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TEXT-BOOK OF POMOLOGY

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TEXT-BOOK OF POMOLOGY

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PREFACE

The purpose of this book is to present the experimental and investigational bases of fruit-growing on the physiological side, omitting consideration of the systematic botany and taxonomy as well as of pathology. Pomology has heretofore been approached mostly from the orchard-practice side, born of the experience of cultivators. Gradually the underlying physiological and chemical reasons for the success of these practices are being uncovered. It is on these rational bases that college teaching must henceforth largely rest.

In the preparation of the present volume, it is assumed that the student is familiar with the more common orchard practices, which statement will explain the omission of much informational material. It has been apparent for some time that much of the experimental results which have been accumulating from year to year should be collected into convenient form for students, for it should be the purpose of the student to study (not merely read) the science on which present-day practices in fruit-production are based. It may seem to some persons that we have here gone far afield for much of the material, but the more careful work of recent years has made use of nearly all the sciences in attempting to solve the problems.

It is doubtless true that the advance which agricultural education is making in secondary schools will force the collegiate work into a still more advanced position and much of the material formerly used with satisfaction will give place to more technical and scientific matter. This means, on the one hand, that the college class-room work will lie more in underlying principles than in practices, and on the other, that the laboratory and the supervised summer instruction will become still more practical; and this we believe will meet with the approval of the best informed fruit-growers as well as educators.

In the preparation of this book, the author has drawn freely from the work of others. He has also invited several of his colleagues to make suggestion and criticism of parts of the manuscript. However, in no case was the final copy submitted and, therefore, any errors that may occur devolve entirely on the author. He is particularly indebted to Dr. E. J. Kraus who offered many helpful suggestions and assisted in the interpretation of some of the experimental work. Similarly, Dr. F. E. Bear assisted with Chapters VIII and IX, and Dr. M. J. Dorsey with Chapter XIII. Others who read portions of the manuscript were Drs. W. H. Chandler, J. K. Shaw, H. R. Kraybill and Prof. W. Paddock. To James Macfarlane and J. L. Hayman thanks are due for their kindness in preparing several of the drawings.

Wooster, Ohio,
April 1, 1922.

J. H. Gourley.

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CHAPTER I

THE COMPOSITION OF FRUITS

For convenience, the composition of the common fruits may be divided into three phases: (1) composition of the tree, (2) composition of the fruits, and (3) the changes in the ripening process and in storage. Unfortunately, there is not as great uniformity of opinion among the chemists in regard to the composition of fruits as might be wished for, yet many experimental data are available and are valuable for the present purpose. Different chemical methods in analysis and widely varying material account in part for the results and therefore for the difference of opinion. While it is not possible here to consider the analysis of all the fruits, some of the more important ones may be used for illustration.

Table I

COMPOSITION OF WOOD AND LEAVES OF TREES
POUNDS IN 100 (PERCENTAGE) [1]

	Nitrogen	*Phosphoric Acid* P_2O_5	*Potash* K_2O
	Apple		
Wood	0.50	0.15	0.25
Leaves	1.00	0.15	0.35
	Pear		
Wood	0.30	0.10	0.25
Leaves	0.70	0.12	0.40
	Peach		
Wood	0.43	0.10	0.22
Leaves	0.90	0.15	0.60

[1] Van Slyke, L. L. Fertilizers and Crops. Orange Judd Co., New York, 1912.

1. Composition of apple leaves.—The net loss in fertility from orchard lands is somewhat reduced by the return of the leaves to the soil. True, a portion of them is blown from the orchard and hence it would not be entirely accurate to assume that the land received an annual fertilization of the full amount of the leaves produced. Thompson [1] has shown the amount of fertility represented in the fall of leaves for a period of nine years as follows:

TABLE II

POUNDS OF PLANT-FOOD TO THE ACRE USED IN GROWING TREES TO NINE YEARS OF AGE (AFTER THOMPSON)

	Peach trees			*Apple trees*		
	P_2O_5	N	K_2O	P_2O_5	N	K_2O
Total plant-food taken up by trees in 9 years	50.83	215.90	237.60	9.26	28.10	27.22
Total plant-food returned to the soil by leaves, etc.	23.16	127.93	177.42	2.53	12.84	12.97
Total plant-food retained in trees at the 9th growing season	27.67	87.97	60.18	6.73	15.26	14.25

"The net loss in soil fertility in growing an orchard to nine years of age is represented by the plant-food retained in the trees at the end of the ninth growing season. This table [given above] is based on the assumption that the leaves have not blown away, but have decayed on the land. The peach trees at nine years of age had reached their maximum size. The apple trees were only about one-fifth to one-eighth their maximum size, but the results indicate that an acre of mature apple trees would take from the soil about the same amount of plant-food as an acre of mature

[1] Thompson, R. C. Ark. Agr. Exp. Sta. Tech. Bull. 123.

peach trees. In other words, the approximate total loss of plant-foods in growing an acre of apple trees to their maximum size would be five to eight times the amount shown in the table. This would make the total loss of fertility in growing an acre of peach or apple trees to maturity approximately equivalent to the plant-food contained in 10 bushels of corn. This is surprisingly small and shows very clearly that soil exhaustion in orcharding is almost entirely due to the removal of plant-food in the fruit crop."

Shutt [1] has determined the analysis of the leaves of several standard varieties of apples in terms of composition of the ash, as follows:

Table III

COMPOSITION OF APPLE LEAVES (AFTER SHUTT)

Average of five varieties	*Composition of leaf*			*Percentage composition of important ash constituents*						*Nitrogen*
	Moisture	*Organic matter*	*Ash*	*Phos. acid*	*Potash*	*Lime*	*Magnesia*	*Silica*	*Oxide of iron*	*Nitrogen in organic matter*
Taken May 25	72.36	25.31	2.33	10.17	10.82	17.40	9.77	1.07	1.49	2.94
Taken Sept. 20	60.71	35.83	3.46	5.82	11.63	27.91	4.81	1.14	1.41	2.48

From these data it will be seen that apple leaves, when practically mature, contain 35.83 per cent organic matter which may be returned to the soil, and that there is 2.48 per cent of nitrogen in the organic matter. Of the ash, 5.82 per cent is phosphoric acid and 11.63 per cent is potash, or the relation of these two ingredients in the mature leaves is 2 to 1. Thus it will be seen that there is twice as great a demand on the soil for potash as phosphoric acid so far as the leaves are concerned. As will be seen later, the ratio is still greater in the ash of the fruit since there is six times as much potash as phosphoric acid present there.

[1] Shutt, F. T. The chemistry of the apple. Ann. Rept. Can. Dept. Agr. Ottawa. 1894.

There are no important differences between the ash of the separate varieties of apples, although some variations occur.

2. Composition of apple fruit.—The degree of ripeness, the variety, and the place where grown affect the chemical composition of apples. In general, they contain from 75 to 85 per cent of water, 82 to 84 per cent being rather common. The total solids will be from 10 to 18 per cent of the whole, 75 per cent of which is sugar or allied carbohydrates, and about half a per cent each is fat and protein.[1] These vary markedly, depending on the variety. Malic acid is the predominating organic acid in apples and may run from .15 per cent to more than 1 per cent. Essential oils are also present and are responsible in no small degree for the flavor of the fruit, but they are not easily handled by the chemist and only recently have they been separated and expressed in terms of percentage of the fruit.

TABLE IV

COMPOSITION OF NORMAL MATURE FRUIT OF RED ASTRACHAN APPLE (ADOPTED FROM CULPEPPER, FOSTER AND CALDWELL) [1]

Analyst	*Sources of fruit*	*Total solids*	*Ash*	*Acidity as malic*	*Crude fiber*	*Reducing sugar*	*Cane sugar*	*Protein*
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Browne . .	State College, Pa.	15.30	0.37	1.038		6.67	3.53	
Jones & Colver	Non-irrigated orchard, Idaho	18.10		.9457		6.98	2.15	0.288
Jones & Colver	Irrigated orchard, Idaho	14.73		.890		6.08	2.91	.560
Culpepper, Foster & Caldwell	Auburn, Ala.	12.94	.2548	.9288	2.10	.574	4.960	.245

3. Ash of fruits.—According to Colby,[2] apples and pears withdraw less mineral matter from the soil than do

[1] Culpepper, C. W., A. C. Foster, and J. S. Caldwell, Jour. Agr. Res. 7: 17–40. 1916.

[2] Colby, G. E. Ann. Rept. Calif. Agr. Exp. Sta. 1897–98. pp. 143–148.

many other orchard fruits, averaging .264 to .250 per cent of ash in the whole fruit, while prunes averaged .486; plums, .535; apricots, .508; oranges, .432; lemons, .526; cherries, .482; and grapes, .500 per cent of ash.

The ash of apples averages over one-half of potash, not unlike the other fruits; however, the analysis shows rather more variation for ash than has usually been noticed in the fruits in general. The same remark may be made as to variation in quantity of $P_2\ O_5$, the next largest and most important ingredient. But, on the average, this amount is found to be much like that in the ash of oranges, figs, and apricots, which contain upwards of 12 per cent of phosphoric acid; as against 21.24 per cent for the grape, 15.1 for cherry, and 14.1 of phosphoric acid for the prune. There is about 4 per cent lime in the ash of apple, and a similar amount in the ash of cherries, apricots, prunes, and grapes. The ash of oranges and lemons contains about five times as much as that of the apple.

Colby, in speaking of fruits grown under California conditions, says, "The figures found for apples (and pears) are, on the whole, so much smaller than those which have been obtained for the other ordinary orchard fruits, that it would seem safe to conclude that here fertilizers will not be necessary for apple crops for many years to come. However, the figures do indicate that the first need will be for a nitrogenous fertilizer. Along with this need will come that for a phosphatic fertilizer. There is no reason to supply potash to apple orchards for a great many years to come."

4. Forms of sugar in fruits.—There is not absolute uniformity in the method of expressing the sugar-content of fruits. In general, however, two kinds of sugar are present, sucrose and invert or reducing sugars. The sucrose is mainly cane-sugar ($C_{12}H_{22}O_{11}$), while the invert sugars or dextrose group ($C_6H_{22}O_{11}$) consist of glucose (dextrose), and levulose (fructose). The invert sugars are formed during the ripening process of fruits and result from the union of one molecule of water and one of sucrose, as follows:

Sucrose		Levulose		Dextrose
$C_{12}H_{22}O_{11}+H_2O$ =		$C_6H_{12}O_6$	+	$C_6H_{12}O_6$

Strictly speaking, invert sugar contains equal parts of levulose and dextrose, as can be seen by the above formula, while reducing sugars include levulose or dextrose alone or combined in varying proportions, and may include other reducing sugars and even reducing substances not sugars.[1] This situation has led to some laxity in use of terms and usually the sugars are stated as sucrose and invert or reducing sugars.

5. Sugar-content of ripe fruit juices.—Thompson and Whittier have determined the percentage of sugars in ripe fruit juices by means of polarized light, as they question the value of determinations made by specific gravity on unknown solutions. Their work showed that levulose is the dominant sugar in apples, pears, quinces, and three of the grapes, and far exceeds the dextrose in the apples, pears, and quinces. With the plum and one variety of grape, the dextrose exceeds the levulose, but only in the plum does it far exceed it and in this case it is lower than the sucrose. Sucrose is the principal sugar in peaches and plums.

6. The essential oils.—Power and Chesnut [2] described the oil of apples as follows: "The essential oil, as extracted by means of ether from a concentrated distillate of either ordinary apple parings or those of the crab apple, is at ordinary temperatures a yellowish, somewhat viscid liquid,

[1] Thompson, F., and A. C. Whittier. Proc. Soc. Hort. Sci. 1912. pp. 16–21.

[2] Power, F. B., and V. K. Chesnut. Jour. Amer. Chem. Soc. 42: No. 7. 1509.

becoming much darker on keeping. When slightly cooled it forms a concrete mass, due to the separation of small ocicular crystals, which consist of a paraffin hydro-carbon. It possesses in a high degree the characteristic, fragrant odor of fresh apples. Besides the esters mentioned, it has been found to contain, by specific tests, small amounts of acetaldehyde and furfural. The yield of oil from the parings of the Ben Davis apple was 0.0035 per cent, and that from the more odorous crab apple 0.0043 per cent, which corresponds to about 0.0007 and 0.0013 per cent respectively of the entire ripe fruit."

The esters referred to above are "the amyl esters of formic, acetic, and caproic acids, with a very small amount of the caprylic ester and a considerable proportion of acetaldehyde."

Amyl valerate, which is usually referred to as "apple oil," has not been identified as present in the apple.

7. Quality in apples.—As mentioned above, certain components of the apple give it flavor or eating quality. The term is used rather loosely in pomology, referring sometimes to the dessert quality, sometimes to the cooking property, and again to shipping and market quality.

Shaw [1] has analyzed apple varieties to determine the ingredients which are associated with dessert quality, and the two apples used for illustrating high and low quality are the Grimes and Ben Davis. The following figures show the relative amounts of the important ingredients, each being the average of eleven determinations.

[1] Shaw, J. K. Proc. Amer. Soc. Hort. Sci. 1912. p. 29.

Table V

ANALYSIS OF A HIGH AND A LOW QUALITY APPLE (AFTER SHAW)

	Water	*Total solids*	*Soluble solids*	*Insoluble solids*	*Reducing sugars invert*	*Sucrose*	*Total sugars*	*Acid as malic*
Ben Davis	84.32	15.66	12.59	3.07	6.91	2.95	9.86	.44
Grimes...	82.12	17.88	15.18	2.70	8.77	4.30	13.00	.45

From these figures it is seen that the high-quality apple has a much larger percentage of total solids, and when it is remembered that upwards of 75 per cent of the total solids are sugars, it will be seen that the Grimes is much to be preferred. (In this case, the Ben Davis has about 62 per cent and the Grimes 72 per cent of sugar in the total solids.) While sucrose is a valuable form of sugar in fruit, it has been shown previously that levulose is dominant in the apple.

The relation of acid to sugar is important for high quality, for here is secured the sprightliness which usually is associated with a dessert apple, although this depends on the taste of the individual. Shaw found from .1 to .2 per cent in sweet apples to nearly 1 per cent or possibly more in very acid sorts. The ratio of acid to total sugars varies from about one to one-hundredth in sweet apples to one to eight-hundredths in very acid sorts.

The flavoring or essential oils which have been discussed are also of great importance in quality.

"It appears then that high table quality in apples depends on (1) good texture which is accompanied by a low content of insoluble solids, (2) an abundance of sugars, especially sucrose, (3) an amount of acid sufficient to blend agreeably with the sugars but not excessive and (4) an abundance of pleasant and agreeable flavoring oils."

8. The effect of location on quality.—While it is recognized that there is a marked difference in quality of fruit depending on where it is grown, there is not much data showing the chemical analysis of such fruits. Colby[1] has shown the effect of location on quality of fruit, particularly for the conditions which obtain in California.

Apples which were grown at a high elevation averaged higher in both sugars and acids, which makes the best combination for a dessert apple. Those raised at elevations (4000 to 5000 feet) analyzed as high as 15 per cent sugar and .55 per cent acid in the juice, while those from lower levels (50–150 feet) analyzed about 2 to 4 per cent lower in sugars and as low as .16 and .17 per cent acid (in terms of sulfuric acid, SO_3).

Eastern apples, according to data cited, analyzed from 10.42 per cent sugar (Baldwin) to 11.36 per cent (Rhode Island Greening) in the juice. European grown fruits showed a still lower sugar-content, averaging 7.22 per cent.

9. Composition of fruits grown on irrigated and non-irrigated land.—The statement has not infrequently been made that fruits grown under irrigation are "flat" or insipid in flavor and are less able to withstand shipment and rough handling than fruit raised on non-irrigated land. To determine whether there is any essential difference in composition, chemical analyses were made by Jones and Colver[2] of various fruits so grown. The results indicate that "From a general survey of analytical results, it may fairly be said that fruits in general manifest a well-defined tendency to elaborate greater percentages of total solids or dry matter, consequently of sugar, acid, and crude protein, when grown in non-irrigated sections. With comparatively few exceptions,

[1] Colby, G. E. Rept. Calif. Agr. Exp. Sta. 1897–98. p. 143.

[2] Jones, J. S., and C. W. Colver. The composition of irrigated and non-irrigated fruits. Idaho Agr. Exp. Sta. Bull. 75. 1912.

however, no marked difference between irrigated and non-irrigated fruits in actual food or market value should be charged to differences in composition."

10. Chemical changes in the growing apple.[1]—Only data for winter apples will be included here, since the same general processes go on with summer varieties; the information, however, is not so satisfactory owing to the uneven ripening of the latter.

This work was carried on with Ben Davis, Huntsman, and Winter Paradise. The curves (Fig. 1) show in a striking way the chemical changes which occurred throughout the season, from June 16 until November 5.

Using total solids as a basis, it will be seen that starch increases until the latter part of July when it has reached its maximum, then it begins to decline constantly but does not entirely disappear. The sucrose curve is almost the exact reverse of the starch. This form of sugar starts with a low percentage and continues low until the middle or latter part of July, when, through the conversion of starch into sugar, it begins to rise and continues until the fruit is ripe. On the date of the first examination of these varieties, June 16, the content of sucrose based on total solids was 4 per cent, and at the last examination, on November 4, it amounted to 25.4 per cent of the total solid content of the apple, the rate of increase being apparently no greater before the maximum content of the starch than afterwards. Unlike the summer apples which had been examined, the percentage of invert sugar here increased from the date of the first examination to approximately the date of the last, so that even in percentage composition the amount of invert sugar did not reach its maximum until the fruit was mature.

In all three of the varieties of winter apples studied, the

[1] Data and comments are taken from work of Bigelow, W. D., H. C. Gore, and B. J. Howard. U. S. Dept. Agr. Bur. Chem. Bull. 94. 1905.

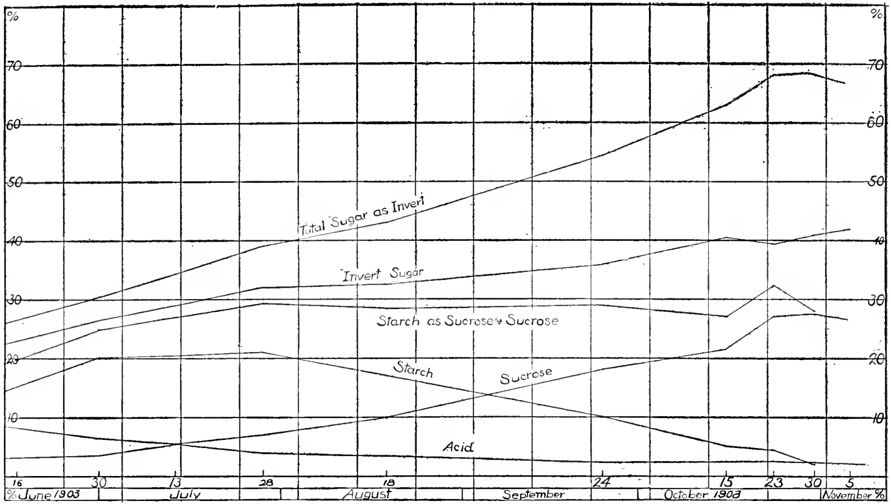


Fig. 1.—Curves showing the average chemical changes in the growing apple.

percentage of malic acid decreased from the first examination to the full maturity of the fruit. The percentage of total sugar estimated as invert sugar increased steadily from the first examination to full maturity. It is notable that after the maximum content of starch is reached, the percentage of starch and invert sugar taken together remains approximately constant.

More recently Thatcher[1] has shown that the only enzymes which were found to participate in the changes in the carbohydrates of apples during the ripening process were the oxidases.

11. Composition of apples in common storage.—It is of interest to follow the ripening process as it occurs after the fruit is picked and placed in storage. The work of Bigelow et al.,[2] Browne[3] and Kulisch,[4] are in substantial agreement, although performed under widely differing conditions.

Bigelow's work with Rhode Island Greening apple illustrates this ripening process, the apples having been picked between October 6 and November 7. The curves in Fig. 2 show graphically the progress of the ripening. By referring to them it will be noted that there was 13 per cent of sucrose on August 25, at the time the experiment was begun, and it increased rapidly until November 7 when it reached its maximum 30 per cent. The sucrose then rapidly disappeared until February 11 when the experiment was discontinued, at which time it was 6 per cent. It is of particular interest to note that the starch declined rapidly from August 25 until November 7 when it entirely disappeared, this being the same date when the sucrose reached its maximum. Here

[1] Thatcher, R. W. Enzyms of apples and their relation to the ripening process. Jour. Agr. Res. 5[3]: 1915: 103–116.

[2] *Loc. cit.*

[3] Browne, C. A., Jr. Penn. State Dept. Agr. Bull. 58.

[4] Kulisch, S. Landw. Jahrb. 1892. 21: 871.

again is evidence that the starch is transformed into sugars as the ripening proceeds.

The malic acid also continues to behave as it did during the growth and development of the fruit. There is a gradual disappearance throughout the storage period.

Invert sugars, unlike the starch and sucrose, continue to increase throughout the experiment, being as high as 62 per cent in February. They gain rapidly as the sucrose disappears, indicating the transformation.

