WINTER STRUCTURE AND DEVELOPMENT OF APPLE BUDS

by

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INTRODUCTION

To the working horticulturist the ultimate object of his labors is to secure maximum fruitfulness of his trees. It is a well known fact, especially to fruit growers, that sometimes trees may become fruitful at a very early age and bear regular crops. On the other hand, the same varieties, under different conditions, may be slow in coming into bearing, the crops may be small, and the trees very unsatisfactory producers.

It is a matter of common observation on the part of fruit growers that the tree which early begins to bear excessive crops is one that is below normal in size and vegetative vigor. On the other hand, the tree which fails to come into bearing at the expected age or which is uncertain in setting its crop, frequently is above normal in size and vegetative vigor. The orchardist says it is going to "wood growth" instead of fruitfulness. The tree which comes into bearing at the age expected and sets the optimum crop of fruit which can be properly developed and supported, is one that is, with respect to balance between vegetative and reproductive activity, normal or intermediate.

There is, therefore, a proper balance between fruitfulness and wood growth which is the ideal or "standard of perfection" that the fruit grower should seek to maintain.

Practical orchard experience shows that much can be done to regulate the fruitfulness of trees. It is apparent, therefore, that if the fruit grower wishes to understand the factors and influences which favor or oppose fruitfulness, he must have a thorough knowledge of all the stimuli affecting fruit bud formation and be so familiar with the general appearance of the buds and with their structures that he can observe and understand the responses to these stimuli and use them as a guide to intelligent orchard management.

CONDITIONS OF FRUITFULNESS WHICH MAY PREVAIL IN AN ORCHARD.

There are three possible conditions of fruitfulness which may prevail in an orchard:

1. A maximum condition in which the trees may sometimes overbear, the fruit failing to develop in size, and the trees dying at a very early age.

2. A minimum condition in which the trees may come into bearing too slowly, and the trees become too old before any returns are received.

3. An optimum condition in which the trees set a maximum crop of fruit that is possible for the tree to mature without materially depleting the tree. This optimum condition seems to be one in which there is a proper balance between fruit production and vegetative growth of the tree.

It has become a current practice among orchardists to regulate to a certain degree the fruitfulness of a tree and bring about any one of the three conditions mentioned above. The orchardist can delay fruitfulness by inducing vegetative growth and prolong the life of the tree; he can incite fruitfulness by checking vegetative growth and shorten the life of the tree; or, he can strive to produce a normal condition that will give proper fruitfulness without material injury to the longevity of the tree.

Anything that will check vegetative growth during the proper season of the year tends to induce fruitfulness provided it is not done to an extreme thereby killing the tree. This checking may be the result of a number of causes which may be natural or artificial.

NATURAL CAUSES OF INDUCING FRUITFULNESS.

<u>Soils and Varieties</u>. These two factors are considered here collectively because of their direct relation to each other. Thin soils tend to produce limited wood growth and bring the trees into bearing at an early age. The trees do not live very long under these conditions. On rich lands, however, the trees become old and large before they produce a crop.

King David or Missouri apple trees mature at a very early age and set large amounts of fruit, which if not properly thinned, mature as small unmarketable apples. On the other hand, Minkler and York trees show great vegetative vigor during their early years of growth, bear much later, and live longer. These facts are very important in orchard practices. For example, one should not plant Missouri on a poor soil unless special treatment is given them because this variety has a tendency to set an abundance of fruit and a poor soil will cause such an oversetting of fruit that it will deplete the tree in perhaps one year. If these varieties are grown on rich soils no excessive fruitfulness will occur and the apples will attain marketable size.

York, in deep rich soil, goes or tends to vegetative growth and will not come into bearing when it should. It may not bear until it is twelve years of age; or, it may bear one year and not again for several years. This suggests the alternate bearing in trees which will be discussed later. On a poorer soil, this excessive vegetative growth is checked and the tendency toward fruitfulness is favored.

It is necessary, therefore, that the orchardist know his land and the characteristics of the different varieties of fruits that he may adjust the variety to its environment. There are varieties that lend themselves well to any soil, but the two extreme types only are here cited.

In his travels over the State of Missouri, Whitten (71) observed the differences in growth and fruitfulness of certain varieties of apples in different types of soil. From these notes and observations the following table has been compiled.

TABLE I. VARIETIES OF APPLES BEST ADAPTED TO RICH SOILS, POOR SOILS, AND INTERMEDIATE SOILS.

Rich land apples	Poor land apples	Medium land but not poor.	Well on thin but better on medium soil.
Winesap	York	Jonathan	Ben Davis
Stayman	Rome	Grimes	Gano
Arkansas	Minkler		Dutchess
Arkansas Black	Champion		Transparent
Ingram	Maiden Blush		
Wealthy			
Benoni			

In addition to the above it was observed that the Delicious and the Missouri are well adapted to either rich or poor soils.

The above observations should be of great service to prospective fruit growers in choosing varieties.

<u>Climate</u>. Some varieties flourish only in restricted districts, while others are much more widely adapted to a wider range. There are, sometimes, other factors that cause different fruits to do well in one climate and poorly in another. The Newtown is a very good example of an apple suited to restricted soils and a maratime climate. In contrast to this the Ben Davis is grown in nearly every part of the United States. Again, the Baldwin apple is particularly suited to the maratime climate of the eastern coast. In some of the fruit growing sections of the semi-arid western planes where the hot winds blow during the summer months, vegetative growth is checked and fruitfulness or rather heavy fruit bud formation is the result. These various environmental factors require considerable study. For example, Batchelor (8) of Utah concludes that summer pruned trees average less marketable fruit per tree than either winter pruned or unpruned trees, and that summer pruning in the orchards of North Logan, Utah has proven neither profitable nor successful in increasing crop yields. His work was with Jonathan and Gano varieties planted on a rich, sandy loam, free from seepage, in a semi-arid climate, and with an abundance of irrigation water available. He found that there was a tendency for the trees to overbear soon

after reaching a productive age and that summer pruning reduced the area of fruit bearing wood, reduced the vitality of the tree, and also its productivity. On the other hand, Dickens (18) working in Kansas caused unproductive ten-year-old apple trees to bear satisfactorily during the fourth year by summer pruning.

It is evident, therefore, that one cannot advocate methods of culture or horticultural practices unless he is thoroughly acquainted with the climatic or other environmental conditions of his locality. Environmental conditions in the same state sometimes vary to such an extent that it is unsafe to advocate methods of culture for one locality that are ideal for another.

Age and Maturity of the Tree. A young tree puts its entire energy into vegetative growth and as it gets older tends more and more to produce fruit until it reaches an age where its vitality diminishes. This length of time varies considerably for there are at present some apple trees over a hundred years of age that are still in good bearing condition, while some other trees die before they reach the age of thirty.

Accidents and Diseases. A tree that suffers an accident may come into bearing several years earlier than other trees making normal growth in the orchard. Branches are sometimes bruised in cultivation, or insects and diseases may cause partial girdling. Winkler (74) showed the girdling effect of canker diseases on a three-year-old pear tree. One half of a small branch which had been partially girdled by the canker was in full bloom while the rest of the tree showed no flower buds whatever.

Soil Moisture. This phase of the problem will be discussed more fully under "Conditions for Growth", but since it is a natural influence in fruit bud formation in all sections where irrigation is not practiced it should be briefly considered here. However, cultural methods have been developed to such an extent that the moisture content of the soil can be controlled to a large degree.

Excessive moisture causes excessive wood growth and lack of moisture favors fruit bud formation. Other factors must, of course, be favorable for either vegetative or reproductive activity, but the moisture content seems to be the dominate factor. Sorauer (67) states, "If there is a plentiful supply of food material, especially of a nitrogenous nature, the multiplication of the cells will be a very active one. If at the same time the organs are continuously and richly supplied with water, the young cells will also be able to grow to their utmost capacity. While for the production of flowers or flower buds, it is essential to decrease the supply of water and of nitrogenous salts, to increase the phosphates supplied to the plants, and to increase the illumination."

ARTIFICIAL CAUSES OF INDUCING FRUITFULNESS.

Girdling. This is a very easy way to bring a tree temporarily into bearing at an early age. The difference between vegetative growth and fruitfulness seems to be the prodigal using up of plant food in contrast to storing it. Girdling causes storage of plant food above the wound because the phloem is reduced and the elaborated plant food cannot descend to the roots. The xylem, however, is still intact and the passage of water and mineral salts is not hindered. Winkler (74) showed that tomato plants which were girdled took up about the same quantities of water as plants that were not girdled. It is evident, therefore, that if the same amount of water and mineral food enters the twigs and the elaborated plant food is prevented from leaving the twigs, there must be a storage above the wound which causes the "relative increase of organic substances" referred to by Winkler.

Ringing. This is much the same as girdling except that a very narrow strip of bark is removed (about one-sixth to one-eighth of an inch) and it is confined more to the smaller twigs than to the larger limbs. The same principles are involved as in girdling and as the sap returns in the bark, it is checked, and tends to the growth and fruitfulness of the branch. In this case, however, granulations form and the wound heals. This allows the sap to pass on again and prevents the death of the branch.

Notching. The same principles are again applicable in the case of notching as in girdling or ringing. However, while girdling affected the limb as a whole in most cases, and ringing affected the twig or branch, notching affects only the individual bud and shows more explicitly the action of the sap when it is redirected. If a small notch is placed below a bud the entire vascular tissue is destroyed at that particular spot and the elaborated plant food cannot descend below the bud. It is, therefore, directed into the bud and causes the sap to be enriched. Chandler (13) made studies of the concentration of sap and in every case the abundance of fruit buds bore a relation to the concentration of sap. On the other hand, if the xylem is destroyed above the bud by making a small notch, no elaborated plant food can reach the bud and the ascending sap, composed chiefly of water and mineral salts, forces the bud into growth. It is a well known fact that elaborated plant food such as descends in the phloem is richer and more concentrated than the rising sap in the xylem. These differences and their application as demonstrated by notching seems to be the clearest distinction between the cause of vegetative growth and fruitfulness as understood by the horticulturist.

<u>Root Pruning</u>. This method of inducing fruitfulness has been practiced for many years, especially by those engaged in producing dwarf plants. Drinkard (21) summarizes his work on root pruning as follows: "Root pruning on April 23rd, at the resumption of growth in the absence of spring pruning, did not give as much stimulation to fruit bud formation as the same treatment applied at later dates. Apparently this was too early for the full effects to be felt by the tree. Root pruning when the foliage was fully developed, and when the fruit buds began to become differentiated, in the absence of spring pruning of the tops, produced very marked stimulation in fruit bud formation.

At these three times the treatment retarded wood growth and foliage development in the current and succeeding year, and the trees suffered from the treatment." It is evident that when the root pruning was done when the leaves were fully developed, that the water supply going to the leaves was reduced. A combination of factors, therefore, caused fruit bud formation. Lack of turgidity in the leaves and cells caused by the lessened supply of water reduced the rate of vegetative growth; lack of moisture in the cells caused a more concentrated sap to be formed which is conducive to fruitfulness; and elaborated plant food from the leaves was caused to be stored in the twigs and branches to a greater extent.

Summer Pruning. It is safe to say that this is the most practical method of inducing fruitfulness that is known to the orchardist. When pruning is done in the winter the tendency is to promote a strong wood growth. This fact is easily understood when we consider that the roots are undisturbed and that the same amount of crude material is absorbed by the roots for distribution throughout the tree. If the top of the tree is reduced the sap goes to the remaining branches and forces them into growth in proportion to the amount of pruning done and usually in direct ratio. This is due to the fact that in a normal tree there is a perfect balance between root and top in regard to the absorption of sap by the roots and its elaboration in the leaves. The orchardist often takes advantage of this fact by rejuvenating old and dying trees which fail to develop adequate new wood. A severe cutting back of the top favors activity and vegetative growth, and subsequently fruitfulness is the result. Jarvis (39) in his report on apple growing in New England, states that "the severity of heading-in, will depend largely upon the vigor of the tree. Nothing will start a tree into renewed vigor like severe pruning during the dormant season. The cutting back, therefore, should be more severe with weakened trees. With moderately vigorous trees, there is danger of producing a rank growth in the form of water-sprouts." Downing (19) and subsequent writers substantiate this by saying that a certain amount of vegetative growth is essential to fruit production, but that an increase of vegetative vigor beyond the optimum condition would not necessarily result in a proportionate increase in productiveness.

The converse, or the stimulation of fruit bud formation by summer pruning, was not so well understood by the early writers. They realized, however, that there was a certain time to prune in summer to produce fruitfulness and that if this pruning was done too soon it usually resulted in the development of secondary shoots which would not readily produce fruit buds. Drinkard (21) of Virginia shows the proper time for summer pruning when he states that summer pruning of the branches of the trees the latter part of June, when fruit buds normally begin to show differentiation , checked wood growth the year in which the summer pruning was done, and greatly stimulated the formation of fruit buds, as was shown by the bloom and crop of fruit the following year. Dickens (18) states that "trees pruned in summer have grown fewer water-sprouts than those of similar age and grown in a similar soil, pruned in winter or early spring. Water-sprouts removed during summer are less liable to be followed by another crop of the same growth than when the pruning is done in winter." This may be explained by Jost's (41) statement in which he brings out the fact that during the period of summer pruning, root growth is retarded and consequently there is not such a preponderance of water and mineral salts even though the top is reduced considerably.

Miscellaneous. There are a number of other minor causes which have a tendency to produce fruitfulness but which are not practical to the commercial fruit grower. Bending the limbs down and fastening them in that position is recommended by Cole (14) who says that this method retains the sap in the branches inducing bearing and improvement of the fruit, without injury to the tree. Such a practice as this is usually confined to European countries where fruit trees are trained along walls or other supports. Transplanting a tree frequently has a tendency to check its growth, and induces early bearing. The same effect is produced as in root pruning as roots are lost in the removal. Dwarfing is also practiced but this method of inducing fruitfulness is decided upon before the trees are set out and, therefore, does not necessarily concern us in a discussion of treatment in the orchard.

ALTERNATE BEARING.

It is a fact that sometimes orchards tend to bear in alternate years. These alternate bearers are usually heavy producers when they do bear, and it seems that the entire two year's energy of the tree is directed into the one year's crop. Sandsten (65) states that "The amount of fruit borne by the trees greatly affected the formation of the fruit buds. A heavy crop invariably delays the formation of fruit buds, and causes the latter to enter the winter stage partially developed. The production of a large crop and maturing of seeds are heavy drains on the tree and it is reasonable to suppose that the maturing of the fruit and the development of the fruit buds cannot proceed simultaneously to any great extent, especially if the season is unfavorable. It is reasonable to suppose that when the fruit buds enter the winter imperfectly developed, they require a longer period in the spring to develop and open, and this would account in part for the difference in time of flowering of the same and different varieties of fruit." Cole (14) (1849) states that most apple trees bear full every other year, and few or none in intermediate years and that the same cause assigned for alternate bearing is that the tree becomes exhausted from a heavy crop, and needs rest and renovation of its powers. "But", he states, "analogy shows that this is no reason, for the same species of trees and shrubs bear abundantly every year and generally if an apple tree produces a little fruit when it is not the bearing year, the fruit is small and knurly, though the tree is in full vigor." Cole offers no explanation in regard to alternate bearing. He further states that in New England most of the varieties of apples, natural and grafted, produced large crops in even years: 1846, '48, and '50, and light crops in the odd years. The view of alternate bearing was undoubtedly a new one at this time for he writes, "Like all new things, this view has been opposed and ridiculed, but never met fairly with facts. We have observed it for thirty years, and the same orchards that bore profusely in even, and sparingly in odd years, in our boyhood, still continue the same." From literature from the New Hampshire Experiment Station the writer notes that the authors speak of the bearing years as the even years. The picture of an interesting Baldwin apple tree is shown by Pickett (60). This tree has two large limbs which bear alternately.

