On

"Some Observations on the Behavior of Roots During the Winter Months"

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In

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By

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Some Observations on the Behavior of Roots
During the Winter Months

-INTRODUCTION-

For some time at the Oregon Agricultural College it has been suspected that roots of fruit trees did some of their growing during the winter months. Consequently, this problem was started primarily to determine whether this was actually the case, and if so, under what conditions they did grow and what were the limiting factors in regard to this growth.

The author hereby wishes to express his gratitude to Professor Brown, Head of the Department of Horticulture, for permission to work on the problem and his kindly interest shown in the work throughout; to Dr. Harvey, under whose direction the problem was carried out, for the valuable suggestions and aid given which made this work possible, and to Professor Hartman, for kind assistance rendered, especially in making the boxes for the observation posts.
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Reason for the Problem:

This work must be considered merely as introductory, because the field for investigation opened up is vast and its importance is such as to necessitate its being carried on over a period of years, both under field and checked under carefully controlled conditions before the problem is entirely solved.

For instance, the growth of roots during the winter months and their continued activity renders them, (and incidentally the tree) very susceptible to freezes in the winter time and we could expect far more so called winter injury in a climate such as this than in a climate where the winters are more severe and the ground remains frozen steadily until the springtime and consequently the roots have to remain in a dormant condition.

Again, it is possible that the growing season here may be of such a nature that in order for a tree to continue its normal development the roots must make a considerable portion of their growth at this time, in order to attain the depth required and avail themselves of a large enough feeding area to cope with the heavy drain on them during the latter part of the season when
moisture is scarce and food little available. Hence if the roots did not make this required growth during the winter months, but for some reason received a check for any length of time, the tree would suffer in varied degrees depending on the length of time this growth did not take place and many physiological disorders could be expected as a result.

Such being the case, it would follow that in the dry mountain valleys of the west where the winters are severe, where the summer months are dry and hot and very little growth is liable to take place, either in winter or summer months, the growing season in the spring must be of such a nature that growth of roots is extremely rapid and the same amount of growth is made in the early spring months after frost gets out of the ground as is made here during the winter and spring months combined.

On the other hand, in the east, the roots while not growing in the winter, due to the severe temperatures, may continue growth all summer long due to summer rains and low relative humidity.

Another important situation arises which is very prevalent here; namely the tendency toward a high water table during the winter months, the effects
of which will be noted in the following discussion.

Previous work having a bearing on this field:

Bergman (1) concludes that roots of land plants do not live under prolonged submergence. The submerged roots die and new ones are developed from the stem at the surface of the water but when the water is aerated, plants are able to endure root submergence as long as aeration is maintained. The roots, however, show some retardation but remain alive.

Cannon (2) (working with desert species of plants) finds that in root aeration two features are of prime importance; namely, the amount of carbon dioxide in the atmosphere of the soil and the oxygen supply. Although aeration of roots is of prime importance to some species, it is not so in others. Again he finds surface roots in all cases to be more affected by submergence than deeper roots.

Franklin (3) in Scotland states that on the slopes of ditches, near hedges and in woods in the case of the roots of herbaceous plants, (especially if protected by a surface layer of dry leaves) if a warm rain comes in December, it will often raise the temperature of the soil to the extent required for growth and these plants may grow and even flower in the middle of a vigorous winter.

Noyes and Weighart (4) find that where soil had never been subjected to CO-2 roots were well spread and extended considerably into the soil but where CO-2 had
been applied roots were shorter and spread out horizontally just beneath the surface as Weaver (7) found was the case with the high water table. Noyes, Yost and Soderland came to the conclusion that soil aeration must be a factor of no less importance in plant growth than water and temperature.

(6)

Weaver claims that in excessively damp places the soil solution is poor in different nutritive solutions, the weather requirement therefore becomes greater under these conditions as if the plant made a greater struggle to produce as much as possible from the very scarce nutrient substances present. The leaves then formed become larger and more well spread. Consequently, these plants forming their leaves in damp localities evaporate much more water in the same unit of time than those in dryer places and if there be a water shortage, later in the season the drought danger is thereby greatly increased. Weaver (7) finds the character and location of the root system in all cases to be correlated with the water content of the soil. Whenever the water table is predominatingly near the surface the roots are shallow and where it is low, they are deeper.

