A study of crown gall caused by Bacterium tumefaciens on rosaceous hosts

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A STUDY OF CROWN GALL CAUSED BY BACTERIUM TUMEFACIENS ON ROSACEOUS HOSTS

by

J. H. Muncie

A Thesis Submitted to the Graduate Faculty for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: Plant Pathology.

Approved:

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1925.
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Introduction

The recent investigations by Riker (19, 20) and those by Robinson and Walkden (22) showing that Bacterium tumefaciens (Sm and Town.) probably does not push through the tissues in intrusive tumor strands have afforded a new angle of attack upon the crown gall problem. In fact the results of the above researches may be said to have reopened the crown gall question in its relation to the nursery industry.

Such biological aspects of the causal organism as viability and longevity in the soil, reduction or loss of virulence, its relation to other types of malformations and pathologic effects upon young and old trees become questions of major importance. Proof that infection is largely local and not systemic in the host tissue presents a new angle of attack on the problem of its pathologic effects.

If Bacterium tumefaciens is not systemic but local in the tissues its injuriousness to the host must be expressed in one of three ways or a combination of these: (1) as in-
interference with water conduction; (2) as causing translocation and appropriation of food materials to the gall to the detriment of the host or (3) as secreting some toxic substance which has a deleterious effect on the plant. This paper presents the results of studies on the pathological effects of crown gall on nursery trees; the effect of the disease on certain herbaceous plants; and the results of cultural and biological studies of the causal organism. Before proceeding with these original studies a brief review of the most important papers relating to the aspects under consideration are included.

Pathological effects of Bacterium tumefaciens

Review of literature

The early studies on crown gall of fruit trees were made before the cause of the disease was known and the results obtained were based largely upon observation. It is not attempted here to review all the literature on the subject but to summarize briefly the more important papers dealing with the subject. As early as 1880 (34) the seriousness of the disease in California led to an investigation by a committee of the State Horticultural Society. However, little was learned except that crown gall was as prevalent
3.

on unirrigated as irrigated land. In 1892 Woodworth (34) described the disease and gave it the name crown gall. In an introduction to the above bulletin Wickson states that during the past twenty years probably hundreds of thousands of galled trees have died. Woodworth assumed the injury caused by the disease to be due to the obstruction to sap flow incident to the gall at the crown, weakening and finally killing the tree or vine. It was also noted that apricot trees after 30 years satisfactory growth showed the presence of galls on the roots. They further observe that the effect of the gall depends upon whether the gall or the tree makes the greater growth during the early life of the tree.

Toumev (32) in Arizona observed the effect of the disease, especially on peach and almond trees. He noted that when the galls occurred upon the deeper roots or were small in size, the galled trees appeared as thrifty as healthy trees. However when the gall occurred at the crown it was frequently two or three times the diameter of the tree. His conclusion was that large galls encircling the crown so interfered with the circulation of sap to the parts directly above as to cause the death of the tree. He also observed that galls on one or two year old were more destructive than on older trees.
4.

Selby (23) observed in a number of cases that peach trees affected with crown gall at transplanting age did not come to successful fruiting and that a large percentage of such trees might be expected to die before reaching bearing age. He also expresses the belief that galled apple trees would not be worth planting. Paddock (16) states that a majority of trees infected in the nursery when planted in Colorado make an unsatisfactory growth and probably but few ever produce paying crops. He notes that crown gall is not so destructive to older trees but that it causes severe damage even in these cases. In irrigated sections the disease is more injurious than in un-irrigated sections.

R. E. Smith (28) states that crown gall is common and injurious on all the stone fruits both in the orchard and the nursery. The disease on apple while causing much trouble in the nurseries apparently is not so serious on orchard trees as crown gall on the stone fruits. Norton (14) made observations on galled apple trees in the Maryland Agricultural College orchard and states that they have never done well. He also notes in a later publication (15) that the presence of a gall may cause the tree to fruit too young or over-bear. In some cases the gall may cut off the tap root. The tissue of the gall may
decay and serve as an entrance for wood rotting fungi.

Alwood (1) notes the effect of the disease in a 14-year-old apple orchard. At this time two trees showed signs of weakness. Galls were found to have developed on the crown to such an extent that the bast tissues were almost entirely gone and the roots for the most part dead and some of them decayed. Later observations in other young orchards show a tendency toward weak, surface, root system.

Sandsten (3) observed that peach trees were more severely injured than apple trees. He cites a case of an eleven-year-old apple orchard of 25 acres which bore only a few crops, and then half of the trees began to fall. Examination showed the trees had been killed by crown gall. Van Deman (33) noted a stunting in growth and a decrease in vigor of galled trees at the time they came into bearing.

Butz (5) in Pennsylvania planted 6 Ben Davis and 5 York Imperial galled apple trees upon the Station Grounds for observation. After two seasons growth he found they all showed injury due to crown gall. Two of the York Imperial trees had died and the other three made only weak growth. All the Jonathan trees grew but they were stunted in size. At the end of three years the trees were still alive but weakly developed. An examination of the galls
at this time showed them increasing in size and more completely girdling the tree than when planted. Heavy production of sprouts was characteristic on these trees along with a weakening of the top growth. No healthy control trees were set for comparison with the diseased ones and one cannot be certain that all the stunting and weak development were caused solely by the gall.

While the foregoing writers have observed injurious effects of the crown gall on apple and stone fruits others find no injury resulting from the gall on apple trees. Popenoe (17) in Kansas planted a lot of two year old Ben Davis trees, one half of which were galled, the other half healthy. After a few years he was unable to see any difference in the above ground parts, between the galled and healthy trees. Galls were also found on some of those trees healthy at the time of setting. In New York while the disease is common on apple trees in the nursery, Stewart, Rolfs and Hall (29) state that they have found no cases where it has caused material loss nor any ill effects from planting diseased trees. They recommend however that infected trees be discarded as the disease may be spread in this way.

The discovery by Smith and Townsend (24) of the causal organism of crown gall and subsequent researches by
Smith and his co-workers shed much needed light upon the whole field and furnished a foundation for further experimental work.

From observation upon the effects of the disease the impetus of the discovery of the cause of crown gall led to attempts to determine by accurate field measurements the effect of crown gall upon its host.

Probably the earliest careful investigation on the pathologic effect of crown gall under field conditions was that of Hedgcock (10). He attempted to measure accurately the injury caused by crown gall on apple seedlings and apple trees in the nursery and orchard. Only small numbers of seedlings were employed in his experiments but from his results and observations in the field he concludes that relatively large galls encircling the one year old seedling root cause a perceptible stunting of the plant. In cases where the galls were small no apparent effect on growth was noted.

As a basis for determining the effect of crown gall on nursery trees, the height of tree at digging time was taken as the basis of measurement. Such measurements were made on 7,883 healthy and 3,603 galled one year piece-root grafted trees in the nursery. For the healthy trees the average height was 37.2 inches while for the galled
trees it was 33.5 inches showing a reduction of 3.7 inches in height of galled trees. At the end of the second season the remainder of the trees were dug and similar measurements made. Of a total 10,159 healthy trees at the age of two years the average height was 56.4 inches while the average for 1,619 galled trees was 51.3 inches showing a reduction of 5.1 inches. A few measurements of height were made on three year old trees and it was found that approximately the same ratio in growth between galled and healthy trees was maintained. Trunk diameter measurements were made on some of the trees in each experiment and these showed the ratio between galled and healthy trees to be about 9.5 to 10. He concludes that taken collectively hairy root and crown gall have a slight stunting effect on root-grafted nursery trees for the first three years and for that reason are not equal to healthy ones for planting in orchards. He also notes that trees with the woolly knot form of hairy root sometimes grow more vigorously for a time than healthy trees.

In the orchard the response of galled and healthy apple trees was measured by taking as a basis of measurement the diameter of trunk six inches above ground. Such measurements were made on the trees in two orchards, planted to the same varieties; one located on well drained soil and the other on similar soil at a lower elevation and subject
to seepage. In orchard number 1 the healthy and galled trees were planted in alternate rows while in orchard number 2 they were planted in blocks, several rows of healthy trees alternating with the galled trees. Orchard number 1 consisted of 112 healthy and 96 diseased trees while in orchard number 2 there were 122 healthy and 159 trees. Most of the galls on the diseased trees were 1\(\frac{1}{4}\) to 2 inches in diameter and with the exception of 36 trees with soft galls, the galls were hard. The orchards consisted of trees of the following varieties, Collins, Cano, Ingram and York Imperial. Before the conclusion of the experiment fire destroyed many of the trees and final readings were made after the trees were eight years old. The data obtained from measurements on 226 healthy and 74 galled trees showed an increase of 0.29 inches in trunk diameter for the healthy trees.

During the six seasons in the orchard 9.8 percent of the healthy and 12.8 percent of the galled trees died, showing slightly lower vitality in the galled trees. From these data Hodgcock concludes that there is only a slight detrimental effect from crown gall. This conclusion however might have been otherwise had the trees been older since it is quite possible that further develop-
ment of the gall would have caused greater stunting of trunk growth.

Observations were also made on apple trees in two other experimental orchards. Records of numbers of trees living at the end of each year were made. In Orchard number three 572 healthy, 417 hairy root and 117 galled trees were planted, dry weather after transplanting and fire destroyed many of the trees. However it was found that 33.4 percent of the healthy, 37.3 percent of the galled and 25.1 percent of the hairy root trees died after two years. These data indicate greater vitality of the hairy root trees as compared with either healthy or galled trees and a reduction in vitality of the galled trees as compared with the healthy trees.

A fourth orchard was planted to Jonathan, Gano and Grimes trees as follows, 225 healthy, 82 hairy root and 193 galled trees. At the end of two years three healthy, two hairy root and three galled trees died. While no conclusions are drawn from these data, the percentage of dead trees was very slightly greater in the galled and hairy root trees.

Fracker (8) sorted nursery run trees as to infection and size; 596 trees of the varieties Duchess, Fameuse
and Transcendent Crab were used. Of the clean trees 229 fell in the number one class, 49 in the number 2 class and 74 in the cull class. With the galled trees there were 92, 77 and 75 trees respectively in the three classes.

On the basis of 1000 trees these data indicate that for the healthy trees there would be 651 in grade 1, 139 in grade 2 and 210 in grade 3. In the same number of galled trees there would be only 377 in grade 1, 316 in grade 2 and 307 in grade 3 or culls. This indicates a loss of 17 to 18 percent in gross return from growing infected trees. He also noted that there was a tendency of infected trees to be reduced in vigor while not forcing the size down below commercial value. This reduction in size he attributes to the injurious effect of crown gall.

Later Swingle and Morris (30) measured trunk circumference on galled and healthy apple trees of eight varieties. These data were taken after the trees had stood in the orchard eight seasons. Trunk circumference measurements were considered more accurate than those of trunk diameter since they took into consideration variation in contour. Their data show that with the exception of the Northwestern Greening and Wealthy there was an increase in the circumference of the healthy trees as compared with
that of the galled trees. The average diameter for healthy trees of all varieties was 13.12 inches, while that of the galled trees was 11.54 inches, an average reduction of 1.58 inches for the galled trees.

Examination of these trees showed a slightly better top growth in the healthy trees and very markedly inferior root systems on the galled trees. The presence of severe injury from fire blight made a fair comparison between galled and healthy Wealthy trees impossible. The tops of the galled Northwestern Greening trees were fully as well developed as those of the healthy trees.

Greene and Melhus (9) made more comprehensive measurements on Jonathan and Wealthy orchard trees at different ages including the trunk diameter, twig length and twig weight. These measurements were made during favorable and unfavorable years and the final data were taken after the trees had stood in the orchard four seasons.

Their results show in every case a reduction in trunk diameter, twig length and twig weight per unit length for the galled as compared with the healthy trees of both varieties. These differences were maintained both on the tree infected when set and those which developed galls subsequently. At the end of the fourth season in the orchard there was a gain of 25 and 37 percent in twig length and
weight respectively for the healthy Wealthy trees and a gain of 33.4 and 42 percent in twig length and weight for the Jonathan trees over that of the galled trees.

The trunk diameter after four years growth showed an average increase in the normal Wealthy trees of 11.3 percent while for the normal Jonathan trees the increase was 21.7 percent over that of galled trees of the same varieties.

**Methods and Material**

Manometer.

The first attempts at demonstrating the effect of crown gall on apple trees were made on a qualitative basis. The apparatus consisted of a J-tube mercury manometer, the long and short arms of which measured 18 and 6 inches respectively. To the short arm was attached a piece of thick walled rubber tubing with an inner diameter of 1.5 centimeters. This was wired securely to the tube and waxed at the union to prevent leakage. A short piece of rubber tubing was attached to the long arm of the J tube. Mercury was then introduced into the tube. The tube was tilted so that the mercury arose in the long arm leaving the short arm empty to the center of the bend of the J. A clamp was tightly screwed on the rubber tube of the long
arm thus creating a vacuum above the mercury column and preventing its recession into the short arm when the J tube was returned to perpendicular. The short arm of the tube and rubber connection were now filled with a 2 percent aqueous solution of saffranin. The specimen was inserted into the heavy walled rubber tube of the short arm and wired securely to prevent leakage. The clamp on the rubber tube of the long arm was released allowing the mercury column to exert pressure against the staining solution. By means of a capillary pipette connected to a thistle tube, additional mercury was added to the long arm of the J tube to maintain the mercury column at a constant height of 6 inches, measured from the bottom of the stain in the short arm of the manometer. This insured a constant pressure against the staining solution.

The specimens employed were 15 centimeters in length consisting of the union and equal lengths of root and stem of the galled tree. The root end of the specimen was inserted into the connection on the short arm of the manometer so that the stain would be forced upward, thus simulating natural conditions of water conduction from root to stem. The test continued until the stain became clearly visible upon the cross section surface of the stem piece.
Farmer's Pressure Method.

In a study of water conductivity of various woods Farmer(7 ) employed a very sensitive apparatus by means of which water was forced at constant pressure through the conducting vessels.

In our work much larger specimens were employed which necessitated the use of an apparatus more sturdy than his which was constructed of glass. A heavier apparatus based on that employed by Farmer was made. It consisted essentially of an inverted T tube through which the water was transmitted to the specimens under a constant head of pressure. Figure 2 shows the apparatus in detail. Water from the tap A passed through a thick walled rubber tube to the inverted T, made of galvanized iron pipe 3/4 inch in diameter. An opening in the upright pipe at B allowed the water to enter the glass chamber C which was connected with the mercury manometer D. By regulating the flow through the rubber tube by means of clamp E and through the outlet of C by clamp F, the pressure could be held within 0.5 cm. of mercury as shown on the manometer scale G. The specimens were attached by means of heavy rubber tubing to the horizontal pipe H and wired securely to prevent leakage, the water being forced through the specimen from root to
axion, simulating the natural flow. The specimens 15 cm. in length, including the union and equal portions of the stock and scion were cut from the tree under water. They were then placed in a vessel of water, previously boiled and cooled to expell the air and this placed within a pressure cooker. After carefully applying a coating of vaseline to the edge of the lid it was clamped on tightly. The cooker was then connected to the suction apparatus, by means of a heavy walled rubber tube attached to the pet cock and the air exhausted. Evacuation of the air continued for one and one-half hours at a reduced pressure of 60 cm. of mercury. Water was forced through the specimens for ten minute periods at a pressure of 15 cm. which is equivalent to a 5 minute period at a pressure of 30 cm.

Fluometer.

For the quantitative tests on water flow and interference of the gall to upward conduction a more refined method was employed. The apparatus, designated a fluometer and previously described by Melhus, Muncie and Ho, (13) consists essentially of a filter pump attached to a graduated burette into which water is pulled through the specimen and accurately measured. Plate 1
illustrates the apparatus in detail. The filter pump (7) attached to a water tap exhausts the air from the system. To prevent the possibility of water backing up into the mercury container a filtering flask (4) is attached between the pump and the rest of the system and acts as a trap. A mercury column (1) with its base immersed in a flask of mercury is connected between the filtering flask (4) and the burette (8). The desired vacuum is obtained by regulating the flow of water through the filter pump so that the mercury column drops to the proper height in the tube (1). A clamp (2) on the tubing connecting the filter pump (7) with the filtering flask (4) can be so regulated as to hold the water pressure and consequently the mercury column at a constant level. In this way a constant negative pressure or suction is obtained through the specimen. The vacuum is released by opening the clamp (3). Water is added to the burette bringing it up to the required mark from the separatory funnel (5) which acts as a reservoir. A meniscus reader (11) marks the water level in the burette at the end of the five minutes period.

The specimen is securely wired into the rubber connection (12) and this wired to the tip of the burette (8).
Water is added through the separatory funnel by opening clamp 10 until it reaches the required mark on the burette. Clamp 2 is opened and clamp 3 is closed creating suction within the system. The mercury column is forced down to the proper level and held constant by tightening clamp 2. Water is pulled through the specimen and when it reaches the required mark on the burette the time is taken as the beginning of the test. The duration of each test is five minutes and a reading of the amount of water passing into the burette is made. The amount of water passing through the specimen under a constant negative pressure for the five minute period is taken as the actual rate of flow.

Trees.

The galled and healthy trees of the varieties Jonathan, Wealthy and Ben Davis employed in the first fluometer tests were one year cut backs. They were selected from the nursery rows during the latter part of April by nursery employees and represent on the one hand cull trees which later would be discarded because of galls and on the other hand clean trees suitable for sale. They were heeled in outside the greenhouse until ready for study. In the records they were numbered consecutively from 15 to 91 inclusive.
The second lot of apple trees consisting of the same varieties as the above were selected by the writer from the same nursery rows July 4, 1924. These also were heeled in out of doors until ready for study. They bear the numbers 92 to 192 inclusive.

