T H E S I S

On

A PHYSIOLOGICAL STUDY OF FOOD STORAGE IN DORMANT
SHOOTS OF TREE FRUITS

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INTRODUCTION

Within recent years there has been much valuable investigation of the problems involved in the pruning of fruit trees. This investigation has dealt more or less thoroughly with the condition of the trees as evidenced by external phemomena such as length of growth, increase in thickness of branches, fruit bud formation, general vigor, and crop production. However, very little of this work, excepting that with fruit buds, has determined, or even attempted to determine, the conditions existing within the tissues of the trees, which may or may not affect their response to the various methods of pruning.

It is generally accepted that one of the important functions of the woody tissues of deciduous trees is the storage of food during the dormant period, and that this stored food is used in the early development of new growth. Assuming that all the wood in a tree contains more or less stored food, it is obvious that the practice of pruning affects food storage in two ways,i.e. directly, by removing food already manufactured and stored, and indirectly, by influencing the amount and type of wood subsequently produced and which in its turn becomes active in food storage. But this is as far as our present knowledge of the matter goes.

The work of a number of investigators has discovered what kinds of food are stored, what classes of tissues they are stored in, and during what seasons the storage occurs. However, we know little concerning the factors affecting food storage, the difference in storage habits of the different parts of the tree, the relation of food storage to leaf area, the difference in storage habits of different kinds of trees and trees of differe ent ages.

A knowledge of these phases of the subject would throw considerable light on the various problems connected with pruning of fruit trees. It would also aid in the selection of cion wood most capable of producing strong vigorous trees.

With these facts and questions in mind, this study of food storage in dormant shoots of fruit trees was undertaken.

OBJECT

The object of this investigation is to attempt to arrive at answers to some of the following questions. Is the most food stored in basal or median or terminal portions of a shoot? Or is the food stored in relatively equal amounts throughout the length of the shoot? Does the percentage of food stored vary with weight and size of the shoot? With the kind of fruit? Or with the variety of fruit? What relation exists between storage in one, two and three year old wood? During what seasons is the most stored food present in the wood? How do root suckers and watersprouts compare with normal shoots? Does food storage vary in trees of different ages? What relation exists between the amount of food stored and the size of the buds on a shoot? What relation exists between food storage and leaf area?

REVIEW OF LITERATURE

The following is an account of some of the important investigations of food storage in plants, which have been reported upon up to date.

As early as 1858 Hartig [1] concluded from his investigations that the materials assimilated in the leaves are passed down in the bark and stored in the wood parenchyma and medullary rays. In the spring, these stored materials arebrought into solution, and passed into the tracheae, where they rise with the upward moving current of water from the roots.

In 1888 Fischer [2] found"reducing sugars in the tracheae of a large number of trees at various times of the year."

Leclerc du Sablon [3] (1902 and 1911) investigated the seasonal variations in the reservematerials of the stems and roots of trees. His analyses deal quantitatively with the total contents of the wood, both of cells and tracheae. He points out the function of the wood parenchyma cells in mobilizing reserve carbohydrates, which are then passed upwards by the elements of the wood and to some extent by the bast also. From his figure it may be seen that the quantities of the stable reserves, polysaccharides, far exceed those of the sugars. During the winter there is a diminution in the storage products, due mainly to respiration. The sugars increase in the spring, and the polysaccharides (starch,dextrin and the more easily hydrolyzable portion of the cellulose) during the late summer and autumn. During the autumn and winter carbohydrates are present in the root in greater quantities than in the stem. In summer the two are more nearly equal.

Nicoloff [4] (1911) has also given a very good account of the functions of the medullary rays and of the tracheae.

Gourley [5] (1915), working with apples, states that the "Tissues mainly concerned in the storage of the reserves are the pith and the medullary rays; other cells within the xylem tissue which have been termed wood pith (parenchyma) cells also function in this way. The pith bordering the wood cells is especially rich in starch, but the whole pith area may show some starch content. The medullary rays are the most important in the storage of starch and apparently are the first to show the reaction to the starch test. The secondary rays which occur within the xylem bundles are well filled with starch as well as the larger rays occurring between the fibrovascular bundles. However, there is no starch found in the rays throughout the phloem region, the cambium ring forming a very sharp barrier to the starch content. The cells in the phloem contain the reserves in another form."

He showed that twigs from trees which had formed fruit buds were furnished with a much larger amount of starch than those which had not formed fruit buds, thereby concluding that a heavy storage of starch is correlated with the formation of fruit buds.

Atkins [(6)] (1916), working with "Acer macrophyllum" found starch present in large quantities in the wood in October. The cells of the medullary rays, the last few layers of the elements formed in each year ring, and the first layer of the next, and elements in contact with the vessels, were densely crowded with starch grains. This was in the root and trunk, while higher up in the tree only some of the elements in contact with the vessels contained starch, but those which did so were densely packed. Also it was noticed that in this region the first layer of the spring wood was without starch, except where it was in contact with vessels. Generally, there appeared fewer starch containing elements at the higher levels of the tree. His work with sap concentration, which may be an indication of food stored, indicates a low concentration during the summer, which rises in the fall and falls rapidly again in the spring when growth starts.

Price[7] (1916), working with apple trees summarizes his findings as follows: "It may be stated that, during the dormant period, starch reserve is stored in the living cells of the pith, wood parenchyma, and medullary rays. With the approach of spring, starch is found in the tissues of the bark, appearing first in the phelloderm and collenchyma."

As the leaves begin to appear, starch begins to disappear from the various tissue in order as follows: bark, wood parenchyma, rays, and pith. It is used first from the youngest wood of the branches in the top of the tree, later from the lower portions of the tree, and finally from the roots. A portion of the starch reserve may never be used in the growth of the tree, but remains behind to be included in the heartwood where it remains indefinitely and renders the wood susceptible to decay."

Howard [8] (1915) made a number of tests of the sugar content of apple twigs during the dormant period. He found that the rest-breaking "treatments such as etherization, warm water bath, alcohol bath, hydrochloric acid, drying, mechanical injury, etc., when applied during early winter, increase the amount of readily soluble reducing sugars within 24 hours after the applications are given. If the treatments are given somewhat later in the season, the agents have little or no effect on the increasing amount of sugar."

Haas and Hill [9] in their text on plant chemistry report the work of several investigators who consider other substances besides such carbohydrates as sucrose, starch, dextrin, glycogen, inulin and some celluloses as reserve materials. For instance, Weevers considers that certain glucosides as salicin, populin, arbutin and others are of the nature of reserve food materials. Amygdalin has been found in Pyrus malus. They also state that fats besides being important in mutrition, form one of the mostimportant food reserves of plants, and as such may occur in vegetative or in reproductive organs.

METHODS AND MATERIALS

A. The Choice of a Method

In an investigation of a subject of this nature, probably the first method to be considered would be that of chemical analysis. There are two principle reasons why this method was not used. First, chemical methods require a great amount of time and difficult technique. Second, the results of such analyses as could be easily performed, namely, determination of carbohydrates, would be inadequate and would not give an absolute or even comparative measure of the stored food. A study of the literature herein reviewed will reveal the reason for this: good or even mediocre methods of chemical or microchemical quantitative determinations have been developed only for carbohydrates. Since with our present knowledge, it is quite impossible to make accurate quantitative or qualitative determinations of such compounds as glucosides and fats, and since these latter are more than likely important as storage products, chemical methods are unsatisfactory except as an indication of carbohydrates present. For these reasons it seemed desirable to adopt a method which would give more reliable results.

Since the stored food is used the next season in the early development of the new growth, until the new leaves are able to manufacture enough food to support the plant, the amount of growth made until all stored food is utilized, will afford a measure of the amount of stored food available for growth. The method followed in this investigation was based upon this consideration. It was assumed that if two cuttings of wood of the same weight contained equal amounts of food, the amount of growth they made would be equal, and of course, if the stored food was unequal in amount, the growths would be unequal. The cuttings were grown in moist sand containing no food matter, thus eliminating all possibility of influences of absorbed food materials.

B. Definition of Terms

In order that all statements and explanations may be perfectly clear, it may be well, at this point, to define a number of the terms to be used later in the discussion of materials, methods and results.

The term <u>shoot</u> will be used to designate the total growth of the previous season from any one bud.

A <u>cutting</u> is a piece, large or small, of a shoot.

As here used, there are three kinds of cuttings: <u>terminal</u>, which is the extreme third (in length) of the shoot; <u>median</u>, which is a cutting from the middle portion of a shoot; and <u>basal</u>, which is a cutting from the attached end of a shoot. Unless otherwise stated, all cuttings from the same shoot were made to weigh the same.

The term *series* designates all those shoots removed from the trees on the same date. *Lot* includes all cuttings of the same variety under similar conditions or treatment (usually thirty cuttings) of the same series. A *group* consists of the three cuttings from the same shoot.

Stored food will be taken to mean the sum total of all nutrient compounds, including carbohydrates, glucosides and fats present in the cutting as reserve materials and indicated by the growth made by the cutting.

C. *Materials*

The dormant shoots were taken from trees in three locations: the O.A.C. Experiment Station orchard at the College, the so-called "South Farm" belonging to the College, and from the orchard of the Corvallis Orchard Company. The varieties and kinds of fruit used are as follows:

Apple -- Wagner, Ortley, Grimes, Yellow Newtown, Arkansas Black, Lowery, King David, Esopus, and Ben Davis.

Pear -- Winter Nelis, Bartlett, Bosc.

Prune -- Italian.

Plum -- Green Gage.

Cherry - Napoleon, Olivet, English Morello.

Peach -- Mayflower, Washington, May Lee Cling, and Wallis.

Walnut -- Placentia, Vourey, Mayette, Chaberte, and Franquette.

In order to study the different factors which might play a part in the storage of food, distinctions (aside from those between kinds and varieties) were made between shoots as follows:

I. Distinctions as to age of tree. Shoots were taken from:

A. Ordinary vigorous trees 7 yrs. old.

B. " " " 3 " "

C. " " " 25 " "

II. Distinctions as to comparative size of crop. Shoots were taken from vigorous 7 year old trees:

A. Which had just borne a medium crop.

B. " " " " light "

C. " " " " heavy "

III. Distinctions as to kind of shoots.

A. 1. Normal shoots in head of tree.

2. Water Sprouts on trunk and branches.

3. Root suckers.

B. 1. Upright shoots on walnut trees.

2. Drooping " " " "

IV. Distinction as to size of buds. This was accomplished by taking from the same tree pairs of shoots of practically the same length and weight but with the difference that one had large and the other small buds.

V. Distinctions as to season of cutting. Shoots were taken in four series:

DISCUSSION OF RESULTS

Rotting and Callusing in Storage.

One of the first things noticed in taking the cuttings from storage was the large percent which had decayed. This may or may not have been due to unfavorable storage conditions, as too much water and insufficient drainage. But the fact remains that not all the series acted alike in this manner. Table I shows that the later in the fall the shoots were taken from the trees, the less was the decay which accurred in storage. A difference was also noticed in the amount of callus the cuttings made while in storage. Table II shows that the shoots cut later in the fall made the most callus. This fact is more significant when it is noted that Series I was in storage for four months, Series II for three months, Series III for 2½ months, and Series IV for 2¼ months. Besides being so well callused, many of the buds on the cuttings in Series IV had also opened and made short growths while still in storage.

These facts might be of importance in a consideration of the best time to select cion wood. Table I also shows that a larger percent of the later collected shoots made a growth when planted in moist sand. These facts would indicate that, aside from being less liable to rot, cuttings collected late in the fall, up to January 1, contained the most stored food and so are of greater value.