Materials used and Methods employed in present experiment:

Observation posts were established consisting of boxes specially constructed (30" x 20") with a rectangular
section cut out of the bottom (20" x 12") and a piece of glass held in place by wooden cleats round the edges of the hole, inserted in such a manner that it could be readily removed when the box was placed in position. (See Figure I Page 6.)

The depths of the sides of the boxes depended on the depth the box was to be planted; namely, six, ten or twelve inches, in other words, the depth at which the observations were to be made.

The soil was then removed from the portion of the root of the tree to be experimented on, until a satisfactory root (or roots) was exposed at the required depth. The box was then placed horizontally over the root (or roots) in such a manner that the glass bottom was immediately over the exposed portion. The soil was then replaced round the box (See Fig. 2 Page 6.) and over the glass bottom was placed a covering of first a piece of felt paper, then a sack, and the remainder of the box stuffed up with straw. Thus the covering could be easily removed and the root exposed any time for examination.

Three of these boxes were established vertically by digging a trench to a depth of approximately two and one-half feet and placing the box sideways against the roots in such a manner that again the glass bottoms covered the roots desired for measurement.
FIG. 1. TYPE OF BOX USED.

FIG. 2. SHOWING BOX IN HORIZONTAL POSITION.

FIG. 3. SHOWING BOX IN VERTICAL POSITION.

FIG. 4. SHOWING POSITION OF TILE FOR MEASURING WATER TABLE.
Thus it was possible to obtain a vertical view of the roots at a depth of one and one-half to two feet. The soil was then replaced around the sides and on top of the box leaving the front open and sufficient of the ditch to get down into, to make observations. As before, the glass was covered with felt paper and sacks, the rest of the box and the trench being stuffed up with straw. Nineteen in all of these posts were established, observations being made on roots of apple and filbert trees in different sections of the south farm as follows:

Plot I (Gardener Pruning Block - Apples)

<table>
<thead>
<tr>
<th>Post of Box Number</th>
<th>Depth Planted</th>
<th>Date Planted</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>6&quot;</td>
<td>11/6/22</td>
</tr>
<tr>
<td>No. 2</td>
<td>10&quot;</td>
<td>11/4/22</td>
</tr>
<tr>
<td>No. 3</td>
<td>10&quot;</td>
<td>11/4/22</td>
</tr>
<tr>
<td>No. 4</td>
<td>6&quot;</td>
<td>11/6/22</td>
</tr>
</tbody>
</table>

In this plot the ground is very low and the water table comes near or up to the surface of the ground every year.* Consequently, these posts were established primarily to note the effect of a high water table on root growth and development.

* - From previous records taken by Dr. Harvey.
Plot II  (Known as the Walnut Block - Apples)

<table>
<thead>
<tr>
<th>Post or Box Number</th>
<th>Depth Planted</th>
<th>Date Planted</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 5</td>
<td>6&quot;</td>
<td>11/16/22</td>
</tr>
<tr>
<td>No. 6</td>
<td>6&quot;</td>
<td>11/16/22</td>
</tr>
<tr>
<td>No. 7</td>
<td>10&quot;</td>
<td>11/16/22</td>
</tr>
<tr>
<td>No. 8</td>
<td>6&quot;</td>
<td>11/7/22</td>
</tr>
<tr>
<td>No. 9</td>
<td>6&quot;</td>
<td>11/7/22</td>
</tr>
</tbody>
</table>

In this plot the water table usually stays well below the surface*, with the exception of a low point in the south-east corner where posts No. 7 and No. 8 were established. Consequently a checking of root development here (other than at the low point mentioned) was assumed would be the result of other factors than the water table.

Plot III  (Known as the Cover Crop block - apples)

<table>
<thead>
<tr>
<th>Post or Box Number</th>
<th>Depth Planted</th>
<th>Date Planted</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 10</td>
<td>6&quot;</td>
<td>11/26/22</td>
</tr>
<tr>
<td>No. 11</td>
<td>6&quot;</td>
<td>11/26/22</td>
</tr>
<tr>
<td>No. 12</td>
<td>6&quot;</td>
<td>11/26/22</td>
</tr>
<tr>
<td>No. 13</td>
<td>10&quot;</td>
<td>11/16/22</td>
</tr>
</tbody>
</table>

In this plot the ground is fairly high also.