Galled and healthy two year cut back trees employed in the later trials were obtained from two nurseries, one in Iowa and the other in Missouri. The galled Wealthy trees were selected from the discards at digging time by Dr. Melhus and the writer because of the large galls at the union. The healthy trees of this variety were number 1 trees selected by the nursery. The galled Salome trees were selected from the field at the same time and healthy trees of this variety were obtained from nursery run number 1 stock. The trees of these two varieties were stored in the nursery cellar until ready for the fluo-meter tests.

The galled Jonathan and Wealthy trees used in these later trials were selected by the nursery employees and shipped to us from storage. They were two year trees.

Galled and healthy two year old peach trees of the varieties Elberta, J. H. Hale, Carman and Salway were secured from a Missouri nursery. The galled trees were badly infected, the galls in general half encircling the
stem. In many cases they were twice the diameter of the stem in size. Details as to size of gall and location are given in the tables showing water flow through the various specimens.

The specimens employed in these tests, both with the manometer, fluometer and pressure apparatus were 15 centimeters in length. One, two or three specimens were taken from each tree. These will be referred to respectively as the union, scion and trunk pieces. The union piece included the union and equal lengths of root and stem. The scion piece, immediately above the union section is so named because it includes the original scion of the graft and the offset in the stem caused by cutting back the yearling tree. The trunk piece was taken next above the scion piece. Figure 3 indicates the portion of the tree from which these specimens were taken.

Measurement.

Since the specimens employed in these tests were not the same diameter it was necessary, in order to make the results comparable, to establish a unit of measure. The greatest and least diameter of the upper cross section surface of the specimen were measured and the average of the two taken as the diameter of a circle. From this the
area of the cross section surface was determined. The actual amount of water pulled through the specimen was then divided by this area giving the flow through one square centimeter of surface. The result obtained is designated as the unit rate of flow. The area of the cross section surface occupied by the pith was practically the same in all cases and was disregarded in the calculations.

Terms.

Crown gall or gall as here employed refers to an excrescence or overgrowth on the root, union or trunk of nursery trees. Under the name "hard crown gall" Hedgcock (10) gives the following description which applies to the apple trees used in this study. "The term "Hard crown gall" has been applied to the form occurring more frequently on older trees in nurseries and orchards. 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. 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.

The term hairy root designates a condition of the tree in which there is an excessive development of fibrous roots from or about the gall. According to the terminology of Hedgcock (10) this condition is classed as woolly-knot. His description follows: "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. This form may develop from hard crown-galls.

Preliminary Tests with the Manometer

The occurrence of crown gall in a majority of cases upon the union of stock and scion in root grafted trees suggested the probability of injury resulting from interference to water conduction due to the gall. If longitudinal sections cut through a galled union, are examined microscopically, it is evident that such tissue is not normal. The water conducting vessels are seen to be disarranged, twisted out of their normal course in passing through the gall and in some cases ending abruptly within the gall itself instead of passing upward into the stem. With such a condition existing in the galled tree it remained to find some means of demonstrating the effect of the gall upon water conduction. A means of determining
the actual effect of the gall upon the upward conduction of water and nutrients would in a large measure, also show whether or not such a gall was injurious to the tree.

Early qualitative tests on interference with water conduction were made employing the manometer and stain method previously described. In these trials a small number of galled Jonathan trees was employed. The test was continued until the stain was forced upward through the specimen and appeared upon its cut surface. As a check a section of the stem above the gall was so tested. With one exception there was no passage of stain through the gall as evidenced by lack of coloration of the cut surface of the specimen immediately above the gall. Staining was uniform on the surface on that side of the specimen not galled, showing normal passage through the vessels. In the one galled specimen mentioned as an exception the staining was quite uniform although passage through the piece was quite slow. Uniform staining resulted from the test on the checks.

The results obtained made it desirable to have not only a qualitative test but also one which would show quantitatively the effect of the gall. The above test was modified in that the time necessary for the passage
of stain through galled and non-galled specimens was recorded. The varieties of apple trees Jonathan, Wealthy and Early June with galls on the union were used in these tests while similar sections of the healthy trees were used as checks. The results of these tests show that the passage of stain through the galled specimens was only half as rapid as that through the healthy sections. The average time necessary for passage through the galled specimens was 34 minutes, while passage through the healthy pieces required 16½ minutes.

Tests using Farmer's Pressure Method

While the manometer and stain method gave fairly accurate results, it was difficult to manipulate the apparatus accurately, especially in the maintenance of a constant head of pressure from the mercury column. In seeking for a better method that of Farmer (7) was tried. This method was employed by him in measuring the conductivity of various woods using twigs and stems of small diameter. As previously described our apparatus was a modification of that used by Farmer, but proved unsatisfactory due to clogging of the conducting vessels by some residue in the galvanized pipes and our inability to properly regulate the water pressure in the greenhouse where the
tests were conducted.

Another disadvantage in the pressure apparatus was the use of specimens with irregular or galled main roots. Since the specimen was attached by the root to the apparatus, it was often impossible to securely fasten them so as to prevent leakage. With the suction apparatus the attachment was made with the upper or stem end of the specimen and no such difficulty was experienced. Also with this apparatus it was difficult to shave off the lower end of the specimen between each test, a procedure necessary to obtain results with the minimum of variation for any given specimen. With such large specimens used in these tests an apparatus of glass such as that used by Farmer would have been impractical. To obviate these difficulties recourse was had to the suction method since it facilitated the ease of operation and was more accurate than the pressure method. The following table presents data obtained from nine consecutive trials on six specimens of galled Wealthy trees. The rate of flow is taken at the end of 10 minutes, with a pressure of 15 cm. of mercury.
Table 1. Water conduction through galled apple specimens measured by the pressure method.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Tree No.</th>
<th>240</th>
<th>238</th>
<th>225</th>
<th>241</th>
<th>230</th>
<th>242</th>
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<td>1.5</td>
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<td>43.0</td>
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<tr>
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<td>20.0</td>
<td>79.0</td>
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<td>51.0</td>
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<td>4.0</td>
<td>54.0</td>
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</table>

While the results obtained with specimens numbers 240 and 241 are fairly constant the variation in these cases is greater than that obtained from the use of the fluometer in such tests. A preliminary period of suction for 10 minutes at a reduced pressure equivalent to 60 cm. of a mercury column was given each specimen before the pressure tests were begun. This treatment served to free the vessels of the specimen from air and tended toward more accurate results. Several series of consecutive tests were made on various specimens both galled and non-galled with similar results. Failing to secure sufficient-
ly constant results with the pressure apparatus all subsequent tests were made with the fluometer. Six specimens could be tested at one time with the pressure apparatus while with the fluometer only one specimen could be tested. While this feature of the fluometer tests rendered them much less rapid, the increase in accuracy of readings and constancy of reduced pressures outweighed the disadvantages.

**Preliminary Tests with the Fluometer**

Water conduction through the union of galled and healthy trees.

In the early tests employing the fluometer, the specimens were prepared as follows: Trees heeled in were brought into the greenhouse and cut into proper lengths as previously described. Before attaching the specimens to the apparatus a fresh smooth cut was made on either end of the piece. A preliminary period of suction was given each specimen until no air arose into the burette, indicating that the vessels of the wood was exhausted as far as possible. In these trials and the preliminary periods of suction a negative pressure equivalent to 73.5 to 74 centimeters of a mercury column was maintai-
ed and the duration of suction was five minutes. Two specimens were taken from each tree, namely the union and the trunk piece. The pieces were not cut from the tree until ready for making the tests so as to avoid drying out the wood. The galled trees employed in the tests consisted of the varieties Jonathan, Wealthy and Ben Davis two year cut backs received from storage in April and heeled in outside until ready for use. Ten healthy trees of each of these varieties were also used as checks. The results of these tests are presented in table II.
Table II. Water conduction through union pieces of Healthy and Galled Trees

<table>
<thead>
<tr>
<th>Variety</th>
<th>Tree</th>
<th>Diam.</th>
<th>Area</th>
<th>Actual</th>
<th>Unit</th>
<th>Tree</th>
<th>Diam.</th>
<th>Area</th>
<th>Actual</th>
<th>Unit</th>
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<td>2.9</td>
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<td>x17</td>
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<td>2.01</td>
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<td>x18</td>
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Average: 2.07 3.36 9.38 2.82

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Average: 1.65 2.13 3.02 1.32

Average: 1.94 2.95 3.10 1.10
and Galled Apple trees

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<th>Unit</th>
<th>Flow</th>
<th>Description of specimen</th>
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</tr>
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<td>0.7</td>
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</tr>
<tr>
<td>1.9</td>
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<td></td>
</tr>
<tr>
<td>7.0</td>
<td>Gall ⅓&quot; x 1&quot; at top of union half girdling. No hairy root.</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Gall 1&quot; x 1&quot; at union ½ girdling. Hairy root abundant. 2-⅛&quot; roots from gall.</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>Gall ⅝&quot; x ⅞&quot; on union. Abundant hairy root. 1-⅜&quot; root opposite gall.</td>
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<tr>
<td>2.9</td>
<td>Gall ⅝&quot; x 1&quot; half girdling union. 1-⅜&quot; root and hairy root from gall.</td>
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<tr>
<td>2.2</td>
<td>Gall 1&quot; x ⅜&quot; half girdling union. 3-⅛&quot; root from gall and 2-⅛&quot; root.</td>
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<tr>
<td>0.6</td>
<td>Flat gall ½ girdling union. Hairy root abundant.</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Swollen union and gall 1&quot; x ⅝&quot; half girdling union. Hairy root abundant.</td>
<td></td>
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<tr>
<td>1.0</td>
<td>Two galls ⅛&quot; x ½&quot; at top of union. No hairy root.</td>
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<tr>
<td>1.0</td>
<td>Flat gall ½ girdling union. Excessive hairy root on gall and main root.</td>
<td></td>
</tr>
</tbody>
</table>

2.86

| 4.9  | Gall ⅗" diameter on union. Hairy roots from gall. 1 root ⅛" rising. |
| 1.6  | Gall ⅜" x ⅞" above union. Hairy roots from gall. |
| 3.2  | Gall size of walnut ⅝ circling union. 3-⅛" roots from gall. |
| 2.1  | Gall ½" diameter on upper end of union. |
| 0.7  | Gall ⅞" diameter on union. 1-⅛; 1-⅜ and 2-½" roots from gall. |
| 1.1  | Rough union and gall size of hickory nut on union. Hairy root from gall. |
| 1.1  | Gall ⅜" x ⅞" half circling union. 2-⅜" and 6 ⅛" roots from gall. |
| 0.7  | Gall ⅞" x ⅞" at top of union. 1-⅜"; 3-⅛" and 2-5/16" roots from gall. |
| 0.9  | Gall ⅜" x ⅞" half circling union. 5-⅛" roots from gall. |
| 0.2  | Two small galls ⅛" diameter from bottom of union. 4-7/8" roots from gall. |
| 1.0  | Gall ⅜" x ⅝" and ⅛" x ⅜" on union 2/3 circling it. 3-⅛" roots from gall. |
| 1.0  | Gall ⅜" x ⅞" half circling union. 1-⅜" root and hairy roots from gall. |

1.10
of union half girdling. No hairy root.

ion ½ girdling. Hairy root abundant. 2-⅛" roots from gall

on. Abundant hairy root. 1-⅜" root opposite gall.

girdling union. 1-⅝" root and hairy root from gall.

f girdling union. 3-1/8" root from gall and 2-⅛" root opposite gall.

ing union. Hairy root abundant.

gall 1" x ⅜" half girdling union. Hairy root abundant.

at top of union. No hairy root.

ing union. Excessive hairy root on gall and main root.

on union. Hairy roots from gall. 1 root ½" rising from gall.

ve union. Hairy roots from gall.

ut ⅛ circling union. 3-1/8" roots from gall.

on upper end of union.

on union. 1-⅜; 1-⅛ and 2-1/8" roots from gall.

gall size of hickory nut on union. Hairy root from gall.

if circling union. 2-⅛" and 6 1/8" roots from gall.

top of union. 1-⅜; 2-⅛" and 2-3/16" roots from gall.

f circling union. 5-⅜" roots from gall.

⅝ diameter from bottom of union. 4-7/8" roots from gall.

⅝ x ⅝" on union 2/3 circling it. 3-⅜" roots from gall also hairy roots.

f circling union. 1-3/16" root and hairy roots from gall.
Table II continued

<table>
<thead>
<tr>
<th>Variety</th>
<th>Tree</th>
<th>Diam.</th>
<th>Area</th>
<th>Actual</th>
<th>Unit</th>
<th>Tree</th>
<th>Diam.</th>
<th>Area</th>
<th>Actual</th>
<th>Unit</th>
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<td>cm.</td>
<td>sq.</td>
<td>Flow</td>
<td>Flow</td>
<td>No.</td>
<td>cm.</td>
<td>sq.</td>
<td>Flow</td>
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<td>1.6</td>
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<td>3.46</td>
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<td>1.8</td>
<td>0.7</td>
<td>49</td>
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<td>7.7</td>
<td>3.0</td>
<td>51</td>
<td>2.1</td>
<td>3.46</td>
<td>3.1</td>
<td>0.9</td>
</tr>
</tbody>
</table>

| Average | 1.82 | 2.60 | 4.60 | 1.89 | 2.12 | 3.52 | 4.07 | 1.22 |

*Specimens used for cross sectioning of gall.*
<table>
<thead>
<tr>
<th>Unit</th>
<th>Flow C.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>Gall 3/8&quot; diameter on union; 1/2&quot; on root and 1/2&quot; gall on trunk. 1-1/3&quot; root from gall.</td>
</tr>
<tr>
<td>2.5</td>
<td>Gall 1&quot; x 3/8&quot; at base of union girdling it. 1-1/2&quot; and 5-3/16&quot; roots from gall.</td>
</tr>
<tr>
<td>1.0</td>
<td>Gall 1/2&quot; x 1/2&quot; at top of union girdling. 6 roots 1/8&quot; to 1/2&quot; from gall.</td>
</tr>
<tr>
<td>2.8</td>
<td>Three galls 1/2&quot; x 1/2&quot; on one side of union. Hairy root from galls abundant</td>
</tr>
<tr>
<td>0.5</td>
<td>Gall 1/4&quot; x 3/8&quot; on union. Hairy root and 6-1/2&quot; roots from gall.</td>
</tr>
<tr>
<td>1.0</td>
<td>Gall 1&quot; x 3/8&quot; at top of union. Abundant hairy root and 3-1/2&quot; roots from gall.</td>
</tr>
<tr>
<td>0.5</td>
<td>Gall 1/2&quot; x 1/2&quot; at top of union. Hairy root from gall.</td>
</tr>
<tr>
<td>0.6</td>
<td>Rough flattened gall on union. 4-3/16&quot; roots from gall.</td>
</tr>
<tr>
<td>1.0</td>
<td>Gall 1&quot; x 1/2&quot; on union. 3-1/2&quot; root and abundant hairy root from gall.</td>
</tr>
<tr>
<td>0.9</td>
<td>Gall 1/8&quot; x 3/8&quot; on swollen union. Abundant hairy roots from gall.</td>
</tr>
</tbody>
</table>

1.22
¾" root and ½" gall on trunk. 1-½" root from each gall.

1½" and 5-3/16" roots from gall. Hairy root.

6 roots ¼" to 1/8" from gall.

Hairy root from gall.

5 roots ¼" to 1/8" from gall.

Hairy root from gall.

Abundant hairy root and 3½" roots from gall.

Side of union. Hairy root from gall.

Abundant hairy root and 3½" roots from gall.

4-3/16" roots from gall.

Abundant hairy root from gall.

4-3/16" roots from gall.

Abundant hairy roots from gall.
Summary of Table II.

On examination of the data from the tests with the Wealthy trees we note a rather wide variation in rate of water flow through both the healthy and galled specimens. In the healthy trees the variation is from 0.7 c.c. to 6 c.c. In the galled trees the slightly greater variation in unit flow from 0.7 c.c. to 7 c.c. exists. A comparison of unit flow in galled trees numbers 52 and 55 with that of healthy trees 73 and 78 shows in the case of the galled trees an average unit flow of 0.2 c.c. greater in the galled trees. It will also be noted that the highest unit flow of 7 c.c. for all trees of the variety is found in the galled class. From the description of the trees we find relatively large lateral roots rising from the gall. We also note that the gall only half encircles the union. These two trees are exceptions to the general rule in this particular lot, since the average unit flow for all the galled trees is 19.8 percent lower than that of the healthy trees.

In the Jonathan trees we find little difference between those healthy and galled in the average actual rate of flow through the specimens. But the average diameter and area of cross section surface exposed to suction in
the galled trees is appreciably greater than in the healthy trees, hence we would expect the actual flow to be greater. However, when the specimens are all reduced to a common basis, that of unit flow, we find that the rate of flow in the galled trees is 16.7 percent less than in the healthy trees. There is little variation in unit flow in either the galled or healthy trees as compared with the healthy trees. While there are two cases in the galled trees in which the actual and unit flow is markedly greater than that of any of the healthy trees, the average is still less than that of the healthy trees.

In the Ben Davis trees none of the galled trees show greater unit flow than the galled trees. There is a slightly greater variation in unit flow 0.7 c.c. to 3 c.c. in the healthy trees than that of the galled trees which is 0.5 c.c. to 2.5 c.c. Here again as with the Jonathan trees the average diameter of the galled trees is greater than that of the healthy trees, but the average actual rate of flow as well as the unit rate of flow is less. The reduction in average unit flow for the galled specimens amounts to 35.5 percent.

These data indicate that in spite of individual variations, as a class, the galled trees are less efficient
in water conduction through the union.