TABLE I

DECAYING AND GROWTH

Kind of Fruit	SERIES I: % of cuttings that decayed	SERIES I: % of shoots that grew	SERIES II: % of cuttings that decayed	SERIES II: % of shoots that grew	SERIES III: % of cuttings that decayed	SERIES III: % of shoots that grew	SERIES IV: % of cuttings that decayed	SERIES IV: % of shoots that grew
Apples	45	36	2	73	.3	85	Very Little	97
Pears	54	0	30	50			0	87
Prunes & Plums	13	16	0	85			0	85
Cherries	25	47	0	77			0	100
Peaches	80	0	100	0			0	59
Walnuts	33	0	Killed by frost in November					
Average	44	34	21	73	.3	85	0	89

TABLE II

Callusing in Storage

Series No.	CLASS A: Well callused	CLASS B: Fairly well callused	CLASS C: Poorly callused or none
I			100%
II			100%
III		29%	71%
IV	21%	43%	35%

as cion wood, in that they could make a quicker union and produce a more vigorous growth.

Seasonal Variations. Previous investigators have shown that the amount of stored food in plants increases in the late summer and remains high thru the fall and winter. In order to check their results and to study the behavior of fruit trees in this respect, shoots were removed from the trees at three different seasons: September 23, while the leaves were still green and the wood unripe: October 25, about the time the leaves were dropping: December 23, when the trees were entirely dormant.

Table III gives the results in terms of the growth made by the cuttings. It is seen that the cuttings gathered while the leaves were still green and the wood unripe seemed to contain very little stored food. A very small percent of the cuttings made a growth, and in some fruits, none at all. The growth that was made was so small and withered so quickly that no weight records could be obtained. Those gathered at the time the leaves were falling showed a larger percent of cuttings which grew. The growth they made was larger and more persistent, making it possible to obtain fairly accurate weight records. The shoots gathered Decmeber 23 showed a still larger percent of growth. Also, the growth made was larger and heavier. This does not show well in the table, because many of the

TABLE III SEASONAL VARIATIONS

Kind of Tree	SERIES I* Percent of cuttings that grew			SERIES II Percent of cuttings that grew			Percent of growth **			Total per-cent of growth	SERIES IV Percent of cuttings that grew			Percent of growth			Total Percent of growth
	#T	M	B	T	M	B	T	M	B		T	M	B	T	M	B	
Apple	27	31	10	5	55	62	.10	.98	.79	1.87	43	74	68	.94	1.31	1.07	3.32
Pear				25	35	30	.47	.71	.62	1.95	48	57	63	.86	.91	.83	2.60
Prune		28		57	70	48	3.43	4.90	2.61	10.94	80	70	20	1.80	2.74	.05	4.59
Plum		20		10	60	20	.20	1.43	.13	1.76	10	60	0	Leaves	fall	off	
Cherry	60	45	5	63	43	0	2.27	1.68	0	3.95	100	90	50	1.65	.60	0	2.25
Peach											30	50	50	Leaves	dried	up	
Average	28	32	7	22	53	47	.74	1.38	.76	2.88	47	69	61	.99	1.22	.89	3.10

* The growth in Series I was not weighed.

** Percent of the weight of the growth is of the weight of the cutting which produced it.

\# T, M, and B will always represent terminal, median, and basal cuttings.

leaves had witherdd before they were weighed, making the figures lower than they would have been if the leaves were fresh.

These records would seem to indicate that food storage in fruit tree wood takes place in the late summer and fall and that the amount of reserve material remains high during the winter. This checks fairly well with the results of other investigators.

A further point of interest here is the fact that the last series showed more stored food than the second. This fact becomes more evident when it is considered that the last series produced much more callus than the second. It is difficult to suggest an explanation for this, since the trees drpped their leaves at the time the second series was cut and had no opportunity to manufacture more food before the last series was taken.

Variations in Kinds and Varieties of Trees. It is Not to be expected that all kinds of trees nor all varieties of the same kind would be alike as to the time, amount and region in which the food is stored. Table IV shows the behavior of the different kinds and varieties of trees in this respect. The comparisons are between vigorous 6 and 7 year old trees.

With respect to time of storage, apples and pears showed an increase in storage materials during the fall and winter, while the prunes and cherries seemed to show a de-

TABLE IV VARIATIONS IN KINDS AND VARIETIES

Variety	SERIES I Percent of cuttings that grew			SERIES II Percent of cuttings that grew			Percent of growth			Total Percent of growth	SERIES IV Percent of cuttings that grew			Percent of growth			Total Percent of growth
	T	M	B	T	M	B	T	M	B		T	M	B	T	M	B	
Wagener				0	30	100	0	.38	1.04	1.42	70	80	50	1.70	1.15	.63	3.48
Ortley				10	80	100	.19	1.52	.96	2.67	70	90	90	2.47	2.80	2.25	7.52
Grimes				25	87	75	.46	.77	1.04	2.26	70	100	100	1.43	1.41	1.26	4.10
Yel.New.	10	30	0	0	80	60	0	1.81	.90	2.71	60	70	50	1.29	1.25	1.25	3.79
Ark.Black				0	20	20	dried up				50	60	40	1.55	1.19	.38	3.12
Lowery				0	30	60	0	.28	.40	.68	60	90	90	.87	1.03	.52	2.42
Delicious	44	0	0	0	10	20	dried up				100	0	0	2.58	0	0	2.58
King David				10	90	80	.12	1.19	1.27	2.58	80	80	50	1.06	.83	.70	2.59
Mean Average				5	53	64	.12	.99	.93	2.04	70	71	59	1.54	1.20	.87	3.61
Bartlett											80	80	80	1.24	.80	.42	2.46
Winter Nelis				40	50	30	.82	.79	.72	2.33	80	80	40	1.58	2.18	.55	4.31
Bosc				10	20	30	.11	.63	.52	1.26	20	50	50	.32	.57	.47	1.36
Mean Average				25	35	30	.46	.71	.62	1.79	60	70	56	1.05	1.18	.48	2.70
Italian	0	28	0	100	70	10	6.67	5.95	.84	13.46	80	70	20	1.80	2.74	.05	4.59
Green Gage	0	20	0	10	60	20	.20	1.43	.13	1.76	10	60	0	dried up			
Napoleon				20	20	0	dried up				100	100	50	dried up			
Olivet	100	50	10	80	50	0	1.96	.86	0	2.82	100	70	40	1.02	dried up		1.02
Eng.Morello	20	40	0	90	60	0	2.58	2.50	0	5.08	100	100	60	2.28	1.20	0	3.48
Mean Average				63	43	0	2.27	1.68	0	3.95	100	90	50				
Mayflower											50	80	50	dried up			
Washington											40	50	80	"	"		
May Lee Cling											0	20	20	"	"		
Wallis																	

crease.

In the amount of storage materials, of course the different varieties of the same kind varied considerably. Apples showed a greater amount than pears, prunes a greater amount than apples, while cherries were nearly the same as apples; however, this may be an unfair comparison, since different kinds of trees may vary in the amount of growth they make from the same amount of food material.

The different varieties of the same kind showed considerable variation as to the region of most storage. They also showed a variation in the region of storage at different seasons. Series II of the apples showed most of the food to be stored in the median and basal portions, while in Series IV the food seems to have moved up into the terminal and median portions. The two varieties of pears were distinctly opposed to each other in the matter of region of storage. However, the pears showed similar regions of storage in the two series. Only cherries showed maximum storage in terminal and median portions at all times and in all varieties, the terminal having more than the median in every case.

These facts are illustrated in plates: 4 (2,3), 6 (1), 7 (2,3), 8, 9 (1, 3), 10, 22 (1), 25 (1), 26 (2), 27 (1,3), 28, 29 (1,3), 30(2), and 31.

Relation of Age of Trees to Food Storage

It is of interest to see whether or not old and young trees differ in their habits of food storage. Comparisons were made between trees of Grimes and Wagener apples and the Italian prune. Table V sets forth the results. It is seen that the younger Grimes tree, seven years old, contained more stored food in the one year old shoots that the twenty-five year old tree. In the Wagener variety, there seemed to be absolutely no correlation between the age of the tree and food storage; the table merely points out the increase of stored food in the same trees during fall and winter. While the data for the Italian prune seems to indicate greater food storage in the older tree, the data is too limited and incomplete to make any conclusions possible. In fact, from the data at hand, it is not possible to state that there exists any correlation between the age of the tree and its capacity for food storage.

Relation of Age of Wood to Storage

The question of the relation of storage to the age of the tree brings up the question of the relation of storage to the age of wood in the same tree. That is, is food stored evenly throughout the length of a

TABLE V. AGE OF TREE AS A FACTOR

Variety	Series No.	Age in Years	Percent of cuttings that grew			Percent of shoots that grew	Percent of growth			Total percent of growth
			T	M	B		T	M	B	
Grimes	I	7	90	80	40	100	.96	1.26	.62	2.84
"	I	25	12	12	12	31	very	small		
Wagener	I	3	0	22	0	22	"	"		
"	II	3	0	60	70	70	0	.86	.62	1.48
"	IV	3	0	89	89	100	0	1.29	1.73	3.02
"	II	7	0	30	100	100	0	.38	1.04	1.42
"	IV	7	70	80	50	100	1.70	1.15	.63	3.48
"	IV	25	50	40	30	80	.90	1.07	.24	2.21
Italian	I	5	no	growth						
"	II	5	14	71	86	86	.19	3.86	4.38	8.43
"	I	7	0	28	0	28	dried	up		
"	II	7	100	70	10	100	6.67	5.95	.84	13.56

branch? To study this factor a large basal cutting was taken from a shoot of the previous season and similar cuttings of the same weight were taken from two and three year old wood of the same branch.

The results, set forth in Table VI, are hardly definite enough to form a basis for judgment, although in most cases it would seem that the greater amount of stored food was contained in the outer end of the branch, or in other words, in the regions adjacent to the leaves.

TABLE VI. AGE OF WOOD AS A FACTOR

Variety	Series No.	Percent of cuttings that grew			Percent of growth			Total Per-cent of growth
		1-year	2-year	3-yr.	1-yr.	2-yr.	3-yr.	
Wagener	I	0	100	100	dried up			
"	IV	83	83	33	1.59	.58	.14	2.31
Bartlett	I	Decayed						
"	IV	66	33	0	.62	dried up		
Wallis	I	no growth						
"	IV	66	0					

The Fruit Crop as a Factor

Since the production of a crop of fruit is more or less of a drain upon the vigor and food reserve of the tree, it was thought that the size of the crop might act as a factor in the storage of food. Shoots were taken from Wagener trees producing comparatively large, medium, and small crops or none at all.

Table VII gives the results. The figures show that in the two cases cited, at least, the lighter the crop of apples, the greater the amount of food stored by the tree. This would indicate that the size of the crop is a factor in food storage, and that when a tree is producing a heavy crop of fruit, it does not produce enough food to lay up a large amount of reserve material the same season. These results are illustrated in plates 6, 22 (1), 23 (1,2).

TABLE VII. SIZE OF CROP

Series No.	Size of crop	Percent of cuttings that grew			% of shoots that grew	Percent of growth			Total percent of growth
		T	M	B		T	M	B	
I	heavy	10	40	0	50	dried up			
I	medium	decayed							
I	light	decayed							
II	heavy	0	30	50	50	0	.79	.48	1.27
II	medium	0	30	100	100	0	.38	1.04	1.42
II	light	10	90	50	100	.14	1.37	.68	2.19
IV	heavy	40	100	90	100	.70	1.36	1.54	2.60
IV	medium	70	80	50	100	1.70	1.15	.63	3.48
IV	light	40	80	90	100	.91	2.01	2.01	4.93

Relation of Food Storage to Leaf Area

The food which is stored up by the wood must first be manufactured by the leaves of the tree. This would suggest that there might be some relation between the leaf area of a tree and its behavior in the matter of food storage. To study this, shoots were taken from a plot of trees upon which defoliation investigations were being conducted. Table VIII gives a comparison of the different amounts of defoliation on similar trees. With one exception, the trees which received the most defoliation exhibited the presence of the least stored food.

