots then treated with copper sulphate, and some were left with knots on. After three seasons of growth these trees were dug by the writer and the roots carefully examined. Very little difference could be seen in any of the trees at this time, and the knots had spread very little, if any.

Norton (37) says: "Apple trees slightly affected, often apparently recover and make good trees, but even then the life of the tree may be cut short and the ground infected."

Garman (15) advocates the removal of the diseased parts with a knife, but does not consider this treatment satisfactory, as it is likely to weaken the tree.

Alwood (2), experimenting with seven trees, from which he cut off the galls, giving the trees a subsequent treatment with strong Bordeaux mixture, found that several of them showed a characteristic growth of crown-gall; two made a more normal growth.

Recommendations for the treatment of the disease in orchards.—The question as to whether it is advisable to remove the galls from trees in an orchard depends, first, upon whether the presence of the gall in itself is of greater injury to the tree than the effect of the wound resulting from its removal combined with that of the antiseptics used for treating the wound; and, second, upon the danger of the disease spreading to other trees. In an apple orchard, from the results of the writer's experiments, it appears that there is no danger of a serious spread of this disease to other apple trees.

There is very good reason to conclude from the writer's experiments and studies that small knots, swellings, or tufts of roots on orchard trees have no effect on their growth. Where these knots, etc., can be removed without serious injury to the tree, it may be best to remove them. Knots or stem tumors on the outer limbs or twigs may be removed when they first appear. In cases where there are small growths, galls, or woolly-knot, on the trunks or roots of large, valuable trees (Pl. IX, fig. 1), it will not pay to injure the trunk of the tree by their removal.

Howard's experiments, previously cited, prove the futility of cutting crown-galls from the young apple trees and treating them with antiseptics. The trees used in his experiments, if they had not been treated, might be alive and bearing to-day.

In a small experiment with seedling trees, the writer cut off the soft galls from a number of yearling seedlings and planted the seed-

lings in a nursery row without further treatment. Of those living at the end of one year, 14, or 36.8 per cent, recovered; 16, or 42.1 per cent, developed traces of crown-gall; 3, or 7.9 per cent, developed large galls; and 5, or 13.2 per cent, developed hairy-root. At the same time there were planted in an adjacent row a number of the same lot of seedlings with both hard and soft galls remaining attached. During one season's growth 12, or 37.5 per cent, made no further development; 15, or 46.9 per cent, increased in size in pace with the growth of the tree; and 5, or 15.6 per cent, developed hairy-root from their surface. All that lived made a good growth. Of the first lot 25 per cent died, presumably nearly all from wounds, and of the second lot only 3 per cent died.

In planting an orchard it is better to plant healthy trees and take no risk of diseased trees recovering, since only about one-third of the trees diseased with crown-gall, as shown by experiments, fully recover. The initial cost of the orchard is only a small portion of the total cost of maintenance, and in general it pays to plant the best rather than to plant and attempt to cure diseased trees.

SUMMARY.

The disease or diseases of apple trees manifested by the forms or types known as crown-gall and hairy-root occur in nurseries and orchards in the United States wherever apple trees are grown. They have been reported in one or more forms from Europe, South Africa, New Zealand, and Australia.

The crown-gall type of the disease occurs on apple trees in two forms; the soft and the hard. The former differs slightly from the latter, especially in its more rapid growth, softer texture, and less permanent nature. Apple crown-gall in both forms is related to the crown-gall of the almond, apricot, blackberry, cherry, chestnut, grape, peach, pear, plum, prune, raspberry, rose, and walnut.

The hairy-root type of the disease is of four forms: The simple form, characterized by numerous roots springing at right angles from a larger or main root; the woolly-knot form, characterized by numerous more or less parallel roots springing from a hard gall or swelling on a longer root; broom-root, a side root which is much fasciated with fine branch roots, often negatively geotropic; and aerial tumors, or knots, which are the woolly-knot form on the limbs of the trees. All of these forms of hairy-root are probably directly related to the forms of crown-gall, but for convenience and clearness they are discussed and treated separately.

The soft form of crown-gall is most common on yearling apple seedlings, though usually not abundant. It is occasionally found on budded and root-grafted trees. The hard form is common on budded

and much more abundant on root-grafted trees. Hairy-root of the simple form is frequent on apple seedlings and on budded and root-grafted trees. The woolly-knot form of hairy-root is the most common form of the disease, especially on 3-year-old root-grafted trees in the nursery and on orchard trees. The broom-root form occurs occasionally on trees grown on loose soils.

Crown-gall of both forms develops chiefly the first year on seedlings and root-grafted trees in the nursery. It gains entrance almost entirely through wounds. On root-grafted trees it occurs most commonly on the lower end of the scion at the union. In the experiments less crown-gall was found on nursery trees the second and third years than the first, which is strong evidence that it ceases to develop to any great extent. Hairy-root develops on root-grafted trees to some extent the first two years, and to a less extent the third.

In the experiments varying the depth of planting the union had little effect on increasing or decreasing the amount of disease present in apple trees grown from root grafts, but a better stand of trees was obtained by the shallower planting of the union. Very little difference was shown in the amount of disease resulting from the use of the upper half and the lower half of seedling roots for making root grafts.

An increase of both crown-gall and hairy-root occurred in root-grafted trees when apparently healthy scions or roots were taken from trees otherwise diseased. The use for making root grafts of roots from apple seedlings diseased with the simple form of hairy-root resulted in an increased stand of trees in the nursery, but also in a large percentage of inferior trees diseased with hairy-root of the simple form. The disease did not as a rule extend from the root to the scion portion of the tree during the three years of growth in the experiment. Cuttings from seedlings diseased with this form of hairy-root usually sent out roots more readily than healthy cuttings and often developed into vigorous-growing trees.

Where scions for root grafts were taken from yearling trees and from bearing trees in the orchard, no great difference in the number of healthy trees obtained from either was noted, but there was a slight increase of disease in the trees from the scions taken from yearling stock.

Leaving a bud near the lower tip of the scion did not increase the disease in trees grown from root grafts. No great difference in the amount of disease present in trees from root grafts was noted where seedlings grown from both French and American seed were used. The results, however, were decidedly in favor of stock grown from American seed, since the stand of trees with the latter was 25 per cent better.

No essential difference was noted in trees grown from root grafts made from healthy seedling trees taken from a locality where nursery stock had been grown for many years as compared with those taken from a new locality where stock had not been grown previously.

Heavy, stiff, clayey, wet soils apparently increase the amount of disease, especially of crown-gall, in nursery stock. Some lighter soils show an increase of hairy-root.

In nursery experiments the amount of crown-gall present after the first year decreased considerably from year to year, while hairy-root increased slightly, especially during the first two years. In the orchard experiments the amount and intensity of the forms of the disease decreased instead of increasing, indicating that older apple trees in many cases successfully resist both hairy-root and crown-gall and that many may recover completely.

Crown-gall and hairy-root affected nursery trees in the experiments, stunting them very slightly and causing them to be only 90 to 94 per cent as large as healthy trees. In the experimental orchards the apparent effect on the growth of trees was even less—in fact, hardly perceptible. These experiments prove that the effect of crown-gall and hairy-root upon apple trees in the orchard has been overrated, at least in the established apple districts of the Central and Eastern States.

A marked difference in the susceptibility of varieties of apple trees to crown-gall and hairy-root has been noted. Trees of some varieties, when grown from root grafts, tend to develop a large amount of crown-gall; others of hairy-root, in both cases chiefly on the scion portion of root-grafted trees. In these experiments, the Wealthy, the Yellow Transparent, and the Wolf River were the varieties most diseased with crown-gall; and the Ben Davis, the Wolf River, and the Northern Spy were most diseased with hairy-root.

The period when most apple root grafts become diseased with crown-gall is apparently the time when the wounds in the union are being healed by the formation of callus. If the disease could be kept out during this period it is quite probable that little would occur on nursery stock except as it gained entrance later through wounds made in cultivation.

In the experiments, with the fitting of root grafts, where poorly fitted, especially if the lower end of the scion projected, an increase of both crown-gall and hairy-root occurred. The disease apparently did not spread from tree to tree in the nursery rows in the experiments, since there was little or no increase of disease after the first year.

Little of the crown-gall occurring in root-grafted trees can with certainty be accredited to the fact that grafting knives as a rule are not sterilized.

Root grafts should be carefully fitted, especially with respect to the lower end of the scion, which should have a sharp end rather than a blunt one. The wrapping used should cover the union completely and should firmly hold the parts together until the graft is planted in the soil; then it should rot away when growth begins.

In a large number of wrapping experiments cloth wrapping gave the best results. In a later experiment good results were obtained with a continuous-thread wrapping applied by a machine evenly and closely over all the union.

Sand was found to be the best material tested for packing and storing root grafts. Cold storage is best for root grafts that must be kept for some time before planting, since it prevents the overdevelopment of callus, a condition which favors the entrance of disease.