Plot IV  (Known as Filbert Block - Filberts)

<table>
<thead>
<tr>
<th>Post or Box Number</th>
<th>Depth Planted</th>
<th>Date Planted</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 14</td>
<td>12&quot;</td>
<td>11/26/22</td>
</tr>
<tr>
<td>No. 15</td>
<td>12-24&quot;(vertically)</td>
<td>11/30/22</td>
</tr>
<tr>
<td>No. 16</td>
<td>6&quot;</td>
<td>11/30/22</td>
</tr>
<tr>
<td>No. 17</td>
<td>12-24&quot;(vertically)</td>
<td>11/30/22</td>
</tr>
<tr>
<td>No. 18</td>
<td>12&quot;</td>
<td>11/30/22</td>
</tr>
</tbody>
</table>

* - From previous records taken by Dr. Harvey.
In this plot with the exception of the south-east corner where post No. 14 was established, the ground is fairly high and in good physical condition, consequently, here the idea of trying the vertical method of planting was carried out with posts 15 and 17. (See Fig. 3 Page 6)

Plot V (Nursery block - apples)

Box 19 was planted here vertically (See Fig. 3 Page 6) on November 30, 1922, as this appeared to be about the highest point in the orchard.

Water Table:

A record was kept of the water table at each post by sinking a two and one-half inch tile vertically into the ground to a depth of four to six feet (See Fig. 4 Page 6) and so measuring the distance of the water from the surface as it stood in the tile. In this way it was possible to note the effect of the water table on the root growth. In some instances, these tiles were already in position, having been used the previous year by Dr. Harvey to make water table records.

Temperature:

To ascertain to what extent temperature was a limiting factor in root growth, thermometers were placed in the ground in representative sections of the orchard at six, ten, twelve and twenty-four inch depths. A special soil thermometer sheathed in a wooden case being used at the twenty-four inch depth.
Check plots on trees Ia, IIa, IIIa, and IVa were established where samples of rootlets were dug up each week at points Ia, IIa and IIIa at a six inch depth and at IVa at a twelve inch depth. These samples were taken into the laboratory and the soil carefully washed away from them and new growth (very easy to distinguish by its pearly whiteness) measured. In general, two to three hundred counts and measurements were made of these young rootlets at each observation from each individual check tree and the mean taken to get the average representative growth made. Thus the samples measured were of sufficient number to get a relative idea of the increase in growth made since the last day of measurement.

As before, the temperature and water table were kept account of at these points.

**Difficulties Encountered:**

As can be surmised especially by anyone familiar with the south farm, the difficulties encountered were many. In the first place, during the month of November, when the posts were established, it rained almost incessantly, with a result that at that time and for that matter, for practically all the winter months, the orchard was a "sea of mud" which caused considerable inconvenience, not only in the initial establishment of the posts but each time records were made.
In fact, during the early part of January the whole of Plot No. 1, and for a few days practically the remainder of the orchard was actually under water.

Whenever measurements were made the roots had to be actually exposed, removing all the covering including the glass. (Before commencing it was considered that this would be the case due to the fogging of the glass, hence the reason for inserting the glass so that it could be easily removed)

The glass not only fogged but became decidedly puddled as well. However, the glass was very beneficial, as will be noted especially in certain cases where it became broken, in the first by keeping the 'preading' away from the roots and giving them freer air circulation and secondly in the latter period, when the orchard began to dry and there was a danger of these rootlets becoming too dry due to the artificial covering they were under, they were kept moist by the vapor given off condensing on the glass and falling back again on the roots.

Another very discouraging situation arose, (not however, without its amusing features). As has been previously stated, three posts were established vertically in the dryer sections.
This vertical method by the way, under conditions where drainage is good and under dry conditions is undoubtedly the best method/observation, especially for the deeper roots. However, as can be seen, such a method was generally impossible under conditions at the south farm with the high water table prevailing there and was tried chiefly as a point of interest. For this purpose therefore, the highest points were chosen and great care was taken to prevent the ditch filling up with mud flowing in from the surface.

This was successfully accomplished by keeping a little dyke around the edges of the trench.

As the author had been particularly fortunate in obtaining good samples of roots at these points and was able to keep them from flooding, the outlook of good results from these posts was very promising and especial pride was taken in them. However, when the water table rose up over the major portion of the orchard so that these vertical posts were in practically the only location on dry land the result, instead of being fortunate was extremely disastrous, inasmuch as all the colonies of field mice in the whole orchard were forced by the high water to seek refuge in the dryer places and con-
centrated "en masse" in the region of these posts where the straw in the boxes and trenches appeared very attractive to them, so they located there.