While these data show that the presence of a gall interferes with water conduction it was thought that the numbers employed in the trials were not sufficiently large to give a fair indication of the real situation. Twenty-five additional galled and the same number of healthy Jonathan and Wealthy trees were lifted from the nursery row in July 1924 and heeled in for about a week before they were studied. The galls on the Jonathan trees were with one exception quite small, none of them being larger than half of a walnut in size. In the exception noted, the gall was about twice this size. Many of the galls were evidently just forming, since they were no larger than a hazel nut. Hairy root from the galls was common as were also fine fibrous lateral roots rising from the gall tissue. The roots though small in diameter appeared normal in number, diameter and length. The Wealthy trees were larger in diameter and had better developed roots. The galls however, were not any larger taken as a whole than those of the Jonathan trees. These trees compared with those of the same varieties observed at digging time in October of the same year were quite below the field average in gall development. The results of these tests are presented in table III.
### Table III. Water conduction through union pieces of galled and healthy trees

<table>
<thead>
<tr>
<th>Variety</th>
<th>Healthy Trees</th>
<th>:</th>
<th>Galled Trees</th>
<th>:</th>
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<td>Tree : Diam. : Area : Actual Unit</td>
<td>:</td>
<td>Tree : Diam. : Area : Actual</td>
<td>:</td>
</tr>
<tr>
<td>No. : cm. : sq. cm. : Flow</td>
<td>:</td>
<td>No. : cm. : sq. cm. : Flow</td>
<td>:</td>
<td></td>
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<tr>
<td>Healthy</td>
<td>143 2.0 3.14 14.4 4.6</td>
<td>168 1.9 2.83 10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>144 1.7 2.27 13.5 6.0</td>
<td>169 1.9 2.83 9.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>145 1.9 2.85 9.3 3.3</td>
<td>170 2.2 3.80 7.4</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>146 2.0 3.14 6.0 1.9</td>
<td>171 1.8 2.54 5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>147 1.9 2.83 7.1 2.5</td>
<td>172 1.8 2.54 8.5</td>
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<tr>
<td></td>
<td>148 2.0 3.14 2.7 0.9</td>
<td>173 2.3 4.15 3.5</td>
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</tr>
<tr>
<td></td>
<td>149 1.7 2.27 3.0 1.3</td>
<td>174 1.9 2.83 9.5</td>
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<tr>
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<td>150 1.8 2.54 1.3 0.5</td>
<td>175 1.9 2.83 9.5</td>
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<tr>
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<td>151 2.0 3.14 9.7 5.1</td>
<td>176 1.9 2.83 11.3</td>
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</tr>
<tr>
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<td>152 2.1 3.46 15.9 4.6</td>
<td>177 1.4 1.54 2.7</td>
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<tr>
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<td>153 1.5 1.76 5.1 1.7</td>
<td>178 1.8 2.54 5.0</td>
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<tr>
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<td>179 2.1 3.46 10.0</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>155 1.6 2.01 2.7 1.3</td>
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<tr>
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<td>156 2.2 3.80 18.1 4.3</td>
<td>181 2.3 4.15 4.4</td>
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<tr>
<td></td>
<td>157 2.1 3.46 3.0 0.9</td>
<td>182 1.9 2.83 4.0</td>
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<td>158 1.6 2.01 5.8 2.9</td>
<td>183 1.8 2.54 4.1</td>
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<td>159 1.8 2.54 12.1 4.8</td>
<td>184 1.9 2.83 6.6</td>
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<tr>
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<td>160 2.1 3.46 9.0 2.6</td>
<td>185 2.2 3.80 7.8</td>
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<tr>
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<td>161 1.7 2.27 5.7 2.5</td>
<td>186 2.1 3.46 5.0</td>
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<tr>
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<td>162 2.0 3.14 8.5 2.7</td>
<td>187 1.6 2.01 8.1</td>
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<td>164 2.0 3.14 4.2 1.3</td>
<td>189 2.2 3.80 4.7</td>
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<tr>
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<td>165 1.8 2.54 6.3 3.3</td>
<td>190 1.6 2.13 1.7</td>
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<tr>
<td></td>
<td>166 1.8 2.54 8.0 3.0</td>
<td>191 2.4 4.52 5.5</td>
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<tr>
<td></td>
<td>167 2.1 3.46 7.8 2.2</td>
<td>192 2.0 3.14 23.6</td>
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</tbody>
</table>

| Average | 1.88 2.77 7.75 2.7 |   | Average | 1.95 2.98 | 7.06 |

| Jonathan | No. : cm. : sq. cm. : Flow | : | 100 1.7 2.27 3.8 1.68 | 126 1.5 1.76 3.5  |   |   |
|         | 101 1.4 1.65 1.6 0.95 | 127 1.7 2.27 5.5  |   |   |
|         | 102 1.8 2.68 7.4 2.76 | 128 1.9 2.83 1.7  |   |   |
|         | 103 1.7 2.40 5.5 2.29 | 129 1.8 2.54 0.6  |   |   |
|         | 104 1.5 1.76 1.3 0.73 | 130 1.6 2.01 3.9  |   |   |
|         | 105 2.3 4.15 4.9 1.18 | 131 1.3 1.32 1.4  |   |   |
Lied and healthy apple trees

<table>
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<th>Trees</th>
<th>Area</th>
<th>Actual</th>
<th>Unit</th>
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<tr>
<td>2.83</td>
<td>10.0</td>
<td>3.5</td>
<td>Slightly swollen union and galls ½&quot; x ¼&quot; one third girdling trunk.</td>
</tr>
<tr>
<td>2.83</td>
<td>9.7</td>
<td>3.4</td>
<td>Flat gall half girdling union. Gall ½&quot; x ¼&quot; above union.</td>
</tr>
<tr>
<td>3.60</td>
<td>7.4</td>
<td>1.9</td>
<td>Flat gall completely girdling union.</td>
</tr>
<tr>
<td>2.54</td>
<td>5.0</td>
<td>2.0</td>
<td>Gall 1&quot; x ¼&quot; at top of union ½ girdling. Hairy root on union.</td>
</tr>
<tr>
<td>2.54</td>
<td>8.5</td>
<td>3.2</td>
<td>Rough union and gall ½&quot; x ¼&quot; at top of union.</td>
</tr>
<tr>
<td>4.15</td>
<td>3.5</td>
<td>0.8</td>
<td>Flat gall on union and 2 galls ½&quot; x ¼&quot; above union.</td>
</tr>
<tr>
<td>2.83</td>
<td>9.5</td>
<td>3.3</td>
<td>Gall ½&quot; x ¼&quot; at top of swollen union. Hairy root from gall.</td>
</tr>
<tr>
<td>2.83</td>
<td>9.5</td>
<td>3.3</td>
<td>Gall ½&quot; x ¼&quot; above union.</td>
</tr>
<tr>
<td>2.83</td>
<td>11.3</td>
<td>4.0</td>
<td>Flat gall completely girdling union. 1-3/16&quot; and 3-1/8&quot; root.</td>
</tr>
<tr>
<td>2.54</td>
<td>2.7</td>
<td>1.7</td>
<td>Gall ½&quot; x ¼&quot; above union.</td>
</tr>
<tr>
<td>2.54</td>
<td>5.0</td>
<td>1.9</td>
<td>Flat gall almost completely girdling union.</td>
</tr>
<tr>
<td>3.46</td>
<td>10.0</td>
<td>3.8</td>
<td>Gall ½&quot; x ¼&quot; one third girdling trunk.</td>
</tr>
<tr>
<td>3.14</td>
<td>4.0</td>
<td>1.3</td>
<td>Gall ½&quot; x ¼&quot; at top of union. Hairy root from stock.</td>
</tr>
<tr>
<td>4.15</td>
<td>4.4</td>
<td>1.0</td>
<td>Surface gall on swollen union.</td>
</tr>
<tr>
<td>2.83</td>
<td>4.0</td>
<td>1.4</td>
<td>Rough union. Probably not gall.</td>
</tr>
<tr>
<td>2.54</td>
<td>4.1</td>
<td>1.6</td>
<td>Rough swollen union. Probably not gall.</td>
</tr>
<tr>
<td>2.83</td>
<td>6.6</td>
<td>2.3</td>
<td>Small gall ½&quot; diameter above union.</td>
</tr>
<tr>
<td>3.80</td>
<td>7.8</td>
<td>2.0</td>
<td>Gall 1&quot; x ½&quot; above union ½ girdling trunk.</td>
</tr>
<tr>
<td>3.46</td>
<td>5.0</td>
<td>1.4</td>
<td>Gall ½&quot; x ¼&quot; at base of swollen union.</td>
</tr>
<tr>
<td>2.01</td>
<td>8.1</td>
<td>4.0</td>
<td>Flat gall at top of union. Few hairy roots.</td>
</tr>
<tr>
<td>2.83</td>
<td>5.0</td>
<td>1.7</td>
<td>Surface gall at union and gall ½&quot; x ¼&quot; above union. Hairy root.</td>
</tr>
<tr>
<td>3.60</td>
<td>4.7</td>
<td>1.2</td>
<td>Gall ½&quot; x ¼&quot; above union.</td>
</tr>
<tr>
<td>2.01</td>
<td>1.7</td>
<td>0.8</td>
<td>Two galls ½&quot; x ¼&quot; at top of union. Hairy root.</td>
</tr>
<tr>
<td>4.52</td>
<td>5.5</td>
<td>1.2</td>
<td>Gall 1&quot; x 1&quot; above union on trunk. Surface gall on union.</td>
</tr>
<tr>
<td>3.14</td>
<td>23.6</td>
<td>7.5</td>
<td>Small galls ½&quot; x ¼&quot; girdling the union.</td>
</tr>
</tbody>
</table>

| 2.98 | 7.06 | 2.36 |

| 2.68 | 3.1 | 1.15 | Gall ½" x ½" half girdling trunk. Hairy root and crown gall. |
| 2.01 | 1.7 | 0.84 | Gall ½" x ½" one fourth girdling union. 1-1/8" and 6-1/16" root. |
| 1.15 | 8.1 | 7.1 | Gall ½" x ½" at top of union. Few hairy roots. |
| 2.15 | 2.6 | 1.2 | Gall ½" x ½" above union. Few hairy roots. |
| 2.27 | 3.7 | 1.6 | Swollen union with small gall at top. Hairy root. |
| 2.54 | 3.3 | 1.3 | Galls ½" x ½" above union and ½" x ¼" below union. |
| 3.14 | 9.1 | 2.9 | Swollen union with gall ½" x ½". |
| 2.27 | 6.2 | 3.5 | Gall ¾" x ¾" at top of union. |
| 1.75 | 3.5 | 2.0 | Gall ½" x ¼" at top of union. Few hairy roots. |
| 2.27 | 3.5 | 1.5 | Gall ½" x ½" at top of union. |
| 2.63 | 1.7 | 0.6 | Swollen union with gall size of pea. Few hairy roots. |
| 2.54 | 0.6 | 0.23 | Flat surface gall on union. Hairy root on stock. |
| 2.01 | 3.9 | 1.9 | Gall ½" x ½" at top of union. |
| 1.32 | 1.4 | 1.06 | Three galls ½" x ¼" at top of union. Few hairy roots. |
Description of Gall

Slightly swollen union and galls 1/4" x 1/4" one third girdling union.

Half girdling union. Gall 1/4" x 1/2" above union.

Completely girdling union.

1" x 1/2" at top of union. Hairy root on gall.

Gall union and gall 1/2" x 1/2" at top of union.

Gall on union and 2 galls 1/2" x 1/2" above union.

3/4" x 1/2" at top of swollen union. Hairy root from gall.

1/2" x 1/2" above union.

Almost completely girdling union. 1-5/16" and 3-1/8" roots from gall.

Gall almost completely girdling union.

3/4" x 1/2" one third girdling trunk.

1" x 1/2" at top of union. Hairy root from stock.

Face gall on swollen union.

Swollen union. Probably not gall.

Swollen union. Probably not gall.

Gall 1/4" diameter above union.

1" x 1/2" above union 1/4" girdling trunk.

1" x 1/2" at base of swollen union.

Gall at top of union. Few hairy roots.

Face gall at union and gall 1/2" x 1/2" above union. Hairy root.

3/4" x 1/2" above union.

Galls 1/2" x 1/2" at top of union. Hairy root.

1" x 1" above union on trunk. Surface gall on union.

Galls 1" x 1" girdling the union.

1/2" x 1" half girdling trunk. Hairy root and crown gall.

1/2" x 1" one fourth girdling union. 1-1/8" and 6-1/16" roots from gall.

1" x 1/2" at top of union. Few hairy roots.

1/2" x 1/2" above union. Few hairy roots.

Ellen union with small gall at top. Hairy root.

Ellen union with gall 1/2" x 1/2" above union and 1/2" x 1/2" below union.

Ellen union with gall 1/2" x 1/2".

1" x 1/2" at top of union.

1/2" x 1/2" at top of union. Few hairy roots.

1/2" x 1/2" at top of union.

Ellen union with gall size of pea. Few hairy roots.

At surface gall on union. Hairy root on stock.

1/2" x 1/2" at top of union.

See galls 1/2" x 1/2" at top of union. Few hairy roots.
Table III continued

<table>
<thead>
<tr>
<th>Variety No.</th>
<th>Tree Diam. cm.</th>
<th>Area sq. cm.</th>
<th>Actual Flow c.c.</th>
<th>Variety No.</th>
<th>Tree Diam. cm.</th>
<th>Area sq. cm.</th>
<th>Actual Flow c.c.</th>
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</tbody>
</table>

Average: Healthy Trees = 1.80, 2.68, 5.62, 1.95; Average: Galled Trees = 1.59, 1.98, 3.23
<table>
<thead>
<tr>
<th>Area (sq. cm)</th>
<th>Actual Flow</th>
<th>Unit</th>
<th>Gall Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.01</td>
<td>2.5</td>
<td>1.24</td>
<td>Gall ( \frac{1}{2} )&quot; x ( \frac{1}{4} )&quot; at base of union.</td>
</tr>
<tr>
<td>1.32</td>
<td>1.7</td>
<td>1.28</td>
<td>Gall ( \frac{1}{2} )&quot; x ( \frac{1}{4} )&quot; at top of union.</td>
</tr>
<tr>
<td>2.54</td>
<td>2.7</td>
<td>1.06</td>
<td>Two galls ( \frac{1}{2} )&quot; x ( \frac{1}{4} )&quot; on union</td>
</tr>
<tr>
<td>2.01</td>
<td>1.2</td>
<td>0.59</td>
<td>Surface gall at union. Hairy root.</td>
</tr>
<tr>
<td>3.14</td>
<td>2.0</td>
<td>0.63</td>
<td>Gall ( 1 )&quot; x ( \frac{3}{4} )&quot; on union and 2 galls ( \frac{1}{2} )&quot; x ( \frac{1}{4} )&quot; girdling union.</td>
</tr>
<tr>
<td>2.01</td>
<td>5.4</td>
<td>2.68</td>
<td>Gall ( \frac{1}{4} )&quot; x ( \frac{1}{4} )&quot; at top of swollen union.</td>
</tr>
<tr>
<td>2.54</td>
<td>5.7</td>
<td>2.24</td>
<td>Gall ( \frac{1}{2} )&quot; x ( \frac{1}{4} )&quot; at top of union.</td>
</tr>
<tr>
<td>1.13</td>
<td>0.6</td>
<td>0.53</td>
<td>Gall ( 1 )&quot; x ( 1 )&quot; ( \frac{1}{2} )&quot; girdling union. Gall ( \frac{1}{2} )&quot; x ( \frac{1}{2} )&quot; above union.</td>
</tr>
<tr>
<td>1.13</td>
<td>0.7</td>
<td>0.61</td>
<td>Flat surface gall ( \frac{1}{2} )&quot; girdling union.</td>
</tr>
<tr>
<td>1.32</td>
<td>0.8</td>
<td>0.60</td>
<td>Gall ( \frac{3}{2} )&quot; x ( \frac{3}{4} )&quot; at base of union.</td>
</tr>
<tr>
<td>1.13</td>
<td>3.1</td>
<td>2.74</td>
<td>Gall ( 1 )&quot; x ( 1 )&quot; on trunk. Union swollen.</td>
</tr>
<tr>
<td>1.98</td>
<td>3.23</td>
<td>1.64</td>
<td></td>
</tr>
</tbody>
</table>
Summary of Table III.

For the galled Wealthy trees we find a greater average diameter (1.95 cm.), than that (1.88 cm.) for the healthy trees. There is only a slightly greater average actual flow (7.75 c.c.) in the healthy trees as compared with that (7.06 c.c.) in the galled trees. However, when placed on a comparable basis we find the average unit flow of the healthy trees 2.7 c.c. to be 12.6 percent greater than that of the galled trees which amounts to 2.36 c.c. In the case of one galled tree (tree number 92) the actual flow as well as unit flow is higher than that of any of the healthy trees.

In this case we note that the gall is flattened and the tree has an abundance of comparatively large roots. The effect of such a swelling at the union is so variable that one cannot predict the result upon water conduction through the union.

In the Jonathan trees we find a reverse condition from that found in the Wealthy trees. Here the galled trees are 0.21 cm. smaller in average diameter with a lower actual and unit flow. It is difficult to make a comparison of behavior between galled and healthy trees in this case since it is possible that the development of conducting vessels in the pieces of smaller diameter is less than in those of larger diameter. If this were true we could not attribute
the lower rate of flow to the effect of the gall. On the other hand it is possible that this retardation in trunk growth is due to the presence of the gall since these trees had the same chance for growth in the nursery row as the galled trees. Be that as it may there is a reduction in unit flow of 12.4 percent in the galled trees as compared with that of the healthy trees.

Effect of piece root grafting and cutting back on conduction through healthy trees.