The total content of sugar (calculated

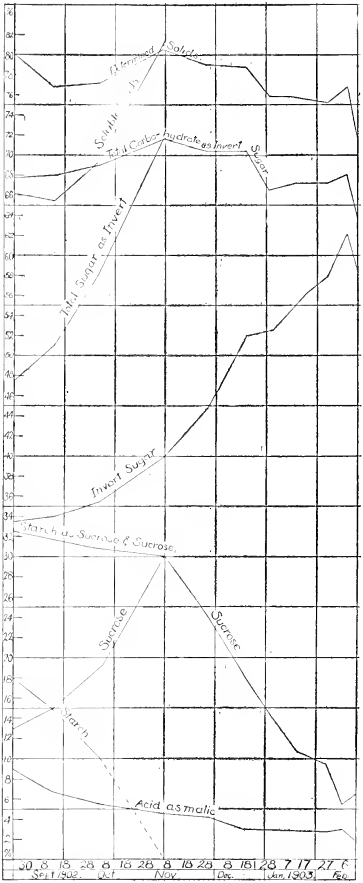


Fig. 2.—Curves showing chemical changes in Rhode Island Greening apple in common storage.

as invert sugar) increased from the first examination to the date of the disappearance of the starch. After this date the curve, representing the total sugar as invert, merges with that indicating the total carbohydrates as invert sugar. In the Rhode Island Greening, the total carbohydrate content decreased to some extent after the disappearance of the starch. This latter was not true, however, of some other varieties studied.

12. Changes in composition of the peach during growth and ripening.[1]—In determining the chemical changes which take place in the growing peach, the fruit was selected at the following times for analysis: (1) after the June drop, (2) when the stone hardens, (3) when market ripe, and (4) when fully ripe. The varieties used were Triumph, Rivers, Early Crawford, Stump, Elberta, Orange Smock, and Heath Cling.

The following data illustrate the marked changes in composition between the early stages of growth and when the peach is fully ripe:

TABLE VI

COMPOSITION OF PEACHES AT DIFFERENT STAGES OF GROWTH

COMPOSITION OF WHOLE FRUIT (AFTER BIGELOW AND GORE)

	Stage of growth	*Weight of peach*	*Flesh*	*Stone*	*Kernel*	*Total solids in flesh*	*stone*	*kernel*
		Grams	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average of six varieties	June drop	9.51	64.55	32.50	2.94	14.77	9.37	6.89
	Stone hardened	16.75	71.54	25.82	2.89	16.97	27.35	7.54
	Market ripe	73.59	92.49	6.86	.65	14.04	66.94	44.78

ANALYSIS OF FLESH

	Stage of growth	*Sucrose by reduction*	*Reducing sugars*	*Acid as sulfuric*	*Ash*
Average of six varieties	June drop	.18	2.71	.28	.75
	Stone hardened	1.57	2.26	.34	.68
	Market ripe	5.70	1.98	.56	.40

[1] After Bigelow, W. D., and H. C. Gore. U. S. Dept. Agr. Bur. Chem. Bull. 97. 1905.

Between the time of the June drop and market ripeness, the peaches increased in weight nearly eight times. During the same time the percentage of flesh in the peach increased less than one-half, while that of the stone decreased from 32.5 to 6.86 and that of the kernel from 2.94 to 0.65 per cent.

The percentage of solids of the flesh remains fairly constant during the life history of the peach; that is, the increase in solids is fairly proportional to that in water. This is shown by the fact that the percentage of solids did not greatly change from the time of the June drop to the period at which the peaches were considered market ripe. On the other hand, in the same period the stone changed greatly in its nature. As it became harder and more mature, the percentage of water materially decreased and that of solids increased from 9.37 at the period of the June drop to 66.94 when the peaches were market ripe. The solid content of the kernel increased from 6.89 to 44.78 per cent. At the same time, it should be noted that the percentage of solids in the kernel did not materially increase until after the hardening of the stone.

By examining the analysis of the flesh, it will be seen that, unlike the apple, the reducing sugars decreased as the ripening proceeded. The same was also true of the percentage of nitrogenous substances in all their forms calculated as total protein, albuminoids and amido bodies, and also of ash. On the other hand, the percentage of sucrose and of acids increased from the beginning to the end of the experiment.

Analyses were also made to determine the changes which take place between what is termed "market ripe" and "full ripe" and the following data present the findings during this stage:

Table VII

ANALYSIS OF FLESH OF THE PEACH (AFTER BIGELOW AND GORE)

		Marc [1]	*Reducing sugar*	*Total sugar invert*	*Sucrose by reduction*	*Acid*	*Ash*
Average.....	Market ripe	2.91	2.20	7.97	6.23	.53	.57
	Full ripe	2.30	2.27	9.13	7.36	.48	.55

While not indicated in the table, there was not much change in the percentage of flesh, stone, and kernel. There is some increase in the percentage of sugar, while that of marc and acid decreased slightly. It may also be pointed out that, comparing the composition of the flesh of the peach with that of the apple, there is practically no starch in the former (only at the very beginning), while the latter is quite high in starch until later in its development.

13. Ripening process in pears.—The pear is unique in its requirements for proper ripening. While many other fruits may be picked when ready for use or when "hard" ripe in order to lengthen their keeping, the pear must be picked much earlier relatively in order to allow the ripening process to proceed off the tree. This produces a fruit of much higher quality for all purposes than when it ripens entirely on the tree. Hence a study of the changes which occur in ripening is of more than ordinary interest, and the work of Magness [2] may be cited in this connection.

Fruit which had been produced in three of the principal pear-growing sections of the Pacific Coast and picked at

[1] This term applies to the total insoluble matter of the flesh of the peach, including the skin.

[2] Magness, J. R. Investigations in the ripening and storage of Bartlett pears. Jour. Agr. Res. 19: 473–500. 8 fig. 1920.

intervals from early summer until after the commercial picking season, were analyzed within a few days after picking and after being in storage one and one-half to three and one-half months at temperatures of 70, 40, and 30 degrees F. Both sugars and acids were determined as well as the alcohol-insoluble, acid-hydrolyzable reducing materials.

Like the apple which has already been studied, the Bartlett pear increased in total sugar from early summer until after the close of the commercial picking season. The increase in the latter part of the season is mainly due to an accumulation of sucrose, while the earlier increase is due mainly to reducing sugar. It will be remembered that the winter apples showed their greatest increase in sucrose also during the latter part of their development, although the invert sugars increased in the apple throughout the ripening process of the fruit.

Further, "A distinct relationship was found between the total amount of sugar present in the ripe fruit and the temperature of the storage at which it had been held from the time of removing from the tree until ripe. Pears ripened at 70° F. contained the highest percentage of sugar; those ripened at 40° possessed the lowest total sugar content, and those held at 30° for from 6 to 14 weeks and then ripened at room temperature were intermediate in amount of total sugar. There was no marked relation between temperature of storage and relative amount of sucrose and reducing sugar."

It is further observed that, "It seems well established, therefore, that the highest amount of sugar will be secured by holding the fruit at optimum temperature for ripening.

"Percentage of titratable acid in the fruit tended to decrease in fruit from the California sections as the season advanced, while it tended to increase in that from Oregon and Washington. There was an increase in acid between the time of picking and the time of full ripening of the fruit when held at 70° F. There was much less acid in fruit ripened at 40° than in that ripened at 70°, and still less in fruit that had been held at 30°. The acid content of fruit that was allowed to become well matured on the tree remained nearly constant during storage." Since there was always a greater amount of acid in fruit which was removed and ripened at 70° F. than when the fruit was picked from the tree, it becomes "of interest especially in connection with the question of whether fruit acids are synthesized in the fruit itself or whether they are carried to the fruit from the leaves. The fact that there is an increase in the acid between the time the fruit is removed from the tree and the time of its becoming ripe is evidence that there is an actual synthesis of acid in the fruit itself.

"There was a progressive reduction in the alcohol-insoluble, acid-hydrolyzable reducing material as the season advanced, not only in the fruit fresh from the tree, but also in the same fruit after ripening. There is a marked reduction in these substances between the time when the fruit is first picked and the time when the same fruit becomes ripe.

"The percentage of total solids is lowest at about the opening of the commercial season. This tends to increase with the accumulation of sugar in the late-picked lots."

CHAPTER II

THE BUDS OF FRUIT-TREES

An accurate knowledge of the "bud system" of the several kinds of fruit-trees is of first importance and should be thoroughly understood by the student before attempting to learn the art and principles of pruning. The intelligent fruit-grower observes the "set" of fruit-buds and their condition as a guide to the response of the trees to cultural treatment; he likewise examines them in the more tender varieties to determine the percentage of live buds in early spring. Similarly, in many other ways the buds afford an index to the functioning of the tree.

The consideration of buds naturally divides itself into three phases: (1) the location of the buds on the tree, and the "bud system" in the different kinds of fruits; (2) the time and details of differentiation of the flower-buds; and (3) the factors that influence the formation of flower-buds.

Although the study of the location of the buds on the tree is no longer a matter of intricate research, yet it requires accurate observation in the field or laboratory, for there is much still to be learned concerning the relative economic value of buds located or developed in different parts of the tree, or of a branch or spur system. For example, it has been observed that in some varieties of the peach and cherry, the fruit-buds are more hardy when they are borne on short growths which are located throughout the inner area of the tree, while in others the reverse seems to be true. Buds in certain positions also are more likely to mature and the fruits will color better or have other advantages over those borne elsewhere on the tree.

14. Buds defined.—Buds are undeveloped shoots or branches, whether their content be of a leafy or floral nature or both. The closed, scaly, resting buds of fruit-trees represent a provision of the plant to protect the tender growing points or partially developed flowers and carry them over a relatively inactive period. This provision is in contrast to the "naked" buds of many tropical trees and shrubs, where climatic conditions do not require a winter resting period, and yet even in the tropical plants a period of rest of greater or less duration does exist. It might be added here also that sometimes there are several such periods of rest, followed by activity, known often as "flushes" of growth. Some northern plants also produce naked buds (as niost herbs, Kalmia, etc.). Buds have also been described as the free extremities of branches or incipient branches.[1]

15. Gross structure.—The buds of all the common fruits are covered with overlapping scales which are, morphologically, specialized leaves. The bud-scales are accompanied in some cases with a mat of soft hairs (pubescence) and sometimes with more or less resinous material of a water-proof nature. Within these scales are the partially developed leaves, flowers or both, depending on the bud in question, and the axis on which they are borne. From the time the buds are initiated in the summer (or autumn) previous, until they open, there is a progressive development, some activity going on even during the milder weather of midwinter. Frequently the exact number of leaves which a shoot will bear are present in the bud, but this is not always the case, for vigorous shoots may develop additional ones during the season. Particularly is this true with the peach, plum, and apricot, and probably to some extent with most fruit-trees. Likewise the size which the leaves will attain is determined

[1] Halsted, B. D. Memoirs: Torrey Bot. Club, 2: Sept. 1890.

by the "growing conditions" of the season in which they expand, and the reserves carried over from the previous years. However, an increased length of shoots may be due to an elongation of the internodes, such as occurs when a tree is stimulated just previous to or while the growth is being made, or if the tree is shaded during the period of growth (the latter constituting a lack of light stimulus).

16. Classification of buds.—Unfortunately there is some confusion in the terminology relative to the classification of buds. This variance in nomenclature by horticultural writers is due to an effort to use terms that are self-explanatory, relating to position of the bud, its structural contents, or to what it will give rise. The following terms as here defined will be used throughout this discussion.

17. Leaf-buds.—A "leaf-bud" contains the rudiments of a leafy branch, which may develop into a shoot or a spur. As pointed out above, the development of parts within the leaf-bud does not necessarily predetermine the length of the shoot or the number of leaves it will bear. Probably such is the case, however, with the short spurs. The term "branch" bud is frequently employed in horticultural writings to describe the same type of bud and has some advantages in clarity, but is scarcely more accurate than "leaf" bud. "Wood" bud is also used by some writers, but is less desirable and still less descriptive.

18. Fruit-buds.—A fruit-bud contains the unexpanded parts of the flowers. The term "inflorescence bud" would be more descriptive but does not follow usage. It may comprise one or more individual flowers and perhaps also leaves or bracts, depending on the kind of fruit-tree. In the apple and pear, the fruit-bud usually contains one or more axillary leaf-buds also as well as the enfolding leaves. That is, the blossom buds of these fruits are "mixed," and when they have opened and fully expanded, a close examination usually reveals a "secondary" growth arising from the axil of one or more of the leaves. This secondary growth may develop into a shoot of several inches in length or into a spur; generally it is short, oftentimes merely a bud. Usually it is terminated by a leaf-bud, but if the blossoms fail to "set," a fruit-bud is often formed. In fact, it is by no means rare for a fruit-bud to form on this shoot even though one or more fruits are developing. (See Fig. 3.)

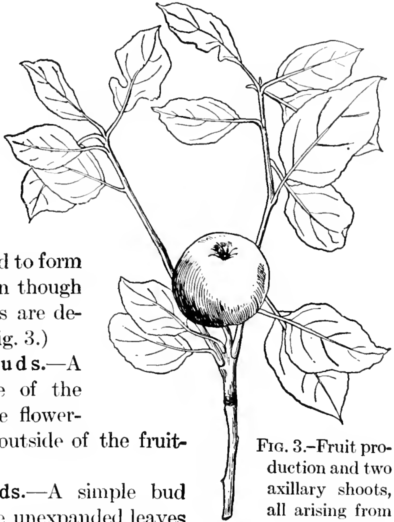


FIG. 3.–Fruit production and two axillary shoots, all arising from a single fruit-bud. (Rome.)

19. Flower-buds.—A flower-bud is one of the individuals of the flower-cluster, inside or outside of the fruit-bud.

20. Simple buds.—A simple bud contains either the unexpanded leaves or flowers, but not both. The term usually refers, however, to the fruit-bud. The peach, plum, and cherry have simple buds, but the latter may contain rather prominent leafy bracts also.

21. Mixed buds.—A mixed bud contains both flowers and leaves; hence it always refers to the fruit-bud. The apple and pear have mixed buds. The fruit-buds of the apple and pear are usually larger, plumper, and less pointed than the leaf-buds, but this is by no means universal. In the Baldwin and many other apples, for example, it is almost if not quite impossible to distinguish the fruit-buds in the winter without dissecting them. Also, different varieties have to some extent fruit-buds which are characteristic in some particular, such as color, shape, size, or the degree to which they are appressed to the shoot.

22. Terminal and lateral buds.—All buds of necessity must be borne either terminally on the end of a shoot, in which case they are called "terminal" (or apical), or on the sides of the shoot, when they are known as "lateral buds." The latter regularly occur within the axil of a leaf and are termed "axillary buds," although at times some lateral buds are adventitious. If more than one leaf-scar is found at the base of a bud, it must be considered terminal though on an exceedingly short shoot, and not an axillary bud. Frequently, a very close examination is necessary to distinguish between an axillary and a terminal bud on an exceedingly short spur. On the other hand, not all buds which appear to terminate a shoot or branch are terminal, for, as in the case of many plums and the apricot, no true terminal bud is formed but the distal bud is axillary.

23. Latent buds.—A latent bud may remain dormant, or fail to expand, for more than one year and then through some impetus or stimulation start into growth. There are a large number of latent buds on fruit-trees, and if this were not true so many shoots would develop that many would perish for lack of light, nutrition, and other factors. Often these dormant or latent buds are overgrown or outgrown by the surrounding tissues, but remain alive. Thus, many apparently adventitious shoots really arise from latent buds.

24. Adventitious buds, as mentioned above, arise in abnormal or unusual places. They arise on both roots and branches, especially if the parts above are removed or injured. After severe pruning operations, it is a common occurrence for adventitious buds to arise from the smooth bark of the large limbs below or from the healing tissue about the wound. It is also common for such buds to form and develop branches below a ringed portion of the trunk or limb.

25. Collateral buds.—Buds may occur singly or in groups of two, three, or more side by side, in which latter case they are said to be collateral, as with the peach and some kinds of plums.

26. Leaf-scars are of some importance in studying buds. They are the former places of attachment of the leaves and should be distinguished from those of the bud-scales, as the latter scars are sometimes rather conspicuous early in the growing season. In the larger leaf-scars of the apple, the points of separation of three vascular bundles can be seen. As an axillary fruit-bud opens, a cleavage plane or "crack" usually occurs in the tissue between the vascular bundles, but this should not deceive the observer into believing each bundle to represent a separate leaf-scar.

27. Fruit-spurs.—The term "fruit-spur" as commonly used in pomological literature designates a short shoot that produces flowers and fruit, in contradistinction to the longer shoots of the tree. Probably no clear-cut distinction can be drawn between these spurs and the other vegetative growths of the tree, since a fruit-spur may become highly vegetative and develop into a large branch. Likewise also a short growth or spur may continue growth for many years without producing flowers or fruits. The general term "spur," however, is of service to distinguish the short growths which are common on fruit-trees and upon which much of the fruit is borne. In the cases of the plum, the cherry, and the peach, when they produce spurs, the fruit-buds are borne laterally, whereas the terminal or distal bud of the spur generally is a leaf-bud, and the elongation of the spur is, therefore, continued in a straight line, or sometimes the spur perishes entirely. With the apple and the pear, on the other hand, a leaf-bud may end the growing axis, in which case further elongation in a straight line is possible. But when fruit-buds are produced they are usually terminal, whether the axis which bears them is long or short, so that further elongation of the spur is forced out of a straight line through the development of lateral buds, which may be produced below the fruit-bud, but as a rule are developed from axillary leaf-buds which have their origins within the fruit-bud itself, as is discussed above. Such growths may be short or several inches long.

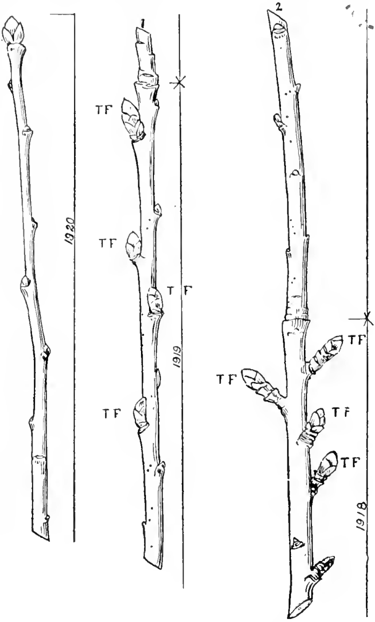


FIG. 4.—Short spurs of apple bearing terminal fruit-buds. TF = terminal fruit-bud.

This secondary growth is of prime importance in the maintenance of the fruit-spur, although when the spur is very weak it may not develop. The power of continuing growth or development in the short spur, especially after it becomes old, is apparently centered largely in the terminal bud, whether this is a leaf- or flower-bud.[1]

28. Fruiting of the apple.—The development of spurs in the apple can be seen in Fig. 4. Several are already short fruit-spurs and others may or may not develop from the short terminal spurs which have produced only a leaf-bud at the terminus. In this case, all the lateral buds and the terminal one on the one-year growth are leaf-buds; on the two-year wood there are four fruit- and five leaf-buds shown in the drawing; and on the three-year wood are four fruit- and two leaf-buds, indicating that none of them behaved in their second year as occurred above, for no flowers were produced on the spurs before. This, then, may be considered one type of fruit-spur formation on the apple. Since they are yet unbranched, they may be termed "simple spurs."

In Fig. 5 is shown a second type of fruiting habit of the apple. In this case, the one-year wood has produced both a terminal and axillary (or lateral) fruit-buds. They can be clearly distinguished by their size. This type of flowering is very common with the apple and pear. This is a case of fruit-bud formation without a spur being first developed, for only one leaf subtended these buds and hence they are, by definition, axillary. The student should make close observations, however, for it is not unusual to find a very short spur (sessile) on the one-year wood, having produced only two or three leaves, and hence a fruit-bud in such a

[1] The author observed for several years the results of "disbudding" spurs by partridge or grouse (*Bonasa umbellus*, L.). The terminal buds of the short spurs were broken off throughout certain trees in an orchard and the question arose as to how long it would be before the spurs were again sufficiently developed to produce fruit-buds. The results were rather uniform in that about 80 per cent of these spurs died.

case in the strict sense would be terminal and not axillary. Some varieties of apples yield annual crops, because the fruit in one of the years is produced largely from axillary fruit-buds on the one-year old wood. Such varieties as the Jonathan, Wealthy, and

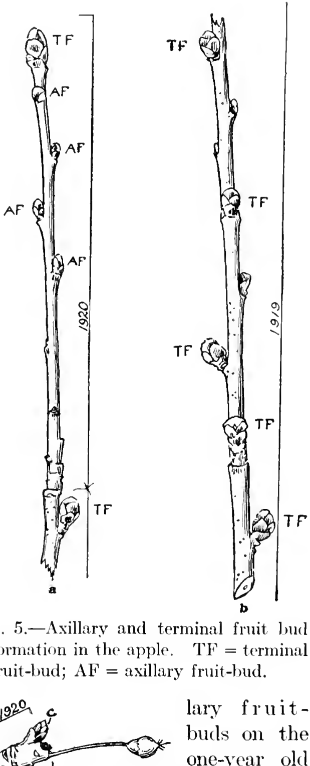


Fig. 5.—Axillary and terminal fruit bud formation in the apple. TF = terminal fruit-bud; AF = axillary fruit-bud.