TABLE VIII. AMOUNT OF DEFOLIATION

Variety	Amount of defoliation	Percent of cuttings that grew			Percent of shoots that grew	Percent of growth			Total percent of growth
		T	M	B		T	M	B	
Esopus	None	10	100	70	100	.17	2.15	.87	3.19
"	Once, June 7	10	100	90	100	.03	2.26	1.18	3.47
"	every 3 weeks	10	60	50	70	.03	.73	.15	.91
Yel. Newt.	None	40	100	100	100	.39	1.05	.94	2.38
"	once	40	100	90	100	.32	1.00	.51	1.83
"	every 3 weeks	50	70	10	80	.67	.45	.08	1.20
Grimes	None	30	80	40	90	.33	.99	.07	1.39
"	once	0	50	40	70	.00	.22	.39	.61
"	every 3 weeks	0	50	20	50	.00	.99	.21	1.20
Wagener	None	0	80	80	90	.00	1.16	1.35	2.51
"	once	0	80	90	100	.00	1.62	1.29	2.91
"	every 3 weeks	0	20	90	90	.00	.41	.74	1.15
Ben Davis	None	0	30	40	50	.00	.30	.23	.53
"	once	0	60	10	60	.00	1.03	.28	1.31
"	every 3 weeks	10	0	0	10	.40	.00	.00	.40

It is of interest to note in Table VIII that those trees defoliated once showed little difference in stored food from those not defoliated. This may be due to experimental error, or else one defoliation, especially as early as June 7, as it is in this case, had very little affect on the total leaf area at the time when storage occurs. See plates 11 to 16 inclusive.

Table IX shows the behavior of trees receiving different types of defoliation. In this case two varieties were used, and the results from each are so different

TABLE IX. TYPE OF DEFOLIATION

Type of Defoliation done June 18	Percent of cuttings that grew T	M	B	% of shoots that grew	Percent of growth T	M	B	Total percent of growth
Esopus								
1. None	20	100	60	100	.13	2.66	.61	3.40
2. Spurs defoliated	0	60	60	70	0	1.27	.69	1.96
3. Current growth defoliated	0	50	60	90	0	.92	.66	1.58
4. Spurs and part of curr.growth def.-def. shoots	20	100	80	100	.25	3.32	1.28	4.85
5. " " " " " " " not " "	10	90	90	100	.46	2.08	1.54	4.08
6. Whole tree defoliated	10	80	90	100	.16	2.32	1.36	3.84
Yellow Newtown								
1. None	0	90	100	100	0	1.63	1.66	3.29
2. Spurs defoliated	80	100	80	100	1.50	2.07	1.19	4.76
3. Current growth defoliated	40	100	50	100	.91	1.68	.76	3.35
4. Spurs and part of cur.growth def.-def. shoots	33	88	66	100	.74	1.38	.10	2.22
5. " " " " " " " not " "	25	87	75	100	.10	1.62	.55	2.27
6. Whole tree defoliated	0	33	66	77	0	.95	.86	1.81

that no very definite conclusions are warranted. In Esopus, the defoliation of the spurs only seems to have affected the whole tree in the way of reducing storage, while heavy defoliation of the current growth and of the whole tree seems to have favored greater storage than in the check tree. In Yellow Newtown the results were just opposite from this. For these reasons, it may be said that this study does not indicate clearly any relation between the type of defoliation and the amount of food storage. Neither does there seem to be any correlation between type of defoliation and the region of storage. See plates 17 to 20 inclusive.

Type or Position of Shoot as a Factor

If the leaves enter in as a factor in the storage of food, it is reasonable to suppose that different types of shoots or shoots in different positions in the tree would vary in their reserves due to variations in leaf area or in some other character. Comparisons were made between normal, fully exposed shoots in the head of the tree, water sprouts on the branches and trunk, and root suckers. The results are shown in Table X.

With one exception, the normal shoots in the head of the tree showed a larger percent of stored food than water sprouts or root suckers. Since the

TABLE X. TYPE OF SHOOT

Variety	Type of shoot	Percent of cuttings that grew			Percent of shoots that grew	Percent of growth			Total percent of growth
		T	M	B		T	M	B	
Wagener	Normal	70	80	50	100	1.70	1.15	.63	3.48
"	Root sucker	70	50	30	100	.95	1.23	.09	2.27
"	Water sprout	20	90	50	100	.27	2.20	.55	3.02
Ortley	Normal	70	90	90	100	2.47	2.80	2.25	7.52
"	Root sucker	0	100	100	100	0	2.04	1.29	3.33
"	Water sprout	10	100	80	100	.03	2.02	.90	2.95
Yellow Newtown	Normal	60	70	50	90	1.29	1.25	1.25	3.79
"	Root sucker	25	87	62	87	.35	.92	.79	2.06
Bartlett	Normal	80	80	80	100	1.24	.80	.42	2.46
"	Water sprout	20	50	60	80	.09	.57	.14	.80
Winter Nelis	Normal	80	80	40	100	1.58	2.18	.55	4.31
"	Water sprout	60	40	40	80	2.19	1.53	2.77	6.49

latter types of shoots were in a more shaded position than the normal shoot, the results would seem to warrant the conclusion that the more shaded the leaves are, the less the food they manufacture and thus the less the material available for storage in the shoot. The decreased storage might also be explained by the fact that the water-sprouts and root suckers are usually less ripe than other shoots, but this unripe condition is in turn linked up with leaf function, so that in the last analysis the leaf area and leaf function must be taken into consideration. These facts are illustrated in the plates. Compare plate 23 (1) with 24 (1, 2); 25 (1, 3) with 26 (1); 27 (1) with 27(2); 29 (3) with 30 (1).

Relation of Size of Buds to Storage

The idea that the leaf is vitally concerned in the process of food storage suggests that there might be some relation between the size of the bud formed at the base of these leaves and the storage of food in the shoot. On the other hand, if the size of the bud is independent of food storage, perhaps the results so far obtained have been due to large or small growths resulting from respectively large or small buds. This study would then be a check on the results obtained. Pairs of shoots of nearly equal weight and length, but with large and small buds were taken from the same tree. Table XI presents the record of results obtained.

Of the three varieties, two showed greatest storage in favor of the large buds, while the third gave opposite results. The amount of data at hand hardly warrants any conclusions.

It is of interest to note that the shoots with large buds came from the south side of the tree, while those with small buds came from the north side of the tree. This again links up food storage with the leaf activities. Compare results shown in plates 22 (3), 25 (2), 26 (3), and 30 (3).

TABLE XI. SIZE OF BUDS

Variety	Size of buds	Percent of cuttings that grew			% of shoots that grew	Percent of growth			Total % of growth
		T	M	B		T	M	B	
Wagener	large	40	60	80	80	1.36	2.48	1.57	5.41
"	small	80	100	60	100	1.95	1.68	.82	4.45
Ortley	large	0	40	100	100	0	.90	2.31	3.21
"	small	0	80	100	100	0	.68	1.62	2.30
Grimes	large	25	50	100	80	wrong weights made			
"	small	40	60	40	100				
Bosc	large	50	50	100	100	.31	.15	.57	1.03
"	small	25	50	75	100	.27	.59	.92	1.78

TABLE XII

COMPARISON OF GROWTH OF T, M, AND B CUTTINGS

% distribution according to % of growth	Most growth in T	Most growth in M	Most growth in B	Most growth in T-M	Most growth in M-B	Most growth in T-M-B
Apples	3.7	22.2	1.8	14.8	48.2	9.2
Pears		12.5	12.5	25.0	25.0	25.0
Prunes				66.6	33.3	
Plums		100				
Cherries	25.0			75.0		
Peaches						
Distribution in percent according to percent of cuttings that grew						
Apples	4.4	11.9	2.9	7.5	45.4	16.4
Pears		12.5		12.5	25.0	50.0
Prunes		25.0		50.0	25.0	
Plums		100.0				
Cherries				100.0		
Peaches					25.0	75.0

Region of Storage in a Shoot

It was noticed that the food reserves were not uniformly distributed throughout the different portions of the shoot and that the different kinds and varieties varied in this respect. Table XII is constructed to show where the most food was stored in each kind of tree. The apple shoots were pretty well distributed through the different storage classes given, however, a large number of them showed most storage in the median-basal regions. Shoots of other fruits were also fairly well distributed through the different classes, but so few samples were used that it is hardly fair to draw any conclusions on this point. However, it was noticed that in every case cherry shoots exhibited the most storage in the terminal and terminal-median portions.

Relation of Storage to Size of Shoots

It was noticed that in some cases the shoots which did not grow were smaller and in some cases larger than the shoots, in the same lot, which did grow. This suggested that there might be some relation between the ability to grow and the length and weight of a shoot. To study this, it was necessary to construct a table (too large to be included here) containing the average lengths and weights (of the terminal cutting) of the shoots which did and those which did not grow in each lot. There were forty-six lots containing shoots which did not grow; of these, in fourteen lots the longest and heaviest shoots grew; in twelve lots, those which did not grow were the longest and heaviest; in the other twenty lots, there was very little difference in size between those which did and those which did not grow.

These facts seem to indicate that there is no relation between storage of food and the size of the shoot, but that a small shoot may store up proportionately as much food as a large one.

Miscellaneous Results

The treatment of the ends of the cuttings of Grimes, in Series I, with Gilson's Mixture was very successful. They formed no callus in storage, and when planted, made the largest and most persistent growth of the Series. It is regretted that this treatment was not further tested.

It would be well to state that many of the walnut cuttings rotted in storage, and of those planted in sand, not one grew. The November frosts killed back the trees so that no more samples could be taken.

It was very difficult to start peach wood into growth. In the last series, what growth did start did not live very long.

Summary

The data obtained by this study of food storage in the dormant one year shoots of fruit trees, although not entirely conclusive, would seem to indicate that:

1. In the trees considered, the amount of food stored in the current growth increases in the early fall and remains high during the winter, consequently it is more advisable to gather cion wood in the winter than in the fall.

2. The different kinds and varieties of fruit trees vary in the time, amount and region of food storage.

3. There is no correlation between the age of the tree and the storage ability of its current growth.

4. The greater amount of food is apt to be stored in the regions adjacent to the leaves.

5. A tree producing a heavy crop of fruit does not store so much food in the current growth as one producing a light crop.

6. The amount of food stored is correlated with the leaf area. Shaded and immature shoots store up less food than well exposed, well matured shoots.

7. There is no relation between size of buds and amount of food stored in the shoot bearing them.

Series I. September 23
" II. October 25
" IV. December 4
" V. December 23

The leaves were still attached and active when the first series was taken. The leaves were yellowing and falling and had probably ceased all synthetic activities when the second series was taken.

VI. Distinctions as to the amount of defoliation of the tree the preceeding summer. The trees were divided into three plots receiving:

A. No defoliation

B. Defoliation once, on June 7.

C. Defoliation on every three weeks during the summer.

VII. Distinctions as to different types of defoliation. The trees were defoliated once on June 18 as follows:

A. No defoliation.

B. Spurs defoliated.

C. Current growth defoliated.

D. Spurs and part of current growth defoliated. In this case samples were taken from both defoliated and not defoliated current growth.

E. Whole tree defoliated.

VIII. A lot of Grimes cuttings were treated with Gilson's Mixture (corrosive sublimate) by dipping both ends of each cutting in the solution for one-half minute. It was thought that this might kill the tissues at the end of the cutting and so prevent its callousing, thereby compelling the cutting to retain all its food for the development of new growth.

IX. Distinctions as to different ages of wood from the same tree. Basal cuttings (one for each year) were made for each of one, two and three year old wood in one variety of each kind of fruit.

X. In all cases (with the exception of IX) comparisons were made between the basal, median and terminal portions of each shoot.