In connection with these earlier tests, the question arose as to whether a piece of the trunk above the union could be used as a check on conduction through either the galled or normal union. Consequently three pieces were cut from ten healthy apple trees of each of the varieties Jonathan, Wealthy and Ben Davis. These specimens were 15 centimeters in length and were designated the union, scion, and trunk pieces as previously described. Fluometer tests as previously employed were made, the results of which are given in table IV.
Table IV. Water conduction through union, scion and trunk pieces of

<table>
<thead>
<tr>
<th>Variety</th>
<th>Union Piece</th>
<th>:NO. :Diam.: Area: Actual: Unit:</th>
<th>Scion Piece</th>
<th>:Diam.: Area: Actual: Unit:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wealthy</td>
<td>72 1.7 2.27 6.43 2.6</td>
<td>1.6 2.01 6.6 3.6 1.8 1.8</td>
<td>1.7 2.27 6.6 3.6 1.8 1.8</td>
<td></td>
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<tr>
<td>Jonathan</td>
<td>62 1.7 2.27 3.3 1.4</td>
<td>1.6 1.76 2.3 1.1 1.2 1.2</td>
<td>1.6 1.76 2.3 1.1 1.2 1.2</td>
<td></td>
</tr>
<tr>
<td>Ben Davis</td>
<td>82 1.7 2.27 5.9 2.4</td>
<td>1.5 1.76 4.2 2.4 1.4 1.4</td>
<td>1.5 1.76 4.2 2.4 1.4 1.4</td>
<td></td>
</tr>
</tbody>
</table>

Av. 1.65 2.13 3.02 1.34 1.46 1.67 2.34 1.33 1.26 1.26 1.26 1.26
through union, scion and trunk pieces of healthy apple trees.

<table>
<thead>
<tr>
<th>Scion Piece</th>
<th>Trunk Piece</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit:</strong></td>
<td><strong>Diam.</strong></td>
</tr>
<tr>
<td><strong>Flow:</strong></td>
<td><strong>cm.</strong></td>
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<tr>
<td>3.86</td>
<td>2.8</td>
</tr>
<tr>
<td>3.7</td>
<td>6.0</td>
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<td>1.8</td>
</tr>
<tr>
<td>3.7</td>
<td>3.7</td>
</tr>
<tr>
<td>0.0</td>
<td>1.3</td>
</tr>
<tr>
<td>3.75</td>
<td>3.8</td>
</tr>
<tr>
<td>2.4</td>
<td>1.7</td>
</tr>
<tr>
<td>0.6</td>
<td>4.6</td>
</tr>
<tr>
<td>3.2</td>
<td>0.7</td>
</tr>
<tr>
<td>1.38</td>
<td>2.81</td>
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<td>1.4</td>
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<tr>
<td>3.9</td>
<td>0.8</td>
</tr>
<tr>
<td>3.3</td>
<td>2.0</td>
</tr>
<tr>
<td>3.9</td>
<td>0.9</td>
</tr>
<tr>
<td>3.3</td>
<td>3.6</td>
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<td>1.2</td>
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<td>3.02</td>
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<td>5.9</td>
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<td>4.6</td>
<td>1.88</td>
</tr>
</tbody>
</table>
Summary of Table IV.

In examining the data in table IV for the Wealthy trees we find the average diameters of the union, scion and trunk pieces is 2.07 cm., 1.71 cm. and 1.52 cm. One would expect in this case that the rate of flow through the piece would be proportional to the diameter. However the data show the average unit flow for these specimens to be in reverse order. The trunk piece with the smallest diameter (1.52 cm.) has the highest unit flow (7.85 c.c.) while the union piece having the greatest diameter (2.07 cm.) has a unit flow of only 2.81 c.c. the lowest of the three pieces. The unit flow through the scion piece amounting to 2.91 c.c. is only slightly greater than that through the union but when one considers the greater diameter of the union piece this difference appears significant.

In the Jonathan trees the average diameters for the union, scion and trunk pieces is 1.65 cm., 1.46 cm. and 1.25 cm. respectively. The unit flow through the union piece is 1.34 c.c., the scion piece 1.33 and the trunk piece 2.40. Here again we find a higher unit flow through the trunk piece although the diameter is smaller, than through the union of the tree. The scion piece with an average diameter 0.46 cm. smaller than that of the union
piece has a unit flow only 0.01 c.c. less. This slight difference in unit flow, representing the average of ten specimens does not appear significant. In fact considering the smaller diameter of these pieces we might reasonably expect a greater difference between the two.

The data from the Ben Davis trees are similar to those from the Wealthy trees. While the average diameters of the union scion and trunk pieces are 1.80 cm., 1.46 cm. and 1.29 cm. the unit flow through the specimens is in the reverse order of their diameters, for the trunk piece 3.29 c.c., for the scion piece 3.05 c.c. and 1.88 c.c. for the union piece.

Further supplementary tests employing greater numbers of trees were made to show the effect of the union on water conduction. For these tests 25 healthy trees of each of the varieties Jonathan and Wealthy one and one half years from cutting back were employed. The trees were dug in July 1924 from the nursery row and heeled in for a period of about one week until ready for study. In these trials only the union and trunk pieces were employed. The results of these tests are given in table V.
Table V. Water conduction through union and trunk pieces of healthy apple trees.

<table>
<thead>
<tr>
<th>Variety: Union Piece</th>
<th>Trunk Piece</th>
<th>Variety: Union Piece</th>
<th>Trunk Piece</th>
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<td>93</td>
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</tr>
<tr>
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<tr>
<td>116</td>
<td>1.70</td>
<td>1.1</td>
<td>1.20</td>
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</table>

Average 1.81 2.16 1.44 2.40 Average 1.92 2.70 1.54 5.18
Summary of Table V.

The results of the trials on the Jonathan trees show only a slight reduction amounting to 9.9 percent in the average unit flow through the union as compared with that through the trunk piece. While this difference in percentage is not high, if we consider the relative diameters of the two sets of specimens the results become more significant. In the union pieces the average diameter is 1.81 cm. and the average unit flow is 2.16 c.c. The average diameter for the trunk pieces is only 1.44 cm. while the average unit flow is 2.40 c.c. With a greater area of the cut surface of the piece exposed to suction one would expect a greater unit flow through the union piece. It appears then that the union itself is responsible for this reduction in flow.

In the Wealthy trees a similar condition exists showing a reduction in unit flow through the union pieces amounting to 47.9 percent in this case. With an average diameter of 1.92 cm. the unit flow is only 2.70 c.c. through the union piece while through the trunk piece with an average diameter of only 1.54 cm. the unit flow is 5.18 c.c.

This series of tests also show quite clearly the
varietal difference in water conduction both through the union and the trunk pieces. While fit of graft might account to some extent for the difference in unit flow through the union of the two varieties such cannot be the case with the trunk specimens. Here we find that the Wealthy trees with an average diameter only 0.1 cm. greater than that of the Jonathan trees, have over twice the water conducting capacity. This greater capacity for water conduction may be an important factor in determining the relative growth of trees of the two varieties.

The effect of the union and also that of cutting back are indicated by a reduction in flow through the union and scion pieces as compared with that through the trunk piece. The old scion of the graft, almost or entirely surrounded by new tissue of the trunk, acts as a serious obstruction to water flow even after two years from cutting back the yearling shoot. Examination of the scion pieces after splitting longitudinally shows a high percentage of the total cross section surface of the piece to be made up of the end of the dead scion through which there is no passage of water. A narrow layer of sap wood encircling the old scion of the graft serves for the conduction of water to the parts above.
The practice of cutting back is general among nurserymen and is held as tending to the production of trees of greater diameter. The young shoot arising from the root requires much less food material for growth than the leader which was cut away. The root therefore is able to grow quite rapidly until the new leader produces branches. At the end of two years from cutting back, as shown by the data in the above table, there is still marked interference with the upward conduction of water due to the offset in the trunk where the leader arises. This consequent reduction in water flow tends to hold in check for a time at least the development of the trunk thus further increasing root growth. The retardation of top growth, however, would disappear with further development of sap wood or active conducting tissue and consequent increase in trunk growth.

The effect of galls at the union upon water flow through the trunk piece.

The results obtained from previous tests on water conduction show a reduction in unit flow through the union pieces of galled trees as compared with that through similar pieces from healthy trees.

The question arose as to whether the effect of the gall at the union would be reflected in the flow through the trunk
piece above the gall.

Water conduction tests were made on the trunk pieces of 25 galled and 25 healthy apple trees of the varieties Wealthy and Jonathan. These varieties represent rapid and slow growing trees and for this reason they were chosen for the tests since this difference in growth habit might have some influence upon the results obtained. The results of these tests are given in table VI.
Table VI. Water conduction through trunk pieces of galled and healthy apple trees

<table>
<thead>
<tr>
<th>Variety</th>
<th>No.</th>
<th>Dia. cm.</th>
<th>Area sq. cm.</th>
<th>Flow c.c.</th>
<th>Ave. c.c.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wealthy</td>
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<td>2.01</td>
<td>10.6</td>
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<td>1.7</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>169</td>
<td>1.76</td>
<td>12.8</td>
<td>7.27</td>
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</tr>
<tr>
<td></td>
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<td>6.1</td>
<td>3.03</td>
<td>1.5</td>
</tr>
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<td>4.1</td>
<td>1.4</td>
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<td>16.6</td>
<td>6.53</td>
<td>1.7</td>
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|          | 126 | 0.96    | 1.1          | 1.14      | 1.2       |
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| Ave.     | 1.19     | 1.11       | 2.79          | 2.42          | Ave. | 1.44     | 1.67       | 3.82          | 2.38          |
Summary of Table VI.

Considering first the data from the Wealthy trees, we find that whereas the average diameter of the trunk pieces from the galled trees is 1.55 cm, that of the healthy trees is slightly less or 1.53 cm. The numbers of trees of the two classes is too small to render this difference in diameter significant. However, when we consider the average actual and unit flow, we find a reduction for the galled trees. Thus, the reduction in actual flow is 12.5 percent, while the reduction in unit flow is 13.8 percent. These data then suggest that the presence of the gall at the union has also affected the development of the trunk above it. With a rapid growing variety such as the Wealthy, the effect of decreased water flow would be more immediate than with slower growing varieties.

Turning now to the data from the Jonathan trees, we find conditions reversed. The average diameter of the trunk piece from the galled trees is only 1.19 cm, as compared with 1.44 cm for the healthy trees. However, in spite of the smaller diameter and consequent reduction in area, the unit flow (2.42 c.c.) through the galled trees is slightly greater than that (2.38 c.c.) through the healthy
trees.

From the description of the galls on these trees as given in table IV it is seen that those on the Jonathan trees were not so large as those on the Wealthy trees. The younger galls would probably not have had time to exert any serious influence upon growth.

From these results it is not possible to draw any definite conclusions. However there is the indication that in the rapidly growing Wealthy trees, the gall at the union affected the trunk above as evidenced by a reduction in unit flow through the piece. In the Jonathan trees, where many of the galls were quite small, no retardation in water conduction is evident.

Relation of duct area to water flow through galled and healthy apple trees.

Water conduction tests having shown that the flow through galled union pieces was on the average less than that through similar healthy specimens, it was thought that histological studies might shed more light upon the cause of the decrease. Consequently thin, free hand sections were cut from the top cross section surface of the union pieces from 25 galled and 25 healthy trees, of
the varieties Wealthy and Jonathan and the size, area and number of ducts determined for each piece. These data were obtained from counts and measurements of the ducts in five different fields under the low power of the microscope using an eye piece micrometer counting square.

The shape of the ducts was taken as an ellipse and the area computed from the formula, $a = 0.7854 \times (a \times b)$ where $a$ and $b$ are the lengths of the two axes of the ellipse. The total conducting area of the cross section surface and the ratio of the conducting surface to total cross section surface of the specimen were determined. The results are presented in table VII.
Table VII. Relation of Duct area to Unit Flow through union pieces of 100 micron unit area ducts.

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Summary of Table VII.

In the Wealthy trees while the average duct area for the healthy trees is approximately 1.5 times greater than that of the galled trees, the difference in average unit flow amounts to only 0.34 c.c. A similar condition exists in the Jonathan trees where with the duct area in the healthy trees about 1.5 times greater than that of the galled trees, the unit flow in the healthy trees is only 0.52 c.c. greater than that in the galled trees.

Since not all the ducts function equally in water conduction under the conditions of these tests it is impossible to draw any definite conclusions from the experiment. However these data suggest that while there may be a greater area of conducting surface, the individual ducts of the galled trees are more efficient in water conduction, due possibly to fewer cross walls which in these tests would permit a more rapid flow.

General Summary.

From the preliminary tests on water conduction through galled and healthy trees, there is shown a reduction in unit flow through the union pieces of galled trees as compared with that of healthy trees. The effect of cutting
back is reflected in a decrease in flow through the piece which includes the offset caused by this process in comparison with that through the trunk. It is also indicated in the Wealthy trees that the effect of a gall at the union is reflected in a reduction in water flow through the trunk section above the gall. This is not borne out in the Jonathan trees. In every case the trunk section of the tree, although of smaller diameter than the union or scion pieces is more efficient in water conduction.

A rather wide variation in rate of flow is evident in individual healthy as well as galled trees. Fit of graft, callusing, size of stock and scion of the graft, effect of shading and spacing of the tree in the nursery row, and the effect of these variations on subsequent growth are reflected in the two year tree. Thus it is not surprising that in material so lacking in homogeneity, wide variations should exist. However, in spite of these variations, it is quite evident that galled trees are not so efficient in water conduction as are healthy trees.

There appears also a variation in water flow due to variety of tree. This is evident from the data on
water conduction through healthy trunk sections. Here it is seen that the Wealthy trees are most efficient as regards water conduction, Ben Davis less so and Jonathan least of all. These results are borne out by field observations on height of tree of these varieties in the nursery row.

It is also indicated that efficiency of conduction is correlated with freedom from winter injury as seen from the higher unit flow through Wealthy trees. As compared with Jonathan or Ben Davis the Wealthy trees are much better able to withstand severe northern winter conditions.

There is little correlation between total duct area and unit flow in galled and healthy trees. This may be accounted for by the fact that all ducts do not function equally in water conduction because of the difference in numbers of cross walls. However it is shown that trees of the Wealthy variety have a greater duct area than Jonathan trees with also a greater water carrying capacity.

Water Conduction after Vacuum Treatment

The results obtained from the early tests on water conduction by means of the manometer and fluometer indi-
cated a marked reduction in flow due to the presence of a gall on the tree usually at the union. However, with certain individuals, the rate of flow was far above the average for this particular lot. A possible explanation for these discrepancies was sought in a modification and refinement of the methods employed.

Also while about 200 apple trees had been tested by the manometer and fluometer methods, the galls on some of the infected trees were not large. Careful field selection at the nursery from discarded trees was made at digging time. Only those trees were taken that showed large typical galls. The selections for further tests were made from two year cut back Wealthy and Salome apples.

Jonathan apple trees two years old were obtained from a nursery outside the state. These trees were neither so large in size nor so badly galled as were the Wealthy or Salome secured from this state. The Jonathan trees had all been dug, culled and sorted before the writer had an opportunity to make any field selections at the Iowa nurseries.

Up to this time only apple trees had been employed in the tests and it was considered advisable to include peaches which present a difficult problem to the nursery-
men in the growing of gall-free stock.

The two year old peaches were secured from a nursery in Missouri and represented typically galled trees, of the varieties Elberta, Carman, J. H. Hale and Salway.

Modifications in methods.

It will be noted that in the early experiments the fluometer tests were made at a negative pressure equivalent to 72.5 to 74 cm. of a mercury column. With such high pressure it was difficult to prevent leakage through the rubber tubing connecting the specimen to the burette of the apparatus and the tubing connections had to be replaced frequently on this account. Also the length of vertical specimen being 15 cm. a pressure head of 30 cm. gives a velocity of flow equal to that of the transpirational current as pointed out by Dixon (6). For these reasons it was decided to employ lower pressure and that equivalent to 30 cm. of a mercury column was selected. In the early experiments evacuation of air from the specimen was attempted by a preliminary period of suction, until no bubbles arose into the burette. In the later experiments the specimens were cut from the tree under water thus minimizing the ingress of air
into the ducts. Following the method used by Farmer (7), the specimens were then placed in water previously boiled to expel the air and cooled, and given a vacuum treatment. For this treatment the pieces now in the air-free water were placed in a pressure cooker. The lid was sealed with vaseline and the ball safety valve sealed with melted paraffin. The cooker was then connected, by means of pressure tubing wired to the exhaust pet-cock, to the fluometer and the air exhausted. By this means the negative pressure under which vacuation was accomplished was registered on the mercury column of the fluometer. The duration of the vacuum treatment was three hours at a negative pressure equivalent to 60 cm. of a mercury column.

A series of consecutive trials were now made on the specimens so treated. To prevent clogging of the vessels due perhaps to the diffusion of substances from the cut end of the specimen immersed in water, a fresh cut was made between each trial. While the readings were not constant for every specimen, many of them were, and a great majority checked within 0.4 c.c. in three consecutive trials. This figure was taken as the maximum variation in water flow allowable for any specimen in three
consecutive trials. Those specimens in which the variation was greater are not considered in the data.

Water conduction tests on Healthy apple trees.

With the methods so modified water conduction tests were made on healthy and galled apple trees.

As stated previously the galled trees employed in these tests were carefully selected from those discarded in the field at digging time and were badly knotted. Hairy, fibrous roots from the galled union were quite common. The root system of these trees, however, was good since in most cases the largest knots occurred on the best developed trees.

After making the fluometer tests, each specimen was sawed longitudinally through the gall splitting the scion lip in approximately equal parts. These then were employed in obtaining the descriptive data given in the table and for further histological study.

The healthy trees were secured later in the season after they had been sorted, graded and stored in the cellar. They represented grade 1 trees having a caliper of 11/16" or over. These trees all showed comparatively smooth unions, some being slightly swollen but none rough or with excrescences. Their root systems were also good
and such as one would expect to find on trees of this grade and variety. The data obtained on water conduction are given in tables VIII and IX.
Table VIII. Water conduction through galled Wealthy Apple Trees.