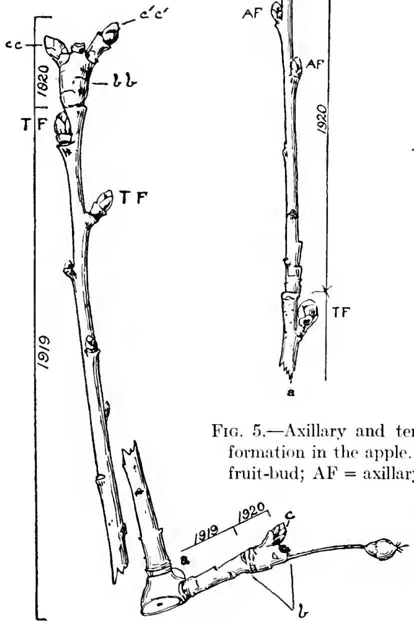


Fig. 6.—The beginning of a fruit-spur system in the apple.

Missouri Pippin produce axillary fruit-buds freely. The short spurs in Fig. 5 are homologous to those in Fig. 4.

A third type or rather an advanced stage of spur formation is seen in Fig. 6. In this case, a terminal fruit-bud was formed in 1918 and two secondary shoots arose in 1919 from the cluster base (a), both of which produced fruit-buds. In 1920 the fruit-buds expanded and developed a cluster base at b and bb, and they gave rise to one short secondary growth at c which is a leaf-bud, and two secondary growths at cc and c′c′, both of which were leaf-buds although from their size they might have been mistaken for fruit-buds. Thus there is the beginning of a "compound spur system" (probably a fruit-spur system).

The Rome Beauty produces a large number of its fruit-buds terminally, *i. e.*, on the ends of rather long shoots. In fact, this is the characteristic method of production in that variety. Usually the same spur would not fruit annually, but every second or third year, depending on the vigor of the tree. If the history of the branches is traced back on the tree, it will be found that the branch (or spur system) continues to elongate and the place where the flowers or fruits were borne is gradually overgrown and the branch appears straight, rather than angular as in the case of the short branched

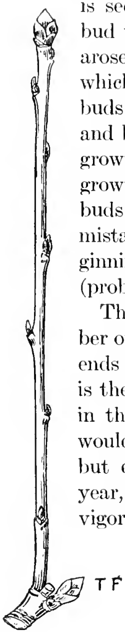


Fig. 7.—A flower-cluster base that has produced a fruit-bud and a long shoot. (Rome apple.)

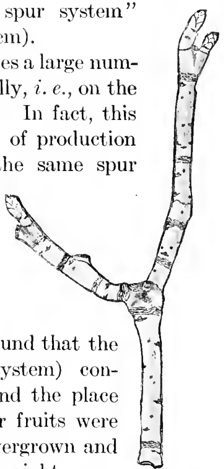


Fig. 8.—Branched fruit-spur system of the apple.

spur system, such as is illustrated in Fig. 8. In Fig. 7 is seen the beginning of the spur systems of the Rome.

What may be termed a typical compound spur for many apple varieties is shown in Fig. 8. Such a spur may continue bearing fruit from its several units for many years.

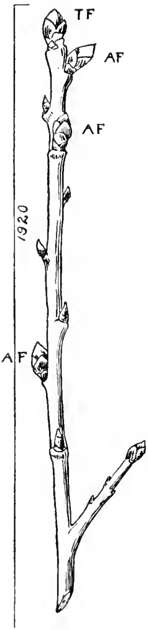


FIG. 9. — Axillary fruit-bud formation in the pear.

29. Fruiting of the pear.—This fruit is closely related to the apple botanically and it forms its fruit-buds in much the same positions. The fruit-bud is usually terminal on a spur, although terminal ones on long shoots or even water-sprouts are fairly common. Fig. 9 shows a shoot of pear which has produced a terminal fruit-bud and three axillary ones, while in Fig. 10 is seen a vigorous fruit-spur on which three terminal fruit-buds appear and also one axillary.

30. Fruiting of the peach.—The peach differs from the apple and pear because fruit-buds occur freely on the vigorous, often much branched, one-year-old wood, which also produces the vegetative extension of the tree. It will be remembered that the one-year-old terminal shoots of the apple yield a very small portion of the fruit-buds only and very frequently none. The lateral shoots on the one-year-old wood of the peach may be rather short (less than one to three inches long) and because of their length may be termed spurs. Such spurs are frequently very fruitful, and the fruit-buds produced on them may be more hardy than those on the more rampant growth of other branches or trees. Also short spur-like growths are frequently found on the older branches or trunk of the peach tree. These spurs arise from latent or adventitious buds, frequently at the place where a shoot or branch has died or been removed. These spurs are often fruitful and may perish after one year's growth or may continue a short unbranched growth from a terminal leaf-bud for two, three, or more years, but usually they are not long-lived.

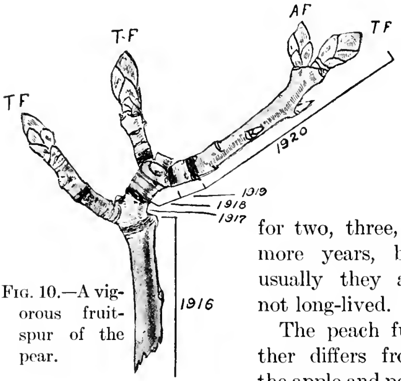


Fig. 10.—A vigorous fruit-spur of the pear.

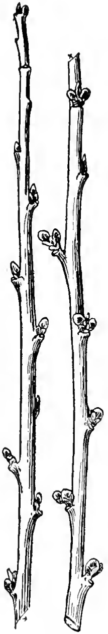


Fig. 11.—Fruiting habit of the peach.

The peach further differs from the apple and pear in the number of buds that may stand at a node. Any of the following conditions may be found at a node on the one-year wood of the peach, and sometimes all of them on a single shoot:

1. A single leaf-bud.
2. An axillary fruit-bud.
3. A leaf-bud and fruit-bud in the axil of a single leaf.
4. Two fruit-buds with a leaf-bud between them or to one side of them in the axil of a single leaf, or with a leaf

subtending each bud, or on a very short sessile spur.

5. Two fruit-buds in the axil of a single leaf.
6. Three fruit-buds in the axil of a single leaf.
7. A fruit-bud between two leaf-buds.

The fruit-buds of the peach are usually large in comparison with the leaf-buds and are also pubescent. They are simple, comprising as a rule only one flower-bud, but in some cases they may contain two. As a rule, a weak or short branch bears only single fruit-buds, while the double or triple ones are borne mostly on the stronger growth. A branch may be so strongly vegetative, however, that no fruit-buds are produced. Fig. 11 illustrates the fruiting wood of the peach.

31. Fruiting of the cherry.[1]—Like the other stone-fruits, the sweet cherry bears from axillary fruit-buds. They are formed both on the terminal growth, more particularly near its base, and on short spurs which are found, characteristically, on the older wood. The terminal buds of both branches and spurs are leaf-buds, with the result that their growth is in a straight line, in contrast to the apple and pear. Whipple states that the sweet cherry spurs will be alternating in their bearing if the trees are not well cared for and properly pruned.

The sour cherry forms its fruit-buds in practically the same positions as does the sweet cherry. At times all the axillary buds on the new growth are fruit-buds, which results in a naked branch the following season. The terminal ones, however, are leaf-buds and hence they continue the growth of the spurs and branches and furnish a leaf area to support the developing fruit below. Fig. 12 shows one type of fruiting wood of the sour cherry.

[1] Whipple, O. B. The pruning of stone fruit trees. Better Fruit. Nov., 1917. Pruning the sweet cherry. Better Fruit, Dec., 1918.

32. Fruiting of the plum.—It is necessary to divide the plums into groups according to species, as follows: *Prunus domestica*, *P. salicina*, and the American species. All, however, bear only simple buds, although bracts may appear when the buds open.

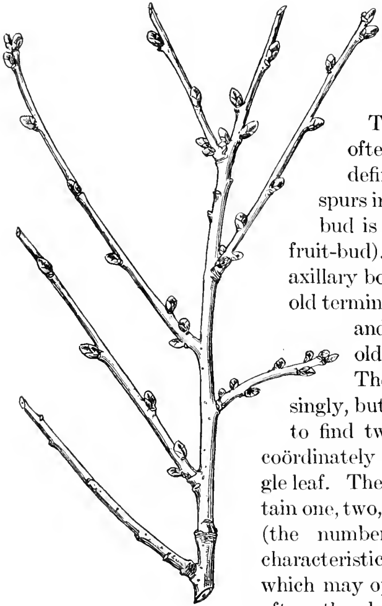


Fig. 12.—Fruiting habit of the sour cherry. A strongly vegetative type.

The Domestica plums often develop a well-defined system of fruit-spurs in which the terminal bud is a leaf-bud (rarely a fruit-bud). Fruit-buds are axillary both on the one-year-old terminal growth of the tree and on the one-year-old wood of the spur. They are usually borne singly, but it is not uncommon to find two or perhaps three coördinately in the axil of a single leaf. The bud itself may contain one, two, or three flower-buds (the number being somewhat characteristic for the variety) which may open before, with, or after the leaves appear. The spur under some conditions may terminate in a thorn rather than in a leaf-bud.

The Japanese plums, *Prunus salicina*, produce axillary fruit-buds only. They are borne on the new wood either singly or in pairs with a leaf-bud between them, or in clusters.

They also are borne singly or in clusters on short spurs on the older growth, and such spurs may also be produced on the new growth.

The American species of plum are much the same as the *P. salicina* in fruiting habits.

33. Fruiting of the apricot.—The fruiting habit of the apricot is practically the same as that of the peach. The fruit-buds are borne singly, or in pairs on the new growth with a leaf-bud between them, or on short spurs on the older growth. There is no true terminal bud, but what appears so is a true lateral bud and it continues the growth of the branch. The cluster of fruit-buds on the new growth is borne in the axil of a single leaf instead, as may occur at times with the peach, each bud in the axil of a leaf. Spurs are formed more frequently with the apricot than with the peach.

34. Fruiting of the quince.—This fruit differs from the apple in the behavior of its over-wintering fruit-buds, in the fact that the terminal bud which contains the flower makes a short leafy growth of one to several inches and the simple (or single) flower is then unfolded. The fruit-buds are usually produced on short shoots (spurs) which become branched somewhat after the manner of an apple spur. Axillary flower-buds may also occur abundantly on the one-year-old terminal shoots.

35. Fruiting of the grape.—This fruit also produces over-wintering mixed buds borne laterally on canes of one year. The flowers occur from lateral buds on the one-year wood. "All species except *Vitis Labrusca* average two inflorescences to the cane but the last-named species, at least in some of its subdivisions, may bear from three to six inflorescences, each of course in the place of a tendril opposite a leaf." (*Hedrick.*)

CHAPTER III

THE DIFFERENTIATION OF FLOWER-BUDS

Before studying the factors that influence the formation of flower-buds in fruit-trees, the morphological changes which take place in bud formation from the earliest stages to completion should be well understood. This has been worked over by several horticulturists[1] and descriptions of the stages of development are available for the apple, pear, peach, plum, cherry, and some other fruits.

It has long been recognized that in the deciduous tree-fruits, generally, the flower-buds are more or less well developed the season previous to their unfolding, although the details of their formation have been worked out but recently. As late as 1899, Goff wrote, "no systematic investigation seems to have before been made that gives us any definite knowledge as to the time when the development of the flowers actually begins, the rate at which it progresses, or the period through which it continues, in any of our fruit bearing plants."

The broader details of the differentiation and development of the various floral structures and organs have been carefully outlined for the apple. The course of development is similar for the pear, and is broadly the same for the drupaceous tree-fruits, except that in the latter the receptacle, or

[1] Goff, E. S. 17th and 18th Ann. Rept. Wis. Agr. Exp. Sta. 1899–1900. Waldron, L. R. N. D. Agr. Exp. Sta. Rept. 10: 31–39. 1899. Quaintance, A. L. Ga. Agr. Exp. Sta. Rept. 13: 349–351. 1900. Drinkard, A. W. Ann. Rept. Va. Poly. Inst. 1909 and 1910. Kraus, E. J. Ore. Agr. Exp. Sta. Res. Bull. 1. part 1. 1913. Bradford, F. C. Ore. Agr. Exp. Sta. Res. Bull. 1. part 2. 1915.

calyx-cup as it is sometimes called, and the carpel or carpels, are not so intimately united during development as they are in the pomaceous types. While there is considerable diversity in morphology among the various wild species, the cultivated varieties are readily placed in one group or the other. The apple, therefore, may well serve as a basis for following out the sequence of developmental changes which take place in the differentiation of the fruit-bud and floral parts in the more common deciduous tree-fruits.

36. The apple.—Just prior to the differentiation of the parts of the flower-bud, it is not possible to distinguish between those growing points from which flower primordia will be developed and those which will remain as vegetative growing points. Each shows a smooth rounded crown of meristematic tissue more or less inclosed by the beginnings of leaves or bud-scales. As the season progresses, the axis from which a flower-bud will develop gradually becomes distinguishable through what appears to be a thickening or more broadly rounding or flattening-out of the growing apex or the crown (growing point), and soon thereafter the contour of this crown becomes slightly irregular or papillated, due to several new growing points becoming organized, which now proceed to develop into new axes (the individual flower primordia) and on these in turn growing points give rise to the individual floral parts and tissues. The development of the floral parts is acropetal, which means that they are differentiated in the same sequence as they occur in the fully developed flower. (See Fig. 13.) Thus their order of development is as follows: calyx (sepals), corolla (petals), stamens and pistils (carpels). As the pistils

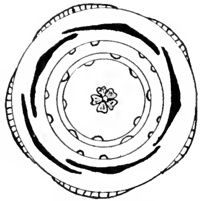


Fig. 13.—Floral diagram of the apple.

develop, the ovarian cavity is formed and upon the placentæ of the latter the ovules are borne. (Fig. 14.)

As the tip of the axis enlarges, the protuberances which arise spirally below it develop into individual flowers, although one or two leaf-buds are also differentiated slightly below the lowermost flower of the cluster.

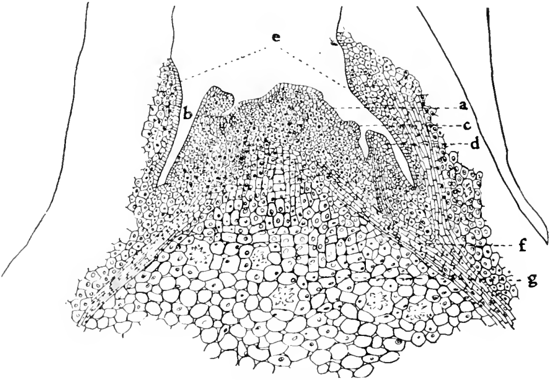


FIG. 14.—Early stages of fruit-bud differentiation in the apple. *a*, growing axis; *b*, incipient lateral flower-bud; *c*, beginning of a bract in the axil of which a flower-bud may develop; *d*, a bract or leaf; *e*, surrounding bracts and bud scales; *f*, vascular bundles; *g*, pith.

The further development of an individual flower-bud of the group may be considered as representative of the others in the cluster. When the central flower-bud is readily recognizable, it appears as a very short, stocky, conical mass, the apex of which is flattened except at the center where there is a small slightly convex elevation or knob, much as indicated in Fig. 15. A section through the bud would reveal a region of actively dividing cells near the upper surface, especially toward the outer edge and a short way down the sides of the cone or cylinder-like growth. The tissue beneath these embryonic regions is differentiated into pith cells and vascular bundles, and inclosing all is the epidermis.

37. Sepals.—A rapid multiplication of the cells at the outer edge of the near upper surface of the bud results in the formation of a slightly elevated ridge, the torus or receptacle. (See Fig. 16.) Growth takes place more rapidly at five points

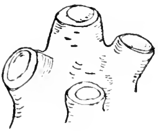


Fig. 15. — Diagram indicating positions of four flower primordia.

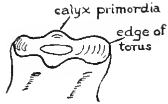


Fig. 16.—Diagrammatic representation of origin of calyx primordia on edge of torus.

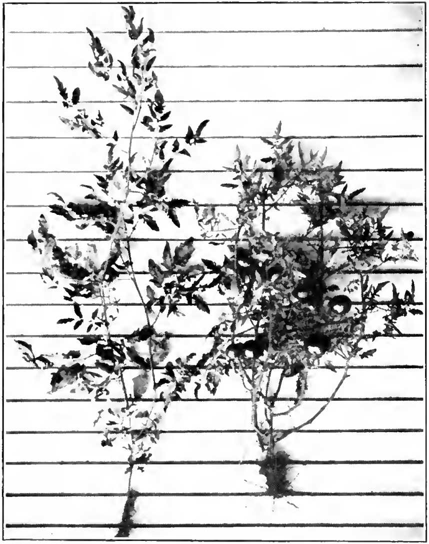
about equally spaced on this ridge, and thus the primordia of the sepals are begun.

Because of the increase in number and size of the cells below and between the calyx primordia, the torus or receptacle of the flower continues development, particularly toward the outer edge, with the result that this outer portion is arched up and the calyx-lobes are elevated along on top of it. The petals, stamens, and carpels arise from the concave side of the torus, and the meristematic tissue out of which the primordia of these organs are finally differentiated exists as a sort of lining beneath the epidermis of the cup-like torus. As development continues, the sepals enlarge and become inclined toward one another at the apex, until they interlap and form a tent-like structure over the depression below them. When the period of winter rest arrives, these parts are structurally the most advanced of any within the flower-bud.

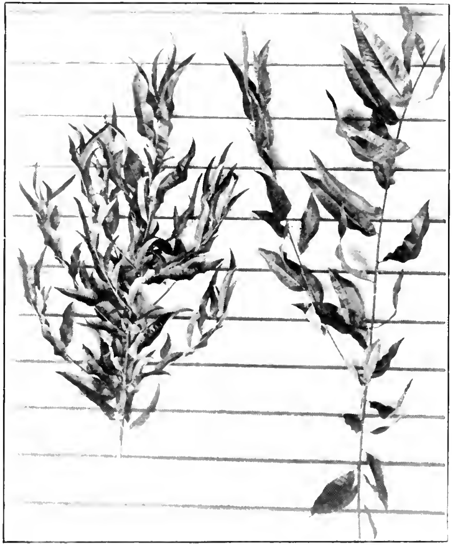
38. Petals.—Almost as soon as the primordia of the sepals are formed, those of the petals appear, the latter in a cycle within and alternating with the former.[1] "Development is less rapid than in the case of the sepals but each outgrowth gradually assumes a thin scale-like appearance, more or less sickle-shaped in longitudinal section, and narrowly attached at the base. Each petal finally assumes an acute angle with the calyx and together they roof over the cup-shaped torus."

39. Stamens.—"Directly after, or in some instances even at the same time that the primordia of the petals are being laid down, those for the stamens appear. They occur in three cycles. Those of the outermost cycle, directly within the petals, are laid down first, though they are immediately followed by the other two, in fact in some cases all three apparently form at the same time though the outermost cycle always develops the most rapidly. The outermost cycle arises so near to the primordia of the petals that in some sections they appear almost if not quite connected, though as a rule they are very distinct. This cycle consists of five pairs of primordia, each primordium appearing at first as a blunt, broad protuberance scarcely to be distinguished from a petal primordium. The middle and innermost cycles each consist of but five primordia. It is a difficult matter to decide whether there are actually three or but two cycles of stamens inasmuch as the two inner cycles are extremely close together. From an examination of many sections and dissections, however, the conclusion that there are actually three, seems to be well founded. The young stamen rapidly assumes a distinctly bi-lobed appearance; the basal lobe is short and slender while the apical broadens out, and it in turn becomes

[1] The following quotations are from E. J. Kraus, Ore. Agr. Exp. Sta. Res. Bull. 1, part 1. 1913.



a



b

PLATE I.—*a*, Showing reduction in flowering, elongation of internodes, and increased area per leaf due to shading. Plant on left was grown under shade; on right in open. *b*, Showing effect of shading peach tree (to right) as compared with an unshaded one.

distinctly four-lobed, each lobe representing a distinct microsporangium. The microsporangia pass the winter in the mother cell stage. Only slight changes take place during the early part of the winter up to the middle of February or the middle of March, when more active growth again takes place.

"The stamens in the outer cycle are borne in pairs side by side at an acute angle to the sepals, while the two inner cycles are borne at nearly right angles to the calyx lobes. Furthermore, of each pair of stamens in the outermost cycle one stands at either side the middle line of each calyx lobe, each stamen in the next cycle of five stands opposite each petal, while each stamen in the innermost cycle of five stands opposite the middle axis of each sepal, thus alternating with the middle cycle of stamens by which they are partially overlapped in the bud. The outermost series stands more or less erect and after the expansion of the petals are the first to dehisce, the two inner cycles remaining incurved and bent down for a varying length of time, depending on environmental conditions. They soon become erect, however, and shortly thereafter dehiscence of the anthers and discharge of pollen occurs."

40. Carpels.—"The five primordia for the carpels are the last to appear, doing so immediately after the primordia of the proximal cycle of stamens have been laid down. They are borne immediately within the innermost cycle of stamens and some distance from the center of the torus, which is now apparently lower than the outer edges which have been undergoing elevation continuously; the torus, accordingly, has become distinctly cup shaped at this time.

"The primordia of the carpels like all other structures previously mentioned, appear first as short blunt protuberances arising from the torus. Directly after this very early beginning, growth does not proceed equally in all directions from the center and form a solid cone-like or spherical structure, but instead, about the circumference of a circle which is not quite closed, thus forming as further growth takes place, a narrow hood-like scale with infolded edges.