RECOMMENDATIONS.

The crown-gall and hairy-root of apple trees is primarily a nursery disease, gaining entrance most frequently the first year. In a well-regulated nursery it is desirable to grow and sell the best trees that can be obtained and at the same time not increase the cost of production. With this in view the following recommendations are made:

(1) In order to keep the nursery as free as possible from the disease all diseased trees should be left in the field at the time of digging and burned as soon as dry.

(2) The nurseryman should, as far as possible, get scions from healthy trees by growing them under careful selection or purchasing them from others who do this. Never plant diseased trees in the scion orchard.

(3) Buy the best grades of healthy seedlings for budding and root grafting. Insist that growers of apple seedlings cull out and burn all diseased ones at the time of digging.

(4) Make close-fitting root grafts, avoiding blunt ends of the root and scion in the union. Wrap with unwaxed cloth or continuous-thread wrapping, covering completely and firmly the wounded edges in the union. The root and scion should be approximately of the same diameter.

(5) Store root grafts preferably in sand. If the period of planting is delayed beyond two weeks they should be placed in cold storage at a temperature a few degrees above the freezing point.

(6) Plant the union of root grafts about 3 to 4 inches below the surface of the ground. Be careful not to break the callus in planting and avoid wounding the young plants in cultivation.

(7) Propagate by budding, as far as possible, the few varieties most susceptible to crown-gall and hairy-root. Among these are the

Wealthy, the Yellow Transparent, the Wolf River, the Ben Davis, and the Northern Spy.

(8) Avoid heavy, wet soils, since they favor an increase of disease.

(9) Growers of seedlings should avoid wounding the young trees with the hoe or other implements of cultivation.

That these precautions will decrease the disease is certain, as shown by the results of experiments, and an increased profit will result from their use. For example, wrapping with a close, tight, cloth covering decreased the percentage of diseased trees 12.9 per cent and resulted in an increase of stand amounting to 23.9 per cent of the original root grafts planted. This, based on 15,000 grafts to the acre, is a saving of $214.80 per acre. The continuous wrapping of root grafts with thread is more easily and cheaply done and promises to give equally as good results.

The orchardist is advised to plant the healthiest trees obtainable, since the initial cost of the orchard is only a small part of the final outlay. If a tree becomes diseased during the first three or four years so that its growth is hindered, dig it up and plant a healthy tree in its place. If trees in an older orchard are diseased, but still bearing profitable crops, allow them to remain in the orchard, unless there is danger of infecting more profitable plats of raspberries, grapes, or peaches. In such case they should be removed, since crown-gall from the apple tree may infect these plants.

If the growing of nursery stock were confined to apple trees, nursery inspection for crown-gall would hardly be necessary. Since the disease attacks and kills grapevines, raspberries, and probably peach trees, and since it may be communicated to them from apple trees, it is clearly the duty of a nursery inspector to insist that apple trees diseased with crown-gall shall not be sold. It is best to include in the same category apple trees diseased with hairy-root.

On the other hand, an inspector should be certain that apple trees are diseased with crown-gall or hairy-root before condemning them. Warts and pimples are not necessarily crown-gall, nor are fibrous roots certainly hairy-root. The tendency to form fibrous roots exists under certain soil conditions (Pl. III, fig. 4). In some localities and under certain soil conditions healthy trees with much-branched, fibrous roots are grown. These roots are to be distinguished from hairy-root formation, which is characterized at the beginning by clustered, fleshy, often fasciated roots, which later become fibrous through shrinking. Only plainly diseased trees should be rejected; other trees in the bundle should not be condemned on account of the presence of a diseased tree, but as a matter of precaution should be dipped in a weak solution of some antiseptic, as one-tenth of 1 per cent of corrosive sublimate, for five minutes and washed in water before planting.

APPENDIX.

METHODS AND CONDITIONS OF EXPERIMENTATION IN THE STUDY OF CROWN-GALL AND HAIRY-ROOT.

In order to prevent useless repetition, a brief description will be given of the methods and conditions under which each set of experiments was performed, the results of which are given in previous chapters and in the tables in the following portion of the appendix.

EXPERIMENTS IN THE GREENHOUSE.

All greenhouse experiments were conducted at the Mississippi Valley laboratory, St. Louis, Mo. Seedlings of various kinds of shrubs and trees were grown in pots and benches, as follows: All soil and pots were sterilized for three hours in an autoclave at a temperature of 239° F. The benches were constructed of new pine and cypress lumber. Before filling the benches with soil they were washed with a strong solution of Bordeaux mixture. All seeds before planting were sterilized in one of two ways—either in concentrate sulphuric acid for ten minutes or for an equal time in a one-fifth of 1 per cent solution of mercuric chlorid, followed in either case by repeated washings in sterile water. In these experiments 6,176 plants were grown and used in five years.

EXPERIMENTS IN THE NURSERY.

The experiments in nurseries were extensive and included the planting of 143,763 apple seedlings and root grafts of 256 varieties during a period of six years. They were of two kinds, independent and cooperative. In each experiment all seedlings, cuttings, or scions were selected from the same stock, all root grafts[a] were made and planted equally well in each portion, and all portions of each plat were of uniform soil and drainage and were cultivated equally well, all of the work being done by skilled workmen under the direction and personal supervision of the writer. Many experiments were duplicated in different localities, insuring greater accuracy in results.

Independent nursery experiments.—These were conducted in nursery plats on land owned or leased by the Department and cultivated by its employees. There were three plats of the following description:

Independent plat 1 was located near Louisiana, Mo., on a slightly sloping piece of upland consisting of a heavy, colluvial clay loam. It was situated so that it did not receive the overflow from adjacent

[a] In all experiments where the term "root graft" is used, unless otherwise specified, reference is made to the form of root graft known as whip or tongue graft.

fields. It had been planted to field crops for twenty years and had a clover crop when taken for the purposes of experiment. In the experiment on this plat 19,700 root grafts and trees were grown during 1903 and 1904 on 4 acres of land.

Independent plat 2 consisted of about one-half acre of level land on the Potomac Flats, south of Washington, D. C. It consisted of an alluvial loam, the soil having been formerly pumped by dredgers from the bottom of the Potomac River. In this plat 6,400 root grafts and seedling trees were planted in 1907.

Independent plat 3 consisted of about one-half acre of gently sloping clay loam on the Arlington Experimental Farm, in Virginia, southwest of Washington, D. C. In this plat 6,043 root grafts were planted in 1908.

Cooperative nursery experiments.—Experiments were conducted during the years 1905 to 1908 in cooperation with six of the largest nurseries in the Mississippi Valley. Eight experimental plats, of about 1 acre each, were planted in as many different localities in five States. A total of 113,620 seedlings and root grafts was planted. A description of the plats follows:

Cooperative plat 1 was located in southwestern Iowa on level valley land consisting of a colluvial clay loam. The previous crops for five years were grain.

Cooperative plat 2 was located in southwestern Iowa on sloping upland consisting of a light clay loam. The previous crops for five years were oats one year, corn one year, and plum trees three years.

Cooperative plat 3 was located in southeastern Nebraska on level upland consisting of a loess loam. The previous crops for five years were corn one year and cherry trees four years.

Cooperative plat 4 was located in western Illinois on level upland of heavy black loam mixed with clay. The previous crops for five years were grain.

Cooperative plat 5 was located on level valley land in eastern Missouri consisting of a colluvial loam mixed with some sand. The previous crops for five years were cowpeas one year and peaches four years.

Cooperative plat 6 was located in eastern Kansas on level valley land consisting of an alluvial sandy loam. The previous crops for five years were corn one year, osage orange one year, Kafir corn one year, and apples two years.

Cooperative plat 7 was located in eastern Missouri on level valley land consisting of a colluvial clay loam. The previous crops for five years were cowpeas one year and peaches four years.

Cooperative plat 8 was located in northwestern Arkansas on level valley land consisting of a sandy loam. The previous crops for five years were grain.

EXPERIMENTS IN ORCHARDS.

Four orchards were planted with both healthy and diseased apple trees. These were situated on land owned or leased by the Department. They were located and designated as follows:

Orchard 1 was located near Louisiana, Mo., on a gently sloping piece of upland consisting of a heavy clay loam. The land had been planted to grain and clover for twenty years. This orchard was planted to 208 apple trees.

Orchard 2 was located on the same block of land as orchard 1, but it was lower and wetter in rainy seasons. It contained 261 apple trees.

Orchard 3 was also located on the same block of land as orchard 1, but followed the trees grown in independent plat 1. It contained 1,108 apple trees.

Orchard 4 was first planted on the Potomac Flats, south of Washington, D. C., on built-up land from dredging, similar to that in independent plat 3. The 500 apple trees in this orchard after one year were transplanted to a block of land with a colluvial clay loam on the Arlington Experimental Farm, in Virginia, where they are now located.