Some varieties are very persistent in their habit of alternate bearing and it may require several years to bring about annual bearing in such trees. Beach (9) says that after four years of work in thinning Baldwin apple trees they did not become regular in their bearing or more productive. At the Ohio Experiment Station essentially the same results were obtained. Gourley (32) concludes that at present it appears that thinning does not bring about a regular bearing of the Baldwin as readily as might be supposed. On the other hand, Barry (7) states very successful results from thinning and pruning out surplus blossom buds.

Alternate bearing may be overcome in most varieties by careful attention. This may be accomplished in two ways:

1. By pruning out part of the fruit branches in early spring to reduce the bearing surface; or,

2. By thinning the fruit as it is set when the tree is overloaded; or, by both these processes.

Some orchardists have been skilful enough to overcome this alternate bearing. In the orchard on the horticultural grounds at the University of Missouri, a tree thirty-five years old which had always been an alternate bearer was brought into annual bearing after three years of careful thinning and pruning.

It must be remembered that to produce the blossom and small apple requires no small amount of food material and energy on the part of the tree. This fact is brought out quite vividly later. Therefore, it is more economical to thin the crop by winter pruning than it is to leave an excess of fruit buds on the tree to utilize all the available food material for the production of small worthless fruits.

Taking advantage of the foregoing observations, the fruit grower has adapted methods of controlling the age at which a tree may come into bearing. One of the fundamental things is to understand how to do this for it is apparent from the foregoing discussion that in order to regulate fruit production the orchardist must have a knowledge of the working power of his trees.

Fruit buds which are to produce blossoms and fruit on a given year are formed the previous summer. Just when this fact was understood is not known, but the principles involved in the works of the early writers imply that fruit bud formation was known to develop during the summer. For example, Quintinye (64) in 1764 states that summer pruning induces fruitfulness for the following year.

Practically the first scientific investigation in America regarding the formation and development of fruit buds was the work of Goff (27), and this may be said to be comparatively recent. His work was taken up by Drinkard, Kraus, and many others and at this time is one of the foremost problems concerning the horticulturist.

Since fruitfulness depends upon the formation of fruit buds, and since it is known that certain conditions effect fruit bud formation, it is, therefore, a fundamental problem of the orchardist.

The published work thus far deals with the development of buds in sections of the country where climatic conditions are more or less constant as compared to the middle west. The bulk of the work has been done in Wisconsin, New Hampshire, New York, Virginia, and Oregon, and also in Germany which has a latitude corresponding to that of Labrador.

Whitten (70) states that"it very often happens that a warm spell as early as February causes the peach buds to make considerable growth.... The peach is quite easily stimulated into growth by warm days, even in winter." Figure 1 shows the highest, lowest, and mean temperatures for Columbia, Missouri during January and February for the year of 1916. This particular year was selected because of its marked variation, and because the warm period lasted for several days.

It was believed that since the winters in Missouri are so variable, and since the buds are partially developed in the fall, that during the winter there is some activity that could be measured except, perhaps, during the rest period, which Howard (36) determined to be about eight weeks.

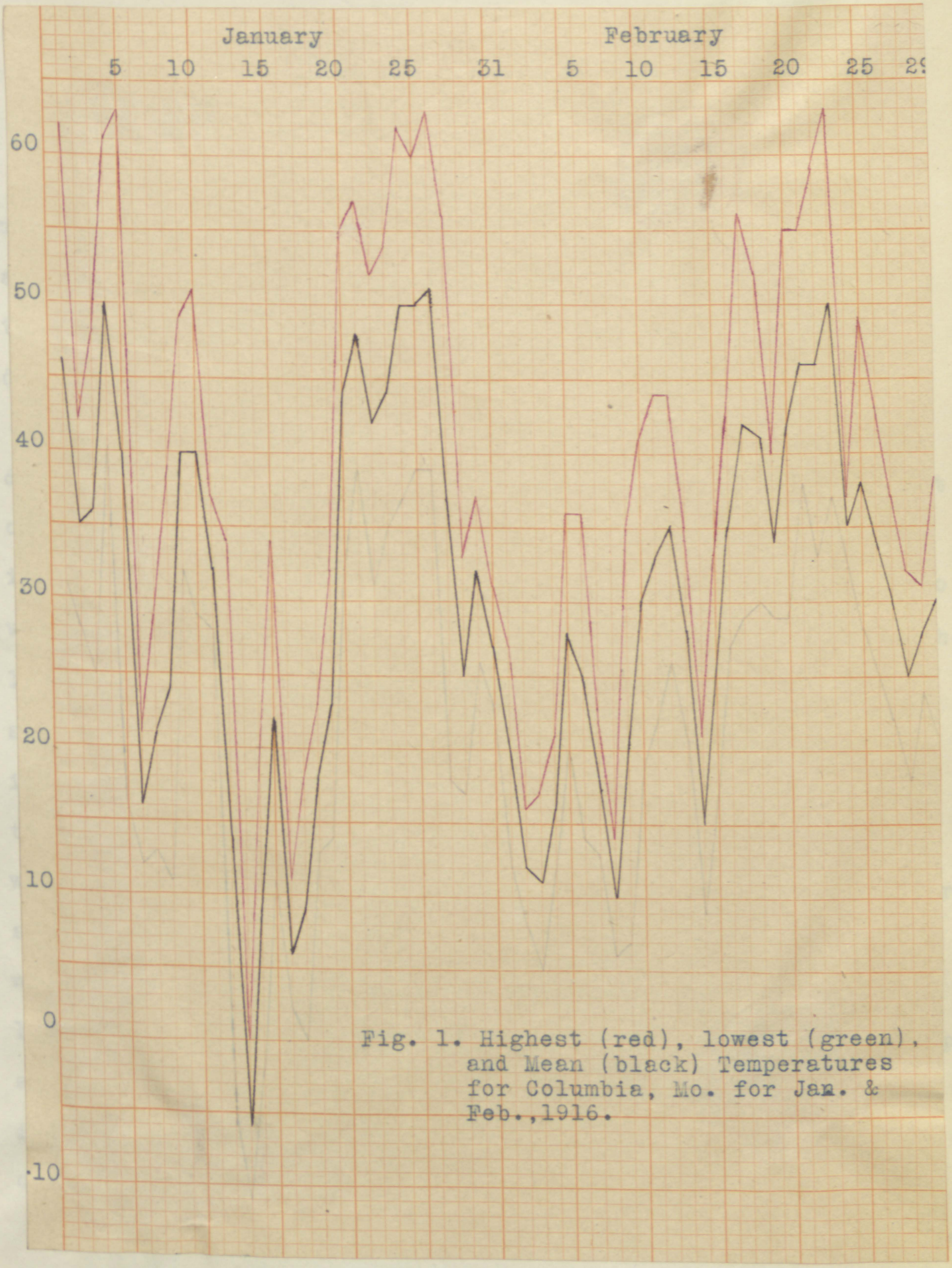


Fig. 1. Highest (red), lowest (green), and Mean (black) Temperatures for Columbia, Mo. for Jan. & Feb., 1916.

OBJECTS OF THIS INVESTIGATION

The study of the winter structure and development of apple buds is the primary object of this work but there are many factors and influences which have an indirect relation to the problem and which must be taken into consideration in dealing with the application of the principles involved.

This study, therefore, deals directly with the developing flower buds and their structures from the latter part of October until early spring and indirectly with the factors influencing fruit bud formation, while the ultimate object is to understand the structure and development of the buds so thoroughly that a reasonably accurate forecast of the bloom for the spring may be predicted in late winter. This latter is very important from a practical standpoint. It is of great service to the fruit grower for the following reasons:- The orchardist wants to know in the winter whether or not he will need to order spray material; he can be guided in his winter pruning which would be more severe if there is prospect of a heavy bloom ~~and~~ leaf surface than if the trees are carrying but few well developed fruit buds; and other factors such as late winter and early spring orchard management can better be planned if a forecast of conditions can be made.

The early development and differentiation of buds into leaf buds and fruit buds is a very important factor in fruit growing and will be discussed briefly in this paper from the viewpoints held by those who have studied their development throughout the summer and early fall.

Since this investigation was not started until October and since no definite data are now available at this Station on the early development and differentiation of the buds, it is impossible for the writer to discuss definitely, this phase of the work.

CLASSIFICATION AND STRUCTURE OF APPLE BUDS.

An apple bud may be said to be an unexpanded branch - stem, leaves, and sometimes flowers being all present in a miniature and undeveloped form. This branch, if it may be so called, is formed in advance during the summer previous to blooming so that when spring ~~and sunshine~~ arrives, no time will be lost in pushing ahead and effecting growth before winter again arrives and checks activity.

Buds are classified by Thomas (68) into leaf buds and flower buds; by Gray (33) as leaf, flower, and mixed buds; and by Lucas (55) as leaf, wood, fruit, and mixed buds. Since the flower buds of the apple contain both flowers and leaves, and are, therefore, mixed buds, it may be generally stated that there are three main types of apple buds - leaf buds, wood buds, and mixed buds. However, for practical purposes they are usually termed leaf and flower buds.

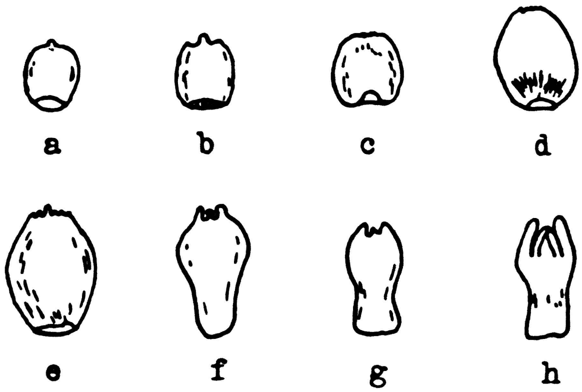
Barry (7) further classifies buds by saying that all buds are either terminal, axillary, or adventitious. A bud forming the apex of a shoot is called a terminal bud; one at the junction of the leaf with the stem (axil) is called an axillary or lateral bud; and one originating accidentally, as it were, or without any regularity on the older parts of trees, and not in the axil of a leaf, is called an adventitious or accidental bud.

These latter are very often produced by the breaking or cutting off of a branch, or by a wound or incision made in the bark.

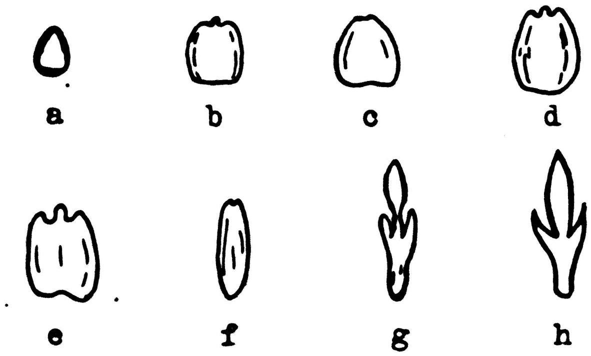
Fruit buds may be either terminal or axillary but more frequently they are the former, especially in apples. Many fruit buds which seem to the casual observer to be axillary, are upon technical observation shown to be terminal on one or more years growth of wood. Sometimes an axillary bud may grow very feebly for a year or two and apparently be in a dormant condition. At the end of this time it may produce a flower cluster and it is commonly thought that it is an axillary fruit bud when in reality it is a terminal bud.

As the buds must live through severe weather during the winter months and withstand adverse climatic conditions, their parts are packed tightly together so that a minimum of surface is exposed, and they are further protected by a covering of scales. Gray (33) states that a bud is nothing more than the first stage in the development of a stem, with the axis so short that the rudimentary leaves within successively cover each other, while the whole is covered and protected by the scales without. The number of scales varies considerably, depending upon the size of the bud, and the stage of development, but the average number of scales per bud during midwinter is about eight.

The outlines of the scales of leaf and fruit buds in Figure 2 show the relative forms of the scales beginning with the outer, smooth, reddish scales, which serve as protection only, and ending with the small green hairy scales in the center.



Bud Scales from a
Flower Bud.



Bud Scales from a
Leaf Bud.

Figure 2. a to h Shows Gradation from the Outermost Scales to the Innermost Scales of Jonathan Apple Buds. (After Black)

TIME OF FRUIT BUD FORMATION.

Several investigators have given us careful studies on the time of differentiation between fruit and leaf buds on various fruit trees for different parts of the country.

Goff (27) of Wisconsin found that the buds began to differentiate as flower buds about the time the wood growth ceased. This he explained on the ground that the energies of the tree up until that time were used up by the vegetative increase and afterward the energies went to the formation of fruit buds, and maturing the wood and fruit. He noted that the terminal bud in a cluster was the first to form and the first to open in the spring. The first clear evidence of flowers in the apple according to his studies was found in buds taken June 30th. He also found flower buds forming as late as October in 1900, and the previous year (1899) he observed trees that began to form flower buds in July, formed enough after September 1st to produce a good crop. He concludes that either there is a prolonged period of fruit bud formation or else there are two periods, first in early summer and again in early autumn and he prefers the latter view.

Drinkard (20) in Virginia found that the fruit buds of the Oldenburg apple began to form the last week in June. He also noted a prolonged period of fruit bud formation although mostly they were formed early in July.

Morgan (56) found that in New York the growth in fruit buds was very uniform and gradual up to about November 15th. At this time the increase in size ceased quite abruptly. He found that from the middle of November until March 1st there was no growth in peach buds. On March 23rd, after there had been several days of warm weather, the peach buds began to grow rapidly and uniformly until April 23rd, when they came into flower. With the apple he found the results were very much the same. Growth almost ceased November 15, and from this time until March 1st the increase was apparent but exceedingly slight, amounting to only ½ to 1 percent. Renewal of activity began March 1st, and from this time until April 23rd, seven weeks later, when the apple buds opened, the growth was very rapid.

Kuster (51) in Germany found that during a specially mild winter the buds of maple showed slight growth both in the lateral organs and in the young axis. No new organs were started either in maple or other species examined.

Albert (1) also working in Germany found that practically all buds became dormant soon after leaf-fall and so remained until early spring. The first change in spring was a stretching of the tissues, further development of the parts taking place only later.

Kraus (46) states that in the case of the Yellow Newtown the fruit bud can be distinguished from the leaf bud early in July at Corvallis, Oregon.

Black (10) at Durham, N. H. found that the time of bud differentiation and flower formation in New Hampshire is somewhat variable. She states that the primordia of the flowers in the Baldwin apple may or may not be established in one growing year. Buds collected March 18, 1913 showed well-established flower parts and by April 14 of the same year, the anther wall, sporogenous tissue, and tapetum were differentiated. The following season, 1914, the buds were a little later in their development, and buds collected April 23, 1915 showed no differentiation other than the shape of the growing apex. The buds for 1916 dissected on July 3, 1915, and July 20, 1915, showed no differentiation into fruit buds.

The consensus of opinion of the majority of the authorities cited above is that fruit bud formation in the apple begins during the latter part of June and early July.

It is interesting to note that the time of differentiation in Wisconsin, Oregon, and Virginia is about the same and that in New Hampshire fruit bud formation was not observed by Black until early in spring even though the latitude is about the same as that of Wisconsin.

It is reported that Howard of the University of Missouri made numerous observations in regard to the early differentiation and development of the apple buds at Columbia, Mo. His work covered a period of several years and it was generally concluded that differentiation took place during the last two weeks in June and in early July.

CONDITIONS EFFECTING FRUIT BUD FORMATION.

Light and Nutrition.

These two topics are considered collectively because of the relation they bear to each other.

The green leaves of the plant have been called by Duggar (22) the "noiseless machines engaged in the manufacture of all that organic material upon which life depends." The energy which makes this manufacturing process possible is light. Sunlight is very important in the orchard and its effect upon the growth of the leaves is apparent. Direct sunlight is not absolutely necessary, however, because it has been demonstrated that only about three percent is used in the process of photosynthesis and it may be as low as .5 per cent. In diffuse light the leaf may absorb 95 per cent falling upon it, while in direct light only about one half is absorbed. The surplus energy absorbed is in part operative in raising the temperature of the leaf, which, according to Blackman, may be in direct sunlight from 10° to 15° C. higher than that of the surrounding air. Duggar states that the relation of food manufacture to the intensity of light is rather complex and that under favorable conditions of temperature the working capacity of many plants is proportional to the increase in light intensity. This fact seems to be especially true in regard to the apple.