D. Method of Procedure

Series I, II, IV, were taken from the same trees, while Series III was taken from a plot of trees upon which an investigation of defoliation is being carried on, shoots being removed but once from these trees. After cutting from the trees, the shoots were immediately stored in a cold cellar. In order to keep them fresh until further treated,they were set in a little water in buckets.

As soon as possible after removing from the trees the shoots were brought into the laboratory and there the length of each was recorded. The shoot was then cut into three pieces of equal length. The terminal piece was weighed and the basal and median pieces were cut down to the same weight as the terminal piece. The cuttings were tied in bundles, tagged, and stored in damp sand to callus.

After the cuttings had been in the sand long enough to callus and had begun to show signs of growth, they were removed from the sand and washed thoroughly to remove all dirt; they were then planted to a depth of one and one-half inches in a greenhouse bench of clean sand. This sand was taken from the seashore and was washed with continually running water for forty-eight hours to remove all soluble salts present. When the cuttings were removed from storage, many of them were decayed; records were made of this condition and those cuttings, of course were not planted. Note was also taken of the amount of callus the cuttings had made in storage.

The cuttings were at first kept watered with distilled water, but owing to an accident to the water containers, it became necessary to resort to ordinary tap water. Perhaps this resulted in an addition of a small amount of nutrient material to the sand, but the error would be negligible, for all of the cuttings were given the same amount of water.

After the cuttings commenced to grow, notes were taken every ten days on the following points:

1. The breaking of the buds.

2. The opening out of the buds into full leaf.

3. The appearance of flower buds and flowers.

4. The withering and yellowing of leaves.

When the growth activities of the cuttings seemed to cease and they began to show signs of withering, two typical groups were picked out from each lot of thirty and these were photographed. Separate weights were then made of the growth from the terminal, median and basal pieces in each lot.

8. There is no relation between the size of the shoots and their ability to grow.

Acknowledgments

The writer wishes to express his appreciation of the many services rendered him in the work of which this is a report. Professor C. I. Lewis afforded the opportunity for the investigation of the problem. Professor V. R. Gardner suggested the problem and offered many other helpful suggestions and criticisms. Assistant J. R. Magness, under whose immediate direction the work was conducted, also offered much advice and criticism. Thanks are due Professors A. F. Barss, Dr. W. Atwood, and R. A. Dutcher for valuable suggestions. Bert Pilkington supplied the distilled water. The Corvallis Orchard Company permitted the use of a number of trees in its orchard.

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Description of Plates

With the exception of plates 1, 2, 3, 5, 11, and 21, these pictures are supposed to show the detailed and characteristic growth of certain lots of cuttings. The tags labelled 1, 2 and 3 indicate the cuttings, usually six, to the right of them. The following is a description of each plate:

Plate 1. A general view of the growing cuttings.

Plate 2. Ditto.

Plate 3, A general view of Series I, cut September 23.

Plate 4. (1) Grimes. The cuttings had their ends dipped in Gilson's Mixture before storing to prevent callus formation. The only lot of apples in the series that made a persistent growth.

(2) Olivet cherry.

(3) Green Gage plum.

Series II

Plate 5. General view of Series II, cut October 25.

Plate 6. (1) Wagener, vigorous seven year old trees medium crop.

(2) " " " " " " heavy crop.

(3) " " " " " " light crop.

Plate 7. (1) Wagener, vigorous three year old trees.

(2) Ortley, " seven " " "

(3) Grimes, " " " " "

Plate 8. (1) Yellow Newtown, vigorous seven year olds.

(2) Lowery, " " " "

(3), King David " " " "

Plate 9. (1) Winter Nelis pear, vigorous seven years, no crop.

(2) Italian prune, " five "

(3) " " " seven "

Plate 10. (1) Green Gage plum, " six "

(2) Olivet cherry, fair vigor, no crop.

(3) English Morello cherry, fair vigor, no crop.

Series III

Plate 11. General view of Series III, cut December 4.

Plate 12. (1) Esopus, not defoliated.

(2) " , defoliated June 7.

(3) " , " every three weeks.

Plate 13. (1) Yellow Newtown, not defoliated.

(2) " " , defoliated June 7.

(3) " " , " every three weeks.

Plate 14. (1) Grimes, not defoliated.

(2) " , defoliated June 7.

(3) " , defoliated every three weeks.

Plate 15. (1) Wagener, not defoliated.

(2) " , defoliated June 7.

(3) " , defoliated every three weeks.

Plate 16. (1) Ben Davis, not defoliated.

(2) " " , defoliated June 7.

(3) " ", " every three weeks.

Plate 17. (1) Esopus, not defoliated.

(2) " , spurs defoliated June 18.

(3) " , current growth defoliated June 18.

Plate 18. (1) " , spurs and part of current growth defoliated, <u>defoliated</u> shoots.

(2) " , spurs and part of current growth defoliated, <u>not</u> defoliated shoots.

(3) " , whole tree defoliated June 18.

Plate 19. (1) Yellow Newtown, not defoliated.

(2) " " , spurs defoliated June 18.

(3) " " , current growth " " "

Plate 20. (1) " " , spurs and part of current growth defoliated, <u>defoliated</u> shoots.

(2) " " , spurs and part of current growth defoliated, <u>not</u> defoliated shoots.

(3) " ", whole tree defoliated June 18.

<u>Series IV</u>

Plate 21. General view of series IV, cut Dec. 23.

Plate 22. (1) Wagener, vigorous, 7 years old, medium crop.

(2) " , comparison of 1, 2 and 3 year old wood from the same trees as in (1), one cutting from each year.

(3) Wagener, same as (1), comparison of shoots with large and small buds. First three cuttings

had large buds, and second three, small buds.

Plate 23. (1) Wagener, vigorous 7 years old, heavy crop.

(2) " , " " " " light crop.

(3) " , not " 25 " ".

Plate 24. (1) " , root suckers from vigorous 7 year old trees.

(2) " , water sprouts " " " " " trees.

(3) " , vigorous, 3 years old.

Plate 25. (1) Ortley, vigorous, 7 years old, medium crop.

(2) " , comparison of shoots with large and small buds.

(3) " , root suckers from vigorous 7 year old trees.

Plate 26. (1) " , water sprouts from vigorous 7 year old trees.

(2) Grimes, vigorous, 7 years old, good crop.

(3) " , comparison of shoots with large and small buds.

Plate 27. (1) Yellow Newtown, vigorous, 7 years old, small crop.

(2) " " , root suckers from same trees.

(3) Arkansas Black, vigorous, 7 years old, small crop.

Plate 28. (1) Lowery, vigorous, 7 years old, light crop.

(2) Delicious, " 6 and 7 " " " "

(3) King David," 7 " " " "

Plate 29. (1) Bartlett pear, vigorous, 7 years old, no fruit.

(2) " " , comparison of 1, 2 and 3 year old wood from (1).

(3) Winter Nelis pear, fair vigor, 7 years old, no fruit.

Plate 30. (1) Winter Nelis, water sprouts from same trees as 29-(3).

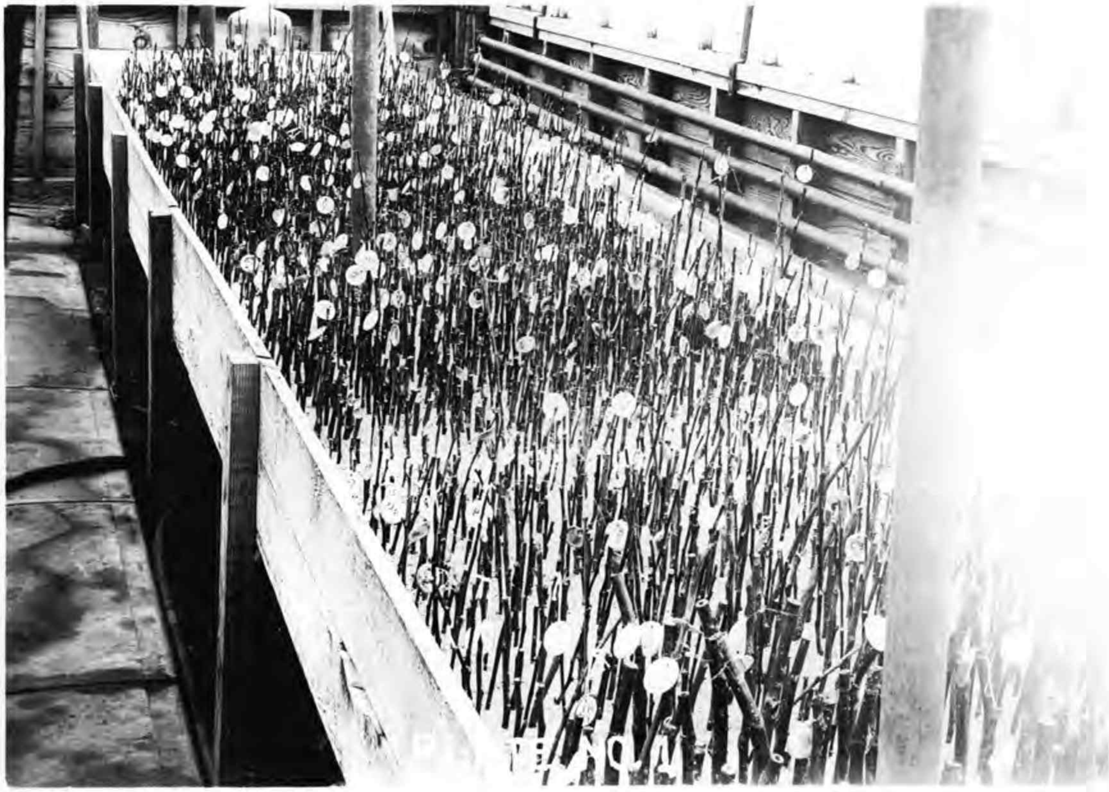
(2) Bosc pear, vigorous, 6 years old, no fruit.

(3) " " , comparison of shoots with large and small buds.

Plate 31. (1) Italian prune, vigorous, 5 and 7 years old.

(2) Olivet cherry, fair vigor, 6 years old.