The trees for planting in these orchards were selected as follows: Healthy, vigorous, 2-year-old apple trees with a well-balanced root system of smooth roots (Pl. III, fig. 3) were selected in each experiment for a check or control. To test the effects of the forms of disease there were selected sets of trees of the same varieties, of equal size, and from the same stock of trees, some of which were diseased with crown-gall (Pl. I, fig. 1) and others with hairy-root (Pl. I, fig. 2). All of the trees used in the experiments were selected by the writer. Both healthy and diseased trees were planted and tended equally well.

All of the data on these orchard and nursery experiments were personally recorded by the writer, notes being taken on each individual tree.

TABLES GIVING THE RESULTS OF EXPERIMENTS IN THE STUDY OF CROWN-GALL AND HAIRY-ROOT.[a]

TABLE I.—*Development of crown-gall and hairy-root on transplanted seedlings in the nursery.*

Age of seedlings.	Number of seedlings.	Seedlings, galled.	Seedlings, hairy.
Years.		*Per cent.*	*Per cent.*
1	350	0.6	3.1
2	116	1.4	11.7
3	114	1.5	9.4

TABLE II.—*Comparative development of crown-gall on grafted and budded trees in the nursery.*

Variety.	Year.	Grafted trees.		Budded trees.		Decrease in budded trees.
		Smooth.	Galled.	Smooth.	Galled.	
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Ben Davis	1904	78	22	91	9	13
Do	1905	60	40	92	8	32
Black Annette	1904	89	11	99	1	10
Grimes	1905	70	30	99	1	29
Oldenburg	1904	83	17	96	4	13
Do	1904	89	11	99	1	10
Wealthy	1904	54	46	93	7	39
Do	1904	83	17	97	3	14
Do	1904	88	12	98	2	10
Yellow Transparent	1904	94	6	99	1	5
Do	1904	89	11	92	8	3

The data in Table II are given from a number of localities in the Mississippi Valley, Virginia, and North Carolina. The names of the nurseries are withheld because the reports were confidential. At the time the reports were received, most nurserymen designated as "crown-gall" all forms of crown-gall and hairy-root, and in the table they are combined under the term "galled."

TABLE III.—*Results on the health of trees of varying the depth of the union in planting root grafts.*

Year.	Trees with long scions.		Trees with short scions.	
	Number.	Diseased.[b]	Number.	Diseased.[b]
		Per cent.		*Per cent.*
1905	754	13.3	769	13.5
1906	980	35.0	870	48.4
Total	1,734	25.5	1,639	32.0

[a] In these tables both forms of crown-gall are included under the term "galled," and all of the forms of hairy-root under the term "hairy," unless otherwise specified. The word "smooth" is used to designate trees free from the disease.

[b] In this table the term "diseased" includes "galled" and "hairy" trees.

TABLE IV.—*Results on the health of trees of varying the depth of the union in planting root grafts, second experiment.*

Year.	Trees with long scions.			Trees with short scions.		
	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
1905	1,288	21.3	7.6	1,446	20.9	7.5
1906	2,450	6.6	10.6	2,960	5.3	13.2
1907	1,079	.1	8.6	1,182	1.6	9.1
Total	4,817	9.4	7.5	5,588	8.6	10.8

TABLE V.—*Results on the health of trees of selecting upper and lower piece roots for root grafts.*

Year.	Trees from grafts on upper piece root.			Trees from grafts on lower piece root.		
	Number dug.	Galled.	Hairy.	Number dug.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
1905	743	19.8	7.7	703	22.0	7.4
1906	1,675	6.0	15.1	1,285	4.5	10.6
1907	580	1.9	10.9	602	1.3	7.5
Total	2,998	8.6	12.5	2,590	8.5	9.0

TABLE VI.—*Results on the health of trees of using seedlings diseased with hairy-root in root grafting, first series of experiments.*

Year.	Trees with hairy-root grafts.			Trees with smooth-root grafts.		
	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
First	1,132	11.5	73.8	751	24.8	7.9
Second	1,922	4.8	79.2	1,481	8.7	11.0
Third	922	7.4	76.5	632	7.1	10.9
Total	3,976	7.3	77.0	2,864	12.6	10.2

TABLE VII.—*Results on the health of trees of using seedlings diseased with hairy-root in making root grafts, second series of experiments.*

Year.	Trees with hairy-root grafts.			Trees with smooth-root grafts.		
	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
First	141	1.4	90.8	125	18.4	5.6
Second	268	2.2	84.2	245	3.7	10.6
Third	81	6.2	72.8	99	2.0	9.1
Total	490	2.6	83.7	469	7.3	8.9

TABLE VIII.—*Results on the health of trees of using seedlings diseased with crown-gall in making root grafts.*

Year.	Trees with smooth-root grafts.			Trees with galled-root grafts.		
	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
First	125	18.4	5.6	118	27.1	10.2
Second	245	3.7	10.6	165	20.1	15.7
Third	99	2.0	9.1	107	13.1	5.6
Total	469	7.3	8.9	390	20.2	11.2

TABLE IX.—*Comparison of the results on the health of trees from the use of scions from young and old trees in making root grafts.*

Year.	Trees with scions from young trees.			Trees with scions from old trees.		
	Number dug.	Galled.	Hairy.	Number dug.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
1905	229	17.5	6.1	215	8.3	10.7
1906	297	6.1	19.7	382	6.3	.2
1907	207	.5	15.0	193	1.0	10.4
Total	733	8.0	14.0	790	5.6	10.9

TABLE X.—*Comparison of the results on the health of trees of root grafts on seedling roots grown from French and from American seed.*

Year.	Trees from French seed.			Trees from American seed.		
	Number dug.	Galled.	Hairy.	Number dug.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
1905	491	46.8	2.7	528	42.8	4.7
1906	913	11.7	6.8	1,282	6.0	7.7
1907	398	1.7	7.3	445	4.0	8.1
Total	1,802	19.1	5.8	2,255	14.2	7.1

TABLE XI.—*Results on the health of trees of using seedlings from localities where nursery stock has been grown for many years.*

Year.	Trees from an old locality.			Trees from a new locality.		
	Number dug.	Galled.	Hairy.	Number dug.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
1905	937	40.2	3.5	491	46.8	2.7
1906	1,816	7.9	5.5	913	11.7	6.8
1907	738	3.6	4.1	398	1.7	7.3
Total	3,491	15.7	4.7	1,802	19.1	5.8

TABLE XII.—*Results on the health of trees of heavy, wet soil compared with drier soil in the same locality.*

Number of plat.	Nature of soil.	Trees grown.			
		Number.	Healthy.	Galled.	Hairy.
			Per cent.	*Per cent.*	*Per cent.*
1	Heavy, wet loam	5,018	75.1	19.4	5.5
2	Light, drier loam	6,038	75.9	14.1	10.0

TABLE XIII.—*Results on the health of trees of heavy, wet soils compared with dry soils in different localities.*

Number of plat.	Nature of soil.	Trees grown.		
		Number.	Healthy.	Diseased.
			Per cent.	*Per cent.*
6	Heavy, wet loam	4,460	76.6	23.4
7	do	4,798	77.9	22.1
3	Light, loess loam	4,454	86.0	14.0
8	Light, sandy loam	4,809	87.7	12.3

TABLE XIV.—*Maximum development of crown-gall and hairy-root, by years, on grafted trees.*

Number of set.	Trees dug.			Galled.			Hairy.		
	First year.	Second year.	Third year.	First year.	Second year.	Third year.	First year.	Second year.	Third year.
	No.	*No.*	*No.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	3,392	3,168	3,254	24.5	13.8	7.7	6.2	9.8	9.7
2	1,521	1,434	1,316	47.7	10.3	3.6	3.0	6.3	6.2
3	2,161	2,014	2,077	24.2	4.3	1.8	7.5	9.1	8.7
4	1,078	1,003	998	13.3	5.1	3.1	2.6	5.3	6.5
5	782	745	612	25.3	8.3	3.6	4.1	9.3	9.8
6	350	309	321	15.7	6.2	.9	7.4	7.4	11.2
7	620	584	567	26.9	6.8	7.6	7.3	10.6	10.6
Total	9,904	9,257	9,145	26.7	9.1	4.7	5.5	8.6	8.7

Total trees in experiment, 28,306.