Leaves in the central part of densely foliated trees are considerably smaller than those on the periferal parts and the development of the apples borne on these corresponding parts shows that there is not enough food for the proper development of the fruit.

The following observations were made to show the comparative areas of leaves in the shade and in direct sunlight:

TABLE II. COMPARATIVE AREAS OF LEAVES IN THE SHADE AND IN DIRECT SUNLIGHT.

Variety	Areas of Leaves					
	Shaded			Sunlight		
	Maximum area	Minimum area	Average area	Maximum area	Minimum area	Average area
Winesap	11.4	6.0	8.6	20.7	14.1	17.3
Jonathan	12.0	5.9	9.4	25.8	16.3	20.1

The average of 30 Winesap and 174 Jonathan leaves was used in the sunlight test, and 30 and 50 respectively in the shaded test.

It can be seen from the above observations that the shaded leaves were checked considerably in their growth and that those in the sunlight developed a larger leaf surface.

The question then arose as to the relation of leaf area on the development of fruit buds versus leaf buds. Twenty Jonathan buds were chosen Oct. 15, 1916, all of which were on the south side of the tree. The leaf areas were calculated and the number of leaves to each bud noted. The length of the current year's growth on the twig on which they were borne was taken as well as the approximate diameter of the twigs. On March 1st the twigs were cut from the trees and placed in the greenhouse to bloom so that the data could be obtained in advance of the regular blooming period. On March 19th the buds had opened and produced several leaves as well as defined flower clusters. At this time the number of flowers in the cluster was observed and also the number of leaves and the comparative vigor of the buds.

TABLE III. RELATION OF LEAF AREA, TWIG GROWTH, AND DIAMETER TO THE FORMATION OF FRUIT BUDS VS. LEAF BUDS.

Twig Number	Observation in October 1916				Observations in 1917		
	Length of current year's twig growth cms.	Number of leaves	Area of leaves sq.cms.	Diameter of twig in inches	Character of bud	Fls.	Lvs.
1	14.0	12	290.4	.125	flr.	6	?
2	13.0	16	281.0	.125	flr.	7	8
3	14.0	14	246.8	.165	leaf		6*
4	5.0	10	204.6	.125	flr.	5	8
5	1.0	11	201.0	.140	flr.	5	7
6	8.0	10	185.4	.130	flr.	6	7
7	14.0	9	176.3	.125	leaf		6
8	7.0	9	174.6	.120			
9	2.0	8	170.5	.175	flr.	5	11
10	8.5	9	164.0	.135	leaf		6
11	2.0	8	156.4	.115	leaf		6
12	7.5	8	151.0	.125			
13	1.0	8	151.0	.150	flr.	6	9
14	6.5	9	146.3	.115	leaf		6
15	1.0	7	137.7	.120	leaf		7*
16	1.5	6	131.0	.100	flr.	6	5
17	2.0	6	116.7	.110	flr.	7	10
18	1.0	5	106.0	.150	flr.	6	9
19	1.0	5	101.3	.135	flr.		
20	1.5	4	71.9	.140			?

*Lateral buds well developed and opening.

While the foregoing data are not sufficient to be regarded as conclusive, still the variety of differences in the nature of the buds under the different conditions seems to point to the fact that there is no one specific factor mentioned above that controls the formation of fruit buds. Chandler (13) found that where the water supply was inadequate the fruit on the branches of an apple tree would give up part of their water content to the leaves which would keep green and vigorous; in other words the leaves drew water from the fruit. This transportation of water was either ascending or descending and sometimes the water had to go as far as two feet. If this happened in regard to moisture it is quite possible that leaves from other parts of the tree help in the storage of food for the buds and that the leaves in the immediate vicinity of the bud do not play such an important role. Gourley (32) found that the area of the leaves in the bearing years was much less than in the "off" year in the case of a bearing and non-bearing Yellow Transparent tree. These data were for the tree as a whole and show that all the leaves were concerned in the manufacture of the food material. When the tree is not bearing, the leaves can manufacture and store in the twigs sufficient plant food to bring about the formation of fruit buds. On the other hand, in a bearing year the leaves are smaller because much of their energy is used in the development of the crop of fruit and as a result there is not a sufficient reserve to supply another consecutive crop. It seems quite evident, therefore, that all the leaves are concerned in the manufacture of food material and in the formation of fruit buds.

When the leaves drop in the fall and the twigs go into the winter rest, there is a certain amount of plant food stored in the buds, twigs, and larger branches. Jones (40) in working with the sugar maple found that the storage of reserve materials in that tree is very great. He calls attention to the fact that the carbohydrates are all manufactured in the green leaves under the influence of sunlight, and the sugar content of the sap depends upon the conditions of the preceding season as to sunlight and leaf development. Defoliation by caterpillars was evidence of this fact because the following season the sap always carried much less sugar than usual.

To determine the amount of available food material in the wood of the apple, twigs were cut from a Jonathan tree and placed in water in the greenhouse to develop. These twigs varied in size from one inch of wood bearing one bud to limbs one inch in diameter bearing nearly a hundred buds. It was found that the buds developed in size and rapidity in proportion to the amount of wood upon which they grew. The buds on the short spurs of one inch grew for a short time and swelled considerably but did not open. They seemed to grow until all the food material in that spur was exhausted and then wilted away even under water pressure. Twigs with a reasonably large amount of wood developed and opened and in many cases the flowers opened. In the case of the very large branches, the flowers opened and the leaves grew very large.

Water.

Water is one of the most important factors in fruit production. It has been stated by Hilgard (35) that "production is almost directly proportional to the water supply during the period of active vegetation." The period of most active vegetation is the latter part of May and early June. Gourley (32) found that growth practically ceased by the first of July. Cranefield (16) reports from Wisconsin that in the year 1899 the fruit trees about Madison had completed their growth by July 1st and few continued to grow after June 1st. At this time the water supply should be at a maximum for all organic food material and nutrients presented to the living cell as well as the mineral salts must be in solution. Again, an abundance of water causes turgor in the cells and turgor accelerates growth. At the present time there is no definite relation known between turgor and growth but it is an accepted fact that turgor accelerates the rate of growth and lack of turgor retards growth. Sorauer (67) states that every plant draws most largely on the soil during the putting forth of new shoots and leaves, and takes up most mineral substances at this time. "As soon, however, as the shoot is developed and the formation of flower buds is expected, the watering may be decreased. The formation of flower buds is best initiated by preserving a period of rest, and the latter is favored by a diminished water supply. If water is freely given, and no resting period is allowed, leaf development alone takes place, as the tip of the shoot grows on continuously, and remains the center of attraction for the ascending sap."

Where watering is controlled by irrigation or in the case of small plants these facts are important. However, certain cultural methods may be employed in the orchard to regulate the moisture content of the soil. The work of Gourley (32) in regard to the rainfall relation to fruit bud formation seems very important. He states that "no relation could be traced between the rainfall of the growing season and the fruit bud formation in this experiment through a period of seven years. This is probably explained in the case of the Baldwin by the strong inherent character of alternate bearing after its bearing habit has been established. However, the plots in this experiment where the moisture ran lowest during the period of fruit bud formation, coupled with good growing conditions earlier in the season, have produced the largest number of fruit buds. "It seems from the foregoing statements that if the drain on the water supply in the soil is very great during the rapid growing season that by the time fruit bud formation is in progress the soil moisture would be so diminished as to make this in harmony with proper development and cause the"period of rest" referred to by Sorauer. Heavy spring rains, however, may cause so much moisture in the soil that fruit bud formation may be retarded.

It has been inferred throughout this discussion that an abundance of moisture retards fruit bud formation at the proper season. This is explained by Winkler (74) when he states that in plants with specialized storage organs an oversupply of water and the consequent rapid vegetative development inhibits the accumulation of reserve food in these organs. A wet season at the time of fruit bud formation is known to materially reduce the fruit crop of the following year, while a dry summer tends to result in abundant flower bud formation. Winkler also worked on the influence of soil moisture on the sap density of the tomato and found that the average depression of sap from plants in dry soil was .903 and from plants in wet soil .784.

The same theory holds true in the case of winter pruning. It was thought that the cutting back of the branches allowed the remaining twigs to receive more nutrients per growing point and, therefore, a more vigorous growth, but the work of Winkler points out that the rapid growth which follows such cutting back in the winter is primarily due to a relatively larger supply of water. By severe pruning the top of the tree is reduced and the root system remains unchanged. The intake of water, therefore, remains the same while the avenues through which it is given off are reduced considerably.

In discussing the transition from vegetative to reproductive activity, Winkler assumes that the accumulation of nutritive matter coincident with a diminution of raw materials absorbed by the roots is a determining factor. In other words, the transformation of leaf buds into fruit buds, which marks the beginning of reproductive activity, is attributed to a relative increase of organic substances in the plant due largely to the decreased water supply.

The critical period in the transition from vegetative to reproductive activity has been definitely worked out (latter part of June to early July). This period of transition has been discussed previously in regard to the differentiation between leaf buds and fruit buds. This fact can be demonstrated quite vividly in the early summer by pruning. If a twig is cut back to two or three buds just before the period of differentiation the rapidly rising sap will force these buds out into very rapid vegetative growth, but if the twig is cut back shortly after the period of differentiation the buds will form as fruit buds.

Figure 3 shows graphically the rainfall for each month beginning February 1916. These meteorological data could be of great service to the farmer as a preliminary forecast for the bloom. The total precipitation for January 1916 was 6.8 inches. This amount of rainfall was sufficient to thoroughly saturate the ground, and in this condition it was easy to maintain a sufficient moisture supply by the rainfall of the months that followed, even though these amounts were below that of normal years. The accumulated excess of precipitation lasted until the end of June. Beginning with the month of July there was a gradual accumulated deficiency. The time of this decrease in moisture accompanied by the amount of water used for the rank growth that occurs during May and early June should be and was conducive to fruit bud formation, as shown later by the percent-age of fruit buds.

Temperature.

The temperature of the orchard during the period of fruit bud formation might be regarded as important if it could be controlled. Since it cannot, however, this factor is not important in this discussion.

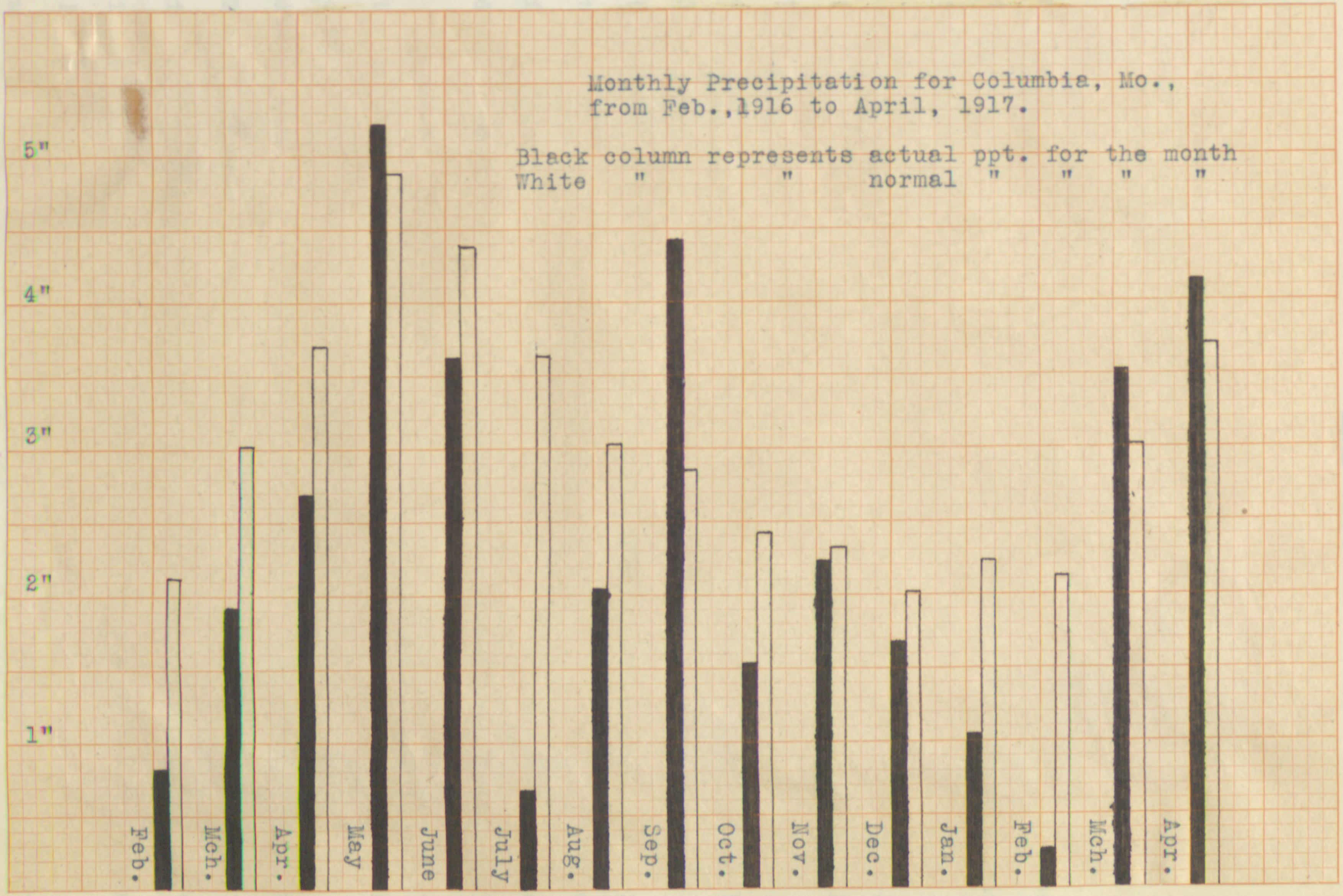

Monthly Precipitation for Columbia, Mo.,
from Feb., 1916 to April, 1917.
Black column represents actual ppt. for the month
White " " normal " " " "
5"
4"
3"
2"
1"
Feb.
Mch.
Apr.
May
June
July
Aug.
Sep.
Oct.
Nov.
Dec.
Jan.
Feb.
Mch.
Apr.

Figure 3.

CHARACTERISTICS OF BUDS AND TWIGS.

Since the principles and practices of pruning depend upon a knowledge of fruit buds, it is necessary to know the external characters of fruit buds and of the wood upon which they are borne as well as their internal structures.

From a practical standpoint, buds are certainly the most important organs of the tree because it is through them that the productiveness of the tree is controlled. If the orchardist wishes to become expert in the controlling of the production of his trees, therefore, he must be able to recognize the different kinds of buds and understand the significance of their peculiar characteristics for different varieties, the superficial differences between fruit buds and leaf buds, and the conditions which favor or retard fruit bud formation.

As a guide to intelligent pruning and to allow the grower to form some conception of the probable crop for the ensuing year, it is necessary that the orchardist be able to distinguish to a certain degree between fruit buds and leaf buds. The shape and character of fruit buds differ, however, for different varieties. In a general way there are several characteristics which may help to distinguish between fruit and leaf buds. In some cases the size and shape of the bud may indicate its nature, fruit buds as a rule being larger and more obtuse at the apex than leaf buds. The position of the bud may also be a guide since fruit buds are generally borne on short, thick spurs, but this is not always true. Gourley (32) observes that the Sutton Beauty sets its fruit on short spurs which occur along the branches, the Willow Twig on the terminus of long slender branches of the previous year's growth, while the Roxbury Russet produces short jointed spurs of many year's growth.

Tables IV and V were tabulated from field observations made on the leading commercial varieties in the horticultural grounds of the University of Missouri.

Figures 4 and 5 are photographs of seven different varieties of twigs. These may be considered in connection with Table IV. It can be readily seen that there is a marked difference between the varieties. This difference is especially noticable between such varieties as the Jonathan and the Winesap.