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9 4-3/16" and 1-½" lateral roots from gall.
5 6.7 Swollen union. Doubtful if gall.
5 4.6 2-½" lateral roots from gall.
3 8.3 No lateral roots from gall.
5 3-¼" Gall decayed.
7 2-½" and 2-1/8" roots from gall.
8 2-3/16" from gall and 1-3/16" from side of gall.
1 5-7 2-3/16" Gall decayed.
2 1.3 Swollen union with rough callus. No lateral roots. Half girdling.
9 1.7 3-½" lateral roots from gall.
5 3.1 1-½" Gall decayed.
4 0.6 2-1/8" Gall decayed.
8 0.9 3-½" and 1-½" roots from gall.
7 2-½" lateral root from gall. Gall decayed.
0 1.3 2-3/16" Gall decayed.
7 0.4 2-1/4" Gall decayed.
9 1.1 2-1/4" Gall decayed.
1 2.2 0.6 3-½" Gall decayed.
9 6.4 0.9 Swollen union, probably not gall.
8 9.5 1.5 No laterals from or above gall.
8 0.5 0.2 Probably wound callus.
7 14.2 2.4 No laterals from or above gall.
8 1.4 0.5 1-3/8" and 1-3/16" lateral roots from gall.
4 2.9 1-3/8" and 1-3/16" lateral roots from gall.
2 33.9 3-3/16" lateral roots from gall.
4 29.9 2-½" Gall decayed.
7 35.7 6.2 2-1/4" above gall. 2-1/8" roots below gall.
6 27.2 5.1 3-3/16" Gall decayed.
6 9.8 4.8 2-½" Gall decayed.
4 39.0 8.6 3-½" and 3-1/8" above gall. 2-1/8" roots below gall.
1 29.4 8.5 5-3/16" above gall.
9 4.7 1.6 No lateral roots from gall.
3 5.3 1.2 2-½" and 1-½" Gall decayed.
4 2.1 1.3 2-3/16" Gall decayed.
5 0.9 0.3 No lateral roots from gall.
8 12.0 1.9 " Gall decayed.
4 6.7 1.4 4-3/16" Gall decayed.
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Table IX. Water Conduction through healthy Wealthy Apple Trees

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Ave. 2.54 5.06 47.94 9.58
Summary of Tables VIII and IX.

The galled trees used in these tests show an average diameter of 2.21 cm., while that of the healthy trees was 2.54 cm. an increase of 0.33 cm. In the galled trees the average actual flow is 14.8 c.c. while that of the healthy trees is 47.94 c.c. approximately 3.4 times as great. The average unit flow of the galled trees is 2.9 c.c. while that of the healthy trees is 9.58 c.c. or 3.3. times that of the galled trees. We also note a wide variation in the unit flow of the galled trees which appears to be associated with the development of lateral roots from the gall. Thus in trees 574, 575, 578, 579, 581, 599, 604 and 605 where there are several relatively large roots from the gall, the actual and unit flow are correspondingly greater. An exception to this condition however is seen in tree number 577 where with no lateral roots from the gall the actual flow is 34.4 c.c. and the unit flow is 8.3 c.c. This may be attributed to lack of penetration of the gall causing little distortion of the conduction vessels. On the other hand there are many galled trees with several lateral roots from the gall which show a low actual and unit flow. Such cases are seen in tree
numbers 618, 619, 620, 622, 627, 628, 629, 630 and 631. Here we may attribute the low actual and unit flow to the effect of the gall overbalancing the effect of the lateral roots in increasing the capacity for conduction.

Complete girdling of the union by the gall does not always result in lower conduction than when the union is only partially encircled. This may result from lack of distortion due to the gall even when it entirely surrounds the tree.

Water conduction tests on Salome apple trees.

The galled trees employed in these tests were two year cut backs also selected in the field and represented badly knotted trees as classed by nurserymen. The healthy trees of the same age were selected by the nursery as number 1 grade. The root systems and tops of both kinds of trees were well developed.

The results of these tests on the galled trees are presented in table X as well as a description of the gall, while the results of the tests on healthy trees are given in table XI.
Table X. Water conduction through union pieces of galled Salome

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<tr>
<th>No.</th>
<th>Tree; Stock; Scion; Union; Eleva; Length; %</th>
<th>Location of Gall</th>
<th>Call Characters</th>
<th>Fibr.; Diam.; Actual; Unit</th>
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*No = Number of trials, *St = Standard deviation.
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<th>Actual:Unit</th>
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**Description of Gall**

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<td>:c.c.</td>
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</tbody>
</table>

- **2.3** 1.4 Not a gall - large callus on unhealed scion lip.
- **2.3** 5.8 1 lateral root 3/16" in diameter and 1-1/8" in diameter from gall.
- **2.9** 8.1 1 lateral 3/16" diameter from below gall on union.

[Table continues with various descriptions of galls and their characteristics]
Table X. continued.

<table>
<thead>
<tr>
<th>Location of Gall</th>
<th>Call Characters</th>
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<td>Tree: Stock: Scion: Union: Eleva-</td>
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<tr>
<td>39.3</td>
<td>3.68 3 roots 1/8&quot; from the gall. Wound callus on stock below the union.</td>
</tr>
<tr>
<td>25.3</td>
<td>7.31 1 root 3/16&quot; and 4-1/16&quot; from gall</td>
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<tr>
<td>8.4</td>
<td>3.70 Wound callus on stock. 2- 3/16&quot; above callus.</td>
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<td>16.7</td>
<td>5.32 1 root 2&quot; from gall and 1-1/2&quot; lateral on opposite side of gall.</td>
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<td>20.6</td>
<td>6.39 Not a gall - callus at union</td>
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<tr>
<td>4.1</td>
<td>1.81 1 root 1/8&quot; and 1-3/16&quot; from side of gall.</td>
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<tr>
<td>21.3</td>
<td>4.52</td>
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### Table XI. Water conduction through healthy Salome Apple Trees

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<th>No.</th>
<th>Tree Diam.</th>
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Summary of Tables X and XI.

From these data we find that the average diameters of galled and healthy trees differ but little, that of the former being 2.27 cm. and that of the latter 2.08 cm. There is also little difference between the average actual rate of flow of the healthy trees (24.4 c.c.) and that of the galled trees (21.3 c.c.). However when we consider the unit flow for galled and healthy trees we find that of the galled trees is 4.52 c.c. while that of the healthy trees is 5.77 c.c. or a reduction in the galled trees of 21.7 percent. We also note the effect of lateral roots from the gall on increased water flow as exemplified in tree numbers 455, 471, 480, 484, 485, 494 and 495. The effect of lateral roots from the union opposite the gall is also shown in tree number 464 which shows the highest unit flow of any of the galled trees.

Only one of the galls completely encircle the union in this variety hence no comparison can be made as to the effect of girdling since the variation in flow through trees only partially girdled is too great. Size of gall also appears to have little correlation with reduction in unit flow in this lot of trees.

A comparison of unit flow through the healthy Salome
trees with that of the Wealthy trees shows the latter to be more efficient in conduction.

Water conduction tests on Jonathan apple trees.

The trees employed in these tests were two years old and grown in a nursery in Missouri. Healthy trees of the same age were also obtained at the same time from this source. The galled trees were taken from discarded trees and when shipped were labelled "knotted". However, it was evident on examination that practically one-third of the trees were not galled nor did all of the remainder show a badly swollen union. Fibrous hairy root from the galls was common. Fleshy hairy roots were also present on the galls of some of these trees.

After making the fluometer tests the specimens were split longitudinally and carefully examined with a view to classifying the specimens as being galled or showing only a swollen callus at the union. The healthy specimens were well developed and of practically the same size as the galled trees. The results of these tests are presented in tables XII and XIII.
Table XII: Water conduction through union pieces of galled Jonathan Apple

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Average of all trees: 1.73 10.27 4.04
Average of galled trees only: 1.75 11.96 4.38
Jonathan Apple Trees.

**Description of Gall.**

<table>
<thead>
<tr>
<th>Actual Unit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>Flow</td>
</tr>
<tr>
<td>c.</td>
<td>c.c.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>1 lateral 1/8&quot; in diameter from gall. Stock dead.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>2.6</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>6.2</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td>5.4</td>
<td>No laterals from gall.</td>
</tr>
<tr>
<td>3.3</td>
<td>1.9</td>
<td>No gall - callus at union.</td>
</tr>
<tr>
<td>2.9</td>
<td>1.4</td>
<td>No lateral roots.</td>
</tr>
<tr>
<td>6.9</td>
<td>3.4</td>
<td>No laterals from gall or scion above.</td>
</tr>
<tr>
<td>1.5</td>
<td>6.6</td>
<td>Not a gall-callus at union.</td>
</tr>
<tr>
<td>1.2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>1.2</td>
<td>No gall. Hairy roots from top &amp; bottom of union.</td>
</tr>
<tr>
<td>3.2</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>2.8</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>4.3</td>
<td>4.4</td>
<td>Small rough callus from between lips. Not gall.</td>
</tr>
<tr>
<td>2.3</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>3.8</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>8.3</td>
<td>12.2</td>
<td>4-1/8&quot; laterals from gall.</td>
</tr>
<tr>
<td>5.7</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>6.4</td>
<td>21.1</td>
<td></td>
</tr>
<tr>
<td>4.3</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>8.2</td>
<td>11.1</td>
<td>Callus at union not a gall. 2-1/2&quot; lateral above union.</td>
</tr>
<tr>
<td>5.4</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>16.6</td>
<td>Not gall-slightly swollen union. 1 lateral root 3/16&quot; diam above union.</td>
</tr>
<tr>
<td>0.5</td>
<td>0.2</td>
<td>Stock lip broken off.</td>
</tr>
<tr>
<td>6.9</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>4.9</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>3.9</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>7.2</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>0.27</td>
<td>4.04</td>
<td>Not gall-slightly swollen union.</td>
</tr>
<tr>
<td>1.96</td>
<td>4.38</td>
<td></td>
</tr>
</tbody>
</table>
Table XIII. Water conduction through union pieces of Jonathan Apple Trees.

<table>
<thead>
<tr>
<th>Tree No.</th>
<th>Diameter (cm)</th>
<th>Area (sq. cm)</th>
<th>Actual Flow (c.c.)</th>
<th>Union Flow (c.c.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>505</td>
<td>1.3</td>
<td>1.76</td>
<td>20.9</td>
<td>11.8</td>
</tr>
<tr>
<td>506</td>
<td>1.6</td>
<td>2.01</td>
<td>47.3</td>
<td>23.5</td>
</tr>
<tr>
<td>507</td>
<td>2.0</td>
<td>3.14</td>
<td>42.4</td>
<td>13.5</td>
</tr>
<tr>
<td>511</td>
<td>1.6</td>
<td>2.01</td>
<td>23.7</td>
<td>11.7</td>
</tr>
<tr>
<td>514</td>
<td>2.0</td>
<td>3.14</td>
<td>30.7</td>
<td>9.4</td>
</tr>
<tr>
<td>515</td>
<td>1.6</td>
<td>2.01</td>
<td>55.8</td>
<td>26.7</td>
</tr>
<tr>
<td>516</td>
<td>1.7</td>
<td>2.26</td>
<td>23.9</td>
<td>13.2</td>
</tr>
<tr>
<td>517</td>
<td>1.5</td>
<td>1.76</td>
<td>17.4</td>
<td>9.8</td>
</tr>
<tr>
<td>518</td>
<td>1.5</td>
<td>1.76</td>
<td>20.3</td>
<td>11.5</td>
</tr>
<tr>
<td>519</td>
<td>2.0</td>
<td>3.14</td>
<td>36.5</td>
<td>11.6</td>
</tr>
<tr>
<td>520</td>
<td>1.7</td>
<td>2.26</td>
<td>37.8</td>
<td>16.7</td>
</tr>
<tr>
<td>521</td>
<td>1.5</td>
<td>1.76</td>
<td>37.5</td>
<td>21.3</td>
</tr>
<tr>
<td>522</td>
<td>1.5</td>
<td>1.76</td>
<td>34.4</td>
<td>19.5</td>
</tr>
<tr>
<td>523</td>
<td>1.8</td>
<td>2.54</td>
<td>20.5</td>
<td>8.1</td>
</tr>
<tr>
<td>524</td>
<td>1.7</td>
<td>2.26</td>
<td>14.5</td>
<td>6.3</td>
</tr>
<tr>
<td>525</td>
<td>1.6</td>
<td>2.01</td>
<td>35.9</td>
<td>18.3</td>
</tr>
<tr>
<td>526</td>
<td>1.5</td>
<td>1.76</td>
<td>23.3</td>
<td>13.2</td>
</tr>
<tr>
<td>527</td>
<td>1.5</td>
<td>1.76</td>
<td>23.5</td>
<td>13.3</td>
</tr>
<tr>
<td>528</td>
<td>1.4</td>
<td>1.53</td>
<td>10.3</td>
<td>6.7</td>
</tr>
<tr>
<td>529</td>
<td>1.7</td>
<td>2.26</td>
<td>3.3</td>
<td>1.4</td>
</tr>
<tr>
<td>531</td>
<td>1.8</td>
<td>2.54</td>
<td>15.3</td>
<td>5.3</td>
</tr>
<tr>
<td>537</td>
<td>1.6</td>
<td>2.01</td>
<td>15.0</td>
<td>8.9</td>
</tr>
<tr>
<td>552</td>
<td>1.5</td>
<td>1.76</td>
<td>8.5</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Ave. 1.63 2.08 25.77 12.40
Summary of Tables XII and XIII.

We note from these tables that with an average diameter only 0.02 cm. greater, the actual flow through the galled trees is 1.69 cm. higher than that through the trees with a swollen union. The highest actual and unit flow for the whole lot is found in the galled trees, number 560 where the value is 66.4 c.c. and this with the absence of lateral roots from the gall. There are however fewer high values for actual and unit flow in the galled trees than in those with swollen unions. A comparison of unit flow of the galled trees with that of the healthy trees shows a marked reduction. The value for the former is 4.38 c.c. while for the latter it is 12.4 c.c. The average actual flow in galled trees is 11.96 c.c. while in the healthy trees it is 25.77 c.c. in spite of the fact that the average diameter of the healthy trees is only 1.63 cm. as compared with that of 1.75 cm. for the galled trees.

It is not possible to draw any conclusions as to the effect of the gall on diameter of trees because the healthy trees were all sorted on the basis of size while the galled trees were graded on the basis of presence of gall regardless of size.
These data however do show quite clearly that the presence of the gall interferes with water flow through the union piece and in this case causes a reduction of 65.49 percent. It is also shown that there is a reduction of 67.42 percent flow through those trees having swollen unions.

The fact that such trees without galls were discarded also indicates the thoroughness of selection and grading practiced by this nursery. Another fact of interest is that many of the trees classed as galled or knotted by the nurserymen are so far as galls are concerned healthy trees. In this lot of Jonathan trees 16 of the trees were galled while 21 trees had no definite gall.

If this is representative of sorting out galled trees it would indicate that many of the galled trees planted in crown gall orchards were in reality not galled. This would account for the absence of galls in later years and the healthy appearance and productiveness of such trees.

Water conduction through galled and healthy peach trees.

It is the consensus of opinion among nurserymen that the effect of crown gall on peach trees is much more serious
than on the apple. Field observations also point to the fact that the planting of galled peach trees is practically wasted labor due to the early death of the tree. Water conduction tests should give a quantitative measure of the injury caused by the galls and make it comparable with the injury on apple.