TABLE XV.—*Average height of healthy and diseased root-grafted trees at the age of one year*

Location of plats.	Healthy trees.		Galled trees.		Hairy-rooted trees.	
	Number.	Height.	Number.	Height.	Number.	Height.
		Inches.		*Inches.*		*Inches.*
Southwestern Iowa	1,689	35.8	724	32.4	265	32.8
Do	1,293	36.3	759	33.7	169	33.2
Southeastern Nebraska	1,936	37.0	653	33.1	287	34.0
Eastern Kansas	1,665	43.1	578	42.4	386	39.9
Western Illinois	1,300	30.5	889	28.8	246	26.6
Total	7,883	37.2	3,603	33.5	1,353	34.0

TABLE XVI.—*Average height of healthy and diseased root-grafted trees at the age of two years.*

Location of plats.	Healthy trees.		Galled trees.		Hairy-rooted trees.	
	Number.	Height.	Number.	Height.	Number.	Height.
		Inches.		*Inches.*		*Inches.*
Southwestern Iowa	1,902	50.7	302	47.7	411	45.3
Do	1,444	63.6	267	57.6	327	56.9
Southeastern Nebraska	2,146	52.2	324	50.7	417	51.0
Eastern Kansas	3,028	61.6	680	59.4	842	59.8
Western Illinois	1,639	52.5	246	48.7	270	48.7
Total	10,159	56.4	1,819	51.3	2,267	53.0

TABLE XVII.—*Average diameter of healthy and diseased trees in orchards 1 and 2.*

Variety.	Number of orchard.	Healthy trees.		Galled trees.		Hairy-rooted trees.	
		Number.	Average diameter.	Number.	Average diameter.	Number.	Average diameter.
			Inches.		*Inches.*		*Inches.*
York Imperial	1	16	2.64	4	2.10	8	2.64
Do	2	47	2.77	8	2.39	22	2.51
Total		63	2.74	12	2.29	30	2.55
Ingram	1	16	2.48	2	2.42	10	2.16
Do	2	23	2.36	9	2.04	10	2.42
Total		39	2.42	11	2.10	20	2.29
Gano	1	44	2.26	11	2.39	22	2.23
Do	2	16	2.16	13	1.88	18	2.23
Total		60	2.23	24	2.10	40	2.23
Collins	1	39	2.23	4	2.67	14	2.48
Do	2	25	2.23	23	2.00	12	2.23
Total		64	2.23	27	2.10	26	2.36
Total for all varieties		226	2.42	74	2.13	116	2.36

TABLE XVIII.—*Number of healthy trees planted of each variety and the number dying in orchards 1 and 2.*

Number of orchard.	York Imperial trees.		Ingram trees.		Gano trees.		Collins trees.		Total.	
	Planted.	Died.	Planted.	Died.	Planted	Died.	Planted.	Died.	Planted.	Died.
1	16	3	16	2	48	3	32	2	112	10
2	45	5	23	5	27	3	27	0	122	13
Total	61	8	39	7	75	6	59	2	234	23

TABLE XIX.—*Number of diseased trees planted of each variety and the number dying in orchards 1 and 2.*

Number of orchard.	York Imperial trees.		Ingram trees.		Gano trees.		Collins trees.		Total.	
	Planted.	Died.	Planted.	Died.	Planted.	Died.	Planted.	Died.	Planted.	Died.
1	16	1	16	2	32	0	32	5	96	8
2	45	8	31	7	27	4	36	3	139	22
Total	61	9	47	9	59	4	68	8	235	30

TABLE XX.—*Number of trees dying in orchard 3 during two years' growth.*

Condition of roots.	Trees planted in 1907.	Trees dead in 1907.		Trees dead in 1908.		Trees alive in 1908.	
	Number.	*Number.*	*Per cent.*	*Number.*	*Per cent.*	*Number.*	*Per cent.*
Healthy	572	182	31.8	9	1.6	381	66.6
Galled	177	60	33.9	6	3.4	111	62.7
Hairy	359	69	19.2	21	5.9	269	74.9

TABLE XXI.—*Results of experiments showing the susceptibility of different varieties of apple trees to crown-gall and hairy-root.*

Variety.	Crown-gall.	Variety.	Hairy-root.	Variety.	Crown-gall and hairy-root.	Number of trees.
	Per cent.		*Per cent.*		*Per cent.*	
Wealthy	34.4	Ben Davis	29.9	Wolf River	46.4	660
Yellow Transparent	27.1	Wolf River	25.3	Wealthy	43.3	6,221
Wolf River	21.1	Northern Spy	19.1	Ben Davis	36.1	2,870
Maiden Blush	19.1	Grimes	15.3	Yellow Transparent.	34.0	2,114
Fameuse	17.8	Gano	12.6	Maiden Blush	26.4	1,698
Oldenburg	17.7	Northwestern Greening.	10.5	Northern Spy	26.0	4,166
Missouri	15.5	Red June	10.5	Missouri	25.9	5,591
Jonathan	15.1	Missouri	10.4	Fameuse	25.8	552
Red June	15.0	Scott Winter	9.3	Red June	25.5	2,152
Whitney	14.8	Rambo	9.3	Gano	24.3	2,284
Rambo	14.2	Yellow Bellflower	9.2	Oldenburg	24.0	1,883
Baldwin	11.9	Wealthy	8.9	Grimes	23.7	2,477
Gano	11.7	Walbridge	8.9	Rambo	23.5	1,148
Salome	11.1	York Imperial	8.3	Jonathan	21.0	1,668
York Imperial	9.9	Fameuse	7.4	Whitney	20.4	2,287
Minkler	9.8	Maiden Blush	7.3	Northwestern Greening.	18.2	3,963
Grimes	8.4	Minkler	7.0	York Imperial	18.1	4,073
Northwestern Greening.	7.7	Salome	6.9	Salome	18.0	623
Scott Winter	7.5	Yellow Transparent.	6.9	Scott Winter	16.8	613
Yellow Bellflower	7.3	Oldenburg	6.3	Minkler	16.8	1,251
Northern Spy	6.9	Jonathan	5.9	Baldwin	16.6	1,497
Ben Davis	6.2	Martha	5.9	Yellow Bellflower	16.5	546
Walbridge	5.2	Whitney	5.6	Walbridge	14.1	2,328
Martha	4.8	Baldwin	4.7	Martha	10.7	1,286

In Table XXI in the first two columns is given the percentage of trees of 24 varieties diseased with crown-gall, arranged in the order of their susceptibility, from the highest to the lowest; in the third and fourth columns is given the percentage of the same varieties diseased with hairy-root, similarly arranged; in the fifth and sixth col-

umns the results of the first four columns are combined; and in the last column is given the total number of trees of each variety grown in five years.

TABLE XXII.—*Results of experiments showing the variation in susceptibility to disease of scions from different localities.*

Number of nursery.	Location.	Trees in experiment.			
		Number.	Diseased.	Galled.	Hairy.
			Per cent.	*Per cent.*	*Per cent.*
VARIETY, WOLF RIVER. EXPERIMENT CONDUCTED IN EASTERN KANSAS.					
1	Iowa	244	40.2	20.1	20.1
2	do	50	38.0	14.0	24.0
9	Missouri	250	36.4	17.2	19.2
3	do	189	33.3	14.8	18.5
6	do	175	30.8	11.4	19.4
8	Iowa	280	30.3	10.7	19.6
5	California	190	26.8	8.9	17.9
4	Michigan	250	26.4	8.0	18.4
7	Ohio	327	22.5	6.4	16.5
VARIETY, WEALTHY. EXPERIMENT CONDUCTED IN EASTERN MISSOURI.					
12	Missouri	345	29.6	18.8	10.8
11	Kansas	800	25.0	20.1	4.9
1	Iowa	300	23.0	17.6	5.4
10	California	90	22.2	16.7	5.5
3	Missouri	200	21.0	13.0	8.0
9	do	85	20.0	14.1	5.9
7	Ohio	377	19.4	14.3	5.1
2	Iowa	190	14.2	7.9	6.3
4	Michigan	315	12.1	8.0	4.1
VARIETY, YELLOW TRANSPARENT. EXPERIMENT CONDUCTED IN EASTERN NEBRASKA.					
1	Iowa	309	19.1	2.8	9.1
3	Missouri	200	10.0	5.0	5.0
4	Michigan	460	8.7	3.5	5.2
2	Iowa	190	7.9	3.2	4.7
6	Missouri	177	7.2	1.7	5.6
5	California	335	6.3	1.8	4.5

TABLE XXIII.—*Results of experiments showing the comparative communicability of forms of crown-gall and hairy-root.*

Treatment of seedlings.	Seedlings in experiment.		
	Number.	Galled.	Hairy.
		Per cent.	*Per cent.*
1, Control, cut	1,447	0.8	6.6
2, Control, chip inserted	1,426	1.1	8.4
3, Piece of soft gall inserted	1,382	8.7	7.2
4, Piece of hard gall inserted	1,324	1.6	6.5
5, Piece from hairy-root seedling inserted	1,330	3.1	6.2

TABLE XXIV.—*Results from using root grafts inoculated with pieces of apple crown-gall of the soft form.*