Not being satisfied with 'rooming' only, they also had to include 'hoard', with the result that the young succulent rootlets under observation afforded some very choice meals for them. Yet, despite the drawbacks, it was impossible to continue observations and as will be seen, the results from a 'pioneer' standpoint can be considered satisfactory.

Results of the Investigation:

Measurements were made of the rootlets under observation as nearly as possible each week as it was considered to be a disturbance oftener than that was liable to be detrimental to growth. The temperatures were taken daily and the water records as nearly as possible twice a week. Chart I indicates the growth made in inches (since the date of last measurement) at all posts established at a six inch depth, also the average temperature of the soil at that depth and in some cases the period during which at this depth the roots were submerged by the high water table.

Chart II indicates the growth made in inches of the rootlets at posts established at the ten inch depth together with the average soil temperature at
this depth and the period during which they were submerged by the high water table.

Chart III indicates the growth at posts established at from twelve to twenty-four inches depth, the average soil temperatures at those depths and the period during which they were submerged.

Charts IV, V, VI and VII indicate the water table measured in inches below the surface of the ground at the dates of measurement at the various posts in Plots I, II, III & IV respectively. The lines XY, XY-1, XY-2 denote the depths at which these posts are established. Consequently, whenever the curve representing the water table of any specific post cuts or comes below its representative line, XY, XY-1 or XY-2 as the case may be, the roots at that period are submerged at this post.

Chart VIII shows relative growth made in inches in Check plots Ia, IIa, IIIa and IVa together with the distance in inches of the water table below the surface at this point and the temperature in degrees Fahrenheit. The line XY indicates the depth at which the samples were taken. Thus, by examining the above charts the following will be noted:
Post No. 1. (See Chart I)

This Post established at a depth of six inches on November 4, 1922, had an initial new growth of approximately .05 inches. This growth continued until sometime between November 30th and December 4th, 1922, whence it ceased, not commencing again until some time during the week ending February 13th, 1923. It will be observed that while from December 11-17th 1922, the temperature of the soil at that depth went down below freezing and again on January 30th, 1923 for a period, growth however ceased between the dates of November 30th and December 4th, at which time the temperature was relatively high. It will be seen by observing Chart IV that the water table on the week ending December 5th, reached within six inches of the surface, consequently, growth ceased about the time the water level reached the post and the roots were submerged. The roots remained submerged until January 13th although it will be noticed that no renewed growth was made until about February 7th or almost a month later, which shows the checking was quite severe. In this case while it appears the check was caused in the first place by a rise of water table, the low temperature of December 11th must also have been a factor, so the cessation of
growth is really caused in this case by a combination of the two factors. Hence a dangerous situation arose here for the roots, evidenced by the long period of no growth.

Posts No. 2 and No. 3.

By observing Charts II and IV it will be seen that posts No. 3 and No. 4 established at a depth of ten inches on November 4th, 1922 had an initial new growth in both cases of approximately 2 inches whence it increased until shortly before December 4th, 1922, in the case of No. 2 and up until somewhere between December 4th and December 9th, in the case of No. 3. From that time no growth occurred until sometime during the week ending February 13th. According to Chart IV at Post No. 2, the roots were submerged about December 2nd, 1922 and at Post No. 3 on December 5th, 1922, both remaining submerged until approximately January 13th. By January 21st, the water went down just five and nine inches respectively below the ten inch depth, coming up again on January 28th, submerging Post No. 2 and reaching but two inches below Post No. 3. Hence, for practically the entire period no growth occurred, the roots were either submerged or the ground was in a stage of supersaturation at that depth.
As it will be noted that the temperature (Chart II) at that depth did not reach freezing point, it is almost safe to assume that in this case that the check was due to the submergence of the roots caused by the rise of the water table.

Post No. 4.

As will be seen (Chart I) the post was established at the same depth and time as post No. 1, and that growth continued about the same throughout except that it was about a month later starting again. This was due to the severity of the check being greater by sufficient care not being exercised in replacing the covering in one instance recorded and so the freeze had a greater influence.

Summary of Plot No. 1

Both temperature and high water table (i.e. submergence of roots) were the direct factors in checking growth, the water table here being especially significant because as was observed, Posts No. 1 and No. 4, or those at the six inch depth stopped growth and (in the case of one) commenced again about the same time as roots at posts No. 2 and No. 3, planted at the ten inch depth.