Commercial varieties of peach, J. H. Hale, Elberta, Carman and Salway were selected for study and included both galled and healthy trees. The specimens were taken so as to include equal portions of the root and stem and were 15 centimeters in length. Representative specimens are shown in plate 2. The data from these tests are presented in table XIV.
### Table XIV. Water conduction through galled and healthy peach trees

<table>
<thead>
<tr>
<th>Variety</th>
<th>Galled Trees</th>
<th>Healthy Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree: Diam. Actual: Unit</td>
<td>Tree: Diam. Actual: Unit</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>cm.</td>
<td>Flow</td>
</tr>
<tr>
<td>Ave.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.C.</td>
<td>C.C.</td>
<td>C.C.</td>
</tr>
<tr>
<td>Ave.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 288 | 2.1 | 2.5 | 0.73 | 388 | 1.9 | 19.8 | 6.39 |
| 289 | 2.1 | 1.1 | 0.30 | 387 | 1.5 | 9.2 | 5.23 |
| 290 | 2.2 | 2.5 | 0.65 | 386 | 1.4 | 8.9 | 5.75 |
| 291 | 1.8 | 0.6 | 0.24 | 385 | 1.5 | 10.4 | 5.91 |
| 292 | 1.5 | 0.7 | 0.29 | 384 | 1.1 | 4.9 | 5.21 |
| 293 | 1.7 | 1.8 | 0.79 | 383 | 1.7 | 3.3 | 1.45 |
| 294 | 1.7 | 1.4 | 0.61 | 382 | 1.5 | 3.9 | 2.22 |
| 295 | 1.0 | 0.7 | 0.26 | 381 | 1.8 | 10.3 | 4.05 |
| 296 | 2.1 | 0.8 | 0.23 | 380 | 1.2 | 4.6 | 4.07 |
| 297 | 1.5 | 1.3 | 0.74 | 379 | 1.4 | 6.1 | 3.99 |
| 298 | 1.9 | 2.1 | 0.74 | 378 | 1.3 | 3.0 | 2.28 |
| 299 | 1.7 | 0.9 | 0.29 | 377 | 1.4 | 4.3 | 2.81 |
| 300 | 1.6 | 0.2 | 0.39 | 376 | 1.7 | 6.1 | 2.69 |
| 301 | 1.5 | 0.6 | 0.39 | 375 | 1.6 | 2.2 | 1.09 |
| 302 | 1.8 | 1.7 | 0.67 | 400 | 1.5 | 8.7 | 4.94 |
| 303 | 2.0 | 0.6 | 0.19 | 401 | 1.9 | 4.8 | 1.71 |

| Ave. | 1.75 | 1.23 | 0.35 | Ave. | 1.52 | 5.90 | 3.73 |

<table>
<thead>
<tr>
<th>Elberta</th>
<th>Ave.</th>
<th>Ave.</th>
</tr>
</thead>
<tbody>
<tr>
<td>314</td>
<td>1.7</td>
<td>4.7</td>
</tr>
<tr>
<td>315</td>
<td>1.4</td>
<td>1.2</td>
</tr>
<tr>
<td>316</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>317</td>
<td>1.8</td>
<td>0.5</td>
</tr>
<tr>
<td>318</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>319</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>320</td>
<td>1.5</td>
<td>0.3</td>
</tr>
<tr>
<td>321</td>
<td>1.3</td>
<td>0.9</td>
</tr>
<tr>
<td>322</td>
<td>1.6</td>
<td>1.0</td>
</tr>
<tr>
<td>323</td>
<td>1.5</td>
<td>0.6</td>
</tr>
<tr>
<td>324</td>
<td>2.0</td>
<td>1.3</td>
</tr>
<tr>
<td>325</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>326</td>
<td>1.7</td>
<td>0.6</td>
</tr>
<tr>
<td>327</td>
<td>1.5</td>
<td>0.4</td>
</tr>
</tbody>
</table>

| Ave. | 1.8 | 1.15 | 0.58 | Ave. | 1.47 | 6.05 | 3.77 |
Table XIV. Continued

<table>
<thead>
<tr>
<th>Variety</th>
<th>Killed Trees</th>
<th>Healthy Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tree: Diam.: Actual: Unit</td>
<td>Tree: Diam.: Actual: Unit</td>
</tr>
<tr>
<td></td>
<td>No.: cm.: flow: cm.</td>
<td>No.: cm.: flow: cm.</td>
</tr>
<tr>
<td>Salway</td>
<td>305 1.5 0.30 0.11</td>
<td>376 1.5 6.4 3.64</td>
</tr>
<tr>
<td></td>
<td>306 2.0 1.00 0.22</td>
<td>377 1.6 12.1 6.03</td>
</tr>
<tr>
<td></td>
<td>307 1.9 0.57 0.20</td>
<td>378 1.4 10.2 6.66</td>
</tr>
<tr>
<td></td>
<td>308 1.7 0.40 0.17</td>
<td>379 1.2 13.6 1.20</td>
</tr>
<tr>
<td></td>
<td>309 1.5 0.40 0.19</td>
<td>380 1.2 4.5 3.98</td>
</tr>
<tr>
<td></td>
<td>310 1.3 0.00 0.00</td>
<td>381 1.5 15.2 8.64</td>
</tr>
<tr>
<td></td>
<td>311 1.7 0.30 0.35</td>
<td>382 1.2 5.0 4.45</td>
</tr>
<tr>
<td></td>
<td>312 1.5 0.00 0.00</td>
<td>383 1.4 5.6 3.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>384 1.1 6.7 7.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>385 1.1 13.3 14.50</td>
</tr>
<tr>
<td>Ave.</td>
<td>1.7 0.45 0.15</td>
<td>Ave. 1.32 9.31 5.98</td>
</tr>
</tbody>
</table>

| Carman  | 328 1.0 1.2 1.52 | 402 1.1 3.9 4.11 |
|         | 329 1.7 1.7 0.75 | 403 2.0 13.1 4.17 |
|         | 330 1.3 3.2 2.42 | 404 1.6 13.5 6.62 |
|         |                | 405 1.5 10.2 5.79 |
|         | 332 1.5 4.4 2.50 | 406 1.2 9.1 9.05 |
|         | 333 2.2 1.5 0.39 | 407 1.1 4.4 4.63 |
|         | 334 2.1 1.3 0.52 | 408 1.3 9.4 7.10 |
|         | 335 2.0 3.5 1.11 | 409 2.0 9.4 2.99 |
|         | 336 1.7 2.7 1.19 | 410 1.7 11.5 5.06 |
|         |                | 411 1.9 10.6 3.75 |
| Ave.    | 1.38 2.50 1.30 | Ave. 1.34 9.49 5.22 |
Summary of Table XIV.

There is a striking reduction in actual and unit flow through galled Hale trees as compared with that of the healthy trees. With an average diameter of 1.76 cm. the average actual and unit flow for the galled trees is only 1.23 c.c. and 0.55 c.c. as compared with that of 6.9 c.c. and 3.73 c.c. for the healthy trees with an average diameter of only 1.52 cm. We note here that in spite of a larger diameter in the galled trees that water conduction is reduced approximately 85 percent.

The healthy Elberta trees are quite comparable with healthy Hale trees as to actual and unit flow, and would appear to fall in the same class on the basis of conduction. In this variety the average actual and unit flow are 6.05 c.c. and 3.77 c.c. respectively.

The galled trees while having a larger average diameter show a low actual and unit flow, 1.15 c.c. and 0.58 c.c. as compared with that of the healthy trees. In the galled trees the reduction in unit flow is 84.6 percent.

In the healthy Carman trees the conduction is quite comparable with that of the healthy Salway trees. Here we find an average unit flow of 5.22 c.c. with the actual
flow 9.49 c.c. The trees of this variety however have a larger diameter than the Salway trees but the unit flow is 0.76 c.c. less. The galled trees while showing higher actual and unit flow than those of either Hale, Salway or Elberta trees also show a reduction of 75.1 percent in unit flow when compared with the healthy trees of this variety.

A similar condition exists in the Salway trees, a larger average diameter in the galled trees than in the healthy trees. However the actual and unit flow for these trees is only 0.43 c.c. and 0.15 c.c. respectively as compared with 9.31 c.c. and 5.98 c.c. actual and unit flow for the healthy trees. The reduction in unit flow for the galled trees is 73.5 percent.

Interference with water conduction in the peach trees is due entirely to the presence of the gall since the specimens were taken below the point of budding. The galls on the peach are unlike a majority of those on the apple in this one important respect, namely that they penetrate more deeply the tissue of the stem. There was also evidence of decay of the tissues of the stem around the gall which would account for the serious injury indicated by the fluometer tests.
From the data on conduction in the healthy trees we find that the varieties tested can be placed in two classes, one including the Carman and Salway with high average unit flow (5.6 c.c.) the other including Hale and Elberta with relatively low unit flow (3.75 c.c.). In this connection it is interesting to note that the Salway and Carman peaches under Iowa conditions at least are regarded as more hardy than the Elberta and Hale. In the peach then we find ability to withstand severe winter conditions correlated with high water conduction thus corroborating this fact brought out in the Wealthy apple trees as compared with the Jonathan and Ben Davis varieties.

Crown gall on peach is also shown to be more injurious than on apple from the standpoint of water conduction thus substantiating field observations of various writers to this effect.

Discussion

Qualitative tests have demonstrated that the presence of a gall on the union of a root grafted apple tree interposes a serious obstacle to the upward flow of water through the sap wood on the side of the tree where the
gall is located. With many of the specimens studied there was no flow through the gall for the duration of the test and at a pressure of 6 to 9 cm. of mercury. While these data do not prove that water flow through the gall is entirely absent under natural conditions, they do indicate the injuriousness of such a growth on the tree.

Quantitative tests corroborate the facts brought out by means of the qualitative tests and show that under the conditions of the experiment water flow through galled trees, as compared with that of healthy trees, is reduced. The data on conduction through galled peach trees is even more striking than those obtained from the studies on apple trees. In the case of the galled peach trees the average water flow in all varieties was reduced 84 percent as compared with that for the healthy trees.

There appear in the results obtained rather wide variations in water conduction through individual trees both galled and healthy. On first thought it might seem that such a condition while to be expected in galled trees, should not occur in the healthy trees. However, it must be borne in mind that we are dealing with a heter-
ogeous collection of material even though it was grown under similar conditions in the nursery and of the same varieties. The fact that piece root grafted trees were employed in these tests, would account to some extent for the tendency toward wide variations in flow.

In spite of these factors tending toward variation in individual behavior, the results obtained, all the more significant on this account, show a marked reduction in the water conduction of galled trees. It is also seen that the rate of flow through the trunk piece, taken from the tree at a point above the offset caused by cutting back the young leader, is materially greater than through the union piece including the union and the scion piece including the offset mentioned above.

Thus if we take as normal the rate of flow through the trunk, it is quite obvious that both the practice of grafting and cutting back serve to lower the efficiency of the young tree in the conduction of water.

There is a tendency on the part of orchardists to select for planting two year trees rather than the two year cut backs. In some cases they prefer a one year tree to a two year cut back if the two year tree cannot be had. The contention on their part is that a two year
tree grows better than the cut back and is more easily headed to suit their special requirements. The data on water conduction through the offset in the trunk caused by cutting back indicate a reason for the better development of the two year trees.

While there are several factors determining hardiness in orchard trees, the results of our tests indicate that efficiency in water conduction may be an important one. This point however needs still further proof based upon trials upon large numbers of trees of several varieties well defined as to their hardiness.

There is also a varietal difference in water conduction which is associated with rapidity of growth. The rapidly growing Wealthy and Salome trees show much higher water conduction than the Jonathan trees.

The results of water conduction tests on peach trees substantiate those obtained on apple trees but show in this case much greater interference. This interference is due entirely to the gall since the pieces used in the tests were taken from below the point of budding. The results obtained on peach trees show that crown gall infection on trees with relatively soft tissue is much more injurious than on those with harder tissue.
As a result of the tests on peach trees we also see a varietal difference in conduction and that this can be correlated with hardiness under Iowa conditions.

Relation of Type of Gall to Water Flow Interference

At the beginning of the study of water conduction in galled apple trees it was believed that size of gall would be more or less directly related to the water conduction through the galled specimen. After the completion of fluometer tests upon 70 galled apple trees, the specimens were classified roughly depending upon the size of the gall and the degree of girdling. Two classes were made as follows: Class 1 consisted of trees with a rough, swollen union or with galls varying from half to full size of a hickory nut partially or completely girdling the union. In class 2 were placed those trees with galls varying in size from that of a hickory nut to that of a walnut half or completely girdling the union and in a few cases galls the size of a hickory nut on the trunk above the union.

The mean rate of flow for 5 minutes is given for each class in table XV.
Table XV. Relation of size of gall to water conduction.

<table>
<thead>
<tr>
<th>Class</th>
<th>No. Speci.</th>
<th>Diam. Actual:Unit</th>
<th>Flow:flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Rough swollen union or with galls from half to full size to hickory nut partially or completely girdling the union.</td>
<td>44</td>
<td>1.72 6.06 2.32</td>
<td></td>
</tr>
<tr>
<td>2 Galls varying from size of hickory nut to that of walnut, half or completely girdling union and in a few cases similar galls on trunk above union.</td>
<td>26</td>
<td>1.87 5.31 1.75</td>
<td></td>
</tr>
</tbody>
</table>

From table XV we note that the trees of class 1 with an average diameter 0.15 cm. smaller than those of class 2, have an average unit flow 29.9 percent greater. This suggests that in general the larger the gall and more complete the girdling, the greater the interference to conduction.

It was realized that this classification was decidedly a rough one and that since more than one variety was included in the specimens a part of the reduction in flow might have been due to varietal difference.

Having completed more accurate water conduction tests on a larger number of trees, measurements on size of gall and girdling of the union were made for trees of the Wealthy
variety and an attempt was made to correlate water conduction with character of gall. The average height of the excrescence above the union, termed elevation, the vertical extent of the gall and percentage of union or stem involved by the gall were measured. These data with the unit rate of flow for the specimens are given in table XVI.

Table XVI. Relation of size of gall to rate of flow in healthy apple trees.

<table>
<thead>
<tr>
<th>No. of Specimens</th>
<th>Elevation of gall</th>
<th>Vertical length</th>
<th>Percent girdling</th>
<th>Unit flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>1.75 cm.</td>
<td>3.83 cm.</td>
<td>43.6</td>
<td>7.02</td>
</tr>
<tr>
<td>16</td>
<td>1.77</td>
<td>4.31</td>
<td>59.8</td>
<td>0.94</td>
</tr>
</tbody>
</table>

The surprising feature of this classification is the reduction in unit flow apparently as the result of increased girdling. With the size of galls in the two classes practically the same it does not appear reasonable that an increase of 16.2 percent in girdling would account for a reduction of approximately 99 percent in the unit flow. These data strongly indicate that size of gall and degree of girdling cannot be accepted as an accurate criterion of interference with water conduction.
Relation of Healing of the Union to Water Conduction and Gall Formation

Water flow having been made on a number of galled and healthy trees, the specimens were sawed longitudinally through the center of the scion lip of the graft. The sections thus revealed the extent to which the union had healed and the amount of callus formation at the tips of the stock and scion lips. It was thought that the degree of healing might throw more light upon the variation in water conduction. The specimens were arranged into three classes as follows. Class 1 consisted of trees in which there was complete healing of the union; class 2 of those in which the tip of the scion lip had failed to unite with the stock cut; class 3 of those in which the tip of the stock lip had failed to unite with the scion. These data are presented in table XVII.
Table XVII. Effect of healing of union on rate of flow

<table>
<thead>
<tr>
<th>Class</th>
<th>Healthy Trees</th>
<th>Called Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>trees</td>
<td>Unit</td>
</tr>
<tr>
<td></td>
<td>flow c.c.</td>
<td>flow c.c.</td>
</tr>
<tr>
<td>1</td>
<td>Union healed</td>
<td>41</td>
</tr>
<tr>
<td>2</td>
<td>Scion lip not healed</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>Stock lip not healed</td>
<td>3</td>
</tr>
</tbody>
</table>

Taking up first the data for the healthy trees it is interesting to note the large number of trees in class 1 as compared with those in classes 2 and 3. Of a total of 53 healthy trees 41 or approximately 77 percent show perfect healing of the union with 9 and 3 trees or approximately 17 and 6 percent respectively in the classes of imperfectly healed union.

It is evident from the average unit flow that the imperfectly healed union causes a serious reduction in water conduction through the healthy tree, amounting to approximately 51 percent.

Turning now to the galled trees it is shown that where the union is completely healed, the presence of a gall causes a serious reduction in water flow. Comparing
90.

the galled trees in class 1 with the healthy trees of the same class we find their respective unit flow values to be 4.58 c.c. and 9.28 c.c. respectively. Thus the presence of a gall on the otherwise normal union reduces its water conduction approximately 52 percent. In class 2 where the scion lip has not entirely healed and there is a break in the continuity of the vessels the unit flow is 3.78 c.c. If we look at the unit flow for this class among the healthy trees we note that it is a little higher than for the galled trees. We find also that the incomplete healing of the scion lip in the healthy trees causes a reduction of approximately 50 percent in the water flow through the union, indicating clearly it is not necessary to have a gall in order to reduce the flow.

This leads us to a consideration of the effect of a gall on a tree where the union is imperfect due to poor grafting. If we take the group where the scion lip has failed to heal to the stock we note the difference between galled and healthy is only nominal, less than 10 percent. However the question at once arises as to the position of the gall on trees of this class. Where they occur on the tip of the scion lip, the effect on flow would probably be negligible. On the other hand where the
gall occurs at some other point on the union the rate of flow would obviously be reduced as it was in the trees where the union healed normally with a gall at some point on the union. As this group with the scion lip free was made up there is no way of ascertaining exactly the position of the galls. Allowing that approximately 75 percent of the galls occurred on the scion lip, the difference in reduction in rate of flow between the galled and healthy trees in this class would be caused by the remaining 25 percent at some other point on the union.

It appears from the above evidence that the practice of grafting in many cases results in as serious a curtailment of the water conducting capacity of the young tree as the presence of a gall. The retardation in water flow due to an imperfect union must certainly be reflected in the subsequent growth of the tree for a period of years.

Another point of interest is the number of galled trees falling into the two classes of trees with imperfect unions. Of a total of 102 galled trees 71 show an imperfect union.

Hedgcock (10) makes the following statement in this connection. "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. In his experiments out of a total of 357 trees grown from smoothly fitted root grafts 7.8 percent were galled while from 217 trees grown from the poorly fitted grafts 17.5 percent were galled. Melhus and Maney (12) in their experiments planted perfect and poorly fitting piece root apple grafts. They conclude from an examination of the three year old trees that the method of grafting is not so important a factor in crown gall infection as previously considered. In those grafts were the stock lip projected over the base of the scion the stand at the end of three years was reduced 50 percent as compared with that of the trees from perfect fitting grafts, while the percentage of galled trees from the poorly fitted grafts was 12.5 percent less than that from the perfect fitting grafts.

The effect of a poorly fitting union upon subsequent growth of the trees appears especially significant. At the end of three years, only half of the trees from this type of graft were living. These results are readily explained when we consider the reduction of 51 percent in rate of flow through the imperfect union as shown in table XVII. It is suggested from the foregoing field and laboratory trials that trees from such grafts cannot
obtain sufficient food material due to the lack of continuity of the vessels through the imperfect union and death results.

It may be said that the tree will outgrow the imperfect union and grow and produce as well as one in which the union healed properly. From the general results of stunting observed on other crops, it would appear unlikely that such trees would fully recover, even after a period of years, from this retardation in the flow of water and nutrients to the growing tops.
The Effect of Crown Gall on Tomato Plants.

Along with the water conduction studies in apple and peach trees it seemed desirable to obtain further data on the effects of crown gall upon the growing host and under better controlled conditions of moisture, soil type, temperature, and infection. Because of lack of space and difficulty of growing apple and peach trees in a greenhouse devoted primarily to herbaceous plants these experiments were carried on with tomato plants. This host is quite susceptible to the disease and also grows rapidly, making it possible to replicate experiments in a relatively short time.

The effect of crown gall upon water conduction in the tomato was first studied. Tests were made on healthy and infected plants grown under conditions favoring the development of the gall. Similar tests were also made on certain galled and healthy plants used in the wilting coefficient experiments.