Figures 6 and 7 are photographs of fifteen varieties of apple buds. These may be considered in connection with Table V. These buds are all fruit buds except those marked with an X. After the photographs were taken the buds were dissected and the leaf buds noted.

TABLE IV. CHARACTERISTICS OF TWIGS.

Variety of Apple	Length	Diameter	Character	Internodes	Color	Lenticels
Jonathan	Medium	Slender	Straight	Short to medium	Brownish-red and dark green	Scattered, nearly round not raised
King David	Short	Stout	Gnarled	Short	Reddish-brown to mottled gray	Scattered, round, raised, numerous, large
Ben Davis	Long or very long	Moderate stout	Straight to slightly curved	Long	Dark brown red; bright	Scattered, round, raised, conspicuous.
Gano	Medium to long	Moderate stout	Straight to curved	Medium to long	Bright brownish-red	Scattering, elongated, raised, not conspicuous
Winesap	Short to medium	Stout	Gnarled	Short	Very dark red-brown	Clustered just below nodes, round conspicuous

Arkansas	Medium to long	Stout	Curved	Short	Dark brown-ish red to black	Scattered, conspicuous small.
Ark. Black	Short	Stout	Gnarled	Short	Dark red-dish brown	Scattered, round, small
York	Short to above med-ium	Moderate stout	Straight or nearly so.	Medium to long	Dull brown-ish red	Scattered, not raised, small.
Rome	Moderate long	Moderate stout	Medium straight	Short to medium	Mottled brownish-red	Scattered, round, rais-ed, large.
Grimes	Medium to long	Moderate stout	Straight	Short	Dull brown	Scattered, oblong, not raised, small
Ingram	Medium to long	Stout	Straight	Medium or below	Olive-green partly cov-ered with brown-red	Numerous round raised conspicuous large
Delicious	Short	Very stout	Gnarled	Short	Brownish-red	Scattered, round.
Missouri	Long	Slender	Straight	Short	Dark brown	Scat. oval, raised.

TABLE V. CHARACTERISTICS OF BUDS.

Variety	Size	Form	Position	Pubescence
Jonathan	Med. to	Obtuse	Free	Moderate
King David	Medium	Obtuse	Moderately free	Moderate
Ben Davis	Medium	Obtuse	Sunken in bark to moderately free	Sparingly
Gano	Small to medium	Obtuse	Slightly sunken in bark	Slight
Winesap	Small to medium	Very acute	Moderately free	Slight
Arkansas	Medium	Obtuse	Free	Slight
Ark. Black	Medium	Broad to acute	Moderately free	Slight
York	Small to medium	Obtuse plump	Deeply set in bark	Moderate
Rome	Large to medium	Obtuse to acute	Deeply set in bark	Moderate
Grimes	Small to medium	Acute	Free	Slight
Ingram	Medium	Obtuse to acute	Deeply set in bark	Moderate
Delicious	Medium to large	Obtuse	Moderately free	Moderate
Doctor	Large	Obtuse	Free	Slight
Missouri	Medium to small	Obtuse	Well set in bark	Slight

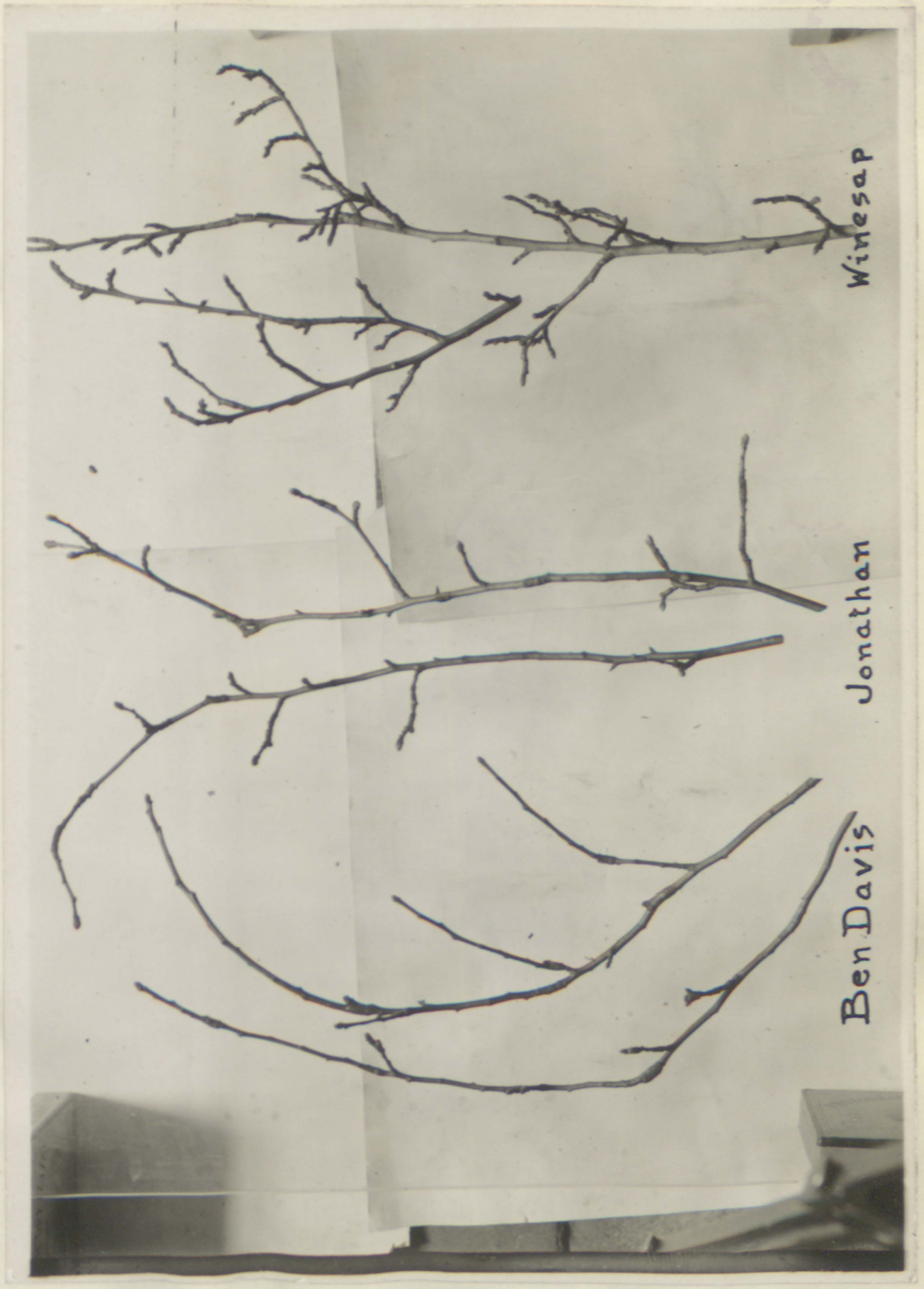


Figure 4. Varietal Differences in Apple Twigs.

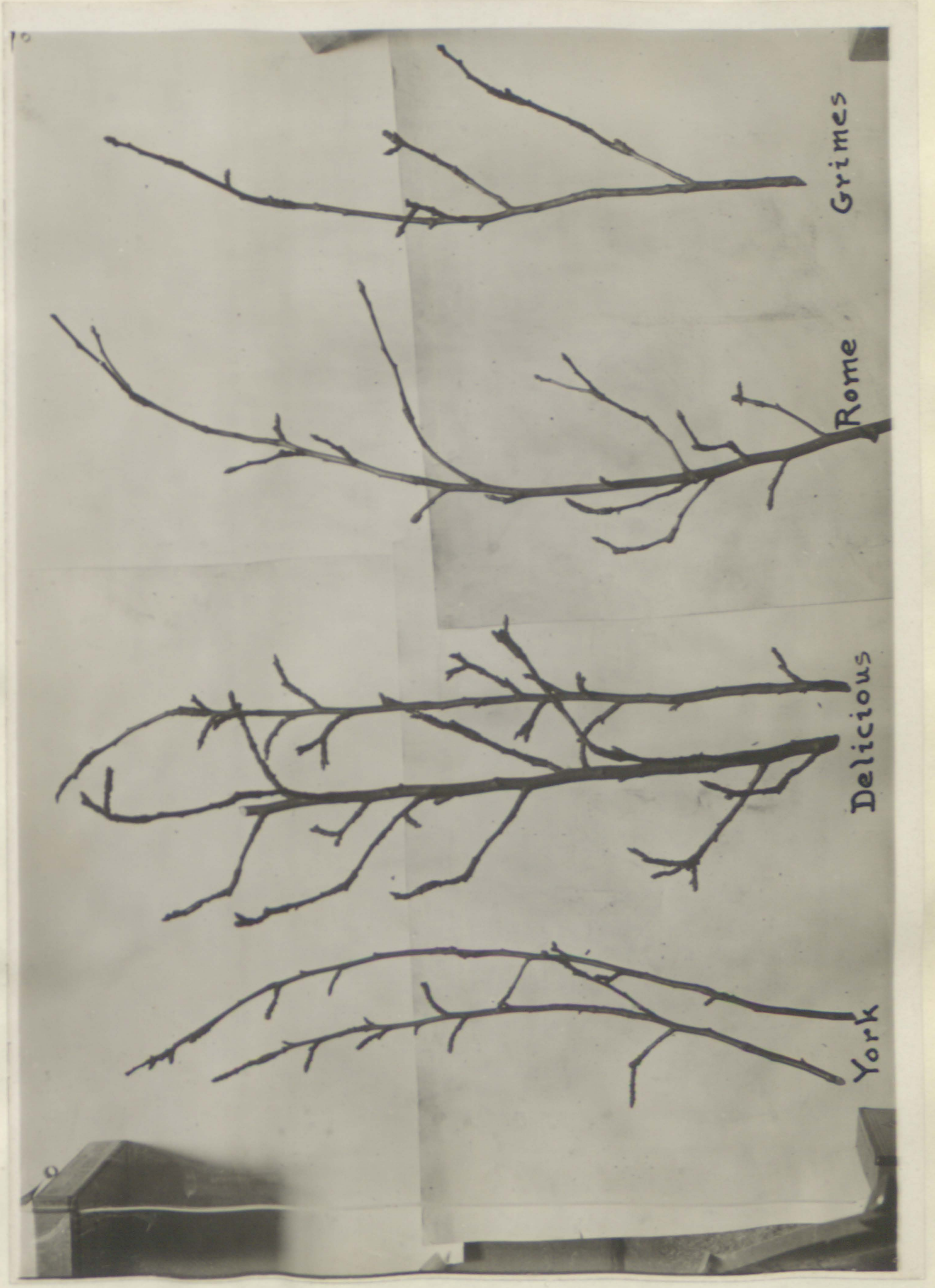


Figure 5. Varietal Differences in Apple Twigs.

Figure 6. Varietal Differences in Apple Buds.
(X denotes leaf buds; others fruit buds)

Figure 7. Varietal Differences in Apple Buds.
(x - Leaf buds ; others fruit buds)

WINTER DEVELOPMENT OF THE BUDS.

Superficial Observations.

In late fall the buds were rather small in comparison with those of late winter and early spring while at the same time many of the buds seemed to be in the same stage of microscopic development. Aside from being small they were husky in the fall, but as the winter progressed the flower buds developed slightly in size and became more and more compact, while the leaf buds grew but slightly in size but still remained in a husky condition. It seemed, therefore, that in the flower buds there was an external development while at the same time the flower part itself did not grow. This may be accounted for by the fact that the innermost scales of the buds are modified leaves, and seem to continue to grow to a slight extent throughout the winter. This was particularly observed by the writer while preparing the buds for microscopic examination. The scales were considerably thicker during January and February than they were in late fall. Again, in the early spring when the buds pushed out on the trees, it was the scales or rudimentary leaves that grew first.

It will be noticed in Figures 6 and 7 that most of the buds conform to the general statement that fruit buds are more rounded and larger than the leaf buds. In Figure 6, the fourth bud, in the Jonathan group, which is a leaf bud, is decidedly more pointed and somewhat smaller than the rest of the same variety. However, the second bud is quite pointed also and might be thought to be a leaf bud. There is a slight difference here, however, which may be observed - i.e., the second bud is more symmetrical than the fourth, which is rather irregular. If one observes these pictures closely, however, he will note that size cannot be depended upon entirely. The third bud of the Delicious variety is the largest bud of the five, and at the same time is a leaf bud, while the smaller buds are fruit buds.

Pictures cannot show the compactness of the buds; neither can size nor shape be a complete guide to the nature of the bud. The Winesap buds are practically all alike in shape and size and one can only tell by the compactness of the buds their true nature. However, this is not always an absolute guide. Figure 8 shows three types of buds that are met with in the orchard. No. 1 is unmistakably a fruit bud; it is large, obtuse, and very compact. No. 4, on the other hand, is somewhat smaller, more acute and less compact, while buds 2 and 3 are intermediate between these two and their nature is doubtful. They may conform more or less to No.1 and at the same time have slight characteristics of No. 4.

If the orchardist wishes to determine whether or not these are fruit or leaf buds, he will be obliged to make free hand sections longitudinally through the center of the bud with a sharp knife. The following descriptions may serve as a guide

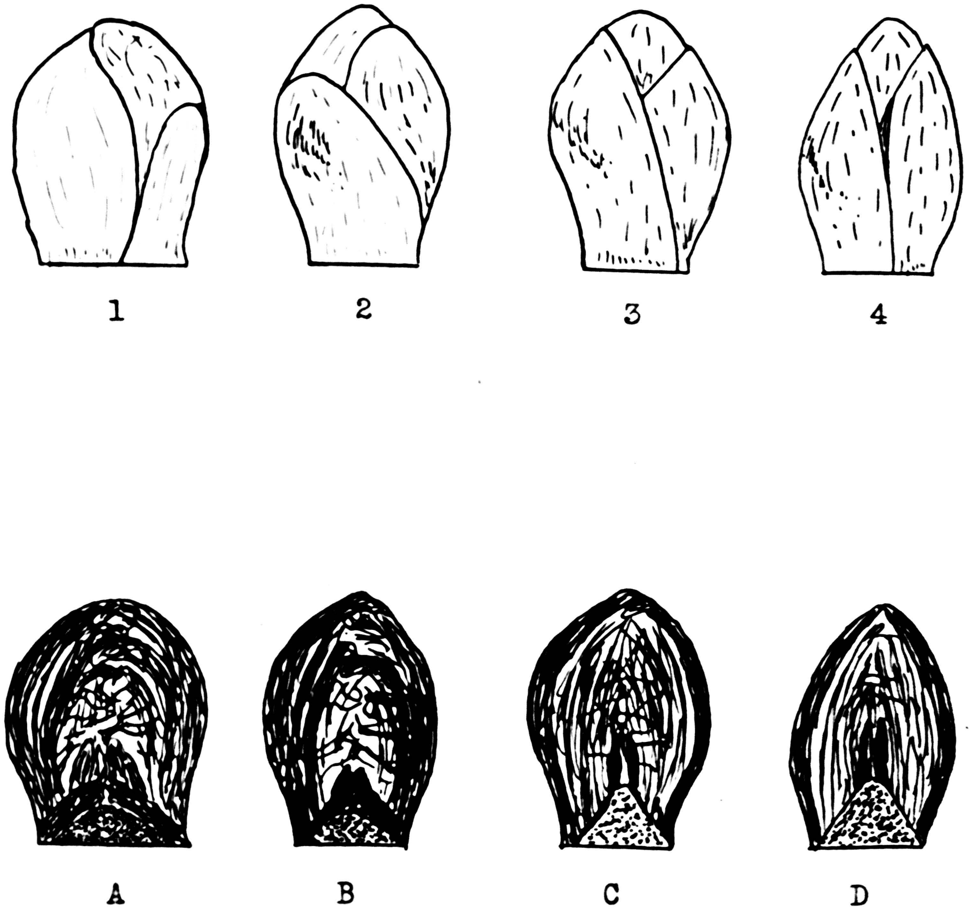


Figure 8. External and Internal Structure of Apple Buds.

for the determination of the character of the buds:

If No. 1 be sectioned, the center of the bud will appear as shown in A. The apex of the growing wood which constitutes the lighter portion of the bud is more of less flattened, and the scales above this portion of the bud are arranged irregularly and loosely. It appears as if there was a hollow space just above the growing wood. Fruit buds as a rule have thicker scales during mid-winter than the leaf buds. If No. 4 be cut longitudinally, it will appear as in D. Here it will be noticed that the growing apex is very acute and extends far up into the apex of the bud. The innermost scales seem longer than in A and are very compact about the growing shoot. From the foregoing descriptions of buds A and D it might be concluded that the leaf buds are more compact than the fruit buds on account of the arrangement of the scales, but such is not the case.