If temperature alone had been the factor we would have seen a far greater check and resting period in Posts No. 1 and No. 4, than at No. 2 and No. 3, on account of the lower temperatures prevalent in the soil at six inches deep than at twelve inches deep.
Plot II (Posts 5, 6, 7, 8, 9.)

By examination of Chart I it will be noted that at posts No. 5 and No. 6, which were established at the six inch depth on November 16th, 1922, the initial growth observed was approximately 0.27 inches. This growth increased steadily until the week ending December 13th, 1922 (or a week later than was the case in Plot No. 1.) commencing again around January 19th, 1923 or almost three weeks before those in Plot No. 1.

On examining Chart V it will be observed that at no time during the experiment did the water table come up to the six inch line. Consequently, these roots were never submerged so that the cessation of growth in this case cannot be attributed to the rise of the water table. However, it will be seen (Chart I) that about the time of growth cessation, the soil temperature at this depth went down well below freezing. Consequently this check can be directly attributed to the low temperature alone.

Post No. 7.

By observing Chart II, it will be noted that Post No. 7 was established November 16th, 1922 at a depth of ten inches. The initial measurements of rootlets was approximately 55 inches. However, in getting the box into position the roots must have had too great a disturbance, either by mechanical means or over ex-
posure, because as will be seen no further growth took place until February 13, 1923.

Post No. 8 and No. 9.

An examination of Chart I shows that at Posts No. 8 and No. 9 established at a six inch depth on November 6th, 1922, growth increased steadily until about December 4th, 1922 whence it stopped commencing again during the week ending February 5th, 1923, in the case of No. 8 but in the case of No. 9, not until more than a month later.

Chart V shows that by December 7th, the water table had submerged the roots at these posts and the ground was either submerged or in a stage of supersaturation until about February 3, 1923. This, together with the drop in temperature around December 11, 1922 a similar situation here presents itself as in the case of posts No. 1 and No. 4 and as will be noticed, with almost identical results.

At Post No. 9, the longer time taken to commence growth again compared to No. 8 can be attributed to the fact that as the glass became broken during the period of submergence and was not replaced until March 5th, 1923, resulting in the packing pressing down on the rootlets causing lack of air circulation and a poor
physical condition of the soil. (Hence the prolonged stationary period of No. 4, and No. 9, while being almost of the same duration in both cases is a coincidence rather than a significant fact.)

Summary of Plot II

On the higher ground where the water table did not submerge the roots, the fall in temperature was directly the cause of the cessation of growth. (Incidentally a distinct change in the appearance of the rootlets took place after being subjected to the freezing temperature. They gradually took on a brown and more woody appearance but apparently were not harmed. However in the case of rootlets at Plot I, and Posts No. 8 and No. 9, this change was not so noticeable and only the larger rootlets (approximately 0.8 - 1.0 inches) survived. The numerous small ones, (one to five mm.) generally turned black and never recovered whereas the browned ones whenever favorable conditions again were commenced growth either by starting to extend the tip, sending out side shoots, or both.)

Plot III (Posts 10, 11, 12, 13)

Posts 10, 11, 12. By observing Chart I, it will be noted these posts established on November 26th, 1922 at a depth of six inches, started out with an initial average growth of approximately 0.65 inches
which continued steadily until about December 13, 1922 whence it ceased. On examination of Chart VI, it will be noted that the water table only reached the six inch depth around January 7th, 1923 so for a very short period only could the water table have had any influence. Therefore the cessation of growth at these points must be attributed to the fall in temperature around December 11th, 1922. By January 9th-14th, the growth had commenced again, continuing fairly rapidly from that date on, with the exception of the short period at the end of January, when freezing temperature was reached, causing a stoppage of growth but not a definite setback as growth picked up again immediately the temperature became favorable.

Post No. 13. - Chart II. This post was established at a depth of ten inches on November 16th, 1922. New growth at the initial measurement being approximately .65 inches which increased steadily until about December 20th, 1922.

Chart VI shows that while not actually submerging the roots at this point until December 28th, 1922, yet from December 18th, the water table was very near the ten inch level so the ground would be in a very wet condition which combined with the prevailing
low soil temperature in the middle of December made
the environment such as to be unfavorable for pro-
moting growth if not giving it a check.

Summary of Plot III:

As in Plot II, whenever the water table does
not saturate or submerge the roots a cessation of growth
is directly due to prevailing low temperature only. More-
ever it appears that growth checked by temperature com-
mensces growth again far more readily than the roots that
have ceased growing owing to a fall in temperature plus
submergence, or by submergence only.