(3) English Morello cherry, fair vigor, 6 years old.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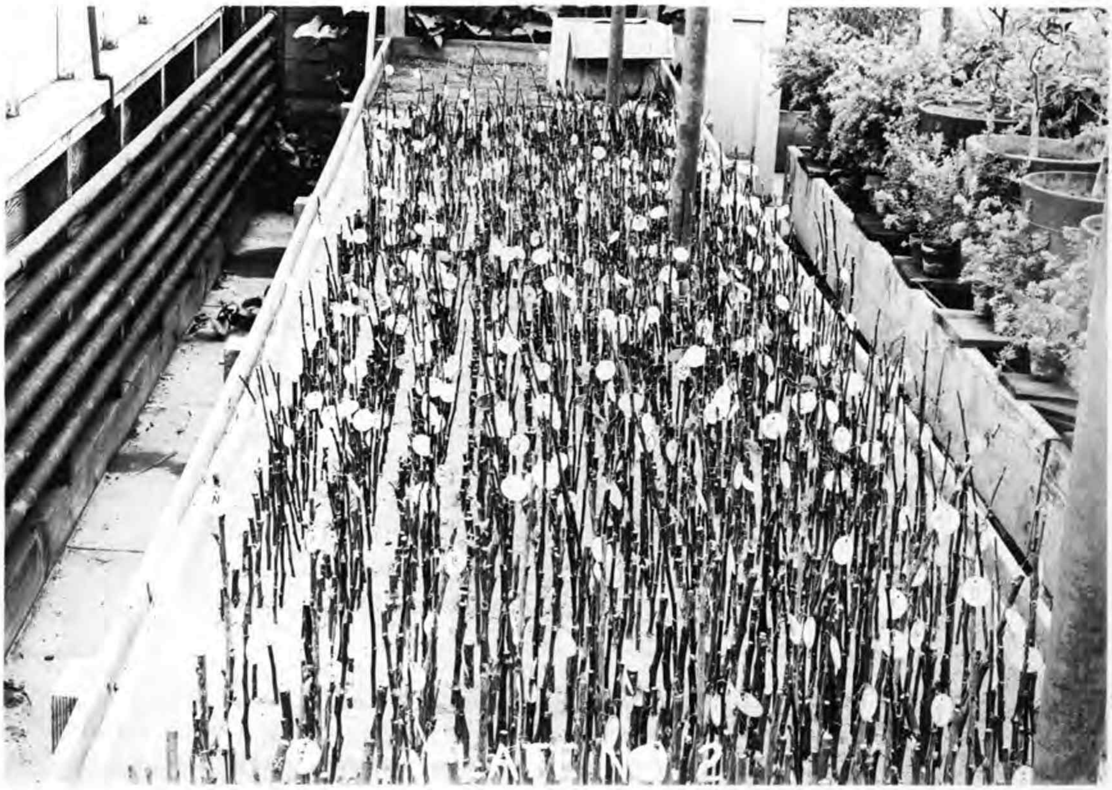
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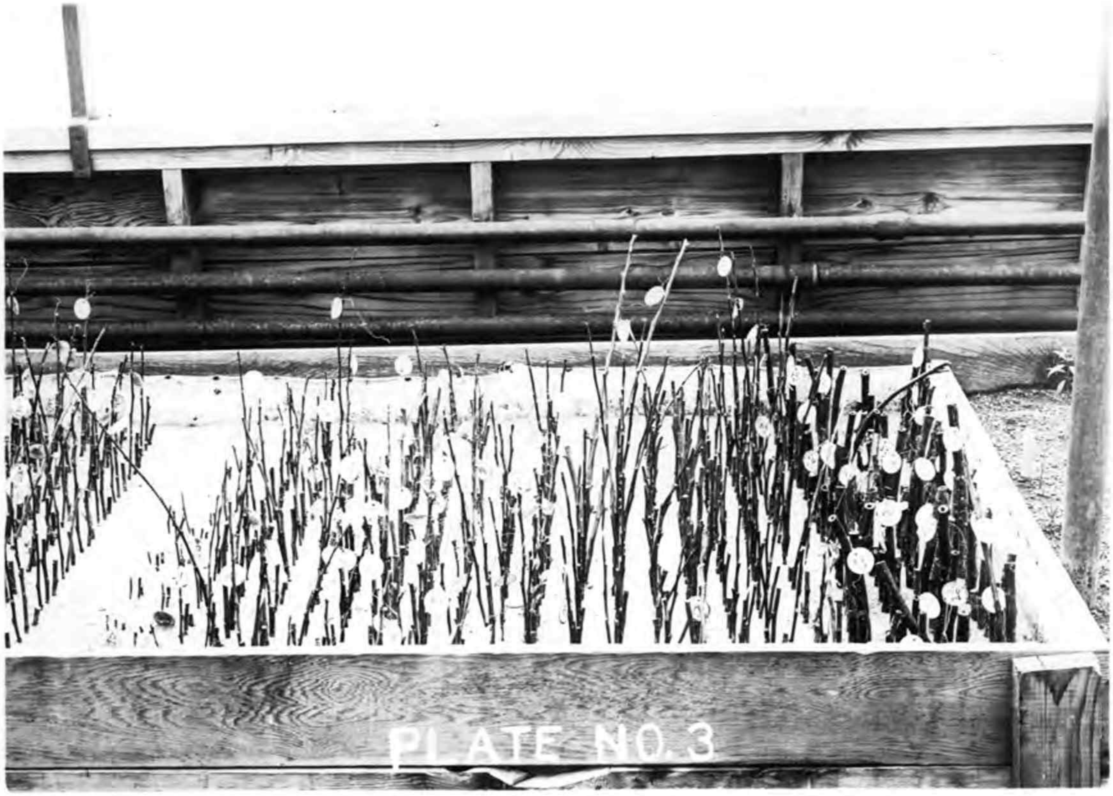

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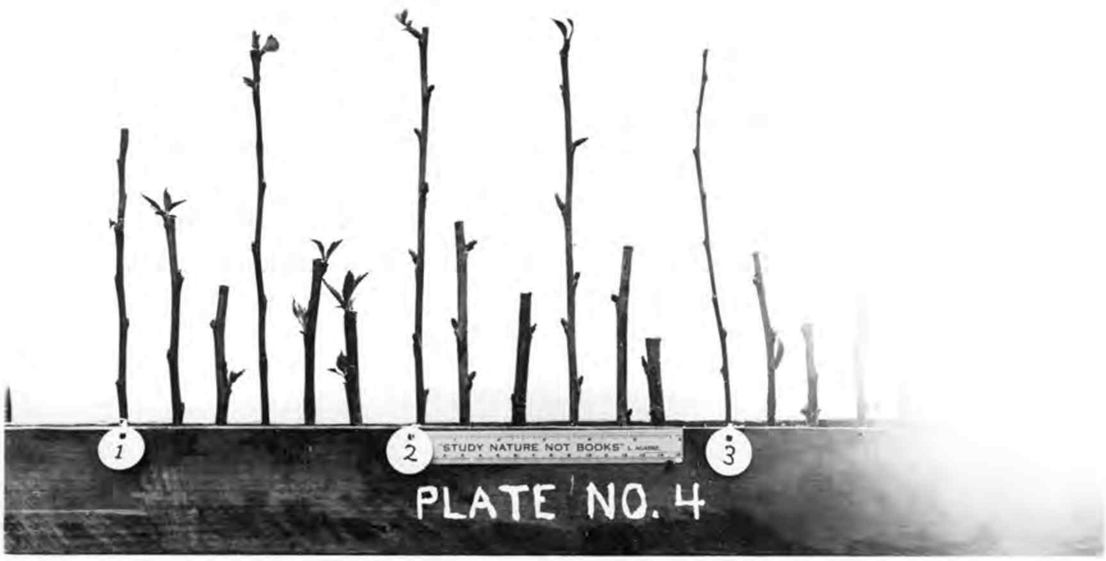

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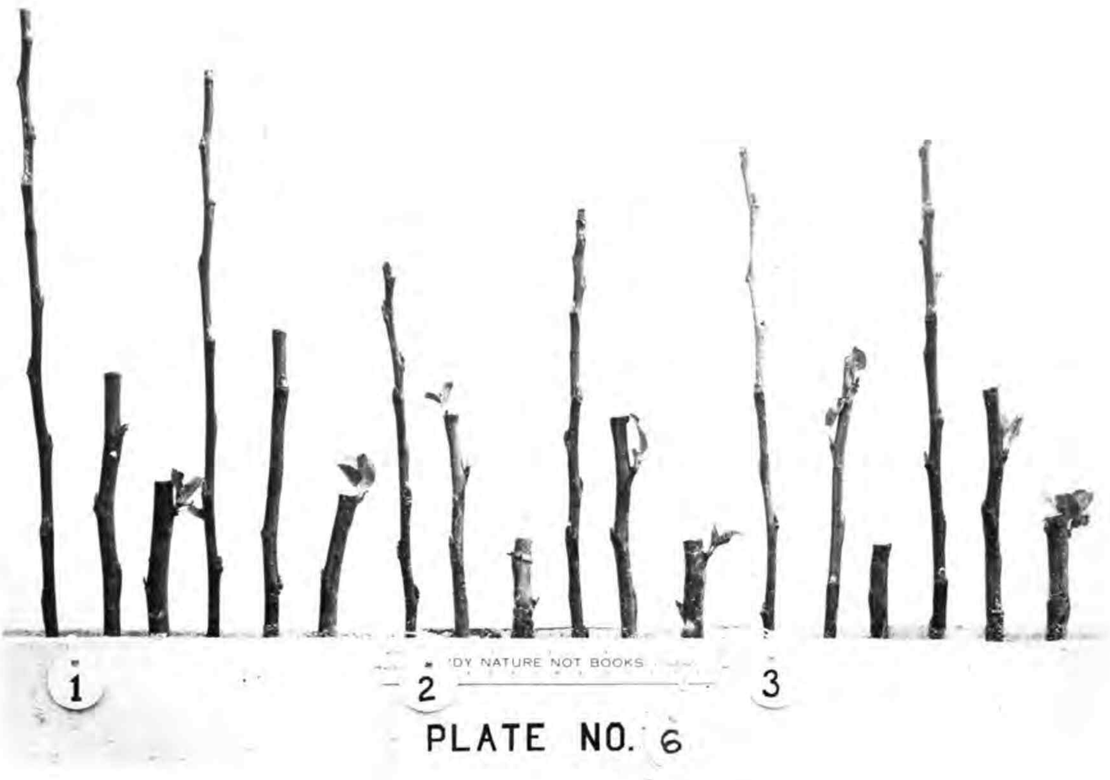

PLATE NO. 6


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"STUDY NATURE NOT BOOKS"
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PLATE NO. 7


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"STUDY NATURE NOT BOOKS"
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PLATE NO. 8