"Actual elevation above the surface of the torus takes place slowly at first; but growth and elevation proceed very rapidly across the entire remainder of the torus except at the center. This central portion becomes elevated very slightly, however, and its level is raised a trifle above the level of the bases of the concavities of the several carpels, thus resulting in the formation, at the center of the torus, of a tube or cavity around which the five carpels are arranged, their inner edges forming the wall of this cavity. . . . Each carpel is furnished with two placentæ which are the result of the infolding of the edges of the carpels. In the case of so-called "open cored" pomes the cavities of the carpels open directly into the center cavity and the placentæ then appear to be parietal about the common center. The ovary becomes one-loculed instead of five-loculed and the placentæ of adjoining carpels are more intimately connected than are the placentæ of any single carpel.

" . . . Later, growth of the carpel takes place most rapidly at the upper surface of the torus involving at the same time a portion of the latter, thus resulting in the elongation of the five styles as a solid column at some distance below their apexes. A careful examination of a median longitudinal section through the fruit and styles will reveal the presence of the tissue of the torus extending for a short distance up the styles. In the mature fruit of many varieties these united style bases persist and are known as a 'pistil point or style point.' Still later growth, shortly before the expansion of the flower, produces an elongation of that part of the styles between the apex (stigma) and the united portion. . . . The conductive tissue is traceable from the stigma, at which point it is not covered by the epidermis, down through the style into the placentæ of the carpels to the ovules.

"There are no traces of the ovule evident at the beginning of the winter rest, nor do they appear until active growth has been resumed in the spring. A small protuberance, slightly below the middle of the carpel, first becomes evident, about the time the winter fruit buds are swelling and almost immediately a second blunter protuberance appears directly below it. . . . The upper protuberance which becomes the ovule develops very rapidly. At first it stands at nearly right angles to the placenta from which it arises. Very soon thereafter, as growth progresses, it begins to assume a slightly downward and outward movement away from the middle line of the carpel toward the side walls. At this time the initial development of the integuments, of which there are two, begins. They develop at practically the same time though the inner may be slightly in advance of the outer. At this time the axis of the ovule no longer remains at right angles to the placenta, but now forms an acute angle with it, the distal end of the ovule pointing downward and outward toward the sides of the carpels. Thus the two ovules in each locule stand back to back, so to speak, their tips pointing toward the base of the carpel. At the time the flower is in full bloom the integuments entirely cover the nucellus, the ovule has become completely anatropous and the micropylar end rests against the obturator below it. The embryo sac and its contents are completely formed at this time and are ready for fertilization." (See Fig. 17.)

41. The peach, plum, and cherry.—The peach in Virginia showed initial differentiation of flower-buds during the first week in August. The plum varied more than other fruits in the time of initial development of the flower-buds. With the Japanese varieties, it was the second week in July, with those of the American group it was the first week, while the

American variety Whitaker (*P. hortulana*) did not differentiate until the first week in September. Goff showed that the plum began differentiation in Wisconsin about the 8th of July. The cherry in Virginia gave evidence that fruit-buds were forming the first week in July and the flower parts had begun to differentiate by the end of the month. Goff's observations are much the same, placing the date at July 11th.

42. Inflorescence.—In the development of the fruit-buds as described above, the arrangement of the individual

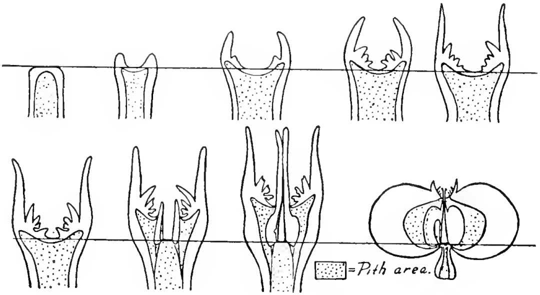


Fig. 17.—Diagram showing development of the apple.

flowers is termed the inflorescence. In the apple (*Pyrus Malus*) it is known botanically as a cyme, which by definition is a convex or flat flower-cluster of the determinate type, the central or terminal flower unfolding first. There are times, however, when several of the central flowers open at the same time as the terminal one, and sometimes the terminal one is abortive and does not open at all. Black[1] has shown graphically the arrangement of the flowers on the axis of the apple. The terminal one is, of course, without a sub-

[1] Black, C. A. N. H. Agr. Exp. Sta. Tech. Bull. 10. 1916.

tending bract or leaf, while the upper lateral flowers are in the axils of bracts and the lower ones in the axils of leaves (or sometimes bracts also). (Fig. 18.)

The pear (*Pyrus communis*) has its inflorescence in a cymose raceme, as the flowers at the base of the cluster often open first, which is the reverse of the apple. The quince (*Cydonia oblonga*) produces solitary flowers which are either terminal or axillary. In the apricot the flowers are solitary and axillary; in the wild black cherry (*Prunus serotina*), the inflorescence is a raceme; in the sweet and sour cherries a fascicled umbel; and in the peach the flowers are solitary and axillary, as a rule.

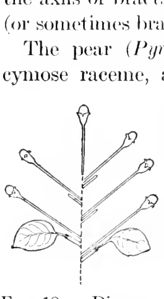


Fig. 18. — Diagrammatic drawing of an apple inflorescence or peduncle from which arise the pedicelled flowers.

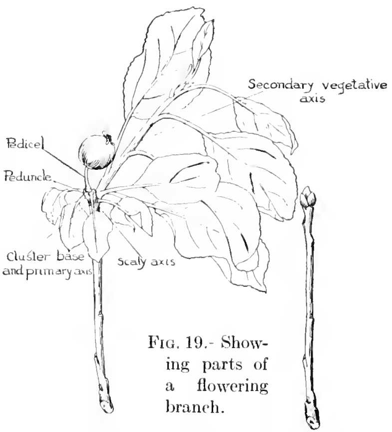


Fig. 19.- Showing parts of a flowering branch.

43. The flowering branch.— There is not entire uniformity as to the nomenclature of the parts of the flowering branch, but for horticultural usage the following terms are satisfactory. (Fig. 19.)

Scale axis.—This part of the flowering branch is the basal portion which bears the bud-scales and which is generally not conspicuous but can always be made out.

Vegetative axis.—This term designates the vegetative branch produced from the fruit-bud and upon which the individual flower or flowers are borne. It is especially conspicuous in such cases as the quince, raspberry, and blackberry.

Cluster base.—A type or specific form of the vegetative axis which remains short and often thickens up or becomes somewhat fleshy, is termed the cluster base. On it are borne leaves, flowers, and frequently vegetative buds which may remain dormant, become fruit-buds, or push out into vegetative branches of greater or less length in the case of the pomaceous fruits, whereas with some of the drupaceous types it may bear only a few bracts in addition to the flowers and become deciduous after the fruit has matured or fallen. In the pear it may become very much enlarged and more or less fleshy.

Peduncle is the main axis of an inflorescence, and to which the pedicle or stem of the fruit is attached. In the apple it is very short, while in some cherries, *e. g.*, *P. virginiana*, it may be long.

Pedicel is the true stem of the individual flower and becomes the stem of the fruit.

44. Vascular anatomy.[1]—The location of the vascular tissues throughout the fruit is important to the pathologist and entomologist as well as to the pomologist and, therefore, it should be briefly reviewed in this connection. The general details have been traced in the Yellow Newtown apple and this variety may serve in general for others of this fruit.

Within the cluster base is an almost complete woody cylinder of vascular elements, and from this cylinder strands

[1] Details of this treatment follow closely after E. J. Kraus and G. S. Ralston. Ore. Agr. Exp. Sta. Bull. 138. 1916.

or fibers extend into the leaves, branches, and bracts. A similar though somewhat smaller vascular cylinder exists in the peduncle and from it vascular elements extend into the flowers, leaves, and bracts which it bears. The vascular cylinder becomes smaller and smaller toward the apex of the peduncle, so that at the base of the terminal flower pedicel there remains, usually, but five prominent strands and between them many smaller fibers. These five main strands continue up through the pedicel to well above the middle or toward the apex where each bundle is divided into two, thus forming ten primary bundles. The smaller longitudinal fibers, together with others which branch from the primary bundles, extend in toward the longitudinal median axis of the pedicel. A secondary cylinder is thus formed within the primary one. Just below the apex of the pedicel, these small fibers and others which extend from the ten large bundles previously mentioned, are bent inward toward the small inner cylinder and a confused branching and anastomosing of all the smaller bundles occurs, thus completely eliminating any resemblance to a circular or cylindrical arrangement of the smaller fibers at this point. At the apex of the pedicel, the ten large primary bundles are arranged as an outer and inner cycle, each of which consists of five bundles. From each of the bundles of the outer cycle, a prominent bundle extends upward and follows the dorsal line of a carpel. In all, therefore, fifteen distinct bundles and a complex mass of small fibers extend from the pedicel into the fleshy portion of the apple. (See Fig. 20.)

The ten primary bundles which diverge at the apex of the pedicel follow closely the so-called core-line of the fruit which has been shown to mark the boundary between the pith and cortical tissues. Each of the main bundles of the outer cycle extends opposite the dorsal suture of a carpel; one of the terminal branches ends in a calyx-lobe, the other

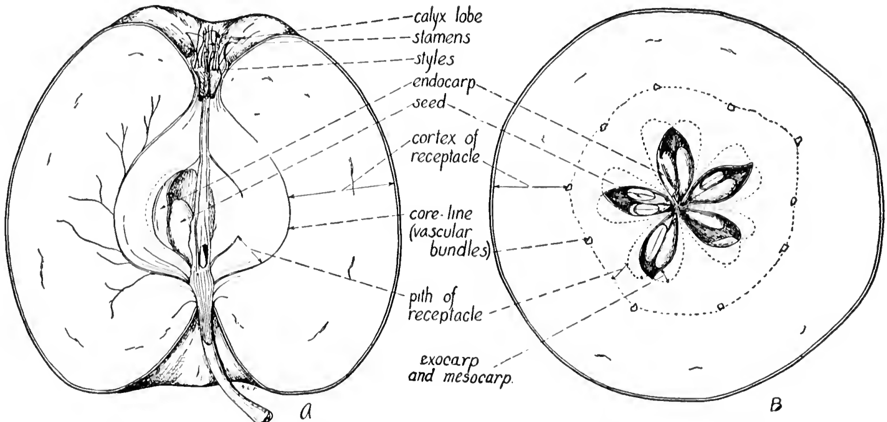


FIG. 20.—A, median lengthwise section of mature apple; B, cross-section of same.

in one of the stamens of the innermost cycle. Each of the main bundles of the inner cycle alternates with a carpel and its terminations are in the stamens of the middle and outer cycle, the petal, and the lobes of the calyx. Large branches

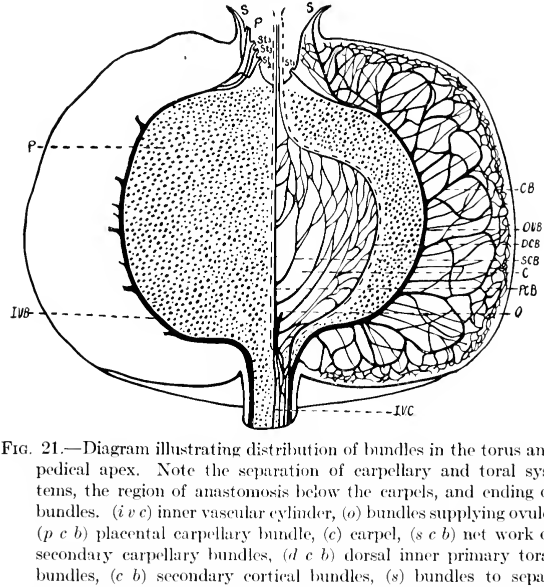


FIG. 21.—Diagram illustrating distribution of bundles in the torus and pedical apex. Note the separation of carpellary and toral systems, the region of anastomosis below the carpels, and ending of bundles. (*i v c*) inner vascular cylinder, (*o*) bundles supplying ovule, (*p c b*) placental carpellary bundle, (*c*) carpel, (*s c b*) net work of secondaiy carpellary bundles, (*d c b*) dorsal inner primary toral bundles, (*c b*) secondary cortical bundles, (*s*) bundles to sepal, (st_1 st_2 st_3) bundles to first, second and third cycles of stamens, (*p*) bundle to petal, (*p* dotted) pit region.

from all of these main bundles also extend outward into the cortex, where they are subdivided into many smaller fibers which anastomose to form a close network in the cortex. None of these bundles extends into the pith. (See Fig. 21.)

45. The carpellary system.—A short distance above the apex of the pedicel, the carpellary system of bundles is entirely distinct from that of the toral region. It consists mainly of fifteen prominent bundles, three for each carpel, and the smaller bundles which anastomose throughout the carpellary tissue. This system is derived from two sources: first, the five prominent strands already noted, each of which extends from an outer primary toral bundle, along the dorsal line of each carpel; and second, the numerous small bundles extending out of the region of anastomosis at the apex of the pedicel into the walls of each of the carpels and the larger strands which extend both from the strands of the inner and outer vascular cylinder more or less obliquely through the pith and into the placentæ of each carpel.

46. Comparative morphology of fruits.—A mature fruit, as used in pomology, usually consists of the ripened ovary or ovaries together with the fleshy edible parts which are intimately associated with the seed production. In the case of parthenocarpic fruits, however, the fleshy portion develops independently. Botanically, the term is used in a broader sense and is described as an ovary and its contents together with any closely adhering part. The structures which enter into the make-up of the several fruits are distinctly different in specific cases and some of those commonly met with in pomology will be mentioned.

A pome, of which the apple, pear, and quince are examples, is composed of more than one ovary located within the core region, and the enveloping receptacle which is the edible portion of these fruits. Other parts are also attached or associated with the ones mentioned, as the pedicel, the modified pith which is within the core-lines and attached to the ovary walls, the calyx which usually persists; and the dried stamens and styles.

A drupe consists of a single carpel, one-celled and one-seeded (or at most two-seeded), in the ripening of which the outer portion of the ovary (pericarp) often becomes fleshy or pulpy as in the peach, plum and cherry, or thinner and hull-like as in the almond, and the inner portion of the ovary becomes stony or crustaceous; hence the term "stone-fruits."

The raspberry consists of an aggregate of drupelets which develop about a thickened portion of the torus but from which they readily separate as they mature. The drupelets may adhere closely after being harvested or they may have a tendency to crumble apart, depending on the variety.

The blackberry is likewise an aggregate of drupelets but it differs from the raspberry in that the drupelets adhere to the fleshy part of the torus and the entire mass usually separates from the calyx and flattened portion of the torus when mature. The loganberry is the same morphologically as the blackberry.

The strawberry, like the fruits just described, is not a true berry. It consists of a much thickened fleshy and edible portion of the torus or receptacle, upon which are located the true carpels which are hard one-seeded achenes scattered over the surface of the receptacle. They may be somewhat depressed or slightly raised and the styles may be deciduous or may persist and give the surface a more or less roughened surface. The persistent calyx is leafy and prominent.

A berry proper is an indehiscent fruit fleshy throughout. There is considerable variation in the details of the construction of the berry. Some of them, such as the blueberry, huckleberry, cranberry, and banana, are inferior ovaries, whereas others, such as the tomato, orange, lemon, and other citrus fruits, are superior ovaries.

In the nut the ovary is hardened into a "shell" and it is frequently covered or surrounded by a husk which consists of the perianth of the flower or bracts which are derived from the receptacle. The edible portion is composed of the embryo.

CHAPTER IV

FACTORS WHICH INFLUENCE FRUIT-BUD FORMATION

The time of the formation of fruit-buds in the more common tree-fruits, as well as the morphological details of development, for the most part have been definitely established as indicated in the previous chapter. However, the physiological, biochemical, or biological factors that influence the differentiation of the elements of a flower-bud out of the growing region are still being investigated. The commercial pomologist is greatly concerned with the regular flowering and fruiting of trees, but unfortunately the literature on this phase of the problem seems to have been widely influenced by tradition and as a result many more or less fanciful theories have gained some prominence. Much confusion would be avoided if the facts were kept to the fore that: (1) several factors may limit the formation of fruit-buds, and the expression of these may be entirely different under varying conditions; and (2) that widely different horticultural practices or operations may influence such factors similarly or variously, with the result that the conditions for the formation of fruit-buds may be either favored or suppressed. The considerations which follow have to do with practices which influence, and theories which pertain to, fruit-bud formation.

47. Vegetative and reproductive processes.—Fruit-trees manifest growth of two rather distinct kinds—that primarily associated with simple vegetative extension and that more closely tied up with reproductive processes or functions. It has been a common notion that they are not only distinct in manifestation but antagonistic in nature. This position, however, is scarcely tenable because the so-called fruit-spurs and buds and even many of the fruits themselves are, in their first inception and development, as truly vegetative as the new shoots and branches. It is a fact, however, that under extreme conditions of vegetative extension, little or no blooming occurs; and, conversely, it is possible to check the growth of a tree and bring about an increased bloom. It is, of course, obvious that vegetative precedes the so-called reproductive growth, for the tree must attain some size before fruitage can be maintained. It is, nevertheless, convenient to distinguish between the type of growth which goes to maintain the tree as an individual and effect the extension of its branches, and the type which primarily functions as the fruit-producing area, thus permitting the use somewhat broadly of the terms vegetative and reproductive tendencies.

Jost [1] says, "All factors which tend to advance foliage development are unfavorable to flower production and *vice versa.*" The experimental evidence in this country is not in line with this doctrine but rather clearly establishes that, in general, strong growth is a natural concomitant of high production and conversely that meagre growth is associated with low yield. Or, as it has been expressed, "mere vegetative extension and fruitfulness are not separate and distinct functions of the plant but each is an external expression of an internal condition." [2] It should be conceived that increased fruitage may parallel increased vegetation or it may parallel decreased vegetation, depending on the starting point. The causes for this seeming anomaly are discussed later.

[1] Jost, L. Lectures on Plant Physiology. (Eng. Trans.) p. 364.

[2] Kraus, E. J., and H. R. Kraybill. Ore. Agr. Exp. Sta. Bull. 149. 1918.

48. The periodic idea.—Closely related to the internal factors referred to above is the time at which trees reach the bearing age. In the first place, as has been noted, a given variety of fruit-tree has a tendency to bear at a definite age: the Yellow Transparent apple bears at about four years of age; the McIntosh at five or six; the Baldwin at nine or ten; while the Northern Spy may be twelve or fifteen years or older before fruiting is established. To such a characteristic botanists have given the term "periodicity," although it usually refers to the periodic phenomena of a single plant. Jost says, "When we examine flowering plants under natural conditions we find that the plant is 'ripe for flowering' just as sexual cells appear in the animal when it reaches a certain age. But although flower formation, generally speaking, takes place at a certain age, which differs with each species, still, exceptions are known, as for example, the oak, which normally is 'ripe' in its sixtieth year, but which occasionally flowers in its first year and then dies," *i. e.*, environment may alter this particular periodic effect.[1] While this does not explain the causes for the flower-bud formation, it is a manifestation that should be recognized.

49. Theory of specific constructive materials.—This theory, which has been proposed by at least one plant physiologist (Sachs) and rejected by some of the others, may be given brief mention, although it relates to plants in general and has no special reference to fruit-trees.

In attempting to explain why flower-buds are differentiated from leaf-buds, Sachs suggested that, in addition to the products of assimilation in the leaf, there are also specific constructive materials which pass from the leaf in all directions and which collect in certain quantities where a definite organ is to be developed. Thus, the flower would be formed out of flower-building material, roots out of root-building

[1] Jost, L. *Ibid.*, p. 363.

substance, and so on. He cites some interesting experiments with the begonia. "In May, Sachs made cuttings of begonia in the usual way, and found that the plants springing from such leaf cuttings gave rise to flowers in the beginning of November, preceded by a luxuriant formation of foliage leaves. If, however, the leaf cuttings are taken from a flowering specimen in the end of July, flowers appear on them in the end of September, but few leaves are previously formed." Other cases of a similar nature can be cited which led Sachs to announce that the plant which was about to bloom contained special flower-forming materials and hence that cuttings taken from a specimen in such condition would soon flower, regardless of the environment.

Jost,[1] objects to the theory, however, and writes, "This hypothesis very conveniently explains anomalies and regeneration phenomena, and this has won it a certain amount of acceptance. Closer examination shows, however, that the difficulties are not thereby removed, but only shifted elsewhere."

50. Reserve food.—The accumulation of reserve food materials within the tissues of the plant has been commonly accepted as the cause of fruit-bud formation. Both botanical and horticultural literature abound in statements to this effect. Sorauer[2] says, "Plants will only develop flowering buds when the food material formed in the leaves is copiously stored up in the stem and branches as reserve material and not when this material is immediately used up in the production of new vegetative organs (leaves). Of our apple trees it is well known that in warm insular climates they grow into magnificent foliage trees, but they

[1] Adapted from Jost, L., *Ibid*, pp. 349, 364.

[2] Sorauer, P. A Treatise on the Physiology of Plants. (Eng. Trans.) p. 222.

remain unproductive of fruit." Jost[1] states, "It would appear that growth is an essential precedent of reproduction. It is so, however, only in so far as growth is associated with vigorous assimilation, for it is shown that the construction of reproductive organs necessitates the previous accumulation of a certain amount of nutritive materials, and these must be all the more abundant the more complex the reproductive organs are."

Fruit-growers, especially, have assumed that there is abundant evidence indicating that overbearing of trees results in exhaustion of their "reserves" and, consequently, in alternate or irregular bearing also, if indeed the trees are not permanently incapacitated. It must also be recognized that exhaustion may be concerned with very different classes of reserves and this makes it evident that the remedies for unfruitfulness may vary greatly in practice. In general, however, the formation of fruit-buds in abundance on the young trees is preceded by a decrease of growth extension and the accumulation of reserve food materials, and furthermore by a proper balance of them within the tissues of the plant. Of the reserve materials that have been considered to play a large part in the process are carbohydrates, nitrogen- and phosphorus-complexes, and fats.