Effect of Crown Gall upon Water Conduction in Tomato Plants

Water conduction tests were made on galled and healthy
tomato plants of the same age and variety and grown in adjoining rows of pots in the greenhouse. The plants were lifted carefully from the pots and the soil washed from the roots. The root and portion of the stem was immersed in water and a piece 7.5 cm. in length including equal portions of root and stem was cut off under water. The specimen was then connected to the fluometer and a preliminary period of suction for 20 minutes at a reduced pressure of 72 cm. of mercury given to free the specimen from air so far as possible. The reading on water flow was taken after a ten minute period of suction. Consecutive trials were made on each specimen. When two readings checked within 0.2 c.c. no further trials were made. If the first two readings checked within 0.4 c.c., a third trial was made and if this checked within 0.4 c.c. of either of the others no further tests were made.

Plants were inoculated artificially in some cases on the main root just below the surface of the soil and in other cases about 2 inches above the soil on the stem.

Needle prick inoculations were made at four places equidistant around the crown of the plant, thus insuring severe infection. When the galls had attained the dia-
meter of approximately 2.5 cm. the plants were ready for testing. With the succulent condition of the plants at the time of inoculation about a month was required for the galls to enlarge to this diameter. The results of these tests are shown in Table XVIII.

Table XVIII. Effect of crown gall upon water conduction in tomato plants.

<table>
<thead>
<tr>
<th>Diameter of specimen</th>
<th>Average rate of flow in 10 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy plants</td>
<td></td>
</tr>
<tr>
<td>Wt: 0.6 cm.</td>
<td>0.60 c.c.</td>
</tr>
</tbody>
</table>

Effect of Crown Gall upon the Wilting Coefficient of Tomato Plants.

The results of previous water conduction tests having shown that the presence of a gall reduced the rate of flow through the plant the question arose as to whether interference might be reflected in the wilting coefficient of galled plants.

With a partial stoppage of water flow through the in-
ected plants it seemed possible that depletion of the soil moisture and permanent wilting would take place less rapidly in the galled plants.

With this possibility in mind experiments were carried out on the determination of the wilting coefficient of galled and healthy tomato plants.

Methods.

Rapidly growing plants of the same age and as nearly the same height as possible were selected for the experiments. After removing from the pots, the soil was carefully washed from the roots and the plants repotted in one gallon stoneware jars of finely sifted greenhouse soil. The water content of the soil in each case was approximately 18 percent of the moisture holding capacity of the soil. Water was added in equal amounts to all the jars, at stated intervals, sufficient to keep the plant in a vigorous growing condition. After the plants had become established a certain number of them were inoculated with a pure culture of *Bacterium tumefaciens*, while others were left as checks. Inoculation was made at the crown of the plant which in repotting was buried about two inches under the soil. An ordinary test tube was inserted into the
soil through which water was added to the plant at intervals. The tube was plugged with cotton to allow for soil aeration and at the same time prevent water evaporation to a large extent.

The surface of the soil in the jars was then sealed over with wax as described by Briggs and Shantz (4). The wax was made from a mixture of eight parts of paraffin and one part of vaseline and applied while warm. Care must be taken that the melted wax is not too hot since the tomato is easily injured in this manner. The injury from the hot wax is not immediately apparent since the killing results to the portion of the plant underground. Later, however, the plant begins to wilt and one might mistake this flagging for the effect of crown gall upon the plant.

A few plants inoculated in the same manner and at the same time as those in the experiment were kept for observation on the development of the gall. When the galls on these observational plants had reached a diameter of 2.5-3.0 centimeters watering of the experimental plants was discontinued. In some cases it was necessary to add water after this time due to absence on field work. This, however, in no way interfered with the results, simply prolonging the experiment.
After watering was discontinued the plants were carefully observed for evidence of a wilting condition which would persist in the shade. When this condition was reached, the plants were placed in a large moisture chamber, the floor of which was covered with soil and in addition a top layer of sphagnum moss. Approximately 100 percent humidity could be maintained in this chamber. The plants were left in the chamber for 24 hours and if the leaves again became turgid, they were removed to the greenhouse bench. This removal was usually repeated three times before permanent wilting took place.

After permanent wilting had taken place, the plants in certain cases were removed from the soil and employed in fluometer tests on water conduction.

A soil sample of 50 grams was taken from about the roots of the plant in each jar. After drying at 120°C for three days the sample was reweighed and the amount of moisture present at the time of permanent wilting was determined.

Wilting coefficient experiments.

In the first experiment the galled plants then 8 inches in height were inoculated with a pure culture of
Bacterium tumefaciens by needle prick on November 25, 1925. When the galls had grown to the size of a small hazel-nut the plants were repotted in the jars and after becoming established sealed with wax. The experiment was terminated on February 6, 1925 when all the plants showed permanent wilting after 24 hours in the moisture chamber.

It was difficult to determine which of the plants wilted first since there was a difference only in degree of wilting and no wide difference in time between that of the healthy and galled plants. This condition was observed in each experiment. The data obtained are given in table XIX.

Table XIX. Wilting Coefficient of Galled and Healthy Tomatoes

<table>
<thead>
<tr>
<th>Height of plant:</th>
<th>Coefficient:</th>
<th>Height of plant:</th>
<th>Coefficient:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galled</td>
<td>15.25 inches</td>
<td>7.94</td>
<td>23.00</td>
</tr>
<tr>
<td></td>
<td>21.25</td>
<td>7.56</td>
<td>24.50</td>
</tr>
<tr>
<td></td>
<td>15.50</td>
<td>8.86</td>
<td>19.25</td>
</tr>
<tr>
<td></td>
<td>18.00</td>
<td>7.38</td>
<td>22.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17.75</td>
</tr>
<tr>
<td>Av. 17.00 &quot;</td>
<td>8.44</td>
<td>21.40</td>
<td>7.97</td>
</tr>
</tbody>
</table>
Nineteen of the plants, six galled and three healthy, were injured by hot wax at the time of sealing and died before the termination of the experiment.

In the second experiment twelve galled and six healthy plants were employed. The plants were inoculated previously and when the galls were about the size of a small hickory nut, they were transferred to jars and sealed on February 20, 1925. The experiment was ended on March 5 at which time all the plants showed permanent wilting after 24 hours in the moisture chamber. The results are given in table XX.

### Table XX. Wilting Coefficient of Galled and Healthy Tomatoes

<table>
<thead>
<tr>
<th>Height of plant: inches</th>
<th>Coefficient</th>
<th>Height of plant: inches</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.50</td>
<td>6.68</td>
<td>19.50</td>
<td>6.02</td>
</tr>
<tr>
<td>15.50</td>
<td>4.66</td>
<td>20.75</td>
<td>6.28</td>
</tr>
<tr>
<td>18.75</td>
<td>5.58</td>
<td>24.75</td>
<td>6.76</td>
</tr>
<tr>
<td>13.50</td>
<td>6.42</td>
<td>27.00</td>
<td>6.40</td>
</tr>
<tr>
<td>12.25</td>
<td>8.64</td>
<td>18.75</td>
<td>6.50</td>
</tr>
<tr>
<td>13.50</td>
<td>7.22</td>
<td>23.00</td>
<td>9.24</td>
</tr>
<tr>
<td>12.50</td>
<td>6.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.75</td>
<td>10.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.00</td>
<td>7.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.50</td>
<td>8.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.50</td>
<td>6.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.50</td>
<td>6.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Average 13.37**

Water conduction tests were also made on a few of the galled and healthy plants. These tests showed that the
average water flow through healthy specimens was 3.87 c.c. while that through the galled specimens was only 1.21 c.c.

A third experiment was carried out employing ten galled and six healthy plants. The infected plants were inoculated on February 12 and on March 6 when the galls were about the size of small hickory nuts, the jars of both healthy and galled plants were sealed with wax. Water was added at intervals to insure favorable conditions for gall development and a like amount was added to the healthy plants. On April 12 the plants were lifted and samples of soil taken from around the roots. Also the green and dry weights or roots, stems and leaves and leaf area were determined. These data are presented in table XXI.
Table XXI. Wilting Coefficient of Galled and Healthy Tomato Plants

<table>
<thead>
<tr>
<th></th>
<th>Galled</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
|       | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | Dry    | Percent | Leaf area | Wilting | Green | D
<table>
<thead>
<tr>
<th>Leaf area (sq. cm.)</th>
<th>Wilting %</th>
<th>Green Leaf area (sq. cm.)</th>
<th>Dry Weight of Plant (grams)</th>
<th>Coefficient of Plant Weight of Plant in Plant</th>
<th>Coefficient at Wilting</th>
</tr>
</thead>
<tbody>
<tr>
<td>822.1348</td>
<td>6.512</td>
<td>32.1976</td>
<td>5.215</td>
<td>83.8</td>
<td>919.5472</td>
</tr>
<tr>
<td>885.6711</td>
<td>5.734</td>
<td>30.0575</td>
<td>5.304</td>
<td>82.3</td>
<td>1178.9958</td>
</tr>
<tr>
<td>645.8996</td>
<td>4.502</td>
<td>34.1222</td>
<td>4.610</td>
<td>85.4</td>
<td>1075.7771</td>
</tr>
<tr>
<td>794.1630</td>
<td>5.672</td>
<td>22.6085</td>
<td>4.553</td>
<td>79.8</td>
<td>624.2601</td>
</tr>
<tr>
<td>935.0599</td>
<td>5.832</td>
<td>25.9539</td>
<td>4.893</td>
<td>81.1</td>
<td>835.2554</td>
</tr>
<tr>
<td>1005.4727</td>
<td>11.064</td>
<td>34.6070</td>
<td>5.403</td>
<td>84.3</td>
<td>992.6444</td>
</tr>
<tr>
<td>1127.6161</td>
<td>4.736</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>909.4984</td>
<td>4.344</td>
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<td>813.1678</td>
<td>5.543</td>
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<td>736.2954</td>
<td>5.944</td>
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<td>857.5176</td>
<td>5.9888</td>
<td>29.9244</td>
<td>4.9963</td>
<td>82.78</td>
<td>946.2466</td>
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</table>
104.

**Effect of Gall on Recovery of Plants from Wilting**

The plants employed in this experiment were approximately the same size and had been grown under the same conditions in sealed jars as used in the wilting coefficient trials. Two of the plants were galled while two were healthy. The plants and containers were weighed, and after twelve days with no addition of water, a second weighing was made. At the end of twelve days all the plants showed quite marked wilting of the leaves. At this time 100 c.c. of water were given each plant and their recovery noted. Three days after the addition of water the galled plants were dead while the healthy ones appeared normal. Soil samples were taken from about the roots of the plants and the percentage of moisture determined.

During the twelve day period the average amount of water lost by the healthy plants was 72.5 c.c. while that lost by the galled plants was 85 c.c. This difference is not significant since the leaf area for the plants was not determined. However, the average percentage of moisture in the soil of the healthy plants was 4.03 while
that of the galled plants was 15.19.

These results while obtained from only a small number of plants indicate that the presence of a gall on the tomato may prevent recovery from wilting after the addition of sufficient water to sustain a normal plant.

Summary of Tables XIX, XX and XXI.

From the data presented in the foregoing tables it is obvious that infection from crown gall has a deleterious effect upon the plant. This is evidenced by the decrease in height of the galled plants. The average height of all the galled plants is 14.23 inches compared with 21.88 inches for the healthy plants. We note also that in the galled plants the rate of water flow is 0.6 c.c. as compared with 1.43 c.c. for the healthy plants.

In herbaceous plants of this type in which the gall is known to contain large numbers of bacteria in the intercellular spaces, it appears that stunting in height may have been due to some extent to the toxic secretions of the pathogen.

The water flow tests, showing a reduction of approximately 60 percent in conduction point to interference incident to the gall as a contributing factor in stunting
the plant.

It is also possible that stunting is caused by the abstraction and appropriation of food materials and water by the gall tissue as suggested by Smith (25).

While the results of the water conduction tests point to interference caused by the gall, this is not substantiated by the data on the amount of moisture remaining in the soil at the time of permanent wilting. It is felt that these data do not express the actual effect of the gall on the plant.

As seen from table XXI there is a reduction of leaf area in the galled plants. Since transpiration is proportional to leaf area, other conditions being equal, the healthy plants would deplete the soil moisture more rapidly than the galled plants. Under conditions of drought, transpiration is reduced, hence after a certain low soil moisture content is reached the healthy plants would lose water less rapidly than the galled plants. This inequality in water loss will continue until the soil moisture content for the galled and healthy plants becomes equal. Thus it is seen that when a condition of permanent wilting is reached the soil moisture will be practically the same in both cases. This would account for the almost identical
values of the wilting coefficient for the galled and healthy plants.

Further proof of interference with water flow by the gall is seen in the reaction of wilted galled and healthy plants to the addition of water. Healthy plants recovered rapidly while the galled plants were dead after three days.

A duplication of these experiments in which loss of water is determined at frequent intervals is now under way.
108.

Cultural and Biological Studies

A review of the literature on crown gall since the discovery of the causal bacterium (24) discloses very few instances in which Bacterium tumefaciens has been isolated from galls on apple. Smith (25) reports 14 successful isolations of the organism from apple galls produced by natural infection. Proof of infectionsness was obtained by production of galls upon various herbaceous plants. However, not all trials were successful for he cites almost as many instances in which the organism isolated, failed to produce crown gall upon artificial inoculation into susceptible herbaceous hosts.

Riker and Keitt (21) made isolations from galled apple trees in an effort to determine the presence of Bacterium tumefaciens in the overgrowths about the union. Five attempts at isolation from each specimen were made from over 175 galled trees obtained from seven nurseries in four states. In no case were they able to obtain infection from any of the organisms obtained, when inoculated into young tomato plants. Isolations were made from 29 apple galls produced by artificial inoculation and the organism obtained from 27 of these.
These negative results suggested the possibility that certain types of overgrowths on the union may be caused by excessive callusing of the graft or imperfect fitting of the stock and scion pieces.

Culture of Bacterium tumefaciens from Apple Galls.

In the experiments on water conduction through apple trees, both galled and healthy specimens were employed. In the later experiments in the case of galled trees, careful selection of material was made so as to include only those trees obviously infected with crown gall. Other excrescences occurring on the apple are those caused by the woolly aphis, Schizoneura lanigera, nematodes, mechanical injury in cultivation and excessive callusing of the graft union.

During the early stages of this work no attempt was made to prove that the galls on the specimens were caused by Bacterium tumefaciens. However, during the latter part of these studies there arose the question as to whether all the excrescences were true crown gall or only in part due to the causal bacteria and perhaps in part due to excess callusing of the graft union.
Cultural studies were begun to obtain proof of the pathological nature of the galls.

The method employed by Smith and his co-workers consisted in removing aseptically a small piece of gall tissue, dropping it into 1-1000 mercuric chloride solution for 3 minutes, rinsing in sterile water and crushing in a petri dish. The crushed fragments were transferred to tubes of sterile water or 1.15 beef broth and allowed to stand for several hours to allow the bacteria to diffuse out of the tissue. Agar plates were poured from the sterile water or bouillon tubes. In from four to eight days colonies of the organism appeared. Robinson and Walkden (22) and Riker (19) show that the disinfection of crown gall tissue, even after repeated washing in sterile water, greatly retards development of the organism. The presence of a trace of mercuric chloride is quite toxic to *Bacterium tumefaciens*.

Riker (oral communication) employs the following method in isolation from apple galls. The gall is thoroughly washed, disinfected in 50 percent alcohol, washed again in sterile water and the tissue cut out aseptically, placed in a sterile petri dish. One-half cubic centimeter of sterile water is added and the tissue thoroughly crushed and allowed to stand for 15 to 30
minutes for diffusion of the bacteria out of the tissues. Plates are then poured from this macerated material.

In attempts at isolation from apple galls both of the above methods have been tried. In certain cases after washing the gall, it was dipped in ethyl alcohol and flamed before cutting out tissue for maceration. That little injury to the causal bacteria resulted from such treatment was first proved by similar treatment of succulent tomato galls from which *Bacterium tumefaciens* was readily isolated in great numbers. Tissue removed aseptically was placed in a sterile petri dish, crushed in 1 c.c. of sterile water and allowed to stand for one to several hours. Inoculations into tubes of melted agar were made with a sterile needle dipped into the suspension in the petri dish and poured plates made.

Galls on red raspberry, weeping willow and peach were treated similarly and the organism isolated, in pure culture. The pathogenicity was established by inoculation into tomato and sugar beet.

After thoroughly washing and then flaming the specimen as above described, attempted isolations of *Bacterium tumefaciens* were made from a number of galls
on apple trees. In each case isolations were made from crashed tomato galls or from pure cultures of the organism originally isolated from a soft black raspberry gall.
### Table XXII. Negative Results of Isolations from Apple Galls and Inocula

<table>
<thead>
<tr>
<th>Date</th>
<th>Variety</th>
<th>Description of gall</th>
<th>Date</th>
<th>Variety</th>
<th>Description of gall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/14</td>
<td>&quot;</td>
<td>Hard gall at union</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot; above union.</td>
</tr>
<tr>
<td>1/16</td>
<td>Wealthy</td>
<td>&quot; with fibrous roots. Tip of scion.</td>
<td>1/22</td>
<td>&quot;</td>
<td>&quot; from center of union.</td>
</tr>
<tr>
<td>1/24</td>
<td>&quot;</td>
<td>Hard gall on union with fibrous roots.</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot; at tip of scion lip.</td>
</tr>
<tr>
<td>1/25</td>
<td>&quot;</td>
<td>Hard gall at middle of union.</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot; along tongue of union.</td>
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</tbody>
</table>
Five Results of Isolations from Apple Galls and Inoculation.