Number of experiment.	Age of trees.	Number of trees.	Uninoculated grafts.		Grafts inoculated with gall chip.		Grafts with root chip inserted.	
			Galled.	Hairy.	Galled.	Hairy.	Galled.	Hairy.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	1 year	1,600	25.3	4.1	45.4	3.6	39.5	2.8
1	2 years	1,445	8.3	9.3	36.6	6.3	10.6	8.3
1	3 years	1,378	3.6	9.4	19.5	7.6	4.6	10.4
		4,423	10.8	7.5	34.2	5.8	18.9	7.1
2	1 year	464	4.2	11.1	38.0	17.0	14.7	17.1
2	2 years	661	14.7	12.9	35.7	20.5	16.5	15.2
		1,125	10.4	12.1	36.5	19.2	15.7	16.0
3		1,586	8.0	8.1	22.6	8.8	10.7	10.7
Total		7,134	11.8	8.5	31.4	8.5	16.5	9.0

TABLE XXV.—*Results of experiments showing the increase in the communicability of disease due to defective root grafting.*

Number of experiment.	Age of trees.	Trees with grafts well made.			Trees with grafts poorly made.		
		Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
			Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
1	1 year	1,078	13.3	2.6	869	55.0	3.1
1	2 years	898	5.1	5.3	771	15.3	7.4
1	3 years	998	3.1	6.5	789	4.3	10.3
		2,974	7.6	5.0	2,429	25.9	6.8
2	1 year	268	11.6	4.1	247	51.5	1.6
2	2 years	447	7.4	9.2	401	16.5	16.2
		715	8.8	7.3	648	29.8	10.7
3	2 years	1,283	6.9	7.9	1,035	19.9	11.9
Total		4,972	7.9	5.9	4,112	25.0	8.8

TABLE XXVI.—*Results of experiments with scions taken from trees diseased with crown-gall and with scions from healthy trees. (Experiment 1.)*

Variety.	Number obtained from scions from healthy trees.			Number obtained from scions from diseased trees.		
	Smooth.	Galled.	Hairy.	Smooth.	Galled.	Hairy.
Collins	122	71	52	105	53	107
Wealthy	29	56	21	19	75	10
York Imperial	112	24	8	99	36	18
Gano	107	30	33	77	16	33
Jonathan	207	36	25	191	58	38
Total	577	217	139	491	238	206
Percentage for all five varieties	61.8	23.3	14.9	52.5	25.5	22.0

TABLE XXVII.—*Results from experiments with scions taken from trees diseased with crown-gall and with scions from healthy trees.* (*Experiment 2.*)

Variety.	Number obtained from scions from healthy trees.			Number obtained from scions from diseased trees.		
	Smooth.	Galled.	Hairy.	Smooth.	Galled.	Hairy.
Gano	236	3	44	200	16	30
Wealthy	281	93	44	388	169	61
Wolf River	87	2	12	104	14	30
Total	604	98	100	692	199	121
Percentage for all three varieties	75.3	12.2	12.5	68.4	19.6	12.0

TABLE XXVIII.—*Results from experiments with scions taken from trees diseased with hairy-root and with scions from healthy trees.* (*Experiment 2.*)

Variety.	Number obtained from scions from healthy trees.			Number obtained from scions from diseased trees.		
	Smooth.	Galled.	Hairy.	Smooth.	Galled.	Hairy.
Northern Spy	70	0	13	68	3	11
Gano	236	3	44	180	7	50
Wolf River	87	2	12	140	2	25
Charlamoff	87	2	12	30	1	70
Total	480	7	81	418	13	156
Percentage for all four varieties	84.5	1.2	14.3	71.2	2.2	26.6

TABLE XXIX.—*Results from experiments with scions taken from trees diseased with crown-gall and with scions from healthy trees.* (*Experiment 3.*)

Variety.	Number obtained from scions from healthy trees.			Number obtained from scions from diseased trees.		
	Smooth.	Galled.	Hairy.	Smooth.	Galled.	Hairy.
Wolf River	46	20	14	38	6	12
Gano	65	4	35	43	0	23
Wealthy	93	83	11	127	153	38
Total	204	107	60	208	159	73
Percentage for all three varieties	54.9	28.9	16.2	47.3	36.1	16.6

TABTE XXX.—*Results from experiments with scions taken from trees diseased with hairy-root and with scions from healthy trees.* (*Experiment 3.*)

Variety.	Number obtained from scions from healthy trees.			Number obtained from scions from diseased trees.		
	Smooth.	Galled.	Hairy.	Smooth.	Galled.	Hairy.
Wolf River	46	20	14	44	20	35
Gano	65	4	35	47	10	38
Wealthy	93	83	11	37	16	8
Northern Spy	16	6	17	13	0	3
Charlamoff	14	0	7	24	1	34
Total	234	113	84	165	47	118
Percentage for all five varieties	54.3	26.2	19.5	50.0	14.2	35.8

TABLE XXXI.—*Results from experiments showing the decrease of disease among trees in nursery rows during the second and third years. (Experimental set 1.)*

Number of experiment.	Number of trees in experiment.	Diseased trees, first year.		Diseased trees, second year.		Diseased trees, third year.	
		Galled.	Hairy.	Galled.	Hairy.	Galled.	Hairy.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	9,814	24.5	6.2	13.8	9.8	7.7	9.7
2	4,271	47.7	3.0	10.3	6.3	3.6	6.2
3	6,252	24.2	7.5	4.3	9.1	1.8	8.7
4	3,079	13.3	2.6	5.1	5.3	3.1	6.5
5	2,139	25.3	4.1	8.3	9.3	3.6	9.8
6	980	15.7	7.4	6.2	7.4	.9	11.2
7	1,671	26.9	7.3	6.8	10.6	7.6	10.6
Total	28,206	26.7	5.5	9.1	8.6	4.7	8.7

TABLE XXXII.—*Results from experiments showing the decrease of disease among trees in nursery rows the second year. (Experimental set 2.)*

Number of experiment.	Number of trees in experiment.	Diseased trees, first year.		Diseased trees, second year.	
		Galled.	Hairy.	Galled.	Hairy.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	2,480	22.6	7.6	19.1	13.1
2	1,187	24.7	6.0	12.0	10.5
3	1,733	9.1	7.9	2.8	9.7
4	1,369	30.7	2.9	11.5	12.5
5	1,105	15.1	14.7	20.6	15.4
6	201	3.4	13.1	3.4	27.3
7	379	14.5	11.4	14.9	12.1
Total	8,454	20.0	7.9	12.8	10.3

TABLE XXXIII.—*Results from experiments showing the decrease of disease among trees in nursery rows the third year. (Experimental set 3.)*

Number of experiment.	Number of trees in experiment.	Diseased trees, second year.		Diseased trees, third year.	
		Galled.	Hairy.	Galled.	Hairy.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	2,308	11.7	6.7	3.3	13.5
2	556	12.5	4.3	1.8	4.7
3	1,005	6.2	6.8	1.1	10.3
4	446	12.6	5.4	9.1	7.2
5	642	20.6	4.6	1.9	5.6
6	133	9.0	10.4	.0	3.0
7	136	14.1	14.1	3.1	13.8
Total	5,226	11.7	6.4	2.6	10.2

TABLE XXXIV.—*Condition of the roots of the trees in orchards 1 and 2 at the time of planting.*

Number of orchard.	Number of trees planted.	Healthy trees.		Galled trees.	
		Number.	Per cent.	Number.	Per cent.
1	208	112	53.8	96	46.2
2	261	122	46.7	139	53.3
Total	469	234	49.9	235	50.1

TABLE XXXV.—*Condition of the roots of the trees in orchards 1 and 2 after six years' growth.*

Number of orchard.	Dead trees.		Healthy trees.		Galled trees.		Hairy-rooted trees.	
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
1	18	8.6	115	55.3	21	10.1	54	26.0
2	35	13.4	111	42.5	53	20.3	62	23.8
Total	53	11.3	226	48.2	74	15.8	116	24.7

TABLE XXXVI.—*Results from experiments showing the development of disease upon healthy trees grown for six years in orchards 1 and 2.*

Number of orchard.	Healthy trees planted.	Condition of trees after six years.			
		Dead.	Healthy.	Galled.	Hairy.
1	112	10	83	1	18
2	122	13	70	10	29
Total	234	23	153	11	47
Per cent	100	9.8	65.4	4.7	20.1

TABLE XXXVII.—*Results of experiments showing the recovery of diseased trees during six years in orchards 1 and 2.*

Number of orchard.	Diseased trees planted.	Condition of trees after six years.			
		Dead.	Recovering.	Galled.	Hairy.
1	96	8	32	20	36
2	139	22	41	43	33
Total	235	30	73	63	69
Per cent	100	12.8	31.1	26.8	29.3

TABLE XXXVIII.—*Results of experiments in wrapping root grafts.* (*Experiment 1.*)