51. Carbohydrates, nitrogen-complexes, and moisture.—It is, of course, understood that carbohydrates are products of assimilation by green plants and that they constitute one of the largest groups of organic compounds that are stored as reserve foods. Of the carbohydrates,—starch, sucrose, dextrose and levulose,—starch is by far the most abundant form in which they are deposited as a reserve, although cane-sugar or sucrose is found in considerable amounts, depending on the plant. It is probable also that hemicelluloses and pentosans constitute an important part of the reserves

[1] Jost, L., *Ibid.* p. 357.

of the fruit-tree. Fats are present as reserves, but in smaller quantities than the other two and are not considered further in this connection.

Nitrogen is essential in the protein synthesis in plants, and is a necessary component of all protoplasmic materials. This element is frequently calculated as total nitrogen in analyses of plant tissues, no effort being made to separate the various complexes, or it may be determined in any of its various combinations. Practically all of this element is derived from the soil as nitrates. Whether these are decomposed and made available for protein synthesis in the leaves alone or in other tissues appears not to be entirely clear at the present time. It has been widely accepted that the nitrates reach the leaves through the water-conducting tissues (xylem of woody plants), but recently it has been argued that a major portion is transported through the cortical layer (phloëm).[1] The relation of the nitrogen in its various forms to the available carbohydrate and water supply seems to be of special significance in connection with the differentiation of flower primordia.

Moisture likewise is essential in the process of flower-bud formation, as it is in all other phases of growth. It is necessary for digestion, conduction, transpiration, photosynthesis, and various other synthetic processes.

These products and materials are found in the branches, trunk, and roots of the tree in somewhat varying amounts at different times of the year. They are constantly undergoing change, even during much of the dormant season. The carry-over effects of these materials from one season or year to another are of the very greatest importance in connection with the early growth in spring, blooming, and indeed the initiation of fruit-bud development. They are quite as important as the materials present in the soil about

[1] Curtis, Otis F. Amer. Jour. Bot. 7: 101–124. March, 1920.

the tree, for it must be remembered that the type of early activity manifested by the growing tree is controlled quite as much by the character of its reserves as by the materials which it absorbs from the media surrounding it. It is the joint interaction or balance of the two which determines the character of growth.

52. Relation of these materials to flowering of plants.—(See Fig. 22.) A favorite theme of speculation by botanists,

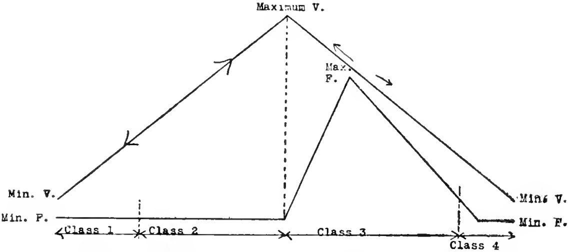


FIG. 22.—Diagram to illustrate the hypotheses involved in Classes I, II, III, and IV. To right of dotted line: fruitfulness will increase for a time as vegetation decreases from the maximum, but will then decrease as vegetation approaches the minimum. Going in the other direction, as vegetation increases from the minimum fruitfulness will increase for a time, but vegetation will persist beyond fruitfulness in either direction. To the left of the dotted line vegetation may either decrease from the maximum or increase from the minimum without affecting fruitfulness provided the plants are in the condition described in either Class I or II.

horticulturists, and others interested in vital phenomena, has been the causes that underlie the flowering and fruiting of plants. Horticulturists have usually approached the problem by means of the field-trial route. Practically the whole category of cultural practices has been brought into play in attempting to regulate fruitfulness. But of special prominence has been the application of the various "essential" elements of plant nutrients, either by means of cultivation, green-manuring, or animal or artificial manures. These various treatments have not been without their results from an economic standpoint, but the field still remains open to investigators interested in determining the part played by these elements and their inter-relation.

The investigations and interpretations of Kraus and Kraybill are highly significant and are of interest in this connection. The statements or premises which they have postulated are given here verbatim. The abbreviations following the various items are: M = moisture; N = nitrogen-complexes (especially nitrates); C = carbohydrates. These formulæ are not a part of the original article and they are not to be taken as actual ratio expressions.

I. Though there be present an abundance of moisture and mineral nutrients, including nitrates, yet without an available carbohydrate supply, vegetation is weakened and the plants are non-fruitful; M/N—C = non-fruitful.

II. An abundance of moisture and mineral nutrients, especially nitrates coupled with an available carbohydrate supply, makes for increased vegetation, barrenness, and sterility; M/N+C = non-fruitful.

III. A relative decrease of nitrates in proportion to the carbohydrates makes for an accumulation of the latter, and also for fruitfulness, fertility, and lessened vegetation; N/C —N = fruitful.

IV. A further reduction of nitrates without inhibiting a possible increase of carbohydrates, makes for a suppression both of vegetation and fruitfulness. C—N = non-fruitful.

According to these views, the behavior or response of the trees as regards growth and fruitfulness is not entirely a matter of total amount of nutrient or food materials available, but a proper balance or relation between them as well.

It also means that it is essential to study the ways in which various cultural practices affect these materials. That abundant storage of carbohydrates is associated with non-fruitfulness as truly as under-storage, is here brought out in contradistinction to the opinions of some other workers. An interesting example of lack of balance of these materials and the results obtained when such balance is restored is noted in the case of an experimental orchard in Oregon.[1] The application of quickly available nitrogenous fertilizers gave almost immediate and conspicuous results in an orchard which was unfruitful and making very little growth extension. The suggested interpretation of these results was to the effect that there was probably a condition of large amount of carbohydrates in the trees and a low supply of nitrate in the soil, and when this latter was increased the carbohydrates could be utilized in the production and development of fruit. This is an interesting explanation of a very common experience in orchard fertilizer experiments. The theory, that the addition of sufficient nitrates and moisture to balance an accumulation of starch and other storage materials within the tissues of the plant, serves as a necessary accompaniment of growth and bud formation, can find ready acceptance with those who have seen such orchard experiments. Fruitfulness would be decreased if plants were reduced from III to II but in the case cited they were shifted from IV to III with consequent fruitfulness.

It has been suggested also that top- as well as root-pruning of trees upsets the balance of the carbohydrate-nitrogen-moisture combination, which appears to influence so markedly the formation of fruit-buds. The reserve materials of the tree are reduced by top-pruning (see discussion in Chapter V), resulting in their limitation relative to the

[1] Lewis, C. I., and G. G. Brown. Rept. Hood River Branch Exp. Sta. (Ore.). 1916.

soil solutes which, according to the generalization above, would depress flower formation. Or if the roots are pruned, it would result in a preponderance of "reserves" over soil solutes taken up by the roots, producing again a lack of balance but in the opposite direction.

53. Relation of leaf area to flowering.—The relation of the amount of leaf surface and the size of the leaves to fruit-bud formation is germane to this discussion, as it is connected with the food supply which can be utilized by the plant. It should not be inferred that large leaves are necessarily associated with the formation of fruit-buds, for frequently the largest leaves appear on the strongest vegetative shoots which are usually barren (*i. e.*, water-sprouts). However, it has been observed that the year an apple tree is fruiting heavily, the leaves are usually smaller than when little or no fruit is borne. This refers particularly to the leaves on the spurs. A report on two Yellow Transparent apple trees which had manifested a noticeable difference in leaf size between the bearing and non-bearing years may be cited as illustrative of this point. It will be understood that the bearing tree one year is non-bearing the next:

Table VIII

AVERAGE WEIGHT AND AREA A LEAF; BEARING AND NON-BEARING TREES

Sample		*Air dry weight in grams*	*Area in sq. in.*	*Average difference in area sq. in.*
Bearing trees	1913	.2535	4.7320	
	1914	.2010	5.1633	
Non-bearing trees	1913	.4226	7.0584	
	1914	.3150	6.9972	2.0802

It has also been observed that there are more as well as larger leaves on the cluster base or on the spur the season that fruit-buds are formed (in the case of biennial bearers), and it may also be inferred that the total leaf area of the tree is greater in the non-bearing year.

54. Effect of leaves on parts immediately surrounding them.—Carefully conducted experiments under widely different climatic conditions have established the fact that formation of fruit-buds depends to a large extent on the leaves immediately adjacent to them. However, a statement does not explain this fact nor does it imply that all buds adjacent to leaves are developed into fruit-buds. In the case of apples, for example, the larger number of axillary buds are leaf-buds, and with the stone-fruits many such buds give rise to a leafy shoot. The work of Magness,[1] however, has shown that buds are not likely to become differentiated into fruit-buds unless the leaves immediately adjacent to or subtending them are intact. Varieties of plum and apple that are likely to form axillary fruit-buds were treated by defoliating the alternate leaves along the current season's shoot. As a result, fruit-buds were formed only at the nodes where the leaves were not removed.

In the case of defoliated spurs, the results were more variable, but the tendency was much the same as in the case of the new shoots.

In line with these observations, the work of Jones[2] is significant. He calls attention to the large storage of reserve materials in the maple tree. Since all the carbohydrates are manufactured in the green leaves under the influence of sunlight, the sugar-content of the sap depends on the conditions of the preceding season as to sunlight and leaf development. He has stated that in recent years there has

[1] Magness, J. R. Ore. Agr. Exp. Sta. Bull. 146. Harvey, E. M., and A. E. Murneek. Ore. Agr. Exp. Sta. Bull. 176. 1921.

[2] Jones, C. H., *et al.* Vt. Agr. Exp. Sta. Bull. 103.

been abundant evidence of this fact, for when the trees are defoliated by caterpillars, the following season the sap carried much less sugar than usual. He also writes that, as the leaf area varied from year to year, so the capacity to form carbohydrates varied in proportion. It was further observed that a tree standing in the open with well-developed branches and large leaves produced more and richer sap (4.39 per cent sugar) than those growing in dense brush with small leaves (2.14 per cent sugar).

55. Horticultural practices that influence fruit-bud formation.—After it is recognized that the immediate cause of fruit-bud differentiation is within the tree itself, the evidence of external factors related to such cause may be considered. As in the case of the internal factors, it is not possible to consider the external ones entirely individually, for they are closely inter-related. Several may bring about a clear-cut response by the tree, either an abundant formation of fruit-buds or excessive vegetative growth and barrenness.

Among the practices that may affect the tree in such a way as to bring about fruit-bud formation may be listed the following: cultural methods (using the term in a broad sense); top- and root-pruning; ringing; grafting on slow-growing stock (dwarfing); fertilizing and methods for controlling insect and disease pests, thus protecting the foliage. Some are special or extreme measures and are not ordinarily to be recommended, while others are regular orchard operations.

56. Cultural practices.—In Chapter VIII it is shown that favorable soil conditions must be provided if maximum commercial results are to be secured. Neither over- nor under-vegetative trees are fruitful and obviously require dissimilar treatment. In the case of trees which are growing too vigorously, it is probable that an abundant supply of nitrates is available together with ample water, and in order to correct the over-vegetative condition any of several cultural practices may be discontinued. The simplest plan might be to seed the orchard down to grass if it is being tilled; or to discontinue the use of fertilizers and manures; to reduce the number of cultivations; to discontinue the use of cover-crops; or in some other way to reduce the nitrates and moisture available to the trees until a better "balance" is maintained.

Under-vegetative and unfruitful trees, on the other hand, require opposite treatment. The probability is that there is a lack of nitrates and perhaps moisture in such cases, a condition which has already been referred to (p. 58). This situation is representative of more unfruitful orchards than the over-vegetative ones cited above. Here also several treatments may be applied: fertilization with some quickly available nitrogenous materials; tillage; the use of leguminous cover-crops; perhaps the ranging of poultry in the orchard; or in some other way to improve the moisture conditions of the soil and to supply nitrates to the trees.

Again reverting to the proposal of Kraus and Kraybill, the following outline may be suggestive of means of regulating the growth behavior of trees. It illustrates an important point of their work, namely, that there is often a double and apparently opposite effect of some orchard practices. In other words, it is not the method in itself which is most important but rather the relationship of materials it influences under varying circumstances, as indicated in the following outline:

→ *Relatively increasing carbohydrates*   *Relatively increasing nitrogen* ←

I	II	III	IV
Nitrogen+(not limiting) Carbohydrates— (limiting).	Nitrogen + (not limiting to use of carbohydrates in vegetation) Carbohydrates+ (not limiting).	Nitrogen + (limiting use of carbohydrates in vegetation) Carbohydrates+ (not limiting).	Nitrogen — (limiting) Carbohydrates+ (not limiting).

Light pruning of natural growth tendencies. N. decreasing through utilization by tree if not renewed.	Lighter pruning, less N. fertilizer.	No pruning, dry soil, no fertilizer.
Excessive pruning, shading of trees.	Heavy pruning, heavy N. fertilizer, heavy moisture.	Pruning, N., fertilization, cultivation, etc.

57. Pruning.—The relation of pruning to fruit-bud formation has already been illustrated in part by the above outline and the subject is treated more fully in Chapter V. Since root-pruning is less frequently practiced than top-pruning, it is briefly discussed in this connection. Summer pruning is taken up later (p. 98), but it is sufficient to say at this point that summer pinching, particularly on the peach, results in the formation of an increased number of fruit-buds on short spurs. More extensive summer pruning has not proved desirable in eastern United States, but certain types find some limited use under western conditions.

Root-pruning has long been advocated as a means of causing barren trees to bear fruit. The theory was that, by cutting off a portion of the roots, the intake of water (and unelaborated food materials) and hence the sap flow was reduced, and this brought about a relative preponderance of reserve materials. Drinkard's[1] experiments with root-pruning, however, show this practice to be of questionable value, if not injurious. The work was conducted with dwarf trees and may have been unusually severe. While fruit-bud formation was stimulated to a marked degree when the trees were severely root-pruned, the effect on the trees was so devitalizing that the fruit which set and matured was small in quantity and size, and hence the advantages were more than outweighed by the serious results of the treatment. When spring pruning was also practiced with the root-pruned trees, the stimulus to fruit-bud formation was generally less pronounced and the trees suffered seriously as in the case above noted.

58. Ringing.—By the ringing of fruit-trees is meant the operation of removing a ring of bark from the trunk or branches. This is an ancient European practice which has not only been used to increase fruitfulness but also to improve the size of fruit, as with the grape. The ring may vary in width but it is usually not over an inch or two, and a half inch will accomplish the desired results as readily. The ring may be removed at any point, usually in late spring or early summer, preferably a little earlier than the time the fruit-buds are beginning to differentiate. In peeling off the bark, the tissues to the cambium are removed and, if this underlying tissue is uninjured and does not dry out, it will immediately begin to form new cells and a cortical layer will be laid down shortly. If the ringing is done before active growth starts in the spring, the chances of new tissue forming are much reduced and bridge-grafting may have to be resorted to if the tree is to be saved, for the callus which is thrown out at the wound will rarely be sufficient entirely to heal the wound.

Results similar to those obtained by artificial ringing are

[1] Ann. Rept. Va. Poly. Inst. 1913 and 1914.

often observed when a tree is suddenly injured by freezing, fire, disease (canker), mice, or similar agency.

The supposition in all these cases has been that there was an accumulation of reserves throughout the tissues above the wound and this was favorable to the differentiation of flowering parts. Since experiments have recently indicated that a major part of the nitrates may be transported up through the cortical tissues as well as that carbohydrates are carried down through them, it would seem that a sudden transfer from Class I or II to that of Class III may take place, owing to the interruption in the supply of available nitrates, and consequent accumulation of carbohydrates. Usually the leaves of ringed trees soon turn yellowish and are checked in their growth, which indicates a lack of nitrogen. If this is true, then an important factor is introduced in connection with any accumulation of reserves which may take place, to bring about a condition for flowering.

Drinkard's results in ringing dwarf trees indicate that, for the conditions with which he worked, the greatest flowering was secured when the ringing was done on May 31st, to a less degree on June 23d, and no results were obtained when it was performed April 23d. On the other hand, the author obtained a 100 per cent bloom when mature trees were ringed on April 30 (in New Hampshire), as compared with a 35 per cent bloom on adjacent untreated trees. The trees were seriously impaired, however, as a result and bridge-grafting was resorted to. This difference was obviously due either to a dissimilar condition of the reserves in the tops of the trees or to an unlike soil condition, as well as to the age and variety of the trees.

Howe [1] ringed a block of five-year-old trees in New York State with marked results in flowering, but the general effect on the trees was devitalizing and it was concluded that

[1] N. Y. [Geneva] Agr. Exp. Sta. Bull. 391. 1914.

such a practice was not to be recommended. The work was repeated the following season with twenty-seven of the trees, but the second ringing did not result in again stimulating fruit-bud formation, for while these particular trees averaged 93 per cent of a crop to a tree in 1911, they yielded only 43 per cent in 1912. Again the following year these same trees were ringed in June. This time rings of 3, 6, 9, 12, 15, 18, and 21 inches in width were made, four trees being used for each of the various widths. These wounds were made around the trunks just above the former rings, all of the bark, whether in three-inch or twenty-one-inch strips, being removed with equal ease. This ringing had no effect on stimulating fruit-bud production, for the crop borne in 1913 was about the same as that of 1912. Injurious effects were experienced in the vigor of the trees, however, and the wider the bands the more serious the injury.

The practice of ringing cannot be applied to stone-fruits as they are practically always killed as a result of the operation, no new tissue being formed over the decorticated area.

In the work of Alderman and Auchter [1] with seven-year-old standard trees, the usual results were secured but the succeeding year the treated trees produced little or no fruit. They state at the conclusion of the experiment that: "From the results of our observations, ringing plainly checks the vigor of the tree for at least three years and although it has been successful in causing trees to bear the year following the operation, this bearing has not been established as a habit."

Hence from the work here considered and from that of others [2] it is seen that ringing apple trees at the proper time

[1] W. Va. Agr. Exp. Sta. Bull. 158.

[2] Sorauer, P. Physiology of Plants. (Eng. Trans.) pp. 159–164. Paddock, W. N. Y. Agr. Exp. Sta. Bull. 151. Daniel, L. Compt. Rend. Acad. Sci. (Paris) *131*:1253–1255. 1900. Sablon, Leclerc du. Compt. Rend. Acad. Sci. (Paris) *140*:1553–1555. 1905.

will increase fruit-bud formation but is a drastic measure and should only be resorted to in extreme cases. With the grape the situation is somewhat different. Husmann[1] has shown that with the currant grape, ringing is not only practical but entirely necessary. The ringing with this fruit must be done annually and when the vines are in bloom. Ringing improved the size, quality, and quantity of the fruit.

59. Stripping.—What may be considered a modified form of ringing was used by Drinkard in his experiments. This consisted in the removal of strips of bark, one-fourth to one-half inch in width, from the trunk of the tree, beginning near the surface of the ground and extending up to and frequently above the main branches. Several of the main branches were stripped for a distance of twelve or eighteen inches. Three to five such strips were taken from each tree.

When this stripping was applied to trees which had been pruned in the spring, the treatment gave no stimulation to fruit-bud formation, but in the absence of the pruning fruit-bud formation was stimulated markedly and a good crop of fruit was obtained. The trees did not suffer from the process of stripping but remained green and vigorous throughout the season.

60. Bending.—In the older horticultural literature frequent mention is made of the advantage to be gained by bending the shoots or branches in order to cause fruit-bud formation. This doctrine seems to have been accepted and based on the principle that "The more the sap is obstructed in its circulation, the more likely it will be to produce fruit-buds." On the contrary, it was stated that if a fruit branch is to be changed into a wood branch, it should be given a vertical position.

[1] Husmann, George C. Developing new grape industries. Proc. Amer. Soc. Hort. Sci. 1918.

Gardner [1] has conducted an experiment on the bending of dormant shoots into vertical, horizontal, or downward positions, and reports that no advantage is to be gained by the practice. "Its most important influence is to reverse the relative locations of spurs and branch shoots on any single season's wood that is bent and such a reversal cannot be regarded as worth the cost if indeed it is in any way desirable."

61. Dwarfing of fruit-trees, which is accomplished by working them on slow-growing stock, is commonly advocated as a means of bringing them into earlier bearing. Doubtless considerable misapprehension exists on this matter. Although some precocity in bearing is often obtained, very little is gained in the yield of commercial crops. Hedrick [2] conducted the most extensive experiment with dwarf apples that has been reported in this country, but several unavoidable inequalities crept into the work during its progress so that the results were affected in some particulars. Trees were worked on Crab (standard), Doucin (half dwarf), and Paradise (full dwarf) stocks. The differences in yield at the time the results were reported (after ten years) were not great, but there seemed to be little preference between the French Crab and the Doucin stocks while the full dwarfs had produced lower yields. The general conclusions of the author were to the effect that dwarf fruit-trees have no place in a commercial orchard.

62. Thinning is commonly cited as a means of bringing about annual bearing. While additional data may modify the present view, it can be stated briefly that such an influence on fruit-bud formation has not been accomplished with mature apple trees but has been reported experimentally with the peach and apricot. With these fruits it has not

[1] Gardner, V. R. Ore. Agr. Exp. Sta. Bull. 146.

[2] N. Y. (Geneva) Agr. Exp. Sta. Bull. 406.

only influenced the succeeding crop but also the crops for several seasons afterward.