Now that these two distinct types are clearly in mind, it becomes a matter of careful observation to determine the differences between buds 2 and 3. As before stated this can only be done at first by sectioning. After one has become thoroughly familiar with the differences between buds 2 and 3, he can usually tell them apart without using a knife. It may be stated here that No. 2 would be more compact through the center and apex of the bud than would No. 3. To become familiar with the external differences in these buds, the writer sectioned many buds which were hard to determine by a superficial examination. It appears in Figure 8 that Nos. 2 and 3 are exactly alike but a longitudinal section as shown in B and C reveals the difference. It will be noticed that the interior of B corresponds to that of A and that C corresponds to D. This internal structure reveals beyond a doubt the true nature of the bud.

Microscopic Observations.

Methods.

In the present investigation Winesap buds were used entirely except for a series of Jonathan buds which was taken beginning January 19, 1917. They were gathered from the orchard on the horticultural grounds at Columbia, and care was exercised to make the material as representative of average conditions as possible.

The buds were collected on spurs as shown in Figure 9, or on twigs of larger size as shown in Figures 4 and 5. This was to prevent excessive loss of moisture, as the buds should not be allowed to become dry under any circumstances.

During the early part of the work considerable difficulty was experienced in making microscopic sections. This was undoubtedly due to two reasons: first, that not enough of the scales were removed from the bud; and second, that the fixatives used made the tissues too brittle for sectioning.

The removal of the scales from the bud is a very important step. During the early part of the work the buds

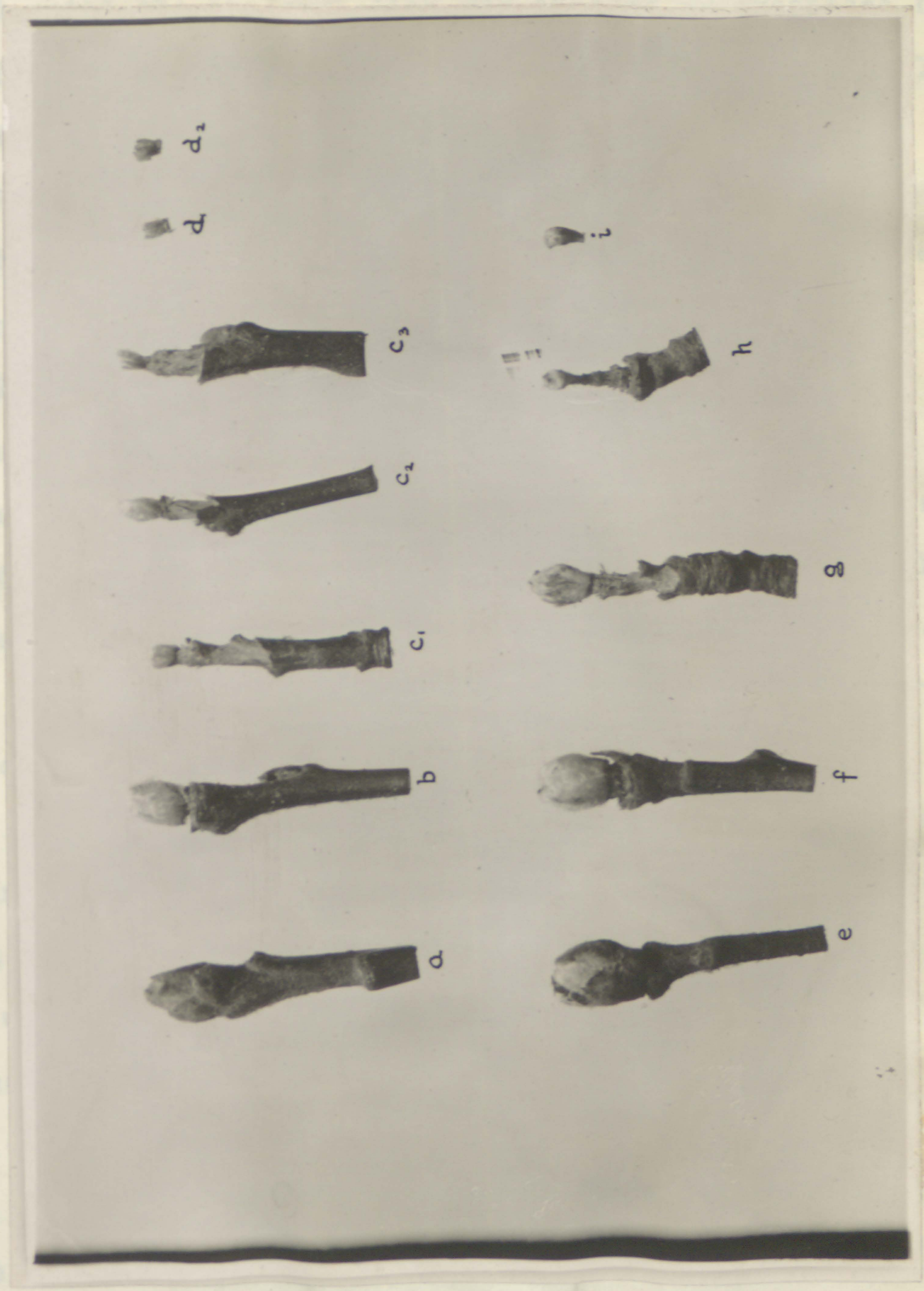


Figure 9. First Steps in the Preparation of a Bud for Microscopic Study.

were cut from the spurs with the scales intact and fixed. Very poor results were obtained even when the opposite "faces" were shaved until the inner portion was exposed as practiced by Bradford (11). Buds were then treated according to Black (10) by removing the heavy outer scales as shown in Figure 9, b, but practically the same results were obtained; i.e., incomplete infiltration of the fixative. The writer then determined to remove the scales down to the naked bud as shown in c of the same Figure, and this cut from the twig as shown in d. When the buds began to swell considerably as illustrated by e, the scales were removed to the naked bud as before. At this advanced stage, however, the buds were very large even with the scales removed (g) and the individual flowers could be separated. Accordingly, all were removed except the central flower as shown in h and cut from the spur as in i.

The wool in the bud of the apple is said by Wiegand (73) to prevent excessive evaporation. It was also found that the wool inhibited infiltration of the fixative. This wool was, for the most part, removed with the inner scales and no difficulty was experienced thereafter in causing infiltration of the fixative.

Considerable difficulty was experienced in securing a good fixative. Mottier (57) and Black (10) used Flemming's solution; Magness (26) and Bradford (11) used Gilson's mixture; Drinkard (20) used Flemming's solution at first and later Gilson's mixture but experienced considerable difficulty with both. In addition to the above the writer used chrom-acetic acid, acid alcohol, and 95% alcohol but all were found to make the tissues too brittle. Kraus (50) advocated the use of a saturated solution of mercuric chloride and this was found to give excellent results.

The following method of procedure has been carried on with the buds since January 1917:

The buds were prepared as shown in d and i of Figure 9 and then dropped in a 50 per cent solution of alcohol. It was found that this aided in the infiltration of the fixative by penetrating the buds and forcing out the air. It also prevented the buds from drying out, since all the buds were placed in the $HgCl_2$ at the same time.

The bichloride solution was brought to a boil, removed from the flame, and while the solution was still hot but <u>not boiling</u>, the buds were plunged into it. They were then allowed to cool and remain in the fixative for about 12 to 24 hours - usually overnight. The solution was then drained off and the buds washed several hours by running them thru several changes of water.

The buds were then gradually dehydrated by soaking them for several hours in increasingly strong alcohol. The following schedule was used in this work:

15% alcohol	. . . .	1 - 3 hours
30% "	. . . .	2 - 4 hours
50% "	. . . .	2 - 4 hours

70% alcohol & Iodine . . overnight

An alcoholic solution of iodine was added to the 70% alcohol to remove any mercuric chloride that might be present in the tissues. Enough iodine was added so that a brown tinge remained after standing several hours.

Complete dehydration was then accomplished by the following schedule:

80% alcohol	. . . . . .	4 - 8 hours
95% "	. . . . .	12 - 24 hours
absolute alcohol	. .	12 - 24 hours

During the time the buds were in the absolute alcohol, at least one change to fresh absolute alcohol was made to remove the last trace of water.

The buds were then cleared in xylol which at the same time replaced the alcohol. This latter was important for the next step since xylol is a solvent of paraffin. The replacing of alcohol by xylol was gradual. The following changes were made:

Absolute alcohol & xylol	2 - 4 hours
Pure xylol	12 - 24 hours

Paraffin was then added to the xylol until no more could be dissolved. The buds were allowed to remain in this condition for about two hours. They were then placed <u>on</u> the paraffin oven and more paraffin added. They were allowed to remain on the oven about two hours more when the xylol and paraffin was poured off and pure melted paraffin added. The bottles were then placed in the paraffin oven for 12 to 24 hours and during this time one change to fresh paraffin was made to remove any trace of xylol.

The buds were then imbedded in paraffin in shallow paper trays. It was necessary to plunge the trays in cold water as soon as a scum was formed on the paraffin. This was to cool the paraffin quickly. If the paraffin was allowed to cool gradually it crystalized and made cutting very difficult.

The paper trays were removed from the blocks as soon as the paraffin was hard and the blocks allowed to remain in water until ready for use or cutting. Water is absorbed by both the paraffin and the buds. This makes the blocks less difficult to cut. They will cut nicely after two or three days storage in water.

When the above method is followed the buds may be sectioned as thin as 10u. After cutting they were mounted by using an albumin fixative and allowed to dry for several hours or a few days.

When the sections were ready to stain, the slides were warmed slightly over a flame. This caused the paraffin to melt and the albumin to coagulate thus gluing the sections to the slide. The slide was then placed in xylol for about five minutes to dissolve the paraffin on the slide.

The following staining schedule was then followed:

95% alcohol	2 minutes
70% alcohol	1 minute

safranin	1 minute
water	rinse (10 minutes)
gentian violet	4 minutes
water	rinse (10 minutes)
orange G from pipette	few seconds

Flood the slide with absolute alcohol from a pipette immediately to remove the orange G.

Wash off the alcohol with clove oil from a pipette and allow to remain in this condition until the desired shade of blue appears.

Wash off clove oil with xylol and place the slide in xylol for several minutes.

Remove the slides from the xylol and wipe clean with a towel except, of course, the portion containing the buds. Place a drop of Damar balsam in the center of the slide over the buds and place the cover glass in position.

In this study a complete serial was not necessary. Only the sections through the center of the buds were used when any difficulty was experienced.

Observations.

The first buds were taken on October 20th and every week thereafter until March 6th when it was decided that the rapid development in the early spring would demand their being taken more often. Buds, therefore, were gathered and fixed every Tuesday and Friday until just before they bloomed.

Owing to the fact that much difficulty was experienced in the early part of this work, very thick sections had to be made. This made exact determinations difficult. However, the following facts could be observed: During the latter part of October, buds were found in different stages of development, some merely past the stage of differentiation, while others had developed to a stage in which they passed the entire winter. This showed an uneven development during the summer months and early fall. In later observations throughout December, January and February, even though hundreds of buds were taken, but very slight difference could be noticed in reference to their microscopic stage of development. This seemed to show that although in the fall all the buds were not developed equally that they grew until they reached a stage where there was more or less complete rest. There must be, therefore, more rapid development in the late fall in the younger or less developed buds than in the more mature buds. However, it seems improbable to think that they all reach the same stage of development for it is a matter of common observation that in the spring all the blossoms do not form at the same time. This is vividly brought to mind when one observes a crop of apple blossoms killed by a heavy frost or freeze and following this another partial crop of blossoms may be borne.

When this work was undertaken by the writer, it was thought, as stated before, that there was a gradual development during the winter months due to the variable climatic conditions in this state and particularly at Columbia. This year, however, has been remarkably constant in temperature conditions and, therefore, practically no growth took place from the latter part of November until March 6th when the buds began to push out very rapidly. From reports from the Columbia Weather Bureau, it was observed that in some years the temperature rose considerably during the winter months and remained high for several days. This has been shown in Figure 1. The microscopic observations were carried on until April 16, 1917 at which time the swelling of the flower buds was so manifest that it was thought unnecessary to continue them further. The winter of 1916-1917, while not a severe one for this climate, had no striking warm periods which remained constant for any length of time. The graphic diagram (Figure 10) shows the maximum and minimum and mean daily shade temperatures from December 1st, to May 1st as recorded at the Columbia Weather Bureau near the Station orchard.

The development from October 20th until no change could be observed and from March 6th until the flowers bloomed, is shown in Figure 11.

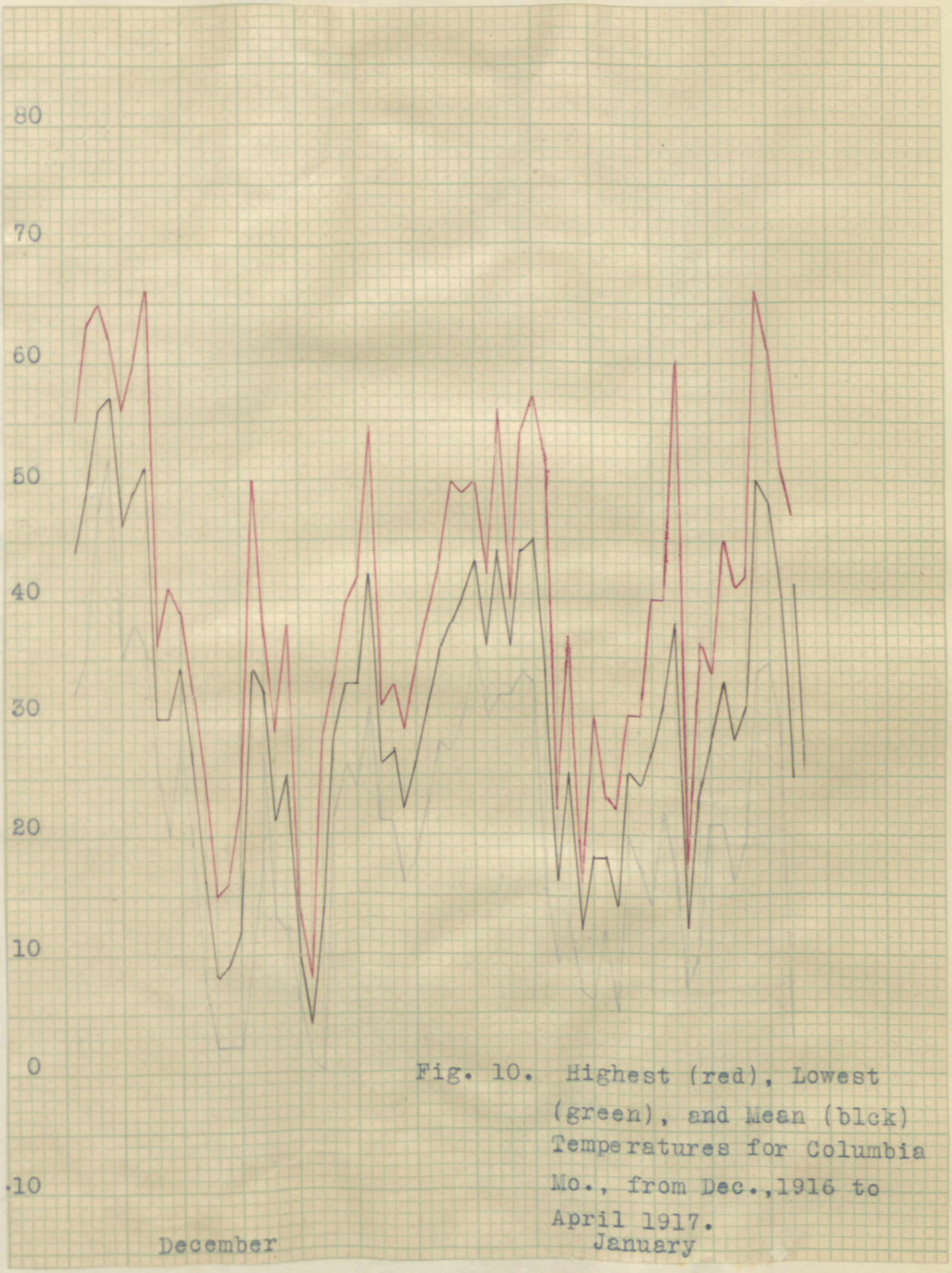


Fig. 10. Highest (red), Lowest (green), and Mean (blck) Temperatures for Columbia Mo., from Dec.,1916 to April 1917.