Plot IV. (Posts 14, 15, 16, 17, 18)

Post 14. As will be noted on examining Chart
III, this post established at a twelve inch depth on
November 27th, 1922 had an initial new growth measuring
approximately 45 inches but this growth remained stationary from that time until March 20th, 1923. On observing
Chart VII it will be seen that by November 28th, 1922,
the water table came up over the twelve inch depth conse-
quently immediately after establishment, the roots
were submerged remaining so until about February 3, 1923
and then the ground was so saturated at that depth for
some time afterwards that it was in a very poor physical
condition and unsuitable for growth.

The temperature however at this depth never went below 39 degrees Fahrenheit which in itself is not sufficient to check growth. Consequently, the long period of submergence was responsible for the long period of no growth.

Posts No. 15 and No. 17. At these posts, the boxes were placed in a vertical position (See Fig. 3 - Page 6) and hence roots from twelve to twenty-four inches were under observation.

It will be seen by observing Chart VII that the water table reached the twelve inch level only from January 2nd - 12th, 1923, the eighteen inch level December 28th to January 17th, 1923 and the two foot level from December 5th 1922 to January 31st, 1923. At the twelve inch depth the growth continued steadily and even at the eighteen inch depth the water table did not absolutely check growth here even though they were submerged for a short time. That growth did not stop was apparently due to the very good condition of the soil in this plot and the water being well aerated. It will be observed that at no time did the soil temperature at twelve inches run below 39 degrees Fahrenheit
or below 41 degrees Fahrenheit at the twenty-four inch depth which temperatures are apparently quite favorable for growth.

On January 24th, 1923, these posts were abandoned owing to damage done by the mice previously mentioned.

Post 16. This post was planted at a six inch depth on November 30th, 1922, on which date a vigorous new growth of approximately one inch was observed. This growth continued until the week ending December 13th, 1922 whence it ceased, again starting shortly after January 15th, 1923 and continuing fairly rapidly from then on with the exception of a short halt around January 30th, 1923.

As will be seen by observing Chart VII, the water table remained well below the six inch level except for a very brief period about January 7th, 1923. Consequently, the low temperature of December 11th, at this depth is directly responsible for the stopping of growth in this instance and the falling of the temperature again on January 30th is responsible for the halt at that time. Thus again, we see that when the
roots are not submerged, temperature is the direct cause of the check in growth.

Post No. 18. This post was put in at a twelve inch depth without any glass over the bottom of the box and the packing pressing directly against the roots, the result being that no increase in growth was observed until after a glass was inserted on March 24th, 1923, whence growth started almost immediately.

As will be seen by observing Chart VII, the water table only came up to this depth January 2nd - 12th, so that conditions would have been favorable for growth if the glass had been inserted in the first place. Therefore, as the temperature was not severe enough at this depth to cause a check of growth, lack of air seems to be the primary cause for the long rest spell here.

**Summary of Plot IV:**

The temperature of the soil at the twelve inch depth never reached below 39 degrees Fahrenheit or at the twenty-four inch depth below 41 degrees Fahrenheit. Consequently at these depths the ground can be considered fairly safe for growth of roots all winter long provided they are not submerged.

It would appear that a temperature as that of December 12th, which dropped down to twenty-two degrees
Fahrenheit is severe enough to not only retard growth but to check it for a considerable period whereas a soil temperature of 29 degrees Fahrenheit merely retards it or holds it at a standstill but does not give it an actual set-back unless possible continued over some length of time.

That lack of aeration is a factor which will check growth no matter how produced, is shown by Post No. 16. This is very probably the reason why submergence has its checking effect on growth.

As in the case of Posts No. 15 and No. 17 roots submerged for a short period do not necessarily become checked immediately, provided the soil is in good physical condition and well aerated and the rise of water table is suddenly caused by excessively heavy rains which are well supplied with a good quantity of oxygen.

Plot No. V.

Post No. 19 was established November 30th, 1922, vertically (See Fig. 3 - Page 6). As will be noted by observing Chart III growth was well along at the initial observation and that it continued right through until January 22nd, at which time the mice chewed off the roots under observation. The temperature at this depth (twelve to twenty-four inches) never reached
freezing and (Chart VI) the water table only reached
the eighteen inch level on January 7th, so here we
have favorable conditions throughout, resulting in a
continuous growth through the severest months.

Summary of Plot V:

Again, as long as the temperature does not
fall too low and the roots are not submerged the roots
continue to grow irrespective of the season.