63. Individuality.—Aside from the many and varied factors that influence fruit-bud formation, the trees themselves are to be considered. Some trees in an orchard may be consistently high yielders, and others very low. But whether this is due to an hereditary difference which can be perpetuated is an open question, with the burden of proof on those who claim such to be the case. Whether it is due to a difference in the original bud or cion or in the rootstock is not clear at present. Probably it is most frequently traceable to environmental factors which may not be apparent.

64. Climate is the sum of all the weather conditions and has a definite effect on the growth behavior of the trees. If northern fruits such as the apple are grown in the tropics, the growth is one of vegetative extension only. In the temperate zone a balance between vegetative and reproductive growth is manifest, while still further north there is a tendency to somewhat dwarfer trees and increased fruitfulness. If it is accepted that there are different optima of temperature for the maximum development of the several plant parts, then it may be assumed that some varieties of fruit will develop flowering parts more readily under one climatic condition than another, other things being equal. Therefore, climate, as is discussed later, plays its part in the flowering and fruiting of trees.

65. Plants threatened by death.—The statement is commonly made that if a tree is seriously injured or threatened by death, it will make a last effort to reproduce itself before it dies. The reason assigned for the phenomenon seems sentimental and offers no real interpretation. That such a tree does flower freely is sometimes true but more frequently it is not. When it occurs, frequently a condition similar to "ringing" takes place with its attendant results as discussed previously; *i. e.*, disease such as canker, or forms of winter-injury, damage by rodents or borers, or mechanical injuries, may interfere with the flow of the sap through the tissues of the tree. Just what disturbance occurs in the reserves of the tree might have to be determined for any given case, but it would be explained on the basis of nutrition entirely.

66. Light.—That a close relationship obtains between the amount of light available and the production of fruit-buds must be patent after a consideration of the foregoing paragraphs. Throughout this discussion it has been pointed out from various angles that the amount of elaborated food materials within the plant together with their quantitative relation (and probably a qualitative) to one another constitutes the crux of the entire problem. Since the synthesis of many of the plant products is dependent on light as a source of energy, it is apparent that neither vegetative extension nor the differentiation of flowering parts could proceed without a proper amount of light. Just what intensity and duration of light is necessary for the maximum production of flower parts is not now known. In general, it requires a greater light intensity for flower-bud formation than for vegetative development. This is seen in the comparative lack of flowering in the interior of dense unpruned trees. Not only is fruit-bud formation partially suppressed under these conditions, but the growth is weakly vegetative and if the shading continues the spurs and branches die.

In Plate I is shown the effect of shading a peach tree with a light-weight cotton cloth. The twig to the left was taken from an adjacent unshaded tree of the same variety. It will be noted that there is a suppression of branching in the shaded tree and usually only one leaf occurs at a node. This modification in growth necessarily lessens the number of fruit-buds which can be formed because of the reduction in fruiting area, but even on the shoots which were produced there was a preponderance of leaf-buds, apparently due to shading. The knowledge on this subject is meager, however, and there is need for additional research.

It has recently been pointed out that the length of exposure to sunlight is of the greatest importance in the growth and development of plants, particularly with respect to sexual reproduction. The following principle has been formulated as a result of extensive experiments with a number of species: "Sexual reproduction can be attained by the plant only when it is exposed to a specifically favorable length of day (the requirements in this particular varying widely with the species and variety), and exposure to a length of day unfavorable to reproduction but favorable to growth tends to produce gigantism or indefinite continuation of vegetative development, while exposure to a length of day favorable alike to sexual reproduction and to vegetative development extends the period of sexual reproduction and tends to induce the 'ever-bearing' type of fruiting." [1]

67. Biennial bearing.—The biennial bearing habit of fruit varieties has long been recognized and its solution constitutes an important practical problem. It was formerly considered to be an immutable varietal characteristic, but this view has been radically changed and it is now regarded as a nutritional problem. This conception is practically necessary inasmuch as there is no biennial-bearing commercial variety which has not been shifted, in some instance, to annual bearing through cultural means. That the problem is nutritional seems evident, even though treatments apparently the same have not brought about annual bearing in all orchards of the same variety. It must be conceded,

[1] Garner, W. W., and H. A. Allard. Jour. Agr. Res. Vol. 18, No. 11. 1920.

however, that some varieties, more than others, are inclined to establish as a habit either annual, biennial, or irregular bearing.

Roberts[1] has pointed out that there is a close relationship between fruit-bud formation and spur growth. For example, with the Wealthy apple under Wisconsin conditions, fruit-buds are formed freely when the spurs make a growth of one-eighth to three-eighths of an inch in length, and when the growth is much less or greater, flowering is partially or entirely suppressed. In the "off" year when 85 or 90 per cent of the spurs formed fruit-buds, this amount of growth was common, but in the "on" year it was consistently shorter, thus producing a cycle or a biennial bearing condition. This observation is comparable to the one already discussed, namely, the alternation in size of leaves in the "on" and "off" years with the Yellow Transparent (and other) apples. While a crop of fruit usually checks vegetative extension, leaf size, and often fruit-bud formation, such check may also be due to other causes, such as the weather or cultural conditions, and, therefore, it is not necessary for a heavy crop of fruit to precede the establishment of the biennial bearing habit.

As a practical solution of this problem, three possible procedures may be suggested. First, when the trees are fruiting heavily and consequently making less than the requisite growth (say less than one-eighth to three-eighths inches), the trees might be stimulated by an early application of available nitrogen. Thinning the fruit has not proved effective in accomplishing this result, as explained in Chapter VI. Second, during the off year when the growth is such as to be conducive to flower formation, nitrogen may be added in order to push the trees into an "over vegetative" condition

[1] Roberts, R. H. Off-year apple bearing. Wis. Agr. Exp. Sta. Bull. 318.

and hence reduce fruit-bud formation. This would bring about a production of fewer fruit-buds but greater likelihood of annual bearing. Third, when the trees are habitually "over vegetative," they may be checked until they are in the condition for fruitfulness.

Class A	Class B	Class C
— $\frac{1}{8}$ inch	$\frac{1}{8}$ to $\frac{3}{8}$ inch	+ $\frac{3}{8}$ inch
"On year"—add N. early in season to stimulate greater shoot growth	"Off year"—add N. to force greater growth and thus reduce the number of spurs which produce fruit-buds	"Off year"—seed down to grass, eliminate N. fertilizer and water

In other words, the problem is practically identical with that outlined earlier in the Classes I to IV.

CHAPTER V

PRUNING

The pruning of plants received attention by the earliest writers on horticultural subjects, and throughout the literature of horticulture it has a very prominent place. The instruction or advice given consisted largely in detailing methods to pursue in order to obtain the ideally shaped tree and hence was concerned with the art of pruning rather than with the effect on the functions of the plant. The European literature on the subject is voluminous and is usually accompanied by well-prepared drawings of the various methods employed. Much of the present teaching in this country can be traced to that source. The European gardeners have often gone to extremes in training trees into unusual forms and this in particular has found its way into the literature of that continent. In commenting on the extent to which tradition has influenced the opinions in regard to pruning, Bedford and Pickering aptly say: "Pruning as an art does not lend itself very freely to scientific investigation and where scientific investigation can be brought to bear on it the teachings of the artist have not always been confirmed." [1]

It is only comparatively recently that experiments planned in sufficient detail have been undertaken to study the effect of pruning on the nutrition of the tree and even now it cannot be said that there is full agreement as to the responses that result. The art of pruning is interwoven with

[1] Science and Fruit Growing. Macmillan and Co., London. 1919. p. 57.

the science of pruning and the practice requires a knowledge of the functions of the tree and its fruiting characteristics, as well as judgment, imagination, and forethought.

68. Definition.—Pruning may be defined briefly as the art and science of cutting away a portion of the plant to improve its shape, to influence its fruitfulness, to improve the quality of the product, or to repair damage.

69. Objects of pruning.—The objects are essentially two: first, to change the shape or growth of the tree itself; and second, to influence the production and the character of the product. Such pruning as is necessary to repair damage is largely due to accident, disease, or neglect. It is easily possible to over-emphasize the importance of training, for the object of pruning a fruit-tree is certainly not alone to produce a beautiful or shapely object, but rather to obtain a tree that is commercially profitable and capable of carrying its crop without breakage of limbs. It is not uncommon, in sections where apple trees grow large (as in western New York), for them to produce a crop weighing as much as a ton and a half, and the ability of the tree to carry such a load must be a matter of foresight by the orchardist. Furthermore, the proper pruning of a tree will facilitate other orchard operations, such as spraying and picking. From an orchardist's viewpoint, it is evident that pruning has a commercial objective, for the grower desires to obtain the most return from the least outgo. It must be remembered, however, that the most return is not always commercially best, as is pointed out more fully in Chapter VI. This then leads to an adaptation of tree type to conform with other orchard practices, which in themselves must be adaptations to environment, variety characteristics, and the like, and it is this ensemble of inter-acting factors that influence the tree, or rather the tree and its product are the organic result of all of this inter-action.

70. Shape or form of the tree.—The general shape or form of a tree is largely a varietal character and is not easily changed. A tree upright in habit of growth, such as the Wealthy or Sutton apple, cannot be made to develop into a strictly spreading type by any system of pruning. Likewise a tree of a spreading habit, such as the Rhode Island Greening, or one drooping as the Wolf River, cannot profitably be changed into an upright growing one by pruning or training. It is true, however, that they can be modified to some degree

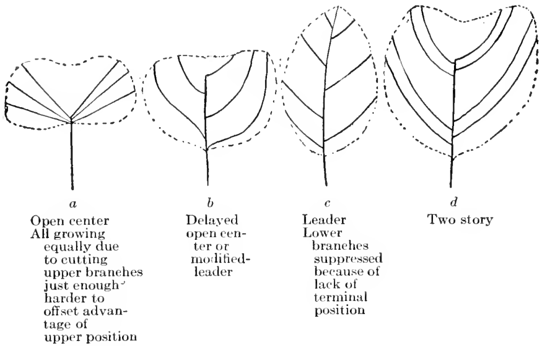


FIG. 23.—Diagrammatic representation of arrangement of scaffold limbs in pruning.

by pruning. These forms or shapes of trees are of some taxonomic value and in many cases afford a ready means of recognizing a variety.

71. The type of tree to be developed refers directly to the placing and spacing of the scaffold limbs on the body and not to the general shape, although the two are interrelated. There are several forms into which a tree may be trained, although the type to be adopted will often depend on the variety.

The principal forms into which the young tree may be trained are: the vase or open-headed; the delayed open center or modified leader; the central leader or pyramidal type; and the two-story.[1] The vase-shaped tree is developed by selecting usually from three to six scaffold limbs that are to be somewhat equal in importance and all of which are lateral branches from the main stem or trunk, the central leader being removed at planting time. These scaffold branches are usually cut back to 4 to 8 or 10 inches in length at the time of planting, provided the tree is two years old. If one year old, the top is cut back to 20 to 30 inches in height and the scaffold branches are selected from the initial ones sent out during the ensuing summer, or the following spring when they receive their first pruning and training. These branches are selected radially about the stem, with no two opposite each other, the idea here being that even cutting of these selected branches will result in approximately even growth. Fig. 23, *a*.

The delayed open center or modified-leader type of tree is essentially different, in that the central leader is not removed at planting time, but is allowed to remain and grow some three or four feet higher than the scaffold in the vase-shaped type. The terminal is then removed to prevent a full leader tree from being formed. Along this axis the scaffold branches are chosen, giving a better spacing and more scaffolding than in the open center tree. The value of this type is that the side or scaffold limbs are more strongly built and not so likely to be broken out by a heavy crop as in the case of the vase-shaped tree; it is gaining in favor in many sections of the East. The chief objection is that the grower is likely to allow too many branches to remain, resulting in a dense tree with all its attendant difficulties. Fig. 23, *b*.

[1] In addition to these four general types of training, the natural or unpruned tree should perhaps be included, although this sort of neglect is not common in commercial orchards.

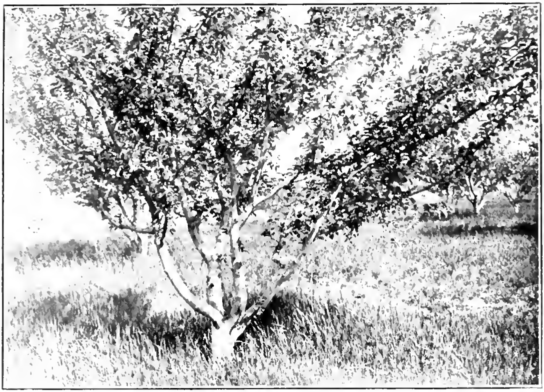
The leader or pyramidal type has a continuous central axis from which its limbs are developed, much as in the pines. The limbs are strongly attached and the loss of any individual scaffold branch is of slight importance compared with the same loss in an open tree, but it is not so desirable as the semi-leader or delayed open center tree. The branches in such a tree also are likely to crowd, and the resulting fruit is often small and of poor color. Fig. 23, *c*.

The "two-story" tree, so called because it has one distinct set of scaffold branches superimposed over another, is in use in some orchard regions and has its advocates. This type has the advantage of a large bearing surface and strongly attached limbs. However, the limbs of the upper scaffold may hang down over those of the lower and make proper pruning difficult. Unequal growth of one or the other of the sets of branches may result in a dwarfing and ultimate starving of the weaker ones. These conditions should be carefully guarded against and a wise selection of limbs about the entire length of the central axis, rather than two distinct sets of scaffold branches, would do much to prevent these objections. Fig. 23, *d*.

72. Obtaining the ideal.—Anyone who has attempted to train a block of trees into a form chosen as the pattern has learned that it is impossible to secure uniform results with all the trees. Some varieties are much more difficult to train than others and the orchardist can only adhere as closely to his ideal as the growth of the trees will permit.

73. Fruiting system of the tree.—Fundamental to any pruning method must be a clear understanding of the habit of the tree in fruit-bearing. This subject, however, has been discussed for the various fruits in a foregoing chapter and need not be repeated here.

74. Effect of pruning on size and development of trees.—It is conceded that the form of the young tree is of great



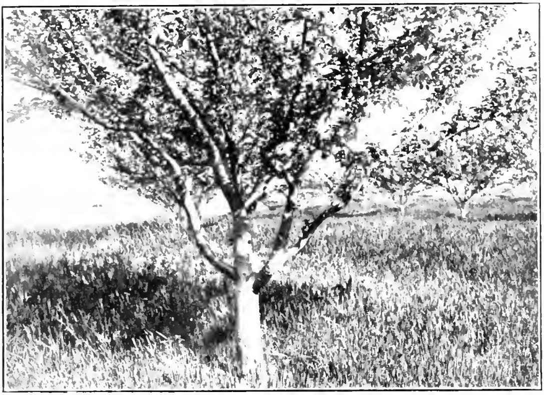


PLATE II.—*a*, An open-headed apple tree. *b*, A two-story apple tree with sets of scaffolds too close together.

importance and pruning should be performed in such a way as to produce the best type of tree when it reaches maturity. Having decided on the form desired, the question arises as to the general effect of pruning on the size of the tree. The position of many writers has been that heavy dormant pruning increases vegetation and that, in order to secure the best specimen, rather severe pruning should be practiced. More recently, however, the inaccuracy of this statement as a general conclusion has been pointed out, although it is conceivable that the total response in wood growth might not be influenced so much under some conditions as under others and, therefore, a lack of full agreement on this point may develop in the literature. The reason for the dwarfing effect is suggested in a later paragraph.

The results have varied somewhat when young trees—one to three years old—have received heavy and light pruning, but with older trees the data available at this time make possible rather uniform conclusions.

Alderman and Auchter[1] conducted an experiment in West Virginia with trees of varying age and found that the younger ones produced greater growth when pruned heavily, but after the third year the lightly pruned ones grew the most. (Plate IV.) The general conclusion from this work was that a tree produces new growth in inverse ratio to the amount of wood removed. The following table presents a digest of the data:

[1] The apple as affected by varying degrees of dormant and seasonal pruning. W. Va. Agr. Exp. Sta. Tech. Bull. 158. 1916.

TABLE IX

RESULTS ON GROWTH OF LIGHT AND HEAVY PRUNING OF YOUNG APPLE TREES (STARK)

(AFTER ALDERMAN AND AUCHTER)

		1911	*1912*	*1913*	*1914*	*1915*	*Height in ft., 1915*	*Width in ft., 1915*	*Diam. of trunk, 1915*
Average total length of growth in feet	Heavy pruning	4.41	16.25	41.53	84.08	161.74	7.57	5.17	2.17
	Light pruning	5.58	15.51	34.33	99.39	224.89	10.79	6.85	2.91

The same observation has been made with regard to bearing trees.[1] After twelve years' work with dwarf apples (the trees were then fifteen years old), they were lifted and weighed, with the following observations: "Those which had not been pruned at all were 20 per cent heavier than those which had been moderately pruned, while those which had been hard-pruned were 16 per cent lighter . . . thus pruning not only doesn't increase the actual size of the tree, but it results in less new wood being formed."

Tufts[2] shows that there is a definite correlation between trunk circumference and the weight of both top and root development of two-year-old black walnut and almond seedlings. Also that the average increase in circumference of severely pruned apricot, cherry, peach, pear, and plum during four seasons was 8.9 centimeters, moderately pruned 10.9, and lightly pruned 12.3. The latter developed stockier and stronger branches and made greater development than heavily pruned trees.

Gardner[3] also points out that unpruned young trees, on the average, increased in size as rapidly or more so than either dormant or summer pruned ones.

[1] Bedford and Pickering. Woburn Exp. Fruit Farm, 7th Rept. 1907.

[2] Tufts, W. P. Calif. Agr. Exp. Sta. Bull. 313. 1919.

[3] Ore. Agr. Exp. Sta. Bull. 139. Pages 3–45. 1916.

Chandler[1] reports on young apple and peach trees of different ages with the same general results as above indicated, and the data from the one-year old nursery stock may be taken as typical of the results. The trees were selected carefully as to uniformity of size and a part of them had their opening buds removed from the trunks to a height of about 18 inches, while the remainder were untreated. At the end of the season, the following data were obtained:

TABLE X

ON PRUNING ONE-YEAR-OLD DELICIOUS TREES (AFTER CHANDLER)

Treatment	*Number of trees*	*Ave. number of leaves, Oct. 19*	*Wt. of tops, grams, Oct. 19*	*Wt. of roots, grams, Oct. 19*
Pruned......	16	149	168.2	24.0
Unpruned....	14	272	236.6	33.2

Reference has been made to sufficient experiments to indicate the status of the subject at this time, and while it would seem that practically all pruning is a dwarfing process, it should not prejudice the student against the necessity of such training of the young tree or pruning of the old one as is necessary for the securing of a well-balanced and fruitful individual.

75. Effect of pruning on early bearing.—Of still greater importance to the orchardist is whether heavy pruning of young trees will hasten or delay their coming into commercial bearing. In this connection it must be remembered that blossoming does not necessarily mean fruit production. In general, it seems well established that the less pruning, the sooner a tree will form fruit-spurs and fruit-buds and establish the bearing habit. It does not necessarily follow

[1] Proc. Amer. Soc. Hort. Sci. 1919.

that heavy pruning may not be conducive to greater fruit production on an older tree, as is pointed out in paragraph 79.

This idea is not new but has frequently been mentioned by early writers. In 1768, Hitt wrote as follows: "If there are two apple, pear, plum or cherry trees, equal in health and strength, at one year old after grafting, let them remain some years after in the same stations . . . and one of them be pruned, and the other not, but suffered to grow in a shape quite rude and natural, the latter will produce fruit much earlier than the other, though, perhaps, its branches will not be in so regular a position as those of the former; hence it may be reasonably inferred that premature pruning a healthy, strong standard, in what manner soever, before blossoming, will keep it longer back from a bearing state than it would be were it left unpruned." [1]

This effect of pruning on early bearing is shown by work at Woburn on dwarf apple trees. Records for twelve years were reported in three periods, wherein the yield of moderately pruned trees was given a value of 100 and the other treatments compared with it, as follows:

Table XI

EFFECT OF PRUNING ON EARLY BEARING (WOBURN)

	1st 5 yrs.	*2d 5 yrs.*	*12th year*
Heavy pruning	75	50	5
Moderate pruning	100	100	100
Light pruning	90	150	145
No pruning	220	200	275

Similar results were obtained by Alderman and Auchter with young trees just coming into bearing, as shown by the following data:

[1] Hitt, Thomas. A Treatise of Fruit Trees. 3d Ed. London, 1768.

TABLE XII

EFFECT OF PRUNING ON EARLY BEARING (AFTER ALDERMAN AND AUCHTER)

Type of pruning	*Bloom clusters to a tree, 1914*	*Fruits to a tree, 1914*	*Bloom clusters to a tree, 1915*	*Fruits to a tree, 1915*		*Percentage fruit-buds to a tree, 1916*
				No.	*Wt., lbs.*	
Heavy	.14	0	1.86	.7	.25	3.7
Moderate	3.4	.2	40.00	12.2	3.35	20.
Light	15.5	2.0	175.00	24.	6.64	38.

In these experiments, more mature trees were also treated with the result that the heaviest pruned yielded more fruit than the lightly pruned ones. However, the trees were reported as in poor condition (making only four inches of terminal growth) and hence the data are not considered so reliable as in the cases of younger trees.