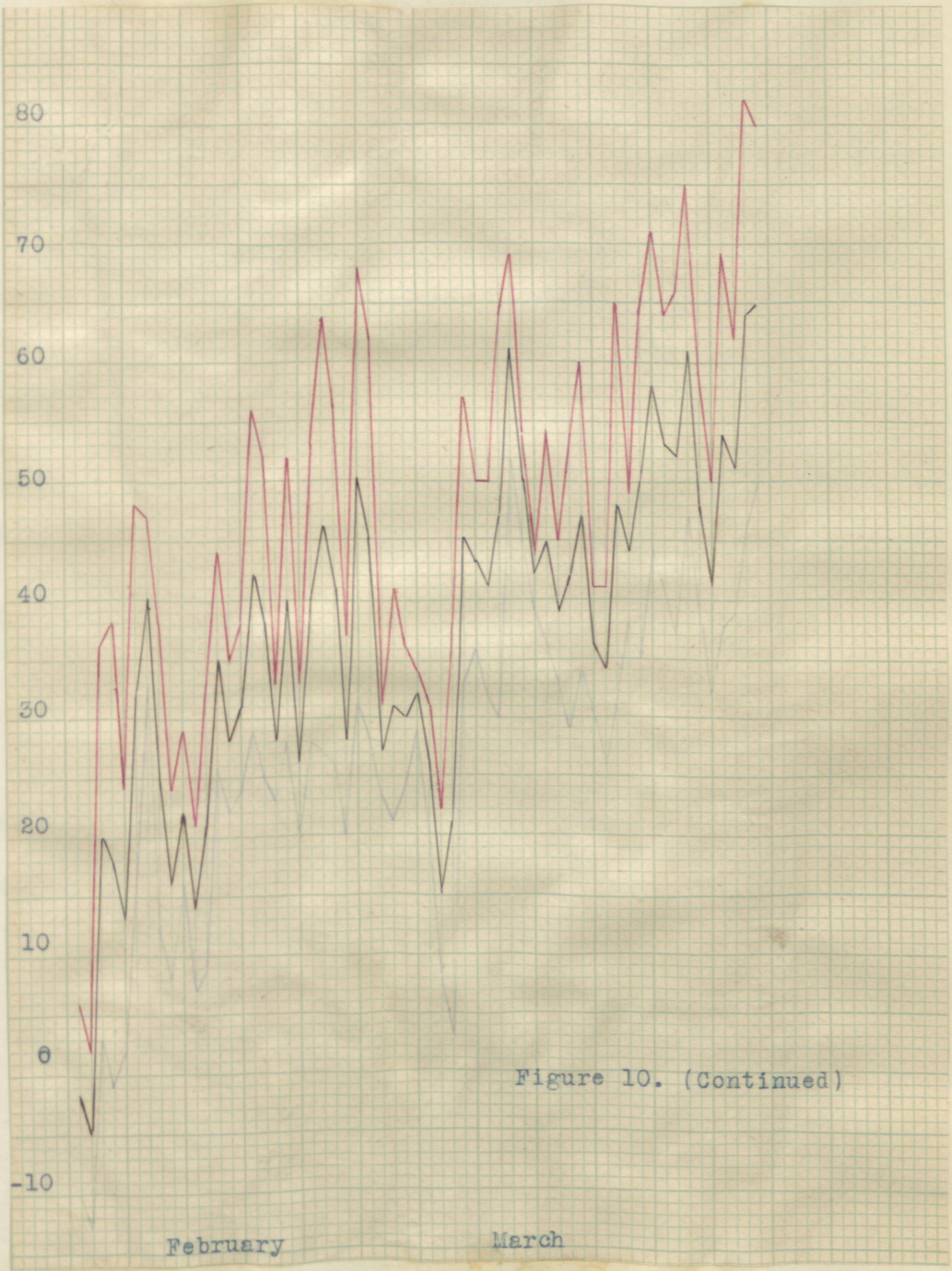


Figure 10. (Continued)

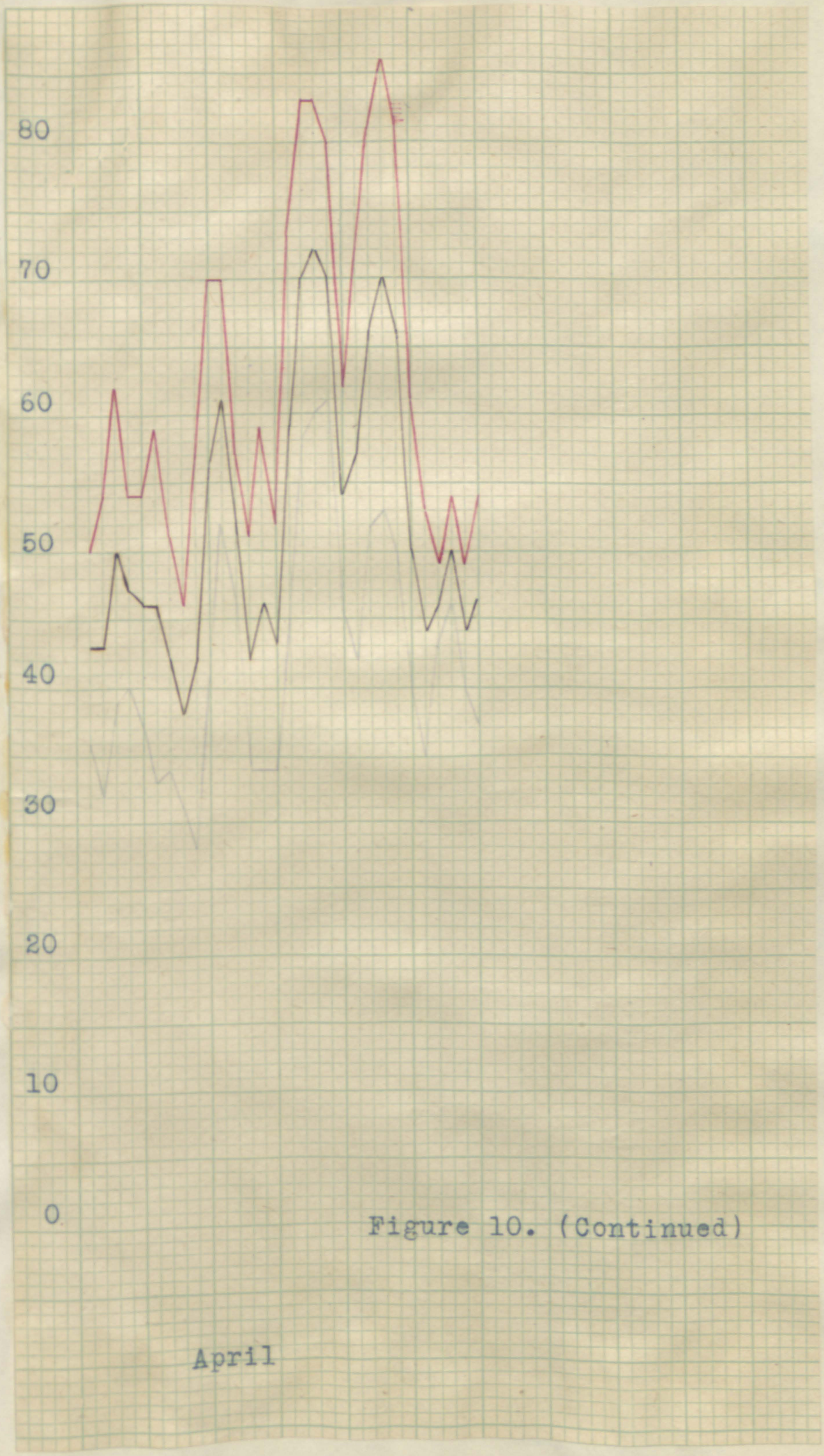


Figure 10. (Continued)

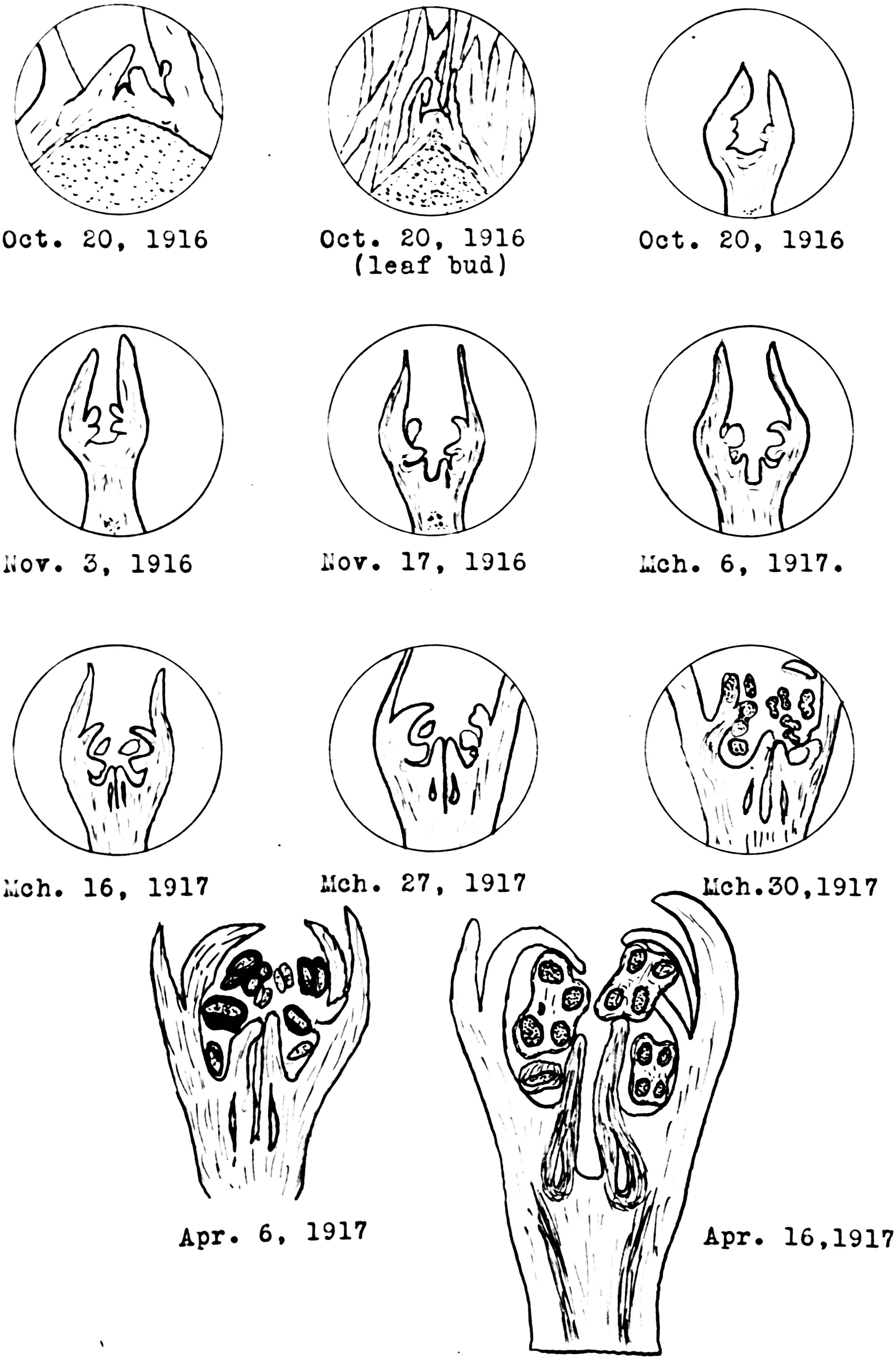


Figure 11. Stages in Fruit Bud Development
From Oct. 20, 1916 to April 16, 1917.

WINTER CONDITION OF THE BUDS AND TWIGS.

It is a matter of common observation that twigs throughout the winter months contain a sufficient supply of moisture to maintain their turgidity except perhaps during the cold spells when the water moves into the intercellular spaces and causes a shriveled appearance. Wiegand (73) in a discussion as to the freezing of buds and twigs in winter states that "since water on freezing increases in volume one would, at first thought, expect the frozen twigs to be larger in diameter than normal; such, however, is not the case. In every instance a distinct contraction occurs, which, in some cases, was very marked. Twigs of plum were much wrinkled and the apple showed slight furrowing."

Wiegand found no stomata on any of the twigs of the species he examined which included the apple. He states that gas diffusion takes place through the lenticels and to a slight extent through the cuticle itself. All living cells contain a large amount of water - 51 to 55 per cent in most fruit trees - and the quantity in each species is remarkably constant, rarely varying more than 4 to 5 per cent and usually even much less.

It was noticed that after a heavy freeze such as occurred on February 2nd, the twigs were in a very shriveled condition such as exists when twigs are removed from the tree and brought into the house to dry. Was this wrinkled condition due entirely to the translocation of the cell sap, or was there considerable evaporation? Water may evaporate to a large extent from ice crystals themselves, as is shown by the drying of frozen soil, damp clothing, and the frequent disappearance of small quantities of snow at temperatures far below the freezing point. To determine whether or not the moisture content of the twigs was greater or less in this shriveled condition than during warmer spells and in a turgid condition, a number of twigs were taken, weighed, cut into small pieces, and placed in an oven at 100° C. for exactly one week. Several days later when the twigs on the trees had again resumed their normal condition, more twigs were taken and treated as above. The following results were obtained:

TABLE VI. WATER CONTENT OF TWIGS IN A SHRIVELED CONDITION (FROM SEVERE FREEZING) AND IN A TURGID CONDITION.

Sample No.	Twigs in Shriveled Condition.				
	Wt. of Wood Feb. 2, 1917.	Dry Weight Feb. 9, 1917	Loss in Weight	% H_2O in shriveled twigs	Average % of water in shriveled twigs.
1	15.892	8.201	7.691	48.4	
2	3.510	1.859	1.651	47.0	
3	9.282	4.797	4.485	48.3	
4	13.076	6.678	6.398	49.0	48.2

TABLE VI. (CONTINUED)

Sample No.	Twigs in Turgid Condition.				
	Wt. of Wood Feb. 7, 1917.	Dry Weight Feb.14,1917	Loss in Weight	% H_2O in turgid twigs	Average % of water in turgid twigs.
1	12.341	5.640	6.701	54.3	
2	6.896	3.269	3.627	52.0	
3	11.255	5.223	6.032	53.6	
4	18.600	8.575	10.025	53.9	53.45

From these results it can be readily seen that the amount of water in the twigs was less while the twigs were in a shriveled condition than otherwise, as shown by the difference in their respective water contents. It is more probable to suppose that this shriveled condition and loss in water content was the result of non-replacement of evaporated moisture rather than excessive evaporation. This seems quite evident since the evaporation of moisture was more from the twigs in the laboratory than those under orchard conditions as shown by Tables VII and VIII.