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NATURE NOT BOOKS
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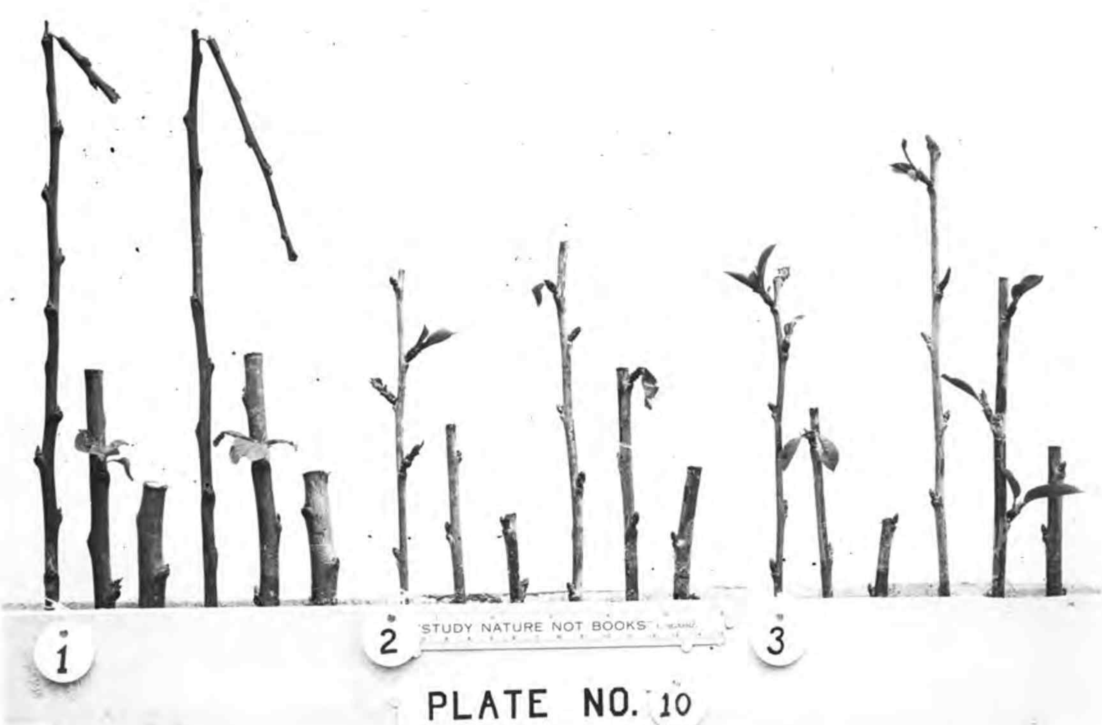
PLATE NO. 9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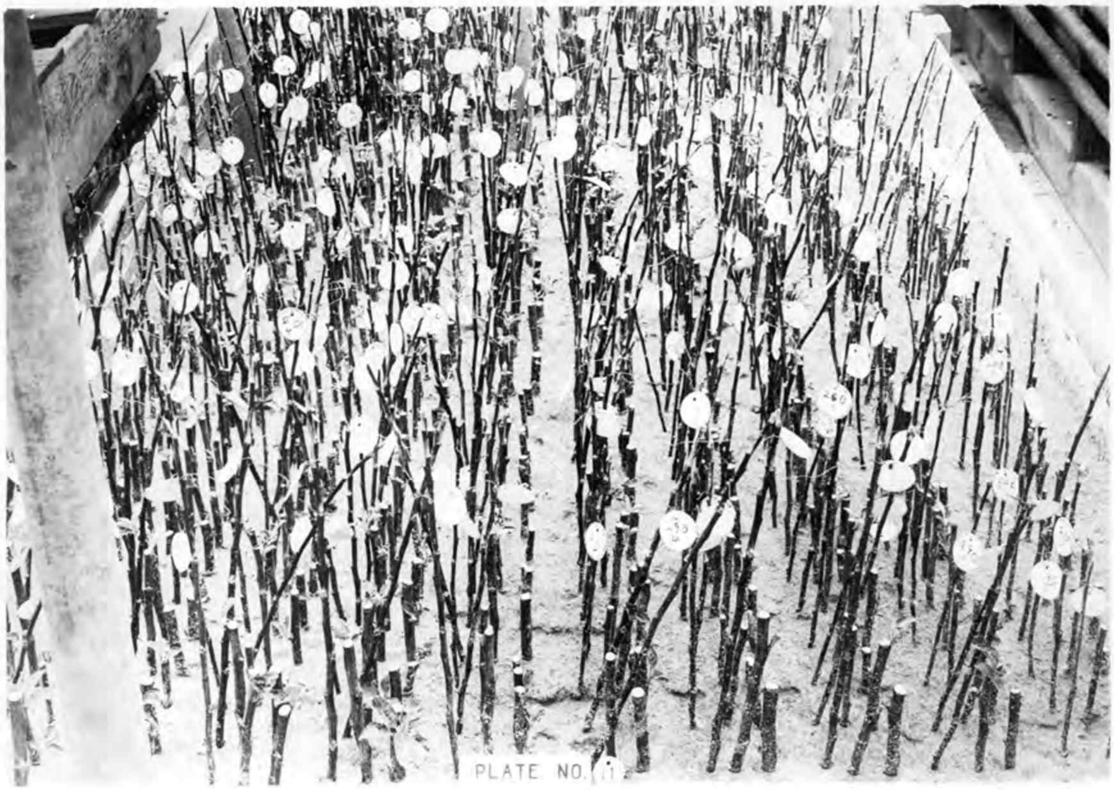
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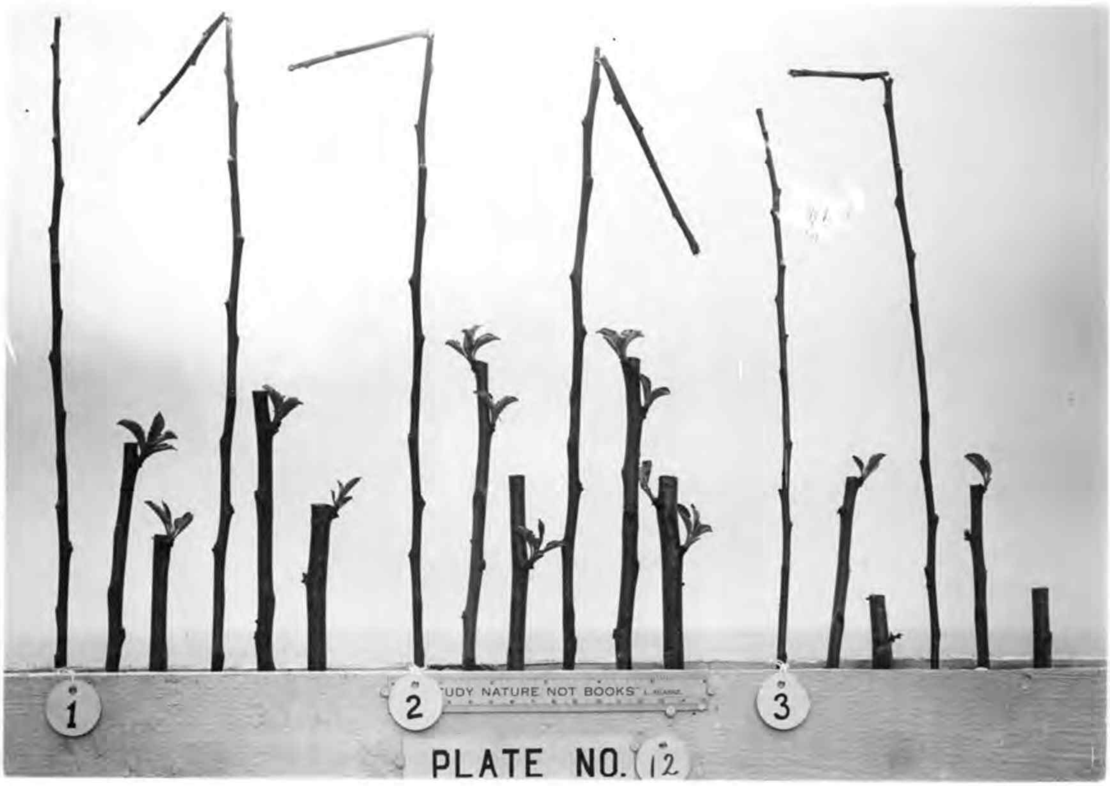
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UDY NATURE NOT BOOKS
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PLATE NO. 12


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"STUDY NATURE NOT BOOKS"
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PLATE NO. 13


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"STUDY NATURE NOT BOOKS"
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PLATE NO. 14