Check Plots Ia, IIa, IIIa and IVa:

As previously stated, samples taken for these
checks were taken from a six inch depth in the cases of
Ia, IIa and IIIa, IVa being taken at a depth of twelve
inches from a higher section of the orchard.
The reasons for choosing such depths being that it was
considered that the effect of temperature would be most
apparent at the six inch depth and as it was surmised
the water table would come to the surface at the loca-
tion of Ia and IIa, it would have been impossible to
get accurately to the twelve inch level. Hence, for
the twelve inch check a dry spot was chosen.

While the author would have liked to have
kept more checks of this kind, this method of deter-
mining growth is a very slow and laborous method on
account of having to wash out, count and measure such large numbers of these rootlets to arrive at a fair average, consequently, time alone permitted only a few checks of this nature.

The first samples were dug at Post No. 1 on November 2nd, 1922 and continued weekly as nearly as possible. It will be seen by observing Chart VIII that growth continued until the week ending December 12th, 1922 whence it remained stationary until sometime between January 14th and 21st, when it re-commenced again. After January 25th, 1923, it became impossible to observe further by this method owing to the wide variability of the samples and the increasing enormous numbers of new minute 'starts' one to two mm in length at this time.

On chart VIII (lower section) the line AB represents the water table as before in inches below the surface. The line XY represents the depth at which the samples were taken; namely, six inches. Consequently where AB cuts and crosses XY at C, the water table has submerged the roots at that depth until such time as it again crosses XY at D.

Thus, wherever the perpendiculars erected CE and DF on XY cut the growth curves, the intersection represents the period during which these roots were submerged.
Thus we find at Ia, the roots submerged from December 7th, 1922 until January 11th, 1923 (with the exception of a brief period - December 11th - 16th, 1922). It will be noted that cessation of growth, submergence and fall in temperature took place so close together that it is almost impossible in this case to determine to which factor to attribute the cessation of growth.

The same situation as will be seen, held true for Check Plot IIa. IIa however did not commence growth until a week later than Ia.

By noting conditions at IIIa and IVa (upper section of Chart VIII) it will be seen that the water table at these points did not reach the six inch line at all and the twelve inch level only for a very brief period consequently here temperatures alone could be responsible for any cessation of growth. As will be observed at IIIa, growth ceased at the time of the low freezing temperature at that depth although it started again a week ahead of Ia and two weeks ahead of IIa. At the twelve inch depth at IVa, the temperature did not reach freezing and as will be observed growth continued throughout.

Summary of Check Plots:

Submergence of roots, freezing temperatures and cessation of growth all took place at so nearly the same time that in the case of Ia and IIa it was almost impossible to know to which factor to attribute cessation
of growth (possibly both).

At IIIa growth was checked by the fall of temperature but commenced again sooner than either la or IIa.

At IVa, a growth continued throughout, having neither freezing temperature nor prolonged submergence to check it. Thus the results agree with previous findings; namely, that a check caused by a freezing temperature plus submergence is more severe than that caused by freezing temperature alone and wherever we have neither freezing temperatures nor root submergence, growth continues steadily throughout the winter and summer months.

GENERAL CONCLUSIONS

Thus in the case of the apple, and the filbert (hence supposedly with many other trees) root growth continues during the winter months unless checked either by freezing temperatures or submergence, either factor in itself being sufficient to check growth.

A check caused by freezing temperatures is
less dangerous than that caused by prolonged submergence as in the former case the rootlets merely turn woody and continue growth again almost immediately conditions become favorable whereas a check by the latter in some cases was actually observed to destroy the minute rootlets and in every case new growth took longer to commence again than after a temperature check.

A combination of a check by freezing temperatures and submergence is likely to be more serious especially if the initial halt is caused by submergence and then shortly after followed by a freezing temperature as was the case in Plot I.

A soil temperature of twenty-two degrees Fahrenheit even for a short time is sufficient in itself to check growth for a considerable period whereas a soil temperature of twenty-eight degrees Fahrenheit for a brief period merely holds growth stationary rather than actually checking it as will be observed by comparing results of temperatures about December 15th, 1922 and January 30th, 1923.

Whereas a freezing temperature will halt or check growth immediately, very brief submergence does not necessarily do so provided the temperature
is favorable and the soil is in good physiological condition and well aerated.