Kind of wrapping.	Trees 1 year old.			Trees 2 years old.			Trees 3 years old.		
	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
		P. ct.	*P. ct.*		*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*
Cloth	553	9.9	2.9	538	7.6	4.3	566	2.6	4.6
Rubber	546	8.6	3.9	478	9.2	8.6	523	5.0	9.5
Waxed paper	525	25.3	3.8	486	10.5	8.2	508	6.3	10.0
Plain thread	504	22.2	10.7	486	12.4	11.3	469	7.7	11.3
Waxed thread	561	31.5	7.5	521	19.8	11.7	520	11.3	9.8
No wrapping	391	41.9	9.5	386	14.8	15.8	389	10.5	11.3
Waxed union	312	46.5	6.1	273	29.7	11.3	273	15.0	12.5

TABLE XXXIX.—*Results of experiments in wrapping root grafts.* (*Experiment 2.*)

Kind of wrapping.	Trees 1 year old.			Trees 2 years old.		
	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Cloth	142	9.9	3.5	254	10.2	5.5
Rubber	147	10.2	4.1	239	12.5	12.1
Waxed paper	143	28.7	9.1	238	17.2	12.6
Plain thread	148	18.9	10.8	234	19.7	14.1
Waxed thread	121	24.8	9.9	253	23.3	15.0
No wrapping	144	33.3	7.6	245	21.6	15.1
Waxed union	65	70.7	7.7	47	42.6	6.4

TABLE XL.—*Results of experiments in wrapping root grafts.* (*Experiment 3.*)

Kind of wrapping.	Trees 2 years old.			Trees 3 years old.		
	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Cloth	201	10.4	8.0	193	3.6	6.7
Rubber	168	7.7	4.8	174	1.7	9.2
Waxed paper	160	11.9	6.3	158	2.5	15.8
Plain thread	173	8.1	10.4	193	4.1	16.6
Waxed thread	185	12.4	6.5	179	4.5	14.0
No wrapping	185	14.6	5.4	174	3.5	18.4
Waxed union	87	21.9	4.6	68	3.0	17.6

TABLE XLI.—*Results of experiments in wrapping root grafts.* (*Experiment 4.*)

Kind of wrapping.	Trees 2 years old.					
	Arkansas plat.			Missouri plat.		
	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Cloth	404	4.0	6.7	340	6.8	5.6
Rubber	385	4.9	10.1	392	5.1	13.5
Waxed paper	374	2.4	13.1	292	8.6	14.0
Plain thread	380	3.2	22.1	293	6.4	13.7
Waxed thread	359	7.5	19.5	344	8.7	11.3
No wrapping	352	6.5	19.0	335	7.8	19.4
Waxed union	175	10.9	17.1	298	13.1	18.1

TABLE XLII.—*Combined results for three years of experiments in wrapping root grafts. (Experiments 1 to 4.)*

Kind of wrapping.	Trees 1 year old.			Trees 2 years old.			Trees 3 years old.		
	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.	Number.	Galled.	Hairy.
		P. ct.	*P. ct.*		*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*
Cloth	705	9.8	4.4	1,737	7.3	5.9	759	2.9	5.1
Rubber	693	8.9	3.9	1,661	7.6	10.2	697	4.1	9.5
Waxed paper	668	26.0	5.0	1,550	9.3	11.0	666	5.4	11.4
Plain thread	652	21.5	10.7	1,566	9.6	14.9	672	6.6	12.6
Waxed thread	682	30.3	8.0	1,662	14.6	13.1	705	9.5	11.6
No wrapping	535	39.6	9.0	1,504	12.4	16.5	563	8.4	13.5
Waxed union	379	48.8	6.6	938	21.5	14.1	341	12.6	13.5

TABLE XLIII.—*Final summary of results of experiments 1 to 4 in wrapping root grafts.*

Kind of wrapping.	Healthy trees.	Galled trees.	Hairy-rooted trees.
	Number.	*Per cent.*	*Per cent.*
Cloth	2,814	6.8	5.3
Rubber	2,571	7.1	8.6
Waxed paper	2,251	12.3	9.7
Waxed thread	2,178	16.9	11.7
Plain thread	2,168	11.6	13.4
No wrapping	1,784	17.2	14.3
Wax covered	1,025	26.0	12.2
Total	14,791		

TABLE XLIV.—*Results of experiments in washing apple scions and roots in a 2 per cent copper-sulphate solution.*

Variety.	Trees grown from untreated stock.			Trees grown from stock treated with copper sulphate.		
	Smooth.	Galled.	Hairy.	Smooth.	Galled.	Hairy.
Wealthy	115	121	23	49	27	3
Northern Spy	57	8	9	33	1	4
Gano	77	2	48	40	2	14
Total	249	131	80	122	30	21
Per cent	54.1	25.5	17.8	70.5	17.4	12.1

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PLATES.

DESCRIPTION OF PLATES.

PLATE I. *Frontispiece.* Fig 1.—A 2-year-old York Imperial apple tree diseased with the hard form of crown-gall. This tree was planted in orchard 1 and is typical of the most seriously diseased trees planted in the experimental orchards. Fig. 2.—A 2-year-old Ben Davis apple tree diseased with the woolly-knot form of hairy-root. This tree was planted in orchard 4 and is typical of many of the trees in this orchard.

PLATE II. Fig. 1.—Two seedling apple trees diseased with the soft form of crown-gall. These were graft-inoculated with pieces of live soft crown-galls from the roots of rose bushes before they were planted out. Fig. 2.—Two seedling apple trees diseased as those in figure 1, except that they were inoculated with pieces of live soft galls from the roots of raspberry plants. Fig. 3.—Two yearling Wealthy apple trees diseased with the hard form of crown-gall. These trees were grown from root grafts, and the galls formed on the scion portion of the trees above the union of the scion and root pieces. Fig. 4.—A 2-year-old root-grafted York Imperial apple tree diseased with the hard form of crown-gall on the lower end of the scion. Fig. 5.—The same form of disease as that shown in figures 1 and 2 on a 2-year-old Wealthy apple tree in which the gall surrounds the union.

PLATE III. Fig. 1.—Yearling apple tree diseased with the simple form of hairy-root. These are typical of the seedlings used in the experiments with this form of the disease. Fig. 2.—A 2-year-old Jonathan apple tree diseased with the broom-root form of hairy-root, from cooperative plat 3. Fig. 3.—A healthy, smooth-rooted apple tree, typical of those planted in orchards 1 to 4. Fig. 4.—A healthy seedling apple tree with an excess of fibrous roots, but not a trace of either crown-gall or hairy root.

PLATE IV. Fig. 1.—An early stage of the aerial form of hairy-root at the base of a terminal bud on a Charlamoff apple-tree twig. Fig. 2.—Another portion of the same twig, showing the knot that formed during each of the preceding years at the base of the terminal bud. Fig. 3.—Early stage of the aerial form of hairy-root at the base of buds on a much larger limb of the same tree from which the twigs shown in figures 1 and 2 were taken.

PLATE V. Fig. 1.—Mature stage of the aerial form of hairy-root on a limb of a Winesap seedling apple tree. Fig. 2.—Another diseased limb of the same tree, showing a development of roots (woolly-knot) from some of the knots after the limb had been placed in a moist chamber for two weeks.

PLATE VI. Fig. 1.—A longitudinal section of a grafted apple tree through a soft crown-gall 2 months old, formed on the lower end of the scion of a poorly fitted root graft in an experiment. Fig. 2.—An early stage in the development of the simple form of hairy-root, showing the origin of roots from the base of buds on a yearling apple seedling when placed in moist sand in early springtime. Fig. 3.—A later stage in the development of the same form. Fig. 4.—An older stage of the simple form of hairy-root, showing how the small roots dry up and become hair-like. It was from this form that the disease received the name "hairy-root." Fig. 5.—A longitudinal section through a Wealthy apple tree diseased with the woolly-knot form of hairy-root. Both the tree and the knot are 2 years old, the latter originating in a wound, as indicated by the dark line in the tissues beneath the knot. Fig. 6.—A longitudinal section through a hard crown-gall on a 2-year-old Wealthy apple tree, showing the origin of the gall from the lower end of the scion.

PLATE VII. Fig. 1.—The root of a seedling apple tree grown from a cutting taken from a seedling apple tree diseased with the simple form of hairy-root. Fig. 2.—The root of a Charlamoff apple tree grown from a root graft, the scion of which was taken from a tree diseased with the aerial form of hairy-root. Both this and the former tree show only traces of the woolly-knot form of the disease and were exceptionally vigorous trees. Fig. 3.—Roots of a yearling Fameuse apple tree grown from a root graft made from a healthy scion united with a root piece diseased with the simple form of hairy-root. The scion has thrown out healthy roots. This is typical of the varieties of apple trees which root readily from the scion. Fig. 4.—Roots of a Jonathan apple tree grown similarly to the previous one. This tree has not thrown out roots from the scion and is typical of those varieties of apple trees which do not root readily from the scion.