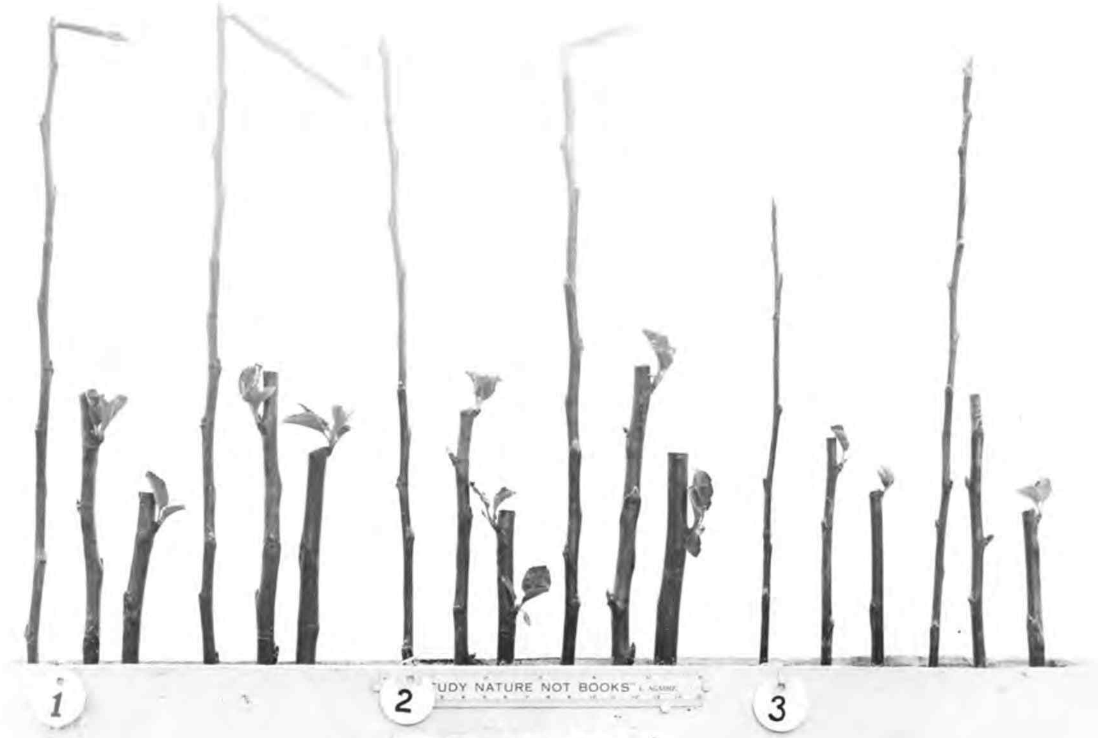

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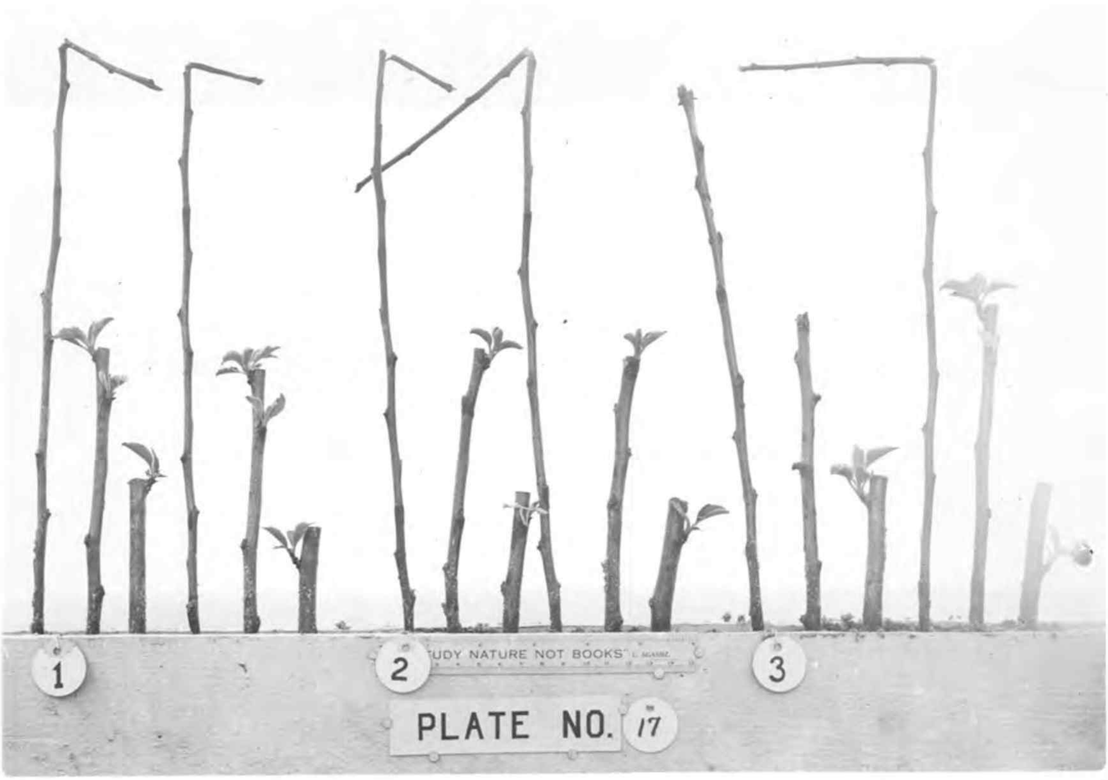
PLATE NO. 16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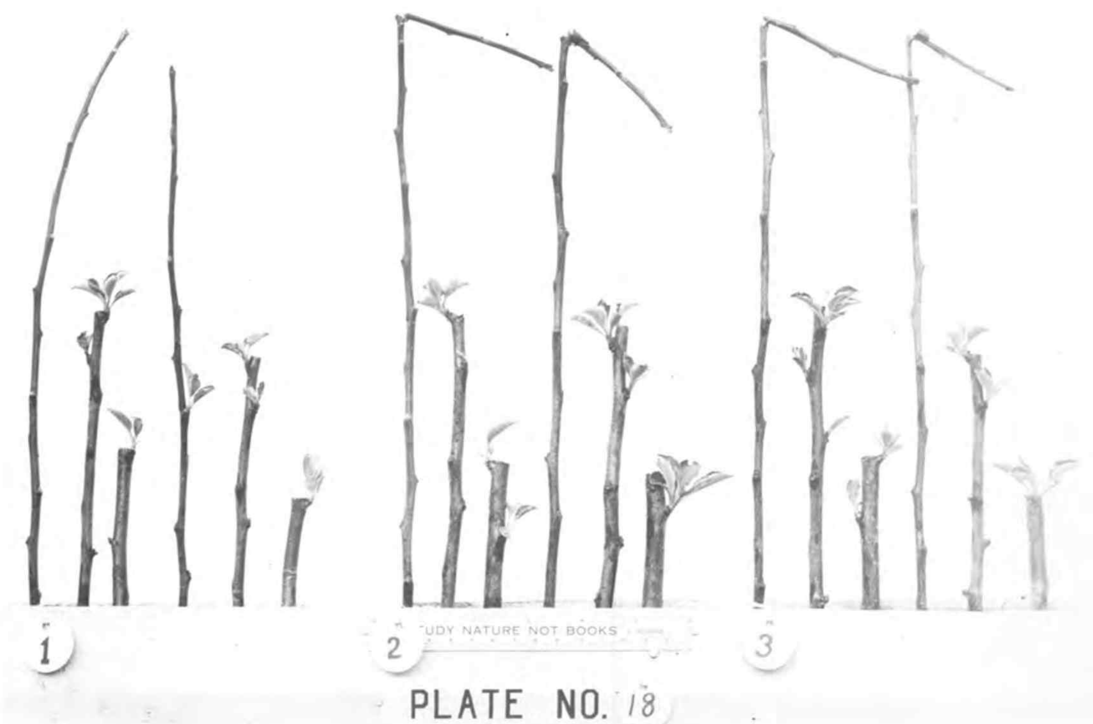
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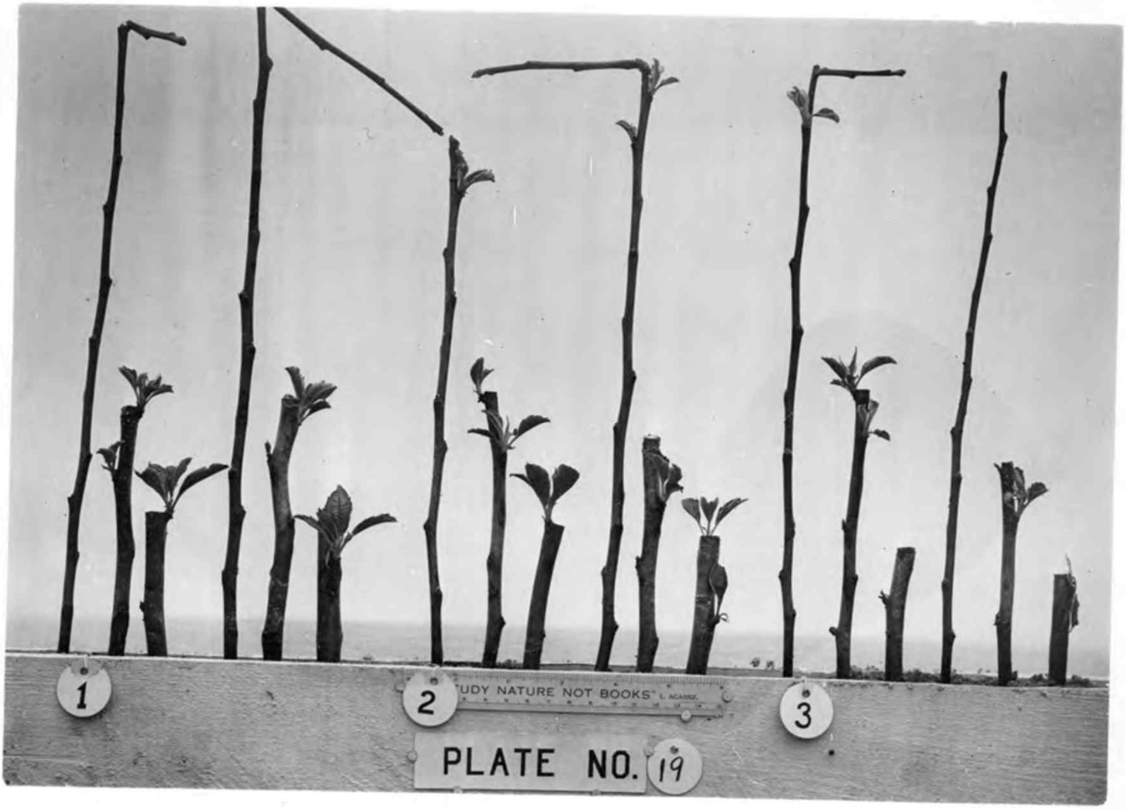
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"STUDY NATURE NOT BOOKS" L. AGASSIZ
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PLATE NO. 19


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"STUDY NATURE NOT BOOKS" L. AGASSIZ
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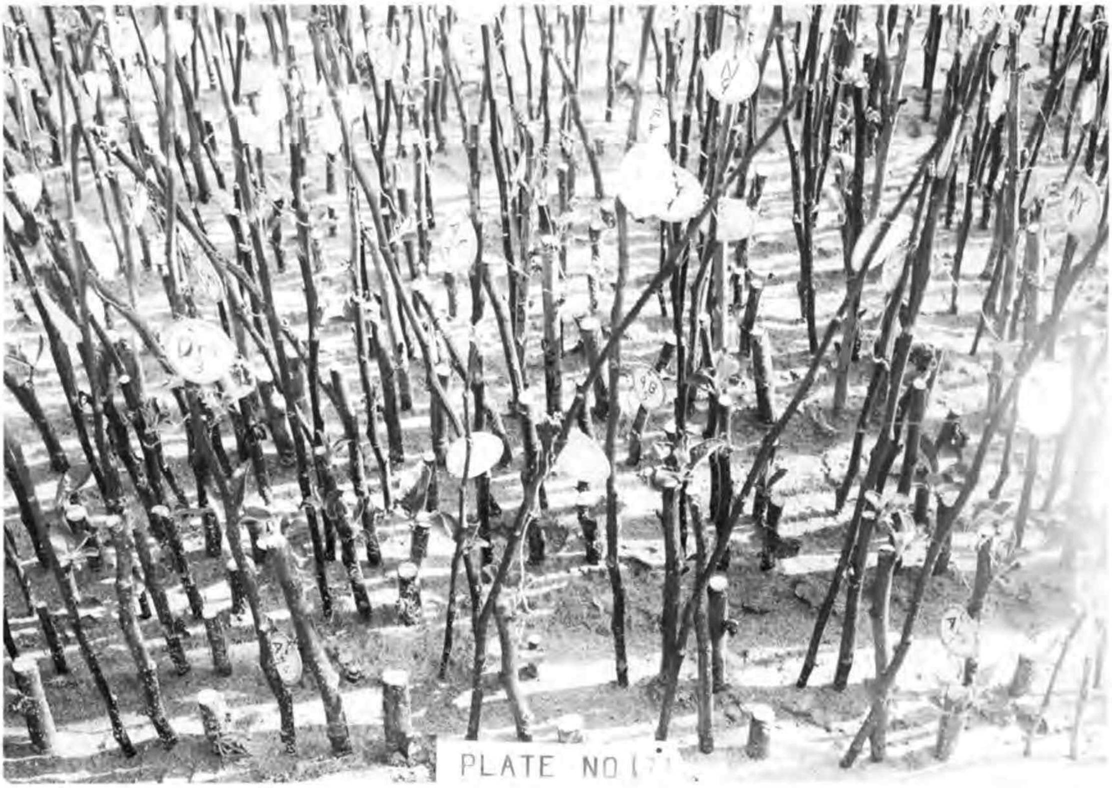
PLATE NO. 20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UDY NATURE NOT BOOKS
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PLATE NO. 22

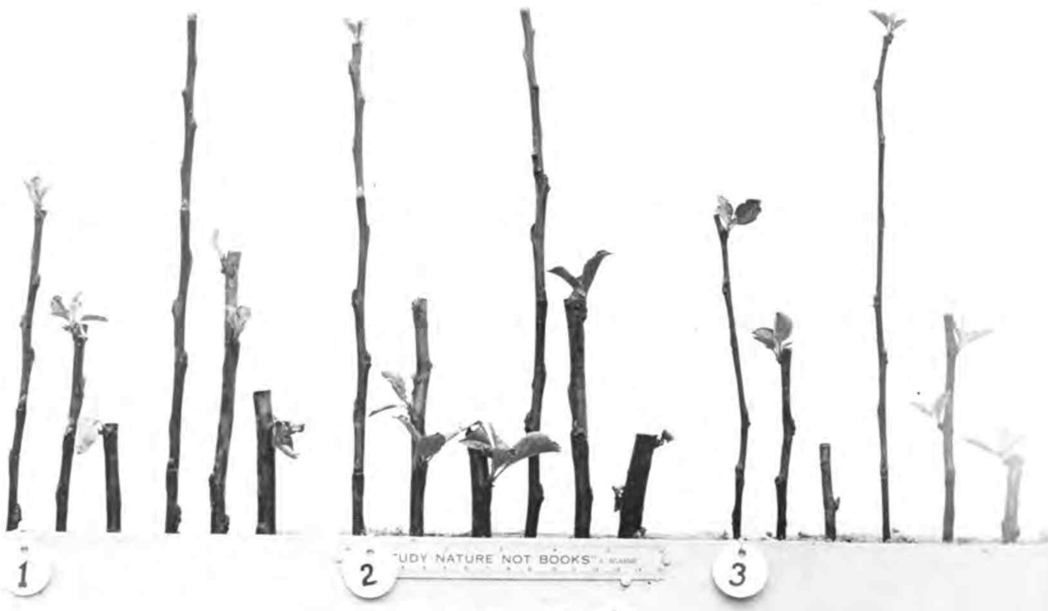
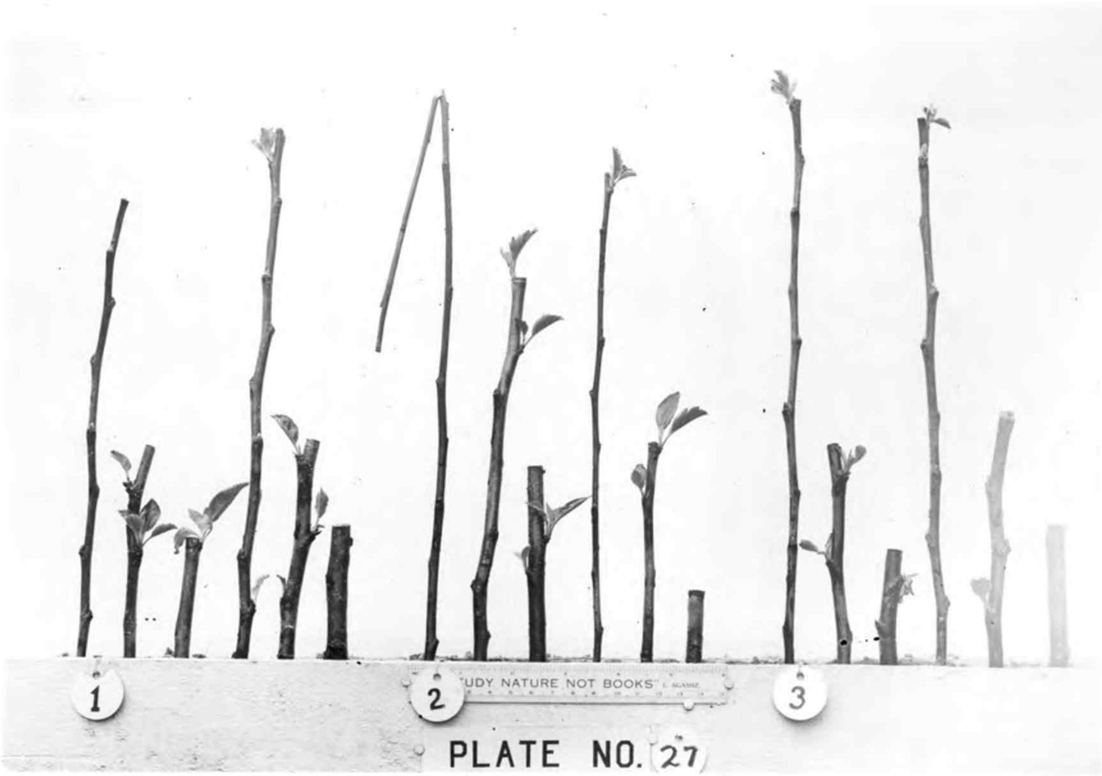