During the winter of 1922-23 the soil at a depth of twelve to twenty-four inches remained at a favorable temperature for growth to continue all winter long and wherever the roots were not submerged, such growth took place.
It was found:

1. That the roots, provided they are not submerged or subjected to freezing temperature, continue their growth irrespective of the season.

2. That in such localities as the Willamette Valley where mild winters are prevalent it is apparently the natural condition for a tree to continue growth during the winter months.

3. The normal development of roots during the winter months is prevented by freezing temperatures in the soil or by prolonged submergence caused by a rising of the water table. If a situation occurs where both these factors are prevalent, a serious situation arises.

4. A check of root growth caused by prolonged submergence is more detrimental than a check due to the effects of freezing temperatures.
CHART NO. 1

POSTS 6 INCHES DEPTH
(NOS 1, 4, 5, 8, 9, 10, 11, 12, 16.)

LEGEND:
- GROWTH IN INCHES
- TEMP. IN DEGREES F. OF SOIL AT 6" DEEP
- PERIOD DURING WHICH ROOTS WERE SUBMERGED.

0 20 40 60 80
0 20 40 60 80

NOV 1923  DEC 1923  JAN 1923  FEB 1923  MAR 1923  APR 1923
POSTS 10 INCHES DEPTH.  
(C no. 2, 3, 7, 13)

LEGEND:
- GROWTH IN INCHES
- TEMPS. DEGREES F. OF SOIL 10" DEEP.
- PERIOD DURING WHICH ROOTS WERE SUBMERGED.
CHART No IV

SHOWING WATER TABLE IN INCHES BELOW SURFACE.
(POSTS. No’s 1, 2, 3, 4)

LEGEND:
- WATER TABLE AT POST NO. 1.
- " " " " No. 2.
- " " " " No. 3 & 4
- (KX, KY') DEPTH POST ESTABLISHED (6 ft)

DISTANCE IN INCHES OF WATER TABLE BELOW SURFACE:

NOV 1923  DEC 1923  JAN 1923  FEB 1923  MAR 1923  APR 1923

5  10  15  20  25  30  35  40  45  50  55  60  65  70  75  80  85  90  95  100

8 x 3
1 + 4

X
X'
CHART No. V

Showing Water Table in Inches Below Surface.
(Posts Nos. 5, 6, 7, 8, 9.)

Legend:
- Brown = Water Table at Posts Nos. 6, 8, 7
- Blue = Posts Nos. 2, 4, 9
- Red = Depth of Observation Posts

Distances in Inches of Water Table Below Surface:

Water Table

- Nov 1926
- Dec 1926
- Jan 1927
- Feb 1927
- Mar 1927

Dates:
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45
- 50
- 55
- 60
- 65
- 70
- 75
- 80
- 85
- 90
- 95
- 100

Water Table Depths:
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45
- 50
- 55
- 60
- 65
- 70
- 75
- 80
- 85
- 90
- 95
- 100

Dates and Water Table Depths:
- Nov 1926: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100
- Dec 1926: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100
- Jan 1927: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100
- Feb 1927: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100
- Mar 1927: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100

Water Table Depths:
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45
- 50
- 55
- 60
- 65
- 70
- 75
- 80
- 85
- 90
- 95
- 100
Chart No. VI

Showing Water Table in Inches Below Surface

Posts No.5, 10, 11, 12, 13, 19

Legend:
- WATER TABLE AT POST NO. 13:
- " " " " " " NO.5, 10, 11, 12
- " " " " " " No.19
- DEPTHS OF OBSERVATION POSTS

Dates:
- Nov 1932
- Dec 1933
- Jan 1934
- Feb 1933
- Mar 1933
- Apr 1933
- May 1933

Units:
- Inches
SHOWING WATER TABLE IN INCHES BELOW SURFACE (POSTS 14, 15, 16, 17, 18)

LEGEND:

- = WATER TABLE AT POST NO 14
- = NO 15, 16, 17
- = NO 18
- = DEPTH OF OBSERVATION POSTS.
CHART No VIII

CHECK PLOTS.

Ia, IIa, IIIa, IVa.

LEGEND:

[-] = SOIL TEMP. AT 12" DEPTH.
= WATER TABLE IN INCHES BELOW SURFACE
= DEPTHS AT WHICH OBSERVATIONS WERE MADE.
= SOIL TEMP. AT 6 INCH DEPTH
= GROWTH IN INCHES
= PERIOD OF SUBMERGENCE.
BIBLIOGRAPHY