PLATE VIII. Fig. 1.—Apple root grafts, showing nine kinds of wrapping used in the experiments: *A*, Ordinary unwaxed thread; *B*, wrapped with thread, then coated with grafting wax; *C*, cloth wrapping, the outer end of the strip fastened down with grafting wax; *D*, ordinary waxed thread; *E*, thin sheet-rubber strip with the end cemented down; *F*, a graft without wrapping; *G*, waxed paper strip; *H*, raffia, completely covering the union; *I*, ordinary raffia wrapping. Fig. 2.—Root grafts showing excessive callus at the lower blunt end of the scions. This callus favors the entrance of the disease. When planted in an experiment in the greenhouse, these root grafts all developed crown-gall at the point of formation of callus.

PLATE IX. Fig. 1.—The stump of an 8-year-old Collins apple tree grown in orchard 1. This tree, the largest in the orchard, was diseased with the woolly-knot form of hairy-root. Fig. 2.—Apple root grafts and seedlings used in the experiments: *A*, A hand-wrapped root graft; *B*, a machine-wrapped root graft; *C* and *D*, poorly fitted root grafts; *E* and *F*, healthy apple seedlings; *G* and *H*, apple seedlings diseased with hairy-root.

PLATE X. Two rows of Collins apple trees in orchard 1 at the age of 8 years: *A*, This row was diseased with the hard form of crown-gall when set in the orchard; *B*, this row was healthy when set in the orchard and remained comparatively so until the end of the experiment.

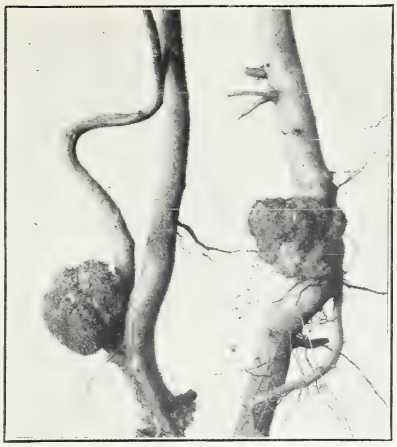

FIG. 1.—SOFT FORM OF CROWN-GALL OF THE APPLE, FROM INOCULATION WITH ROSE GALLS.

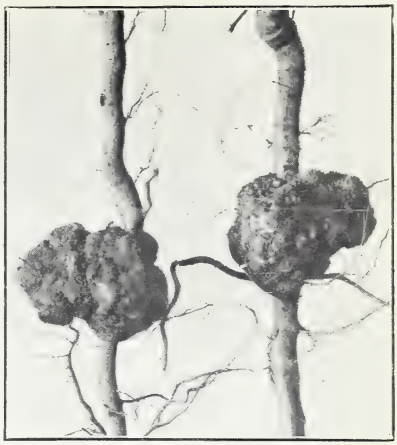

FIG. 2.—SOFT FORM OF CROWN-GALL OF THE APPLE, FROM INOCULATION WITH RASPBERRY GALLS.

FIG. 3.—HARD FORM OF CROWN-GALL ON THE SCION PORTION OF ROOT-GRAFTED APPLE TREES.

FIG. 4.—HARD FORM OF CROWN-GALL AT THE LOWER END OF THE SCION IN A ROOT-GRAFTED APPLE TREE.

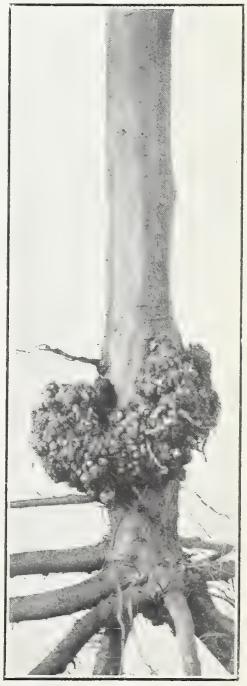

FIG. 5.—HARD FORM OF CROWN-GALL SURROUNDING THE UNION IN A ROOT-GRAFTED APPLE TREE.

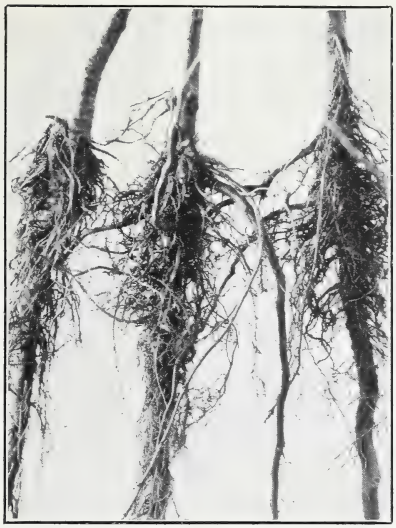

FIG. 1.—SIMPLE FORM OF HAIRY-ROOT ON APPLE SEEDLINGS, TYPICAL OF THOSE USED IN THE EXPERIMENTS.

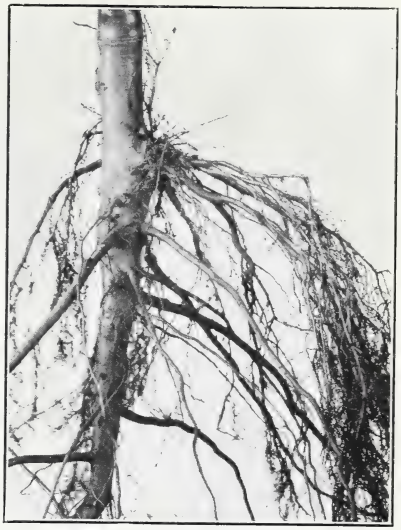

FIG. 2.—BROOM-ROOT FORM OF HAIRY-ROOT ON A 2-YEAR-OLD APPLE TREE.

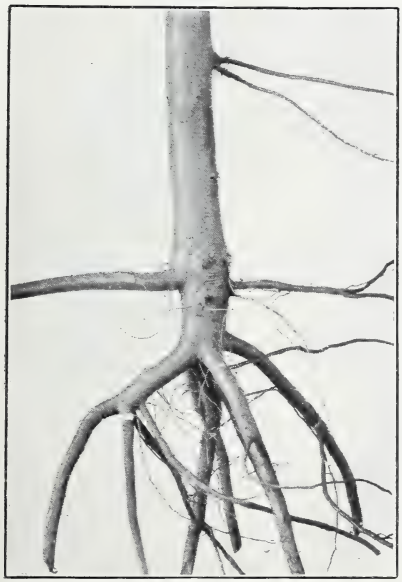

FIG. 3.—HEALTHY ROOT-GRAFTED APPLE TREE, SHOWING THE TYPE OF THE HEALTHY TREES PLANTED IN THE EXPERIMENTAL ORCHARDS.

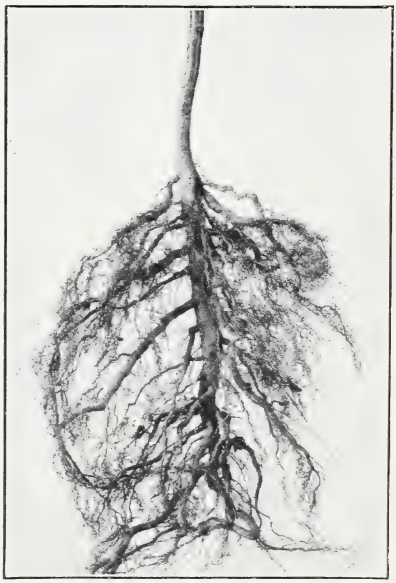

FIG. 4.—HEALTHY SEEDLING APPLE TREE WITH FIBROUS ROOTS.

FIG. 1.—EARLY STAGE OF THE AERIAL FORM OF HAIRY-ROOT ON AN APPLE TWIG.

FIG. 2.—LATER STAGE OF THE AERIAL FORM OF HAIRY-ROOT ON THE SAME TWIG AS THAT SHOWN IN FIGURE 1.

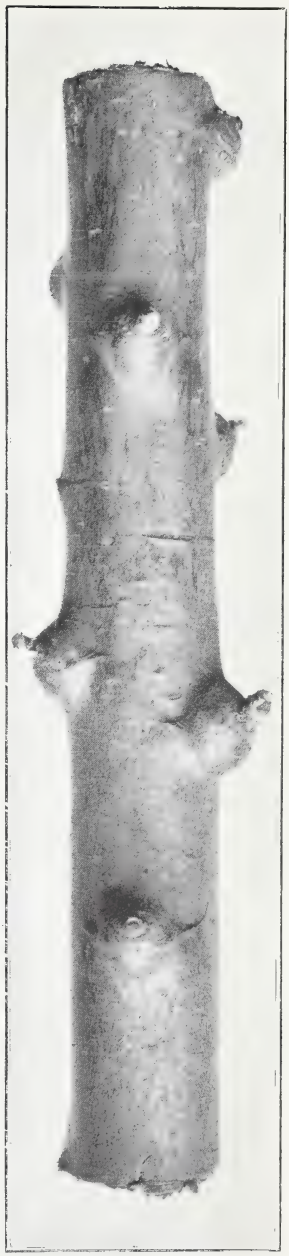

FIG. 3.—EARLY STAGE OF THE AERIAL FORM OF HAIRY-ROOT ON AN OLDER LIMB OF THE SAME TREE AS THAT FROM WHICH THE TWIGS SHOWN IN FIGURES 1 AND 2 WERE TAKEN.