It was now to be determined how much evaporation actually took place during the winter months under normal winter conditions. This was determined by the loss in weight of twigs when detached from the tree. Evaporation of water from the twigs could still proceed as in nature but the loss of water could not be replaced from below. Five twigs were cut from a

Jonathan tree and the cut end immediately paraffined. The twigs were then weighed and hung in the orchard in their natural position. Five other twigs were treated in like manner except that the cut end was exposed. The results in Table VII were obtained.

TABLE VII. LOSS OF MOISTURE IN TWIGS UNDER ORCHARD CONDITIONS

No.	Loss in weight in grams			No. of buds on each twig	Loss per bud in 14 days	Loss per bud per day
	Week ending 1/16/17	Week ending 1/23/17	Total loss			
	Twigs with cut end paraffined.					
1	.555	.07	.625	9	.069	.005
2	.395	.325	.720	10	.072	.0051
3	.865	.830	1.695	16	.106	.0075
4	1.170	.690	1.860	16	.116	.0083
5	.875	.875	1.750	16	.110	.0080
	Twigs with cut end exposed.					
1	1.280	.585	1.865	12	.155	.011
2	1.205	.515	1.720	15	.121	.009
3	1.360	.475	1.835	10	.183	.013
4	1.240	.400	1.640	15	.110	.008
5	1.115	.335	1.450	14	.104	.0074

From Table VII it will be observed that the loss in moisture is very small. In every case, however, the loss in moisture is very constant. It is also obvious that the twigs with the cut ends exposed lost more water than those with the cut ends paraffined. In the latter case the loss of moisture was almost entirely through the buds.

To find out the amount of evaporation from the buds under laboratory conditions, five five-hundred c.c. vessels containing twigs as shown in Figure 12, were placed in the laboratory on December 30, 1916. The scales were removed from No. 4 the following day to see if the scales prevented evaporation of water. The amount of evaporation was determined by the loss in weight of the vessels. No. 5 was placed under a bell jar at the bottom of which was a jar of sulphuric acid to absorb the moisture in the air. The results in Table VIII were obtained.

From Table VIII it will be observed that the loss in moisture is comparatively large compared with that of Table VII. Table VIII shows that the amount of evaporation per bud was very constant throughout the period for twigs 1, 2, and 3 which were left under laboratory conditions. No. 4 which had the scales removed, showed a very great loss in moisture and at the same time grew considerably. The other buds remained in an apparently dormant condition for several weeks and did not begin to expand until February 2nd. The twig in the dessicated atmosphere under the bell jar lost more moisture than either of the three under laboratory conditions and began to show signs of growth much sooner (Jan. 18) but not as soon as the twig with the scales removed. This latter will be referred to later.

TABLE VIII. LOSS OF MOISTURE IN TWIGS UNDER LABORATORY CONDITIONS.

No. of Twig	Loss in weight in grams.					Number of buds on each twig	Loss per bud in grams in 24 days.	Loss per bud per day in grams.
	12/31 to 1/3	1/8	1/15	1/24	Total			
1	1.1	2.1	2.7	3.5	9.4	8	1.175	.049
2	1.7	1.7	2.3	3.2	8.9	8	1.113	.046
3	.1	.9	.8	2.2	4.0	3	1.330	.055
4*	3.1	3.1	2.7	5.5	14.4	5	2.880	.120
5**	---	4.0	2.0	3.2	9.2	5	1.84	.077

*Leaves removed December 31st.

**Placed in dessicating chamber December 31st.

Buds on 1, 2, and 3 began to swell visibly February 2nd.

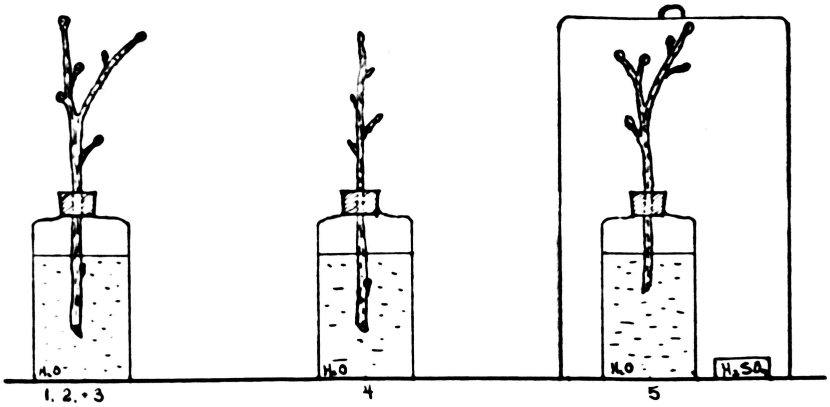


Fig. 12. Cut Twigs in Sealed Vessels for Water Loss Determinations.

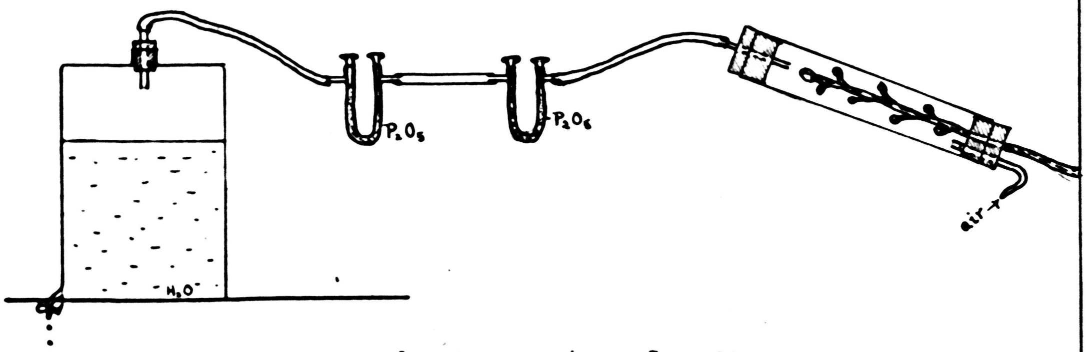


Fig. 13. Freeman's Apparatus for Measuring Water Loss in Plants.

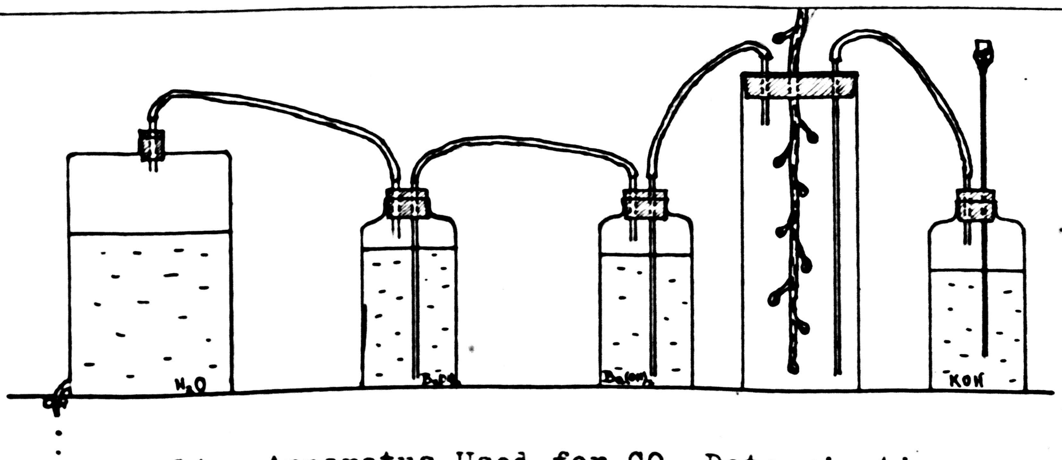


Fig. 14. Apparatus Used for CO_2 Determinations.

As a check for natural conditions in the orchard the apparatus as described by Freeman (24) and shown in Figure 13 was set up in the orchard. No definite results were obtained because of the very slight evaporation of moisture from the twigs.

When we consider the evaporation that takes place from the buds and the low temperature under which the tree lives during the winter months, it is remarkable to note the more or less constant amount of moisture in the twigs. As the water evaporates from the buds and branches it must certainly be replaced by water from below. This might seem impossible when the roots appear to be in a frozen condition and the temperature far below freezing but it might be explained by the series of temperature observations made at this Station by Whitten and his co-workers. The following data is adapted from the work of Cowart (15) to show the differences during the winter months between atmospheric temperatures and the temperature of the tree trunks. The remarkable difference in temperature may partially explain why water would have free circulation throughout the tree during the coldest of spells in the presence of sunshine.

TABLE IX. COMPARISON OF THE ATMOSPHERIC TEMPERATURE WITH THE TEMPERATURE OF THE TRUNKS OF APPLE TREES ON SUNNY DAYS

Date	Time	Trunk Temperature	Atmospheric Temperature	Difference in Temperature
1914				
2/7	11.00 A.M.	20.9	3.0	17.9
2/7	1.00 P.M.	26.4	9.0	17.4
2/7	2.00 "	39.0	11.0	28.0
2/10	1.00 "	62.8	33.5	29.3
2/10	2.20 "	67.0	36.0	31.0
2/16	2.00 "	52.0	25.0	27.0
2/19	2.00 "	70.2	28.0	42.2
2/24	2.15 "	68.6	24.0	44.6

OXYGEN AND ITS RELATION TO GROWTH IN THE APPLE BUD.

Experiments were now made to determine whether or not oxidation took place in the buds and twigs. This was measured by the liberation of carbon dioxide. Appleman (3) states that "respiration is the process which furnishes energy and as such is one of the most important processes in plant metabolism. It unlocks in the tissues, where it is needed, energy of the sun which is stored up in complex organic compounds by photosynthesis." The apparatus as illustrated in Figure 14 was used to determine the amount of carbon dioxide liberated from the buds. Eight buds on a short branch were inserted in the vessel. The aspirator was allowed to run for two hours but no precipitation of barium carbonate could be noticed. The scales were then removed from the buds and the aspirator run again. At the end of 55 minutes a slight precipitation was noticed and this precipitation kept forming until the end of the two hours.

Appleman cites the work of Palladin and others showing that respiration is due to the summation of enzyme activity and this is comfirmed by the fact that plants killed without destruction of the enzymes continue to give off carbon dioxide and absorb oxygen. Appleman states: "These enzymes are oxidizing ferments and Bertrand was led to believe that the oxidizing ferments are more or less specific in their action and proposed the term oxidases as a group name for these ferments."

Appleman's work, however, with the potato tuber shows that the oxidase content of potato juice gives no indication of the intensity of respiration in the tubers; in other words, there is no correlation between oxidase activity and the rate of respiration in these organs. He claims that the limiting factor must lie elsewhere and states that among the possibilities may be mentioned the following: Oxygen supply to the respiring tissue, availability of oxidizable material and other enzymes.

The work of Appleman (4) on the biochemical and physiological study of the rest period in the tuber of Solanum tuberosum shows that oxygen is the limiting factor in the breaking of the rest period of the tubers. As soon as oxygen was supplied to the tubers growth began. Among his conclusions he states: "Potatoes may be sprouted at any time during the rest period by simply removing the skins and supplying the tubers with favorable growing conditions, which include in this case the maximum partial oxygen pressure of the atmosphere. The elimination of the rest period by this means is not due to water absorption from the exterior, as tubers with skins removed will sprout, even in dry storage, much earlier than those with skins intact."

"If tubers are cut in half transversely or cut into half-inch slices, the buds on the stem half located near the exposed surface will sprout much earlier than normally, provided suberization of the surface cells is prevented. This may be accomplished by laying them on wet soil, or, better still, sawdust, and covering them with wet excelsior. Sprouting in this case also was not due to water absorption, because the rest period of these buds may be greatly shortened in dry storage if drying of the exposed surface is prevented by covering it with a thin layer of paraffin."

"The earliest sprouting occurred when the skins were removed and the tubers also cut in the manner described above."

"All the foregoing treatments greatly accelerate the rate of respiration. It may be safely concluded, therefore, that the elimination or abbreviation of the rest period under the conditions employed in this work is correlated with increased oxygen absorption."

Crocker's work (17) on the mechanics of dormancy in plants shows that practically the same is true in regard to Xanthium seeds. Crocker concludes that problems in dormancy lend themselves beautifully to the attack of the mechanic; That dormancy in seeds results generally from the inhibition of one or more of the processes preceding or accompanying germination; that seed coats have a surprisingly important role to play in both primary and secondary dormancy.

Kidd's work (42) on the controlling influence of carbon dioxide on Brassica alba seed shows the relation of oxygen and temperature to the inhibitory action of carbon dioxide and states: "The inhibitory value of a given carbon dioxide pressure diminishes with a rise of temperature, and also with a rise of oxygen pressure."

Shull (66) found that naked embryos of Xanthium seeds absorb much more oxygen from the air than embryos in the testas. Embryos in intact seeds show an increase in oxygen absorption with increase in the partial oxygen pressure of the atmosphere. These facts establish the important point of increased consumption of oxygen under oxygen supplies favoring germination.

Just what conditions cause growth to start in the apple twig either in the winter months when twigs are brought into the greenhouse under forced conditions, or in the early spring when the buds push forth under natural conditions, is hard to state definitely. It has been shown in Table VIII that when the bud scales were removed growth seemed to take place at once; also that the twig in the desiccating chamber grew sooner and faster than those under normal laboratory conditions. These experiments were carried on throughout the year with similar results, except that in early spring when growth naturally started in the orchard only a slight difference was observed between the scaleless buds and the others. It seemed, therefore, that when growth had once started that this removal of the scales made very little difference.

While the work of the writer does not prove that oxygen is the limiting factor in the pushing out of the apple buds in the laboratory or greenhouse in winter or in the orchard in the spring, it seems reasonable to suppose that the same might be true in regard to the apple bud as the case of seeds and tubers. To substantiate this theory it will be noted that when the scales were removed the oxygen of the air had free access to the growing point of the bud. Howard (36) states that the rest period is broken by"the activity of the enzymes" but there must be some factor which causes enzyme activity. This factor may be that which was advanced by Appleman - "oxygen supply to the respiring tissues". Howard shows that alternate freezing and thawing broke the rest period. The writer also found that buds in a dry atmosphere or those deprived of water also came into growth much sooner than those under normal conditions. This may be explained from the oxygen theory standpoint by supposing that drying reflexes the scales allowing the entrance of oxygen. The twigs which were placed in the orchard, as stated in Table VII, were placed in water at the end of two weeks. Fresh cuts were made on the stems to allow the entrance of water. At the same time five other twigs, fresh from the orchard, were placed in the water on January 24th. On February 7th they were observed and the following noted: The twigs that had been paraffined were pushing their buds more than those that were exposed, while the twigs cut fresh from the orchard showed no outward signs of growth. Figure 15 shows the relative growth of the twigs.

In the above experiment two twigs out of each set of five had no scales on the buds. The scales were removed from the buds when placed in the greenhouse. In the case of the paraffined and exposed twigs there was considerable growth but there seemed to be very little difference in the rate of growth while in the fresh twigs growth was very slight but considerably

Figure 15. Relative Growth of Twigs Forced in the Greenhouse after Various Treatments. (See p. 79)

more than the fresh twigs with the scales intact.

To determine whether or not the desiccating atmosphere caused the acceleration of growth rather than the entrance of oxygen some twigs were allowed to grow under bell jars under the following conditions:

1. In a desiccated atmosphere with the scales intact.
2. In a desiccated atmosphere with the scales removed.
3. In a humid atmosphere with the scales intact.
4. In a humid atmosphere with the scales removed.

The twigs in No. 3 remained practically dormant throughout the experiment. The twigs in the rest of the jars grew considerably. Growth was a slight bit more in the desiccated atmosphere than in the humid atmosphere.