76. Effect of the unequal cut.—A common weakness in the framework of the tree is a sharp-angled crotch or fork wherein one branch of the fork is about equal to the other in size. This produces a condition which is likely later to result in a poor type of development and a breaking of the tree. This can be avoided by the "unequal cut"; that is, by not cutting back the two branches of such a fork equally, but by making one decidedly shorter than the other so as to suppress its development and make it subordinate to the longer one which becomes a leader. By this method, a much stronger tree can be built.

On first thought this principle would not seem to be in harmony with the observed fact—which is discussed later—that there is a stimulation to vigorous growth at the point where the cut is made. An explanation seems available, however, to account at least in part for the effect of the unequal cut. The case is at once different from one in which the entire top of the tree is pruned. When only a few shoots are cut back, there is no measurable unbalancing of the root system and top of tree and, therefore, no excessive supply of water and soil nutrients, for the other branches of the tree will make use of any additional amount. As a result, no special stimulation is manifest and the branch which was pruned is reduced in size in comparison with its former rate of growth.

The following experiment may be cited on this point:[1] A shoot of equal length was chosen for observation on a number of three-year-old nursery trees. This shoot was cut back one-third its length in all cases, but with half the trees under observation all the other branches were likewise pruned back. The answer to the question here involved will depend on whether the selected shoots will respond similarly on both blocks of trees. The following data show that, if the remainder of the tree is pruned, the selected shoot makes a much greater growth than if it is the only one which is cut:

TABLE XIII

NURSERY STAYMAN WINESAP, 1919 (AFTER CHANDLER)

Treatment	*Number of trees*	*Ave. twig length, inches, before pruning, May 23, 1919*	*Ave. twig length, inches, after pruning, May 23, 1919*	*Inches of new growth from each pruned twig, Sept. 20, 1919*
Tree pruned..	30	29.2	9.9	32.0
Tree unpruned	30	29.2	9.9	9.9

77. Heading-back versus thinning-out.—In discussing the effect of pruning on the size and development of trees, no differentiation was made between types, but rather the

[1] Chandler, W. H. Proc. Amer. Soc. Hort. Sci. 1919. pp. 88–101.

general bulk pruning was treated, consisting in both heading-back and thinning-out of the young trees. The effects of these two types of pruning on the branch growth and the development of fruit-spurs may now be studied to advantage.

Heading-back refers to the cutting of the shoot or branch, removing the terminal growing point and a certain number of the lateral buds or shoots nearest the end of the branch.

Thinning-out, on the other hand, means the removal of surplus branches or shoots without any heading-back process. The effects of these two types of pruning are different and should be carefully examined.

The experiments of Gardner [1] in Oregon were so arranged that the responses to these two types of pruning could be studied in detail. They show in general that thinning-out is more favorable to fruitfulness than heading-back, although both practices would be included in orchard operations. The general response from the total or bulk pruning was not entirely in accord with the experiments cited above, in discussing the effect of pruning on size of tree, but varieties varied to a considerable degree. With Grimes on Doucin roots it made little difference whether a shoot was left unpruned or was headed-back lightly or severely, the subsequent units of growth the following season being about the same. The number of shoots resulting if a branch was severely headed-back would, however, be fewer than if lightly headed-back or left unpruned. With the varieties Esopus, Rome, and Gano, on the other hand, heavy pruning checked their growth. These latter statements refer to the effect of pruning on the subsequent size of the tree and are not to be confused with those in regard to the development of spurs and fruit-buds when trees are headed-back or thinned-out.

[1] Ore. Agr. Exp. Sta. Bull. 139. pp. 3–45.

With all the trees in the experiments, heading-back resulted in a decrease in the number of fruit-spurs to which the individual shoot gave rise, this being more marked with increase in the severity of the heading. In other words, fruit-spur formation on the individual shoot was correlated with its length after rather than before the pruning.

A statistical study of the two types of pruning as applied to Grimes, Gano, Rome, and Esopus seemed to warrant the following conclusions:

1. A general heading-back of the shoots of a tree acted as a stimulus to new growth. The amount of the stimulus varied considerably with variety.

2. An equally severe thinning acted as a check to new growth, but this also varied somewhat with variety.

3. Heading-back resulted in a more marked check to fruit-spur formation than did equally severe thinning-out, with such varieties as Grimes and Esopus. The reduction was not so marked with Gano and Rome, as they bear a large percentage of their fruit-buds laterally on the new, terminal shoots, especially when young.

4. Thinning-out increased the production of fruit-spurs, as compared with equally severe heading. On the other hand, heading generally augmented the production of terminal fruit-buds on the few shoots. In some varieties, thinning was accompanied by a greater production of lateral fruit-buds on shoots than equally severe heading; in other varieties, the reverse was the case. In general, thinning-out tends to increase flower and fruit production, while the heading-back is likely to decrease those functions.

These two types of pruning are further considered in detail as they apply to young trees.

78. Detailed response of young trees.—As is described and discussed above, thinning-out refers to the removal of a portion of the limbs, branches or shoots in order to "open up " the tree and is essentially different from heading-back, inasmuch as the ends of shoots or branches are not cut off. As a result, the terminal bud continues the growth of the branches and the lateral buds usually develop into branches or spurs or remain dormant. Gardner has calculated on this basis that of 100 shoots bearing ten lateral buds each and also a terminal bud in this case, a light thinning out (30 per cent) would leave 770 buds—700 lateral and 70 terminal. It was then assumed that from these 70 shoots "we obtain 140 shoots and 490 spurs, leaving 140 dormant buds," which is considered not far from what would actually be obtained. From a heavy thinning-out (60 per cent) of this same number of shoots there would be 40 untouched ones. These would probably behave in much the same manner as the branches on the lightly thinned tree. "Were this the case the result would be eighty new shoots (forty from the terminal buds and forty from as many lateral buds), about three hundred twenty spurs, and forty dormant buds. The individual spurs would be thicker and more vigorous in appearance, but probably the proportion of buds to develop into fruit-spurs would remain about the same." Thus a light thinning-out gives more shoots and fruit-spurs than a heavy one.

The results of this estimate, based on extensive observation and experiment, are summarized in Table XIV.

Table XIV

PROBABLE RESULTS FROM DIFFERENT METHODS OF PRUNING ONE HUNDRED SHOOTS, EACH HAVING TEN EQUALLY SPACED LATERAL BUDS (AFTER GARDNER)

	Light (30%) heading-back	*Heavy (60%) heading-back*	*Light (30%) thinning-out*	*Heavy (60%) thinning-out*
Number terminal buds left	0	0	70	40
Number lateral buds left	700	400	700	400
Number new shoots formed	200	250	140	80
Number spurs formed	300	150	490	320
Number buds remaining dormant	200	50	140	40

Not only is it concluded that thinning-out has a beneficial effect on fruit-spur development, but also on their vitality and longevity. The trees that are headed back have a strong development of new shoots, mostly on the outside and top of the tree and, as a result, the spurs on the inside suffer and become non-productive, if indeed they do not die. On the other hand, thinning-out tends to strengthen the spurs already formed as well as to develop new ones.

79. Relation of pruning to nutrition.—That the relation of the stored food materials and the soil nutrients and moisture may be profoundly affected by pruning as well as by cultural practices has been emphasized by Kraus and Kraybill. Any one of four sets of conditions may be encountered, similar to those described in Chapter IV.

1. A marked reduction in or limitation of carbohydrates, even though there were an abundance of available moisture and nitrates, would result in a depressed vegetative condition as well as a reduction in blooming and fruit production. This condition would result from heavy pruning as well as lack of photosynthetic activity, and, therefore, additional

pruning would have a tendency to restrict further the growth activity.

2. An abundance of moisture, nitrates, and carbohydrates would result in rapid vegetative extension. Under these conditions, it is probable that more time would be required to manifest a dwarfing of the tree by pruning than when one or more were lacking.

3. The ideal situation would exist if there were present or available a moderate but ample amount of nitrogen, together with carbohydrates, in case the latter are synthesized in excess of the quantities utilized in vegetative extension, that is, an ample reserve food supply would be present within the tree. The result would be a good growth and a rather free development of reproductive parts. It is suggested that pruning may or may not be needed, but usually some is required. Pruning would furnish a ready practical means of regulating the nitrogen-moisture-carbohydrate relation.

4. A fourth condition is frequently encountered in old neglected orchards or with trees damaged in such a way as to approximate girdling. In such cases, there is usually a depressed vegetative condition, the trees bearing small light-colored leaves, and they may or may not produce abundant blossoms which are not likely to "set" well. Frequently such trees contain carbohydrates in excess, as compared with the available nitrate nitrogen, or moisture, or both. In order to effect a balance and induce vigorous growth and blossoms capable of setting fruit, either of two procedures might be followed but preferably both. Top-pruning would reduce the total

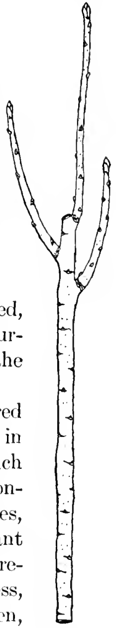


FIG. 24. Showing the type of growth that commonly follows the cutting of the terminal.

relative carbohydrates and hence increase the relative proportion of moisture and nitrogen; or the application of a quickly available form of nitrogen, such as nitrate of soda or sulfate of ammonia, would produce the desired result. An excess of either treatment would push the tree into vigorous growth and again reduce flowering.

80. Theoretical considerations.—Any theory of importance on pruning must have as its background a body of facts based largely on chemical, biochemical, and physical analyses, and with plants as bulky to handle as fruit-trees such information comes slowly. The speculations or postulates now available can scarcely be termed theories, but recent work is in material advance of the former "philosophy" expressed on the subject and the near future will undoubtedly reveal much of fact that is now lacking.

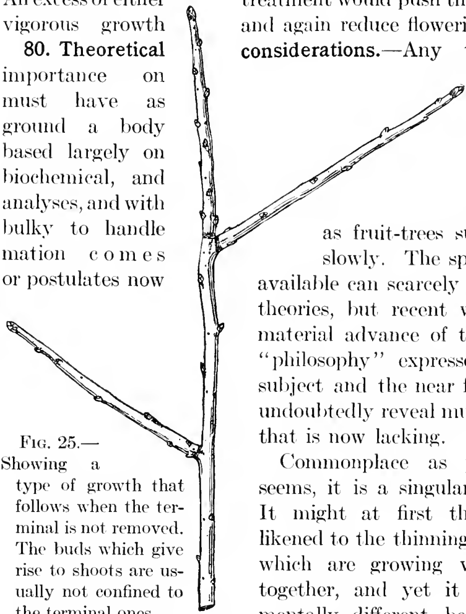


Fig. 25.—Showing a type of growth that follows when the terminal is not removed. The buds which give rise to shoots are usually not confined to the terminal ones.

Commonplace as pruning seems, it is a singular practice. It might at first thought be likened to the thinning of plants which are growing very close together, and yet it is fundamentally different because the various parts of the tree possess a single or common root system. Again, the branches of a tree seem, in many ways, to be independent units, yet they are members of a single whole. However, all the different parts are usually not so placed as to be favorable to high-grade fruit production or for the strongest mechanical structure. If this dense growth is allowed to develop unchecked, it will result in an excess shading of certain parts with a resultant condition that might be loosely called starvation, followed by a dying of the branches.

If limbs or branches are removed, it is common knowledge that certain shoots are likely to develop which would otherwise remain as latent buds, and especially there is a stimulation or increased cellular activity near the point where the cut has been made. This response on the part of the tree is a type of regeneration—a provision through which some organisms replace lost parts—which leads to the point here involved: why or how does the plant manifest this increased activity near the point of injury? See Figs. 24 and 25.

One theory commonly accepted is that a reduction in the number of growing points and cambial area would make available to the remaining parts an increased amount of the tree's reserve food supply, from which at least the initial growth is made. With this increased food supply, the opening buds would make a much greater growth than would have been possible had no growing points been removed.

A second theory would account for the growth response following pruning by assigning the cause more particularly to the increase in amount of moisture and mineral nutrients, particularly nitrogen, to carbohydrates that are made available to the parts remaining. That is, it is due to a disturbance in the balance of the materials within the tree. These two views may be considered briefly together.

In the first place, it is well known that a fruit-tree usually manufactures more food material than is utilized in the various phases of growth, including the production of the crop. The unused portion is translocated downward throughout the whole tree and remains in the cells of the storage tissues; it is termed "reserve material" because it can be used later in growth.

Secondly, the amount and form in which the reserves occur in the parts of the tree vary at different times of the year, and one year with another. The following table illustrates this point by showing the amounts of dry matter, starch, and saccharose at time buds are swelling, in case of a seven-year-old Bismark apple tree that has been growing in sod for four years.

Table XV

AMOUNTS OF DRY MATTER, STARCH, AND SACCHAROSE IN SEVEN-YEAR-OLD APPLE TREE AT TIME BUDS ARE SWELLING (AFTER CHANDLER)

Part of tree	*Pounds dry wgt.*	*Pounds starch*	*Pounds saccharose*
1-year twigs	3.15	0.98	.12
Older branches	21.00	6.72	.17
Trunk	15.13	5.14	.11
Large roots	14.15	5.43	.28
Small roots	6.49	2.37	.06

Furthermore, it is significant in this connection to note that the reserves seem to be lower in the tree in spring and early summer when growth is very active than at other seasons, indicating that they are utilized in growth. It should also be recalled that growth activities are going on within the tree before leaves or blossoms are put forth. The following data would seem to establish this conception so far as the soluble materials are concerned. According to Chandler, the freezing point of the sap seems to be a fair measure of the amount of soluble carbon compounds present at different seasons:

TABLE XVI

FREEZING POINT DEPRESSION OF BARK SAP OF ELBERTA PEACH AND WILD SWEET CHERRY TWIGS (AFTER CHANDLER)

1916	*Elberta peach*		*Wild sweet cherry*	
	Freezing point depression, °C	*Moisture percentage*	*Freezing point depression, °C*	*Moisture percentage*
March 25	3.010	....	2.255	....
April 17	2.096	....	.....	....
May 3	1.880	....	1.485	....
May 10	1.378	....	1.295	....
June 1	1.540	59.2	1.120	60.1
June 19	1.810	....	0.985	....
July 6	2.158	....	1.553	....
August 17	2.230	62.0	1.730	61.4
October 5	2.233	....	1.763	....
December 29	2.567	54.6	2.563	54.3

According to Price,[1] the starch also is practically exhausted in the early growing season in all parts of the tree above the ground. If these statements are accepted, according to the first theory there should be no stimulation if the pruning is done at the beginning of the growing season. Chandler has shown, however, that it makes no difference whether the pruning is performed during the growing season or in late spring, so far as growth response is concerned. Hence this evidence would weaken the first theory and the latter calls for more careful attention.

From what has been said, it would seem evident that any pruning whatsoever would reduce the total amount of reserves available for future growth. However, top-pruning will also reduce the future leaf area that is to maintain the

[1] Price, W. A. Ohio Jour. Sci., Vol. 16. pp. 356–359. 1916.

synthesis of the tree and hence profoundly disturb its relation with the amount of soil-moisture and nutrients taken up by the undisturbed root system. To what extent a reduction in the top of the tree will affect the amount of water and mineral nutrients absorbed by the roots cannot be stated definitely at this time, but certainly each growing point remaining must receive a greater supply than had no pruning been practiced. This, then, would seem to account in part for the apparent stimulation to growth which takes place.

Critical observation has shown that heavy pruning will result in dwarfing of a tree, as already noted. This is explained on the grounds that fewer growing points must necessarily produce less total linear growth and hence less weight and, therefore, the top of the tree is somewhat reduced. This dwarfing in the top will react on the root system and it will become restricted.

81. When to prune.—Divergent views have been held as to the best time to prune fruit-trees, but careful observations are bringing about more unity of opinion. An old adage says "Prune when the knife is sharp," but another admonishes not to prune frozen trees and not to prune when the sap is "running"; so the layman has been left somewhat confused. Little actual experimental work has been done along these lines but much experience may dictate practice. From an experiment with apple trees conducted in Minnesota, where the winter temperatures are low, it is concluded that no difference in the healing of the wounds resulted whether the cutting was in fall, midwinter when the trees were frozen, or in the spring.[1] With hardy fruits it is not uncommon to prune at any time during the dormant season, but preferably in late winter or early spring. With the grape, peach, and other fruits liable to winter in-

[1] Brierley, W. G. Proc. Amer. Soc. Hort. Sci. 1919. p. 102.

jury, it is best to delay pruning until severe freezing weather is past. In Oregon it was observed that whether apples were pruned in November, *i. e.*, just at leaf fall, December, or March (when buds were swelling), the results were identical. The amount and type of pruning was far more important than the time.

82. Pruning at planting time.—Since the balance between the root system and top is disturbed when trees are dug for transplanting, it becomes desirable to prune the tree at planting time. Occasionally a block of trees is seen that was not pruned when planted and the result is a number of small growths on the long slender branches, making it almost impossible to prune with any satisfaction at a later period. Unless the moisture conditions are very favorable, many of such unpruned trees are likely to suffer permanent damage.

Dr. Warder once said that the hole for a tree should be as big as the orchard. If his advice is taken, the soil well prepared and the hole made large, it is possible to plant without reducing the root system more than is done in digging the trees. There appears to be no virtue in reducing the roots to mere stubs unless they are broken or mangled, diseased, or seriously dried out. Long weak roots should, of course, be made to conform to the others in length for convenience in handling. The first new growth of the tree is made from the reserve material within it, but as soon as the leaves appear they require moisture for functioning. Therefore, the reduction in leaf surface through pruning gives the roots an opportunity to develop a new area of root-hairs more nearly proportional to the leaf surfaces which are instrumental in absorbing the soil-moisture.

Some extensive tests were made at the Woburn Fruit Farm to determine the effect of careless planting on the after growth of the trees. The results were surprising in most respects, as they showed that trees carelessly planted and the soil rammed about the roots produced a greater growth than those set in the "orthodox" way. No injurious effect resulted from planting trees with mangled or broken roots, provided a reasonable portion of the root system was left intact. Neither did the huddling of the roots into a small hole have any apparent effect. The conclusion is drawn that trimming of the roots is altogether unimportant, the omission having sometimes one effect and sometimes another.[1]

83. Pruning young versus mature trees.—The problem of pruning the young tree is essentially different from that of pruning the mature one so far as purpose is concerned, but the basic principles remain the same. In the first place, the great essential is properly to select the future scaffold branches and prune consistently to develop the type of tree selected as the ideal. The first three or four years of the apple and pear and the first two years of the peach tree represent the formative or vegetative period in which the chief aim of the grower should be to develop a well-formed specimen, regardless of fruit-spurs or buds. The tree then enters a period when it is desirable to consider the growth of fruiting wood, and with the apple and pear it means a cessation of a systematic cutting back of the terminals and usually as little pruning as possible. This, of course, does not mean that small rubbing branches and water-sprouts should not be removed or that a long rangy branch should not be suppressed.

The tree next passes into the period of fruitage when the type of pruning will develop very largely into a thinning-out process with the apple and pear but also heading-back with the peach. As trees of the former fruits become older and larger, it will often be desirable also to head-back some

[1] Bedford, Duke of, and Spencer Pickering. Science and Fruit Growing. London, 1919. Ch. 4 and 5.

of the longest and highest branches, depending on the variety, distance of planting, and other conditions of locality and preference. The cherry as well as the peach should be kept pruned to an open tree as the spurs and shoots will be more fruitful and the branches more vigorous. The same practice should also be followed with the plum.

84. Salient features in pruning mature trees.—The following points should be borne in mind by the pruner in handling mature trees:

1. Remove all dead branches, also diseased or injured parts in order to safeguard the remaining portions of the tree. Some exceptions to this may be noted in case of such a disease as black-rot canker (*Sphæropsis malorum*) if it is abundant through the tree. If all diseased limbs were removed, little of the tree would remain, hence the practice is to remove only such limbs as show evidence of decline.

2. Open up the tree. If the tree has become too thick and "bushy," it will be necessary to remove a portion of the limbs or a weakening of the fruit-spurs will result and fruit inferior in size, color, and quality will be produced. Rubbing limbs should be cut off, and long rangy ones that are out of proportion should be headed-back.

3. Avoid the removal of fruit-spurs. This is paramount, and a thorough understanding of the way a tree bears its fruit must be one of the basic guides in the removal of branches. There are times when it is desirable to remove some of the spurs, or portions of the individual spur, in order to improve those that remain.

4. Stubs are to be avoided. In removing limbs or branches, no matter how small, they should be cut close to the trunk or adjoining branch to which they are attached. This is not so important with the peach as with the apple, owing to the strong growth of the former which will more quickly envelope a small stub.

5. As a rule, it is desirable to remove the "suckers" or "water-sprouts" that may arise throughout the tree. Strong sucker growth along the main limb may be an evidence of decline in the branch and the outer extremities may be robbed of vitality if they are allowed to develop. On the other hand, it is often desirable to retain a portion for replacing limbs. In such a case, it is usually desirable to head them back and treat in about the same way as a young tree.

85. Renovation pruning.—The dehorning of apple trees or the cutting back of one-third, one-half or even more of the tops of old trees, leaving naked branches from which to grow a new top, has had its advocates. This procedure requires great caution, for it is not uncommon to find that trees subnormal in vitality may have their death hastened by such a practice, although for the first two or three years the operation appears successful. It is usually better to cut back a portion of the tree at a time and always cut to a side branch rather than trust to the outgrowth of "suckers" or water-sprouts. Such trees should be stimulated by tillage or the application of manures or fertilizers as a safeguard against injury. The peach, on the other hand, may be headed-back severely with comparative impunity. Branches may often be developed in desirable places on an old tree by making use of water-sprouts which arise in those places. These sprouts may come into bearing in about three years and are handled in pruning in much the same way as a young tree.