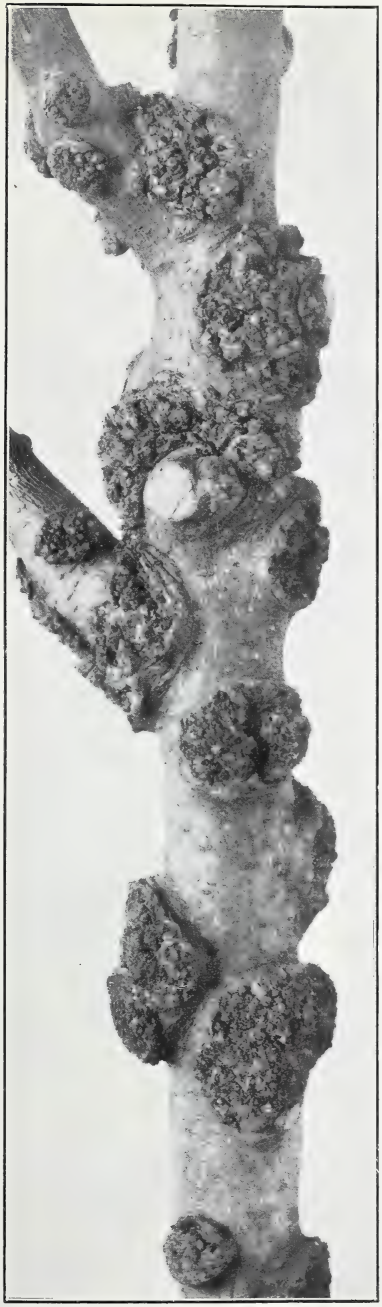

FIG. 1.—MATURE STAGE OF THE AERIAL FORM OF HAIRY-ROOT ON A WINESAP SEEDLING APPLE TREE.

FIG. 2.—ROOT PRODUCTION FROM THE AERIAL FORM OF HAIRY-ROOT ON A LIMB FROM THE SAME TREE AS THAT FROM WHICH THE LIMB SHOWN IN FIGURE 1 WAS TAKEN.

FIG. 1.—RADIAL SECTION THROUGH A SOFT CROWN-GALL IN AN APPLE ROOT GRAFT.

FIG. 2.—EARLY STAGE OF THE SIMPLE FORM OF HAIRY-ROOT ON AN APPLE SEEDLING.

FIG. 3.—A LATER STAGE IN THE DEVELOPMENT OF THE SAME FORM AS THAT SHOWN IN FIGURE 2.

FIG. 4.—AN OLDER STAGE OF THE SIMPLE FORM OF HAIRY-ROOT, MANY ROOTS BEING HAIR-LIKE.

FIG. 5.—RADIAL SECTION THROUGH A WOOLLY KNOT ORIGINATING IN A WOUND ON THE SCION OF A ROOT-GRAFTED APPLE TREE.

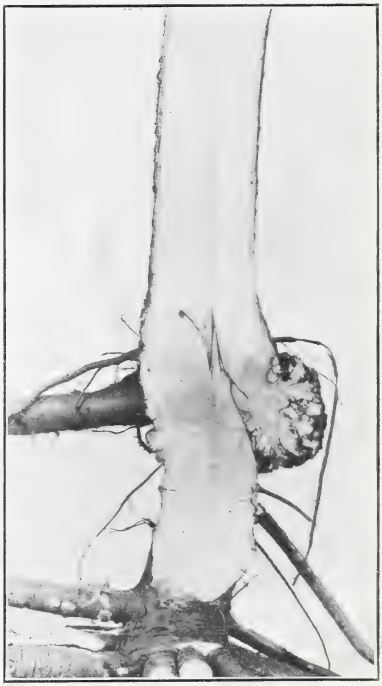

FIG. 6.—RADIAL SECTION THROUGH A HARD CROWN-GALL ORIGINATING ON THE LOWER END OF THE SCION OF A ROOT-GRAFTED APPLE TREE.

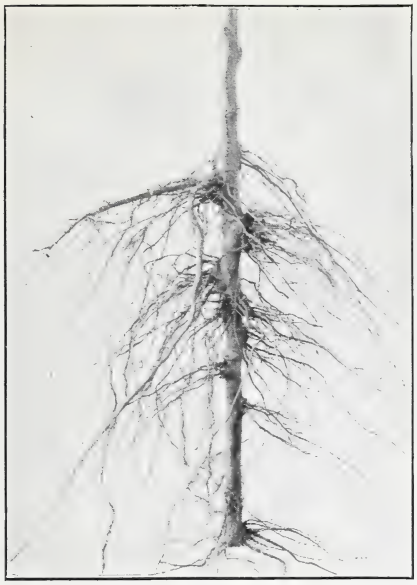

FIG. 1.—ROOT OF AN APPLE TREE GROWN FROM A CUTTING TAKEN FROM A SEEDLING APPLE TREE DISEASED WITH THE SIMPLE FORM OF HAIRY-ROOT.

FIG. 2.—ROOT OF A GRAFTED APPLE TREE GROWN FROM A SCION TAKEN FROM A DISEASED LIMB OF THE TREE TWIGS AND A LIMB OF WHICH ARE SHOWN IN PLATE IV.

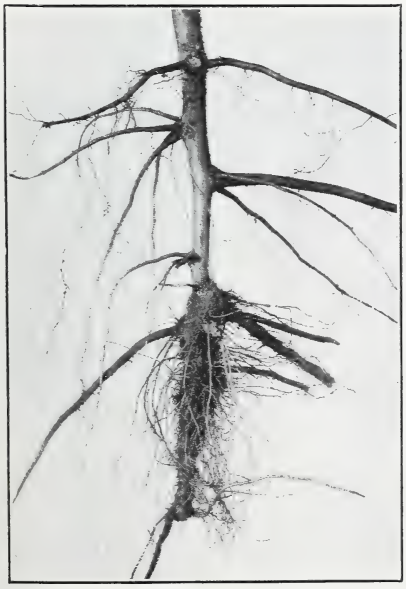

FIG. 3.—ROOTS OF A FAMEUSE APPLE TREE GROWN FROM A ROOT GRAFT WITH THE ROOT PIECE DISEASED WITH HAIRY-ROOT, BUT WITH HEALTHY ROOTS ON THE SCION.

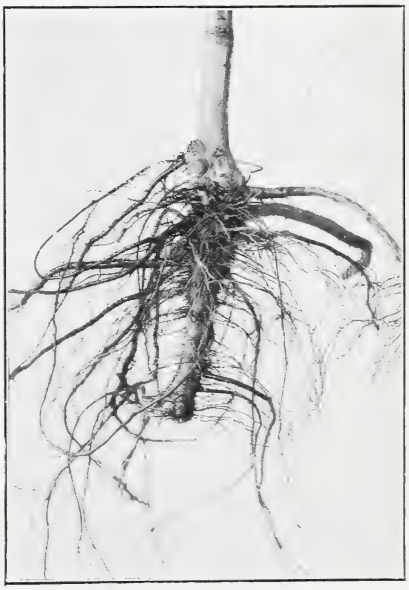

FIG. 4.—ROOTS OF A JONATHAN APPLE TREE GROWN FROM A ROOT GRAFT DISEASED WITH HAIRY-ROOT, BUT WITH NO ROOTS ON THE SCION.

FIG. 1.—APPLE ROOT GRAFTS SHOWING NINE KINDS OF WRAPPING USED IN THE EXPERIMENTS.

FIG. 2.—ROOT GRAFTS LEFT TOO LONG IN STORAGE, SHOWING EXCESSIVE DEVELOPMENT OF CALLUS. THE SCIONS WERE CUT WITH THE LOWER TIP BLUNT.

FIG. 1.—THE WOOLLY-KNOT FORM OF HAIRY-ROOT ON THE CROWN OF A COLLINS APPLE TREE IN ORCHARD 1.

FIG. 2.—APPLE ROOT GRAFTS AND SEEDLINGS USED IN THE EXPERIMENTS.

TYPICAL ROWS OF TREES IN ORCHARD 1: *A*. A ROW OF COLLINS APPLE TREES DISEASED WITH THE HARD FORM OF CROWN-GALL WHEN PLANTED IN THE ORCHARD; *B*. A ROW OF THE SAME VARIETY, PLANTED AT THE SAME TIME, BUT WITH HEALTHY ROOTS.

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