<table>
<thead>
<tr>
<th>Description of Gall</th>
<th>Date</th>
<th>Kind of Plant</th>
<th>Plant Infected</th>
<th>Inoculation</th>
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</thead>
<tbody>
<tr>
<td>Red gall with fibrous roots. On scion tip.</td>
<td>1/24</td>
<td>4 tomato</td>
<td>0</td>
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<tr>
<td>Red gall at union</td>
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<td>0</td>
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<td>Red gall with fibrous roots. On union.</td>
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<td>Red gall on union with fibrous roots.</td>
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<td>Red gall at middle of union.</td>
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<td>Red gall at tip of scion.</td>
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<tr>
<td>Red gall with fibrous roots. Tip of scion.</td>
<td>1/28</td>
<td>4 tomato</td>
<td>0</td>
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<td>Red gall with fibrous roots. Tip of stock.</td>
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</table>
| Red g...
Table XXIII. Positive Results of Isolation and Inoculation

<table>
<thead>
<tr>
<th>Date</th>
<th>Source</th>
<th>Gall</th>
<th>Variety</th>
<th>Description of galls</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/18</td>
<td>x</td>
<td>Wealthy</td>
<td>Raspberry</td>
<td>Hard gall at union. Fibrinous hairy roots from gall.</td>
<td>4/3</td>
</tr>
<tr>
<td>3/4</td>
<td>x</td>
<td></td>
<td></td>
<td>&quot; Soft gall on two year tree dug from nursery row.</td>
<td></td>
</tr>
<tr>
<td>3/23</td>
<td>x</td>
<td>Weeping</td>
<td></td>
<td>Gall from inoculation with organism from black raspberry.</td>
<td></td>
</tr>
<tr>
<td>4/19</td>
<td>x</td>
<td>Red</td>
<td></td>
<td>Galled raspberry from nursery storage.</td>
<td>4/2</td>
</tr>
<tr>
<td>3/20</td>
<td>x</td>
<td>Jonathan</td>
<td></td>
<td>Small soft gall with fleshy hairy roots. From storage.</td>
<td>3/2</td>
</tr>
<tr>
<td>4/20</td>
<td>x</td>
<td>Crawford</td>
<td></td>
<td>Gall size of walnut on crown of 2 year tree.</td>
<td>5/2</td>
</tr>
</tbody>
</table>
## Isolation and Inoculation

<table>
<thead>
<tr>
<th>Variety</th>
<th>Description of galls</th>
<th>Date</th>
<th>Kind of plant: Plants</th>
<th>Inoculated</th>
<th>Infected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>Hard gall at union. Fibrous hairy roots from gall.</td>
<td>4/24</td>
<td>6 sugar beet</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soft gall on two year tree dug from nursery row.</td>
<td>3/30</td>
<td>6 tomato</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Keeping</td>
<td>Gall from inoculation with organism from black raspberry.</td>
<td>4/24</td>
<td>2 sugar beet</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>Gall on raspberry from nursery storage.</td>
<td>4/24</td>
<td>2 &quot;</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Jonathan</td>
<td>Small soft gall with fleshy hairy roots. From storage.</td>
<td>3/30</td>
<td>4 tomato</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Swollen union. Gall size of walnut, hard. Few fibrous roots.</td>
<td>3/30</td>
<td>2 &quot;</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Rawford</td>
<td>Gall size of walnut on crown of 2 year tree.</td>
<td>5/13</td>
<td>3 &quot;</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
From eighty-four galled apple trees 246 isolations have been attempted usually making three dilution plates from each piece of macerated gall tissue. Suspicious colonies from these plates were streaked upon neutral potato dextrose agar and inoculations made into tomato. Representative data on these isolations are presented in table XXII.

The organism has been isolated from four apple galls and its pathogenicity proved by inoculation, into tomato or sugar beet as shown in table XXIII. The galls produced on tomato after six weeks while typical in appearance are still only 1 cm. in diameter and rather hard in texture. The galls on sugar beet appeared 16 days after inoculation and are now as large as those on the tomato.

In this connection it is interesting to note that the organism isolated on February 18 after making unsuccessful inoculations on tomato plants was discarded. Later another series of inoculations with this culture produced galls on sugar beets. These results point to the fact that the host plant may have some effect upon the organism. Small typical galls produced on tomato from the organism isolated from apple March 20, developed into atypical galls six weeks later after forcing the inoculat-
ed plants with sodium nitrate solution. These inoculations were made into succulent young tomato plants but due to the slow development of the organism and hardening of the stem tissue of the plant, atypical galls were produced. It is possible that other inoculations might have proved positive had these facts been known in the earlier stages of our work.

Galls from 14 Wealthy apple trees after careful washing and flaming were cut off with a flamed knife and ground in sterilized quartz sand in a mortar. This tissue was then allowed to stand in sterile water from four to twenty-four hours and inoculations made from the suspension into tomatoes. No infection was obtained by this method.

There has appeared almost constantly in our plates from macerated apple gall tissue, an organism closely resembling Bacterium tumefaciens in pure culture plates from raspberry. This organism appears in 2 to 4 days forming a circular, wet shining, translucent slightly raised colony with a very small slightly opaque center. The colonies differ from those of Bacterium tumefaciens in that they grow more rapidly, are slightly less translucent and the centers are more opaque. When streaked
upon neutral potato dextrose agar, they produce a fili­
form, pearly white, lustrous growth which clearly differ­
entiates this organism from the true crown gall bacterium.

A large number of inoculations directly from such
colonies on the plates has failed to produce crown gall.
Since it is almost impossible to distinguish \textit{Bacterium}
tumefaciens from this organism in plate cultures the
following expedient has been tried. A suspension from
plates with suspected colonies of the crown gall bacter­
i um is made by adding a small amount of sterile water
under aseptic conditions. Inoculations are made by dip­
 ping a sterile needle into the suspension and cutting
a long shallow slit in the stem of the tomato plant or
making repeated punctures into the crown of the sugar
beet. In one case galls resulted on sugar beet (by Mr.
Patel) from this type of inoculation.

Loss of virulence of the organism

Smith (25) states that frequently colonies which
seem identical morphologically with \textit{Bacterium tumefaciens}
appear in plates poured from crown gall material. How­
ever on inoculation into a susceptible host no typical
galls or overgrowths but "very slow growing, feeble, soon stationary hyperplasias", are produced. At first these organisms were regarded as intruders but later some of them were thought to be non-virulent strains of the gall-producing organism and not other species of bacteria. In a later publication (27) he mentions a strain of *Bacterium tumefaciens* which retained its virulence after repeated transfers on agar slants for several years, while in another case a strain lost its virulence in a very short time.

The fact that virulent and non-virulent strains of the organism are known to exist, may account for lack of infection from organisms morphologically like *Bacterium tumefaciens* isolated from apple galls.

Longevity of *Bacterium tumefaciens* in the Soil.

From the results of field and greenhouse experiments by Riker (*) there seemed to be some doubt as to whether *Bacterium tumefaciens* lived over in the soil for any great length of time. Also the question arose as to the ability of the organism to produce crown gall when growing in competition with other soil organisms.

* Crown gall progress report Jan. 20, 1925. (Unpublished)
Reddick and Stewart (18) show that the organism persists in moist sterilized soil under conditions of repeated change in temperature for at least nine months. They were also able to recover the organism at a depth of 60 cm. in sterilized soil.

Viability of the organism.

Studies of the organism in unsterilized soil under greenhouse conditions were made to obtain some information on the ability of the Bacterium tumefaciens to retain its virulence in the presence of soil organisms.

A series of six inch pots filled with unsterilized compost soil was inoculated with a liquid culture of Bacterium tumefaciens. After wetting the soil thoroughly approximately 80 c.c. of the liquid culture was poured upon the soil. The inoculum consisted of 50 c.c. of a four day old culture of the organism in dextrose peptone broth diluted to one liter with sterile water.

Succulent young tomato plants six inches in height were then transplanted to these pots, after washing the adhering soil from their roots. Inoculations were made after the plants had recovered from the effects of transplanting, usually in three or four days.
The method of inoculation employed was to dig away the soil from the crown of the plant to a depth of one-half inch and smear the exposed stem with the inoculated soil in which the plant was growing. Needle pricks into the plant tissue were then made through the soil smeared upon the stem. In this way relatively large numbers of the bacteria would be introduced into the tissue.

After galls had been produced upon the plants they were removed from the pots and other healthy plants reset in their places and inoculated as before. The results of a series of such inoculations are given in table XXIV.
Table XXIV. Longevity of Bacterium tumefaciens in Non-sterilized Soil.

<table>
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<th>Date</th>
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<th>Soil</th>
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<th>Infect-ation</th>
<th>Inoculated</th>
<th>Infect-ation</th>
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Plants rotted at point:
3 plants rotted and
Plants rotted at point:
Activity of *Bacterium tumefaciens* in Non-sterilized Soil.

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</table>

Plants rotted at point of inoculation.

3 plants rotten and 1 dead.

Plants rotted at point of inoculation.
The results from these experiments show clearly that *Bacterium tumefaciens* retains its viability for a prolonged period in non-sterilized soil. It is also shown that in competition with various soil organisms in wounds its viability and pathogenicity are still retained. Another point of interest is the apparent inability of the organism to produce galls after the tissue of the wound has been invaded by rot-producing organisms. This fact suggests the possible inhibitory effect of secretions from other wound invading bacteria upon *Bacterium tumefaciens* and may account for lack of infection under nursery condition when wounding of the tree occurs. It is also possible that lack of infection might have been due to the appropriation of food material in the wounded tissues by the rot-producing organisms and consequent starvation of *Bacterium tumefaciens*.

The results of inoculations also show that the organism does not rapidly leach out of the soil. This is in accord with observations in the field where even after three or four years rotation with non-susceptible crops, infection results when nursery trees are again grown.
General Discussion and Conclusions

The vessels of the sap wood of the apple tree serve as a reservoir for water and also for the upward conduction of inorganic food materials to the growing plant tissues. In the normal development of the plant it is essential that the water supply shall be sufficient at all times to preserve the normal concentration of solutes in the developing tissues as well as to provide raw materials to the leaves for elaboration into organic nutrients.

The results on water conduction tests show quite plainly that the presence of a gall at the union of the apple tree decreases the velocity of the transpiration stream. Thus trees so affected receive less water and inorganic nutrients in a given time than healthy trees. The resulting growth in such trees is less on the average than in healthy trees under similar conditions. Proof of this statement is shown where accurate records of height, diameter, twig length and weight per unit length of galled and healthy trees have been made.

Auchter (2), Knowlton (11) Blake (3) and others show that mineral nutrients taken up by the roots on one
side of the tree are not used by the tops on the opposite side. There appears to be no crossing over of the nutrients in the apple and peach. Any obstruction to the upward sap flow on one side of the tree must be reflected in a less vigorous growth above the obstruction, depending upon the degree of interference. While there are no data from twig measurements of Greene and Melhus (9) to show from which part of the tree relative to the position of the gall, the smallest twig growth was obtained, it seems reasonable to suppose that the least twig growth would come from directly above the gall. Observations upon a number of twelve year old galled apple trees showed quite consistently a flattening of the trunk above the old gall, pointing to stunting of growth due to interference in conduction.

Not only does the gall affect the upward conduction of materials in the tree but also see that the graft union acts as an obstruction if the unit flow through the trunk is taken as the standard of measure. While in a perfectly healed union this retarding effect will probably disappear after a time, the unhealed union may present a serious obstacle to upward flow over a period of years.
Cutting back while tending toward the production of more vigorous trees also interferes with water flow through the offset in the trunk caused by the operation, and results in a reduction in flow equal to that produced by a gall in many cases.

Under conditions of abundant water and food supply in the soil it is possible that the ill effects of any of these interferences may be quite small. In regions of scant rainfall or where orchards are irrigated to suit the needs of the healthy trees it is readily seen that such obstructions might lead to serious injury. In peach trees where the presence of a gall reduced the average unit flow 22.4 percent it is quite obvious that even under normal conditions of moisture there would result serious injury to the trees.

There is also a varietal difference in rate of water flow in both the apple and peach. While many factors contribute to the ability of trees to withstand winter injury it appears that a high rate of water flow is a contributing factor to this condition. This hypothesis is supported by the relatively high rate of flow through Wealthy apple and Carman and Salway peach trees which are less severely winter injured than Jonathan apple or
Attempts to correlate size and character of gall with its effect upon water conduction show that the effects of the gall lie deeper than is indicated by gross appearance. Even the presence of lateral roots from the gall may fail to increase water conduction to a measurable degree. On the other hand lateral roots arising from above the gall or from the side of the tree opposite the gall in many cases may counteract the effect of the gall on rate of flow. However it is not to be understood that the presence of such lateral roots would cause the selection of such galled trees for planting upon an equal basis with healthy trees.

Experiments with tomato plants show that the presence of a gall materially interferes with water conduction through the plant and also results in a reduction in height. Whether this stunting is due to the secretion of toxic substances by Bacterium tumefaciens in the gall and their diffusion through the plant or the appropriation of food materials by the rapidly growing gall is not known. It is a well known fact that conditions favoring rapid plant growth also favor rapid enlargement of the gall. It has also been shown by Smith (25) that Bacterium tume-
faciens produces alcohol, acetic acid and ammonia in peptone beef broth cultures. Thus it seems quite probable that the stunting effect might be due to a combination of these factors.

The causal organism of the disease retains its viability in non-sterilized greenhouse soil for at least 102 days and is able to cause infection in competition with other organisms introduced into the wound with infected soil. This accounts for the ease with which infection is obtained under field conditions where the plant is wounded in cultivation. It also points to the necessity for more careful cultural practices and to the protection of the union of the grafts as possible means of reduction of infection in the nursery.

The results of cultural studies indicate that there may be loss of virulence in the organism isolated from certain types of crown gall and raises the question as to the subsequent injury from the presence of such galls. As far as known no work has been done on this phase of the problem and it is not known whether the virulence of the organism can be restored under favorable conditions of growth of the host. It may well be that with changed conditions in the gall, the bacteria might again become
virulent stimulating growth of the gall with a consequent deleterious effect upon the host. The biological aspects of *Bacterium tumefaciens* have received scant attention and further fundamental studies should reveal facts of great significance not only to the crown gall disease but to the study of bacteria as a whole.
Summary

In the preliminary tests the average reduction in water flow through the union pieces of galled trees of the varieties Wealthy, Jonathan and Ben Davis was 30.6, 30.2 and 35.5 percent. In later tests after vacuum treatment of the specimens the reduction in flow through similar galled pieces from Wealthy, Salome and Jonathan trees was 69.7, 21.7 and 64.6 percent. The offset in the trunk due to cutting back the yearling tree also acts as an obstruction to water flow. In trees of the varieties Wealthy, Jonathan and Ben Davis this reduction amounted to 61.5, 44.6 and 7.9 percent as compared with the flow through the trunk pieces. The average water flow through the union of/root-grafted apple trees of the varieties Wealthy, Jonathan and Ben Davis is 53.4, 20.0 and 42.9 percent less than through the trunk pieces.

The average reduction in rate of water flow through peach trees of the varieties Carman, Salway, Elberta and J. H. Hale caused by the presence of the gall is 82.4 percent.

There is a varietal difference in water conduction in both apple and peach trees. Wealthy trees, resistant
to winter injury show a higher rate of flow than trees of the varieties Jonathan and Ben Davis which do not withstand severe winter conditions. The varieties of peach trees Carman and Salway show a higher rate of flow and are less liable to winter injury under Iowa conditions than Elberta or Hale trees.

Of 155 healthy and galled Wealthy trees examined, 41 percent of the healthy trees were included in the class in which there was a perfect union; 70 percent of the galled trees showed imperfect healing of the union. Size of gall and degree of girdling of the union cannot be taken as an accurate index of interference with water conduction through the tree.

Lateral roots rising from above or from the side of the tree opposite the gall may counteract the obstruction to flow caused by the gall. While lateral roots rising from the gall may balance the reduction in water flow caused by the gall such an effect is not constant.

Tomato plants affected with crown gall show an average reduction in height of 7.6 inches as compared with healthy plants grown under the same conditions.
Badly wilted galled plants do not regain turgidity as rapidly as similarly treated healthy plants on the addition of water.

_Bacterium tumefaciens_ retains its viability and virulence in moist non-sterilized soil for a period of at least three months. When rot-producing organisms have attacked the wounded tissues of the tomato plant, _Bacterium tumefaciens_ does not cause infection. Isolations of the causal organism have been made from naturally infected apple trees and its pathogenicity proved by inoculation into tomato and sugar beet. The galls produced on the tomato were slower in development than on the sugar beet suggesting a possible retarding action of the host upon the parasite.
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Figure 1. Manometer employed in water conduction tests.
Figure II. Pressure apparatus used in water conduction tests.

A. Water tap.

B. Connection for admitting water into chamber C.

C. Glass chamber connected with mercury manometer.

D. Mercury manometer.

E. Clamp for regulating water flow into the system.

F. Clamp for regulating outflow of water from chamber C.

G. Scale for measuring height of mercury column in manometer.

H. Horizontal pipe to which specimens were attached.
Figure III. Diagram showing portion of tree from which specimens employed in tests were taken.

A. Trunk piece.
B. Scion piece.
C. Union piece.
Plate I. Fluometer employed in water conduction tests.

1. Mercury column showing reduced pressure obtained by filter pump.

2. Clamp for maintaining vacuum in mercury flask.

3. Clamp for releasing vacuum in the system.

4. Filtering flask which serves to prevent water from entering system after filter pump is shut off.

5. Separatory funnel reservoir. Water is admitted from this funnel into burette (8).

6. Specimen attached to burette (8).

7. Filter pump by means of which vacuum is created.

8. Graduated burette into which water is pulled through the specimen.

9. Jar of water into which the end of the specimen is immersed.

10. Clamp for closing connection between the reservoir (5) and burette (8).

11. Rubber connection between burette (8) and specimen (6).
Plate II. Typical apple specimens employed in water conduction tests.

Specimens 1, 2, 4, 5 from galled trees.

Specimen 3 from healthy tree.
Plate III. Typical peach specimens employed in water conduction tests.

Specimens 1, 2, 5, 6 from galled trees.

Specimens 3 and 4 from healthy trees.
Plate III.