PLATE NO. 23

PLATE NO. 24

PLATE NO. 25

PLATE NO. 26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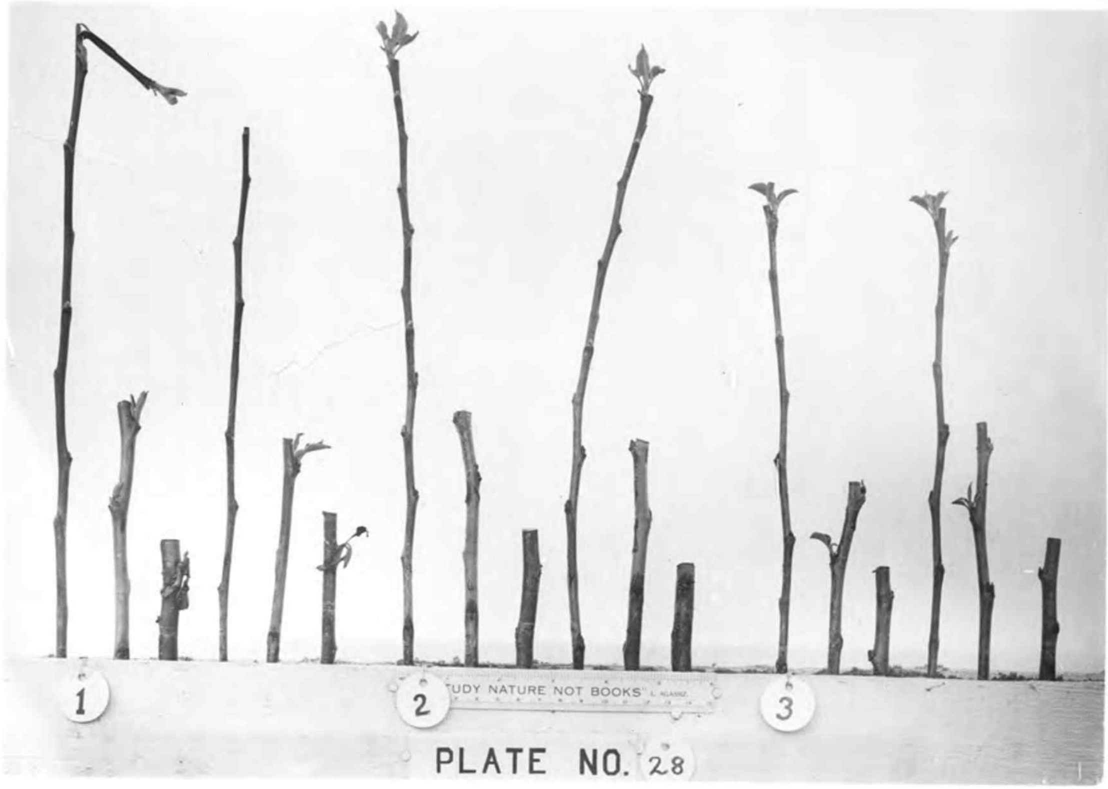
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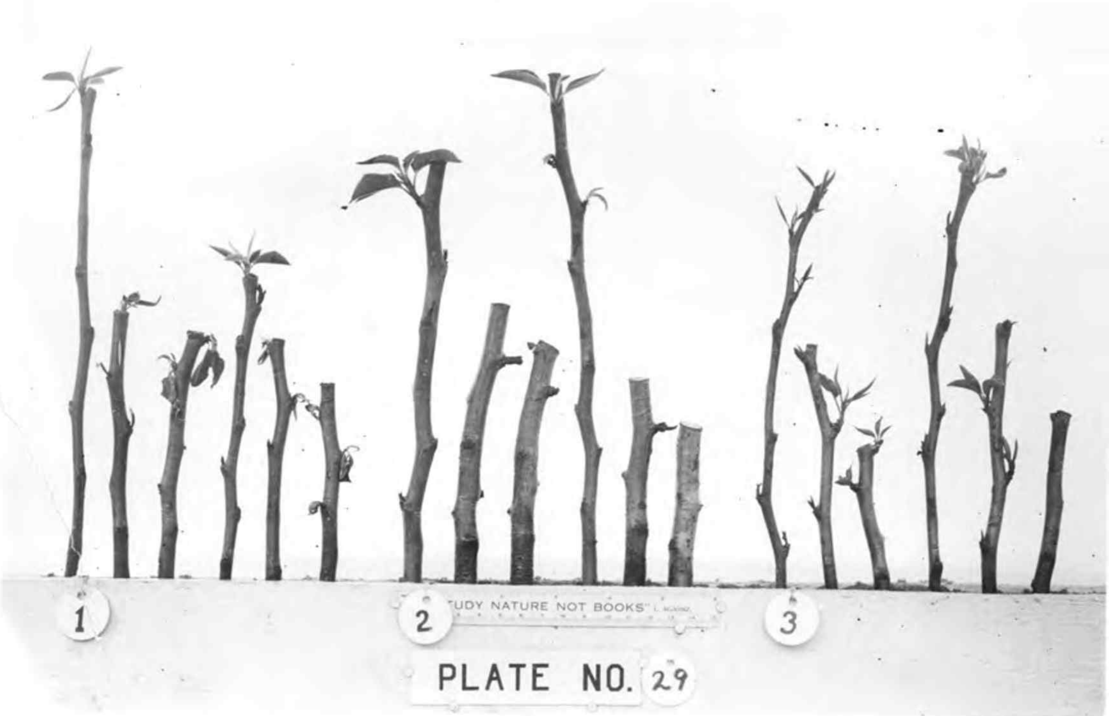
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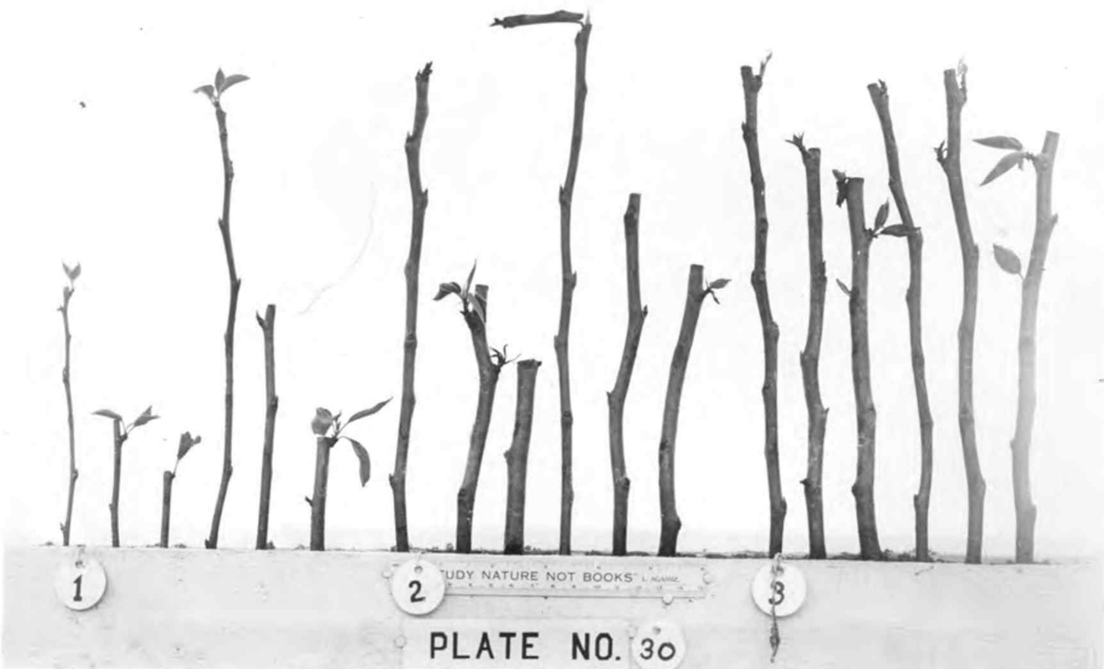
3
PLATE NO. 29


1
2
TUDY NATURE NOT BOOKS"
3
PLATE NO. 30

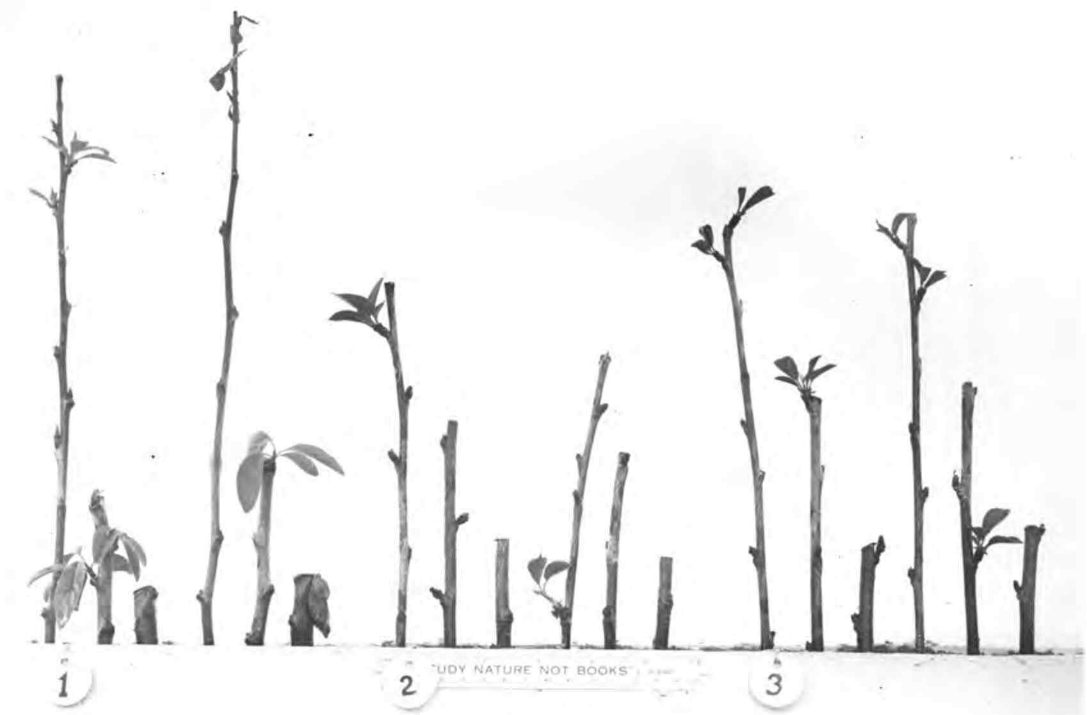


PLATE NO. 31