The writer now wished to determine whether or not growth of the buds would take place under greenhouse conditions if the cut end of a fresh twig was paraffined. Four twigs were placed in the greenhouse on February 6th with the cut ends paraffined. No swelling of the buds took place other than the drying out of the scales which caused them to reflex. The wood at length became considerably shriveled. On March 10th notches were cut in the twigs just above the paraffin and the twigs placed in water. On March 19th a great many of the wrinkles had disappeared. Fresh cuts were made in the notches every few days. What swelling did take place occurred uniformly over the twig and not particularly on the side where the notches were made. On March 27th not all the wrinkles had entirely disappeared and the buds were still dormant. It was thought that an insufficient supply of water was getting to the buds. Therefore, a full cut was made across the end of the twig to expose more tissue to the water. From this time on growth took place more rapidly but the larger buds still remained dormant. On April 1st adventitious buds at the bases of the twigs were pushing out and several leaves were forming. It was found that the larger buds had been killed by the excessive desiccation and that the available plant food now made available by the increased water content of the branch was forcing out the small dormant buds and adventitious buds considerably.

Since twigs would not grow on a good sized branch in the greenhouse in the absence of water and would grow considerably with the cut end immersed in a vessel of water, the question arose as to whether twigs would grow more rapidly under water pressure. Therefore, the apparatus was set up as shown in Figure 16. The method used was adapted because if the tubing is placed directly on the twig, the pressure on the cut surface stops to a great extent the passage of water by closing up the ducts. It will be noted in the drawing that the cut surface is perfectly free. By this method also, the operator can see that there are no air bubbles next to the wood surface, which sometimes happens under the other method. When the increased water pressure was used, it was found that the rate of development compared almost exactly with buds with the scales removed and considerably ahead of those with the scales intact or under normal conditions. In-

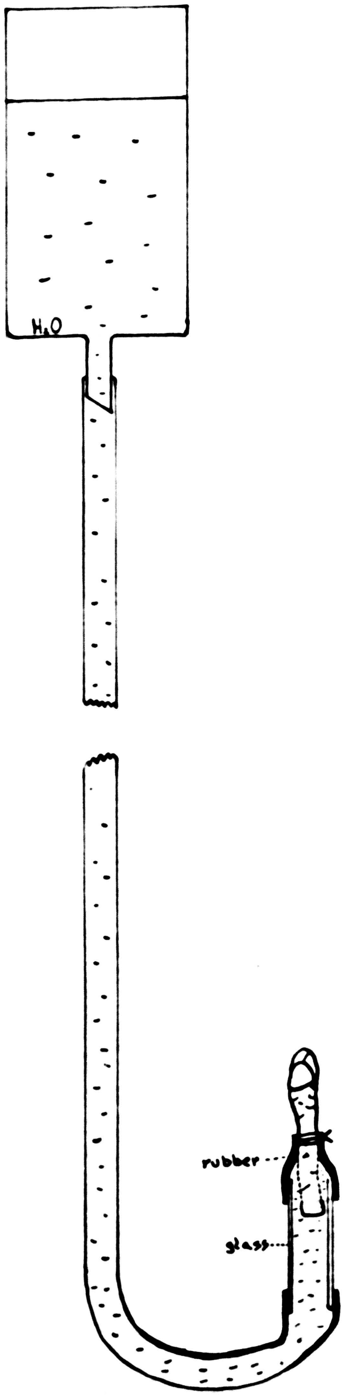


Fig. 16. Apparatus Used for Water Pressure Experiments.

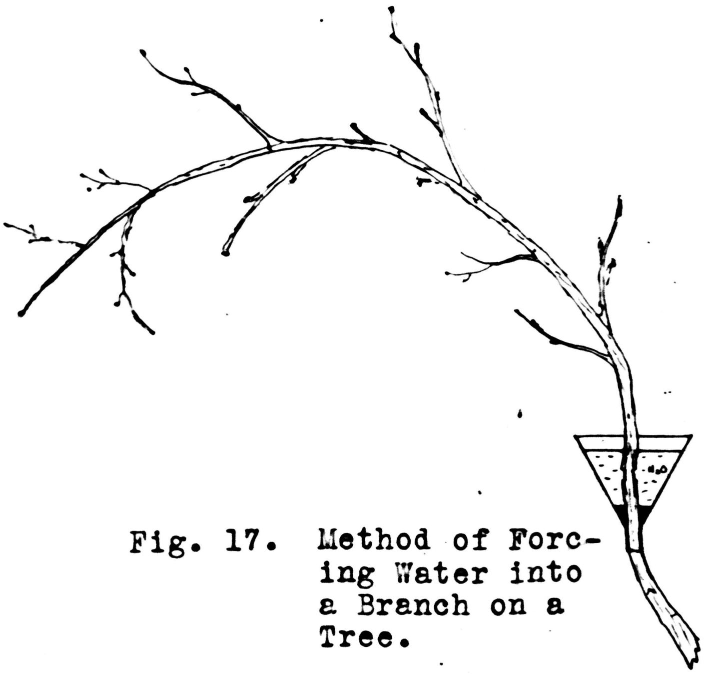


Fig. 17. Method of Forcing Water into a Branch on a Tree.

creased water pressure, therefore, according to these experiments accelerates the rate of growth.

It seemed that in every case when the twigs were cut and allowed to remain in the air for even as short a time as one minute, and then placed in water, that some growth would always take place above that under normal conditions in the orchard. At the same time, if the twigs were cut under water in the orchard and placed in bottles so that the cut end was not exposed to the air at all that growth would be considerably less than when exposed to the air. This seems to show that the entrance of air or oxygen seemed to play some part in growth.

On March 21st at about the time when the buds in the orchard began to show swelling, a paraffined funnel was placed about a branch as shown in Figure 17, and the funnel filled with water. The twig was then girdled under water to prevent the entrance of air. Fresh cuts were made on the girdle every two days to facilitate the entrance of water. On the same date when this apparatus was set up twigs were placed in the laboratory and greenhouse and the same difference in the rate of development was observed as before - i.e., greater growth with increased temperature and no growth above normal in the orchard on the twig with an increased water supply.

OBSERVATION OF FRUIT BUDS IN WINTER FOR FORECAST OF FRUIT CROP.

A technical discussion of the differences in mid-winter between fruit buds and leaf buds has been previously given in this paper (p.49). To apply this work and to forecast in mid-winter the probable fruit crop of several Jonathan apple trees in the orchard, and to determine the easiest way that this might be done, a number of experiments were made with this aim in view. These experiments are divided into three sections:

Section 1.

Observations were made in the orchard, in which the buds were marked by the writer as leaf buds or fruit buds. These buds were allowed to remain on the trees and their nature determined in the early spring by the natural pushing out of the buds.

On February 16, 1917, 264 buds were estimated and marked in the orchard. The buds were observed April 3rd and the calculations made. The results of this forecast are tabulated in Table X.

From Table X it will be observed that the writer estimated the number of fruit buds at 80 per cent of the total number of buds. The correct per centage of fruit buds was approximately 85 per cent. However, the per cent of leaf buds

TABLE X. ESTIMATION OF FRUIT VS. LEAF BUDS IN MID-WINTER.

Estimated Nature of the Buds.					Actual Nature of the Buds.	
Total No.of Buds	Est. No. Leaf Buds	% of Error	Est. No. Fruit Buds	% of Error	Leaf Buds	Fruit Buds
264	53 or 20%	32	211 or 80%	2	40 or 15%	224 or 85%

TABLE XI. ESTIMATIONS OF FRUIT VS. LEAF BUDS IN MID-WINTER.

(Forced in Greenhouse)

199	38 or 18.6%	31.5	161 or 81.4%	6.2	35 or 17.6%	164 or 82.4%

TABLE XII. PER CENT OF FRUIT BUDS VS. LEAF BUDS CALCULATED BY BRINGING DORMANT TWIGS INTO A GREENHOUSE.

No.of	Leaf Buds	% Leaf Buds.	Fruit Buds	% Fruit Buds
438	51	11.7	387	88.3

estimated was only 68 per cent. The per cent of error in the estimation of the fruit buds was very small.

Section 2.

Observations were made in the orchard in mid-winter in which the buds were marked as before. This time, however, the twigs bearing the buds were cut from the trees and placed in water in the greenhouse and forced into bloom. This was done more or less as a check for No. 1 to see how much difference there would be between forcing the buds under artificial conditions in the greenhouse and allowing them to bloom naturally in the orchard.

On February 23, 1917, 199 Jonathan buds were marked as before and placed in water in the greenhouse. On March 8th the buds had pushed out sufficiently to determine their nature and Table XI shows the results.

Section 3.

Observations were made in the house or greenhouse on twigs cut from the trees and placed in water. This was similar to No. 2 but no estimations were made as to the nature of the buds. The object here was to devise a plan whereby the orchardist, not yet acquainted with the differences between fruit and leaf buds, could make a forecast of the probable bloom by "hastening spring."

A number of Jonathan branches were brought into the greenhouse and placed in water on February 23, 1917. The buds were counted on March 16th and the number of fruit buds and leaf buds observed. The data in Table XII was obtained.

To determine the easiest method of forcing these buds into bloom, a number of experiments were made under different conditions. In the first place a comparison was made between twigs forced in the greenhouse and those forced under laboratory conditions. It was found in every case that those forced in the greenhouse pushed out sooner and grew faster than those in the laboratory. This, of course, was to be expected. Price (62) found that the twigs of the Oldenburg apple bloomed in 12 days in an incubator at a temperature of 70° F., and in 7 days at a temperature of 88° F. The buds were placed in the incubator on April 1, 1910. However, every orchardist does not have a greenhouse available for use in the winter and practically all of the experiments were conducted in the laboratory. Laboratory conditions corresponded to conditions that would ordinarily be met with in the average home.

As previously stated the removal of the bud scales incited growth. Every experiment performed verified this statement. If the orchardist wishes to force his buds in the house or in the greenhouse, and will take the time to remove the outermost bud scales, as in Figure 9, b, he will be able to determine the nature of the buds a week to ten days earlier than if the bud scales were left intact. If the branches are merely placed in water, they will force out in from ten days to three or four weeks; depending upon the time of year.

To determine whether or not a change of water or the making of fresh cuts on the stem to facilitate the entrance of water would make growth more rapid, the following experiment was performed: Four bottles of water each containing five twigs, were placed in the laboratory ~~to bloom~~. They were treated as follows:

1. This served as a check since the twigs were not cut or the water changed.

2. The water was changed every other day, but no fresh cuts were made on the twigs.

3. Fresh cuts were made on the twigs every other day but the same water remained in the vessel throughout the experiment.

4. The water was changed every other day and a fresh cut also made every other day.

The following observations were made: In No. 2, 3, and 4, very little difference could be detected, but there was a marked increase in growth over the check. It is to be concluded, therefore, that either cutting the stem or changing the water, or preferably both of these, aids the twig materially in coming into bloom. For all practical purposes, however, it seems that changing the water every other day has just as much effect as the other two treatments and it is much easier, and takes less time.

Summary

~~CONCLUSIONS~~.

1. The orchardist can regulate to a certain degree the fruitfulness of his trees. He can also regulate the age at which the tree will begin bearing.

2. Rich soils tend to produce excessive vegetative growth and poor soils tend to produce fruitfulness.

3. Varieties of apples are affected differently by rich soils and poor soils. A table has been compiled showing the adaptations of certain varieties to different types of soil.

4. Climatic conditions may affect the productivity of a tree.

5. The age and maturity of an apple tree may be a limiting factor in fruit production.

6. A tree that suffers an accident may come into bearing several years earlier than other trees making normal growth in the orchard.

7. Excessive moisture causes excessive wood growth and lack of moisture favors fruit bud formation.

8. There are a number of artificial causes that may induce fruitfulness. The most important of these are girdling, ringing, notching, root pruning, and summer pruning.

9. Alternate bearing in apple trees may be overcome in most varieties by either pruning out part of the fruit buds or branches in early spring; or, by thinning the fruit as it is

set when the tree is overloaded; or, by both these processes.

10. There are three main types of apple buds - leaf buds, wood buds, and mixed buds.

11. Fruit buds are usually terminal buds.

12. Fruit bud formation begins during the latter part of June and early July.

13. Leaves in the central part of densely foliated trees are considerably smaller than those on the periferal parts. Shaded leaves, therefore, are checked considerably in their growth and those in direct sunlight develop a larger leaf surface.

14. In the experiments performed it was found that leaf area, the length of the current year's growth of wood, or the diameter of the wood, bore no direct relation to fruit bud formation.

15. It seems quite evident that all of the leaves are concerned in the production of food material for the formation of fruit buds.

16. When buds are detached from a tree and forced into bloom in water, the development in size and rapidity is in proportion to the amount of wood supporting the bud.

17. The period of most active vegetation is the latter part of May and early June.

18. The formation of fruit buds is favored by a diminished water supply after the period of most active vegetation.

19. Varieties of apples differ in the nature of their fruit-bearing wood.

20. There is a gradual superficial development in the flower buds of apples throughout the winter months.

21. It is possible, by a superficial examination, to differentiate between fruit buds and leaf buds. In determining the true nature of a bud three things must be observed - size, shape, and compactness or huskiness.

22. The true nature of doubtful buds may be determined by making a longitudinal section through the center of the bud.

23. In preparing buds for microscopic study it was found that the removal of the scales down to the naked bud allowed complete infiltration of the fixative.

24. A saturated solution of mercuric chloride as a fixative gave best results in this work.

25. Apple buds developed slightly in the fall from October 20th until November 17 after which time no visible growth took place within the buds until March 6th.

26. Rapid development took place in the buds from March 6th until April 18th when they bloomed.

27. Frozen twigs in a shriveled condition contain less water than those in a turgid condition. This loss of water is probably the result of non-replacement of evaporated moisture rather than excessive evaporation.

28. Twigs in the laboratory lost more moisture per bud than those under normal orchard conditions.

29. The evaporation of moisture per bud was very constant throughout the experiments.

30. The differences in the temperatures of the tree trunks and the atmospheric temperatures may partially explain why water would have free circulation throughout a tree during mid-winter.

31. Apparently no respiration took place from the buds in the orchard in mid-winter with the bud scales intact.

32. Respiration from the buds was apparent 55 minutes after the bud scales had been removed.

33. Experiments were performed ~~to show~~ that oxygen may be the limiting factor in the breaking of the rest period of apple buds.

34. Growth of twigs in the greenhouse in mid-winter may be accelerated by removing the bud scales or by allowing the twigs to dry out for about ten days or two weeks.

35. Buds would not grow in the greenhouse with the cut end of a fresh twig paraffined. The twigs shriveled and the buds died from excessive loss of moisture.

36. Twigs were found to grow considerably more under water pressure than when allowed to stand in a vessel of water; in other words, increased water pressure accelerates the rate of growth.

37. A forecast in mid-winter of the probable fruit crop for the ensuing year can be made reasonably accurate.

38. The orchardist can become very expert in differentiating between leaf buds and fruit buds and thereby forecast the bloom.

39. The orchardist, not yet acquainted with the dif-

ferences between fruit and leaf buds, can also forecast the probable bloom by cutting twigs from the trees and placing them in water in the house or greenhouse.

40. Either cutting the stems of the twigs or changing the water in the vessel every other day, or preferably both of these, aids the twigs considerably in coming into bloom.

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Dean Walter Miller,
Columbia, Missouri.

My dear Dean Miller:

I am hereby submitting to you the master's thesis of Mr. Leon Chapman Dennis with the recommendation that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts.

Before final acceptance for binding, this thesis requires a few minor corrections such as punctuation or changing the spelling of a word. These corrections would have been made before submitting the copy of the thesis to you, except for the reason that when the thesis arrived there was no available thesis paper in town and the necessary paper is not yet available.

Mr. Dennis has proven himself to be a brilliant student. His master's examination was not only satisfactory but highly pleasing to each member of the examining committee. His thesis represents a creditable piece of original work and in my judgment amply meets our standards.

Inasmuch as paper is not yet available for inserting minor corrections, I have indicated in the thesis those corrections which are due, and I desire to approve the thesis subject to these corrections ~~as~~ which I have indicated.

Very truly yours,

J. C. Whitten