86. Summer pruning.—As dormant pruning has been widely advocated to induce vigorous wood growth, so summer pruning has been recommended to encourage fruitfulness. The practice is an old one and has commonly been credited as a means of bringing tardy bearers into fruiting. There is very little experimental evidence on which to base this teaching, but it is well entrenched in the literature.

The value of the practice seems to depend on the variety, soil, climate, time, and particularly the type of pruning (of which there are very many), and doubtless on the internal condition of the tree. It is true that summer pruning will often decrease vegetative growth, but it does not necessarily follow that fruitfulness accompanies such enfeebled growth. Some experiments have been conducted to determine the value of this practice, but it scarcely seems possible as yet to harmonize the views held by different investigators on its value, but certainly it is pernicious at times. Doubtless the difficulty is due to the different methods employed and to the varying influence exerted on the materials manufactured and stored. Some have practiced both a thinning-out and heading-back of the branches relatively early or late in any given season, while others have merely pinched the tips of the branches. The results must, therefore, vary accordingly.

For eastern conditions the consensus of opinion seems to be that summer pruning is not a desirable practice, as the trees are enfeebled and the effects on bearing are doubtful, often negative, and frequently the yield is decreased. In England where dwarf trees are rather widely grown, there is some difference of opinion on its value,[1] but the growers are more favorable to summer pinching if any treatment is to be given. However, Bedford and Pickering [2] report after ten years' work that "Summer pruning, shaping, or pinching, seem to have been followed by no good results in the case of our trees, rather the reverse; and we should not, therefore, recommend such treatment."

Dickens [3] reports a successful use of summer pruning

[1] Gardener's Chronicle. 3d Series, Vol. 41, pp. 400–403; 406–407. 1907. Jour. Royal Hort. Soc., Vol. 33, Part 2, pp. 487–499. 1908.

[2] Woburn Expt. Fruit Farm, 5th Rept. 1905.

[3] Dickens, A. Kans. Agr. Exp. Sta. Bull. 136. 1906.

with ten-year-old apple trees that had not previously fruited. The extent of the results reported, however, are scarcely sufficient to justify the practice.

Batchelor and Goodspeed [1] conducted pruning investigations with the Jonathan and Gano apples. The trees were five years old when the work started and it was continued for four years. The winter-pruned trees averaged 1055 pounds to a tree for the four years as compared with 937 pounds from the summer-pruned trees, or a loss for the period of 257 boxes to the acre. Thus the summer pruning resulted in less fruit rather than more in this experiment, but whether the reduction is due to a lessened area of fruit-bearing wood removed by the summer pruning, or to an actual depression of fruit-bud formation is not clear.

Drinkard,[2] working with dwarf apple trees, found that: "Summer pruning of branches of the tree the latter part of June, when fruit-buds normally begin to show differentiation, checked wood growth the year in which the pruning was done, and greatly stimulated the formation of fruit-buds, as was shown by the bloom and crop of fruit the following year." The foliage of these trees was reduced 50 per cent by the pruning and as a result the "trees made very short growth in annual shoots."

Summer pruning has been advocated by Lewis for western conditions, for young trees of non-bearing age in order to produce a development of laterals and to gain practically one season by the operation.[3] The pinching or pruning should be done rather early in the season, or as soon as the rampant growth can be observed, which will be about the middle of June under Oregon conditions. The pruning would

[1] Batchelor, L. D., and W. E. Goodspeed. Utah Agr. Exp. Sta. Bull. 140. 1915.

[2] Drinkard, A. W. Jr. Va. Agr. Exp. Sta. Tech. Bull. 5. 1915.

[3] Ore. Agr. Exp. Sta. Bull. 130. 1915.

be much the same as for the following spring, although the trees may also need some thinning-out again and perhaps some cutting back the following season at the time of dormant pruning. The object of summer pruning for these young trees is to balance up the tree and to avoid heavy dormant pruning rather than to induce fruitfulness. Trees just reaching bearing age (four to seven years) are sometimes summer-pruned to induce fruitfulness and hence the time for the operation is later in the season, about the middle of July, or when the terminal bud begins to form. The cutting is again made where it is desired to force out new laterals and has a tendency on some varieties to bring about fruiting the following season. When this work is done properly, it is claimed that very little secondary growth will take place and practically no devitalizing effect will result to the trees, as is often the case under the conditions of the East.

Vincent [1] reports that in a four years' experiment in Idaho with summer pruning, the results are not entirely consistent. With Wagener the increase in yield amounted to 111 per cent, with the Grimes 52.8, Jonathan 2.4, and Rome 1.6 per cent. The color of the fruit from the summer-pruned trees was superior.

[1] Vincent, C. C. Idaho Agr. Exp. Sta. Bull. 84. 1915.

CHAPTER VI

THE THINNING OF FRUIT

THINNING of fruit is an established orchard practice at the present time. It has long since passed the experimental stage. However, many successful commercial growers do not include it among their operations because its necessity has not been so apparent as has that of pruning or spraying. The western growers have been pioneers in this work from a commercial standpoint probably because their practice of packing fruit in small packages, notably the standard box, has made thinning not only necessary but profitable. The present tendency is for all fruit-producing states to have a packing and grading law, and when this is accomplished the thinning of fruit will doubtless become still more general.

87. Definition.—By thinning is meant the removal of a portion of the crop of fruit from the trees shortly after the June drop (*i. e.*, soon after it has set) to prevent over-bearing.

88. History of thinning.—The practice of thinning fruit is by no means modern, but like many other agricultural operations, no definite time or place seems recorded as its origin. The pomological writers for many years have mentioned it as desirable and have urged its use. In his "Treatise of Fruit Trees" published in London (1768), Thomas Hitt says, "When there is too great a quantity of fruit suffered to remain upon any part of a tree, it is not so good as if there were only a proper quantity left on; and sometimes a tree becomes weak by bearing too plentifully. . . .

"Fruits are thinned the best either with a very narrow-pointed penknife or scissors; for by nipping them off with the thumb and forefinger, those designed to be left on are often displaced, as also the young branches and leaves . . . .

"Though I advise to thin fruit at different times, yet it should not be done later than the month of May; for if they are suffered to grow pretty large they rob one another, and none should be left on so near together as to touch before they be full grown; for they are apt to throw each other off or at least to spoil their shapes. Besides, they never come to the size they would otherwise do, and large fruit when ripe is always the best flavored. . . ."

Many of the same ideas have been repeated in subsequent works on fruit-culture, some writers enlarging and elaborating on these views. Two or three points are practically always mentioned by the early as well as modern writers, such as: the value of the practice to increase the size and appearance of the fruit; as a means of bringing about annual bearing; and to prevent the breaking of trees from overbearing.

89. Philosophy of thinning.—The theory of thinning is very simple, a theory that is paralleled in many branches of agriculture. The farmer thins his corn, the gardener his carrots and beets, the florist disbuds his carnations, chrysanthemums, and many other plants, and the forester thins his stand of timber, all for the same general purpose of allowing the remaining plants or parts ample room and food for development, or in other words to relieve the struggle for existence. For the same reason the fruit-grower also removes a portion of his fruit when it sets too heavily.

It is natural for every plant to reproduce itself, for two of the fundamental laws in plant and animal life are nutrition and reproduction. Fruit-trees, however, very often set a great many more fruits than they can properly mature. This distributes the moisture and food materials in so many channels that it results in small and inferior fruit. In this connection must be considered the characteristics of certain varieties, for it is well known that some heavy bearers are not apparently injured by their large crops, and conversely some light bearers never so utilize their energies as to produce heavy yields.

90. Fruit production exhaustive.—It is an exhaustive process for plants to produce pollen and seeds. The more the tree can be relieved of seed production and not sacrifice the crop, the more it is helped to balance up its life processes, namely: wood growth, crop production, fruit- and leaf-bud formation, and the laying up of reserve materials. Green [1] has shown that asparagus plants which fruit do not produce as large "tips" for cutting in the spring as those that are barren. While this is not entirely relevant, it illustrates the principle involved:

Table XVII

ASPARAGUS.—PRODUCT FROM FIFTY PLANTS EACH, MALE AND FEMALE (AFTER GREEN)

	Product from fifty male plants	*Product from fifty female plants*
	ounces	ounces
First period, 10 days	37	21
Second period, 10 days	104	68
Third period, 10 days	266	164
Fourth period, 10 days	203	154
Total for the season	610	407

"This shows a gain of the male over the female plants of seventy-six per cent for the first period and a fraction less than fifty per cent for the whole season."

[1] Green, W. J. Bull. Ohio Agr. Exp. Sta. Vol. III, No. 9, 1890, p. 242.

Green[1] also suggests that the varieties of imperfect flowering strawberries are more productive than the perfect flowering sorts because of the latter's exhaustion in pollen production. Later[2] the Ohio Station reported as follows: "The average yield from each eighteen foot row of perfect varieties (139 varieties) was 5.47 quarts, and from each row of the same length of imperfect varieties (66 varieties) was 7.19 quarts. There are some high-yielding perfect flowered varieties, and some among the imperfect that give low yields; but it is generally recognized as a fact that the former, as a class, are less prolific than the latter." Fletcher,[3] however, states that while this probably is correct if applied to a grand average of all pistillate and staminate varieties, it is not true when individual varieties are considered. "For all practical purposes staminate and pistillate varieties are equally prolific." So this evidence from other plants would seem to add weight to the theory that fruit production is an exhaustive process in the economy of the plant.

91. Dependence of fruit on foliage immediately surrounding it.—The amount of elaborated food manufactured by the tree is governed by the area of healthy foliage that it possesses. And, furthermore, each fruit depends largely on the leaves in rather close proximity to it. Therefore, because only one side of the tree or one branch is heavily loaded, it does not obviate the need of thinning that part.

92. Objects of thinning.—The objects of thinning fruit may be summarized as follows:

1. To increase the size, color, quality, and uniformity of the fruit.

[1] Green, W. J. Bull. Ohio Agr. Exp. Sta., Vol. III, No. 7, 1890, p. 221.

[2] *Ibid.*, Bull. 236 (1912).

[3] Fletcher, S. W. Strawberry-Growing. p. 130. New York, 1917.

2. To prevent the breaking of the limbs.
3. To reduce disease and insect injury to the fruit.
4. To maintain the vigor of the trees.
5. To secure more regular bearing.
6. To decrease the labor of handling the crop.

93. To increase the size of the fruit.—Probably the greatest advantage of thinning is the increase in the size of the remaining fruits and this is well borne out by experimental evidence. In fact, practically all data are expressed in terms of percentage of large and small fruits from the thinned and unthinned trees, and the amount of each. It is true, of course, that the increase in size will depend on several factors, especially the amount of fruit which has set. It is seldom that a heavily laden tree will not show a marked increase in size of fruit, if it is thinned sufficiently early and enough is removed. Disappointment is likely to result if a grower has his first experience in thinning a tree that is carrying but a moderate crop. The age and vigor of the trees are also important factors determining the amount of fruit an individual tree can carry through to maturity. The varietal factor again plays an important part, as does the cultural treatment. The following tables are fairly representative of the influence of thinning apples on the size of the remaining fruit:

Table XVIII

THINNING APPLES

All imperfect fruits were removed and all others thinned to not less than four inches apart. Yield to a tree for three years

(AFTER BEACH)

Treatment	Barrel fruit				
	No. 1		No. 2		Total
	Bu.	Per cent	Bu.	Per cent	Bu.
Baldwin					
Thinned	39.2	75.5	12.7	24.5	51.9
Unthinned	37.5	60.9	24.1	39.1	61.6
Greening					
Thinned	30.2	80.8	7.2	19.2	37.4
Unthinned	28.1	79.4	7.3	20.6	35.4

Table XIX

THINNING APPLES IN AN OHIO ORCHARD. ROME BEAUTY

(AFTER BALLOU)

Tree No. 1. Unthinned. Number of apples set and matured on tree 4376

	No. of apples picked	Weight, pounds	Bushels	Per-centage of grade
Firsts	1756	488	9.76	48.22
Seconds	1950	390	7.8	38.53
Defective and small	670	134	2.68	13.24
	4376	1012	20.24	

Table XIX—*Continued*

ROME BEAUTY

Tree No. 2. Thinned to 8 inches apart. Number of apples set 4178; number taken off, 771

	No. of apples picked	*Weight, pounds*	*Bushels*	*Percentage of grade*
Firsts	2656	830	16.6	83.24
Seconds	445	99	1.98	9.92
Defective and small	306	68	1.36	6.82
	3407	997	19.94	

Table XX

THINNING APPLES IN A NEW HAMPSHIRE ORCHARD. BALDWIN (AFTER GOURLEY)

	Original number of apples	*After thinning*	*Per cent No. 1*	*Per cent No. 2*	*Per cent culls*
1. Unthinned tree	4055	....	16	78	4
2. Thinned tree	3453	2415	58	40	1
3. Thinned tree	3350	2061	82	16	.6
4. Thinned tree	3130	1760	79	19	1
5. Thinned tree	3895	2277	71	26	1
6. Unthinned tree	2938	....	48	43	7
Average for unthinned trees	....	....	32	60	5
Average for thinned trees	....	....	72	25	—1

Auchter[2] says, "In thinning bearing Ben Davis trees in 1914 it was found that the apples on the unthinned trees were

[2] Auchter, E. C. W. Va. Agr. Exp. Sta. Bull. 162. 1917.

so small that 65.7 per cent of the crop was less than 2¼ inches in diameter, 34.1 per cent of the crop was between 2¼ and 2¾ inches and practically none was above 2¾ inches. In contrast to this, the crop from those trees thinned six to seven inches apart had only 13.6 per cent of the fruit less than 2¼ inches, while 71.6 per cent was between 2¼ and 2¾ inches, and 14.6 per cent was more than 2¾ inches. Although there were nearly 2000 more apples per tree on the unthinned trees at picking time, still due to their small size, they produced less than one-half as great a total marketable quantity."

The following average results of several experiments on thinning apples are tabulated and may be considered as fairly representative of the increase in size from thinning:

10 experiments, 100 trees.

8 varieties, Baldwin, Greening, Stark, Ben Davis, Rambo, Rome, Winesap, Jonathan.

5 states, Nova Scotia, New Hampshire, New York, Ohio, Colorado.

TABLE XXI

EFFECT OF THINNING ON SIZE OF FRUIT

Per cent No. 1		*Per cent No. 2*		*Per cent Culls*	
Unthinned	Thinned	Unthinned	Thinned	Unthinned	Thinned
43	71	45	23	6	3

94. Thinning to improve color.—An increase in color is one of the usual results of thinning. In most experiments the color of the fruits (especially on peaches and apples) has been increased, although it must be seen to be appreciated. In an unpublished experiment conducted by the author with Grimes Golden apples, the size was not so materially affected as was the color. Practically every apple was a fancy "box" grade, having developed a rich golden color and a pink blush on one cheek, as compared with the check trees on which nearly all the fruit was a little undersized, of a greenish color, and had no evidence of the pink cheek.

95. Quality improved by thinning.—Quality is more difficult to define and tabulate, but the unanimous report of experimenters and orchardists is that the enlarged and highly colored fruit is better in quality than the smaller and poorer specimens.

96. Thinning to prevent breaking of limbs.—No one who has been observing orchards for a period of years has failed to notice the appalling breaking of limbs as a result of overbearing. Some trees and even orchards are so ruined after some exceptionally heavy crop that they never regain in form and symmetry what they lose in one season from lack of proper pruning and thinning. The use of props is also much reduced or entirely obviated in an orchard that has been well thinned.

97. Thinning to reduce disease and insect injury.—In thinning the fruit, any that have been injured by insect stings or early attacks of fungus, as well as ill shaped specimens, would be removed. In the case of peaches and plums, the amount of such disease as brown-rot is much reduced when the fruit does not hang so close together and also the spray solutions can better cover the entire surface of each specimen. In the case of the apple, there would be less opportunity for the second brood codlin-moth to find an entrance if no two fruits touch. Thus the instances might be multiplied of greater injury from insect and disease if the fruit is not thinned.

98. Thinning to maintain the vigor of the trees.—It is difficult to present experimental evidence directly on this problem, but it has been the experience and observation of fruit-growers for many years that a tree (especially a young one) which bears an excessive crop of fruit may be permanently injured as a result or may at least require several years again to bear fruit in quantity. This difficulty may be obviated by nature through a lack of setting of the blossoms and indeed this is common, notably with peach trees just reaching the bearing age. However, when a natural abscission does not take place, it is desirable to thin the fruit.

It would probably be difficult to cite a season when the above principle was so evident as after the winter of 1917–18. Winter-injury was common throughout the northern portions of the country and the testimony of a vast number of growers was that the trees that bore heavily in 1917 suffered the greatest injury from the following winter and many were killed outright. Hence not only young but also mature trees may have their vigor maintained by judicious and systematic thinning.

99. Thinning to secure more regular bearing applies more particularly to the peach than to the other tree-fruits. In experiments with mature apple trees, the results have usually been negative. This is explained on the grounds that the fruit-buds have started to differentiate as such before the thinning and hence it can have no effect. Writers have, however, often urged that annual bearing was one of the greatest advantages to be gained by thinning. This seems most reasonable, and the teachings of plant physiology would give it some support. Just why the peach should be so responsive in this direction and the apple be unaffected is not clear unless it is due to a longer period of fruit-bud formation and type of bearing.

Walker reports as follows in regard to the peach:[1] "The trees on which the first lot (which had been thinned) grew had a strong set of fruit buds for the next season's crop; the trees on which the second lot (unthinned) grew were scarcely able to live."

[1] Walker, E. Ark. Agr. Exp. Sta. Bull. 79. 1903.

The same observation is made by Gould [1] who says: "The effect on the tree (peach) of wise thinning extends far beyond the current crop, for it is a mortgage on future crops if the tree is seriously depleted by overbearing."

With the apple, however, the evidence is not satisfactory and usually the statements are general and without sufficient experimental evidence. It is possible that thinning younger trees may promote annual bearing, but there is no satisfactory evidence to present on this point. It is probable that growers may be inclined to credit one practice with the results obtained when several factors are involved, and thus prejudiced statements arise.

Downing's writings ranked high in the pomological literature of a half a century ago, and his statement may be cited as fairly typical of others. "When half the fruit is thinned out in a young state, leaving only a moderate crop, the apple, like other fruit trees, will bear every year, as it will also if the soil is kept in high condition. The bearing year of an apple tree, or a whole orchard, may be changed by picking off the fruit when the trees show good crops, allowing it to remain only in the alternate seasons which we wish to make the bearing year." [2]

Against this statement of Downing the work of Beach [3] must be considered, in which after four years' investigation he says, "It will not, on mature, well established trees, materially influence the regularity of production or the amount of fruit setting for subsequent crops. The profit, if there be any, must come from the crop thinned." Also, Auchter [4] after five years' work on this subject, "while final

[1] Gould, H. P. Peach-Growing, p. 299, New York, 1918. Rural Science Series.

[2] Downing, A. J. Fruits and Fruit Trees of America, p. 63. 1900.

[3] Beach, S. A. *Loco cit.*

[4] Auchter, E. C. *Loco cit.*

conclusions are not attempted, results indicate that thinning does not influence subsequent crops nor cause trees, naturally biennial in bearing habit, to bear a crop each year." The author also has reported that "Trees which were thinned to twelve inches apart produced no more blossoms the following spring than did the unthinned trees which had borne an excessive crop." [1]

100. Thinning to decrease the labor of handling excessive crops of small fruit is of considerable consequence from a commercial standpoint. The work of picking and handling a crop in which a considerable proportion of the fruit is small or below a standard merchantable grade is not economical. That this labor can be appreciably reduced is established in the foregoing paragraphs.

101. The effect of thinning on the total crop.—As indicated by data previously cited, not infrequently the total crop from a tree from which half the fruit has been removed will be as great as from an unthinned tree carrying practically the same amount of fruit as was originally on the thinned one. This of course is possible because of the increased size of the remaining fruit. Often the crop is reduced in total yield and in some cases it results in actual loss. Perhaps the experience of the workman is the only safeguard in determining how much fruit should be removed, and even he will err in judgment at times.

Excerpts from experiments conducted in several states show the range of variation in this regard and fairly represent the situation. It is presumed that the trees in any given experiment are similar in size and amount of total fruit originally set.

[1] Gourley, J. H. N. H. Agr. Exp. Sta. Tech. Bull. 9. 1915.

TABLE XXII

RELATION OF THINNING VERSUS NON-THINNING TO THE TOTAL CROP

			Average a tree, lbs.
Colo.	Unthinned	2 trees	843
	Thinned	8 trees	610
Utah	Unthinned	4 trees	254
	Thinned	4 trees	269
Ohio	Unthinned	6 trees	924
	Thinned	9 trees	954
W. Va.	Unthinned	3 trees (young)	159
	Thinned	10 trees (young)	116
	Unthinned	1 tree	664
	Thinned	1 tree	648
	Unthinned	1 tree	670
	Thinned	1 tree	468
	Unthinned	1 tree	534
	Thinned	1 tree	528
Average unthinned trees			578 lbs.
Average thinned trees			513 "

The average difference in these particular experiments is 65 pounds or about 1½ bushels to a tree in favor of the unthinned tree. While no set of figures could be accepted as representing the exact relation of thinning to the total crop, as no two experiments would be alike since so many factors are involved, yet they are indicative of what might be expected. Although these figures show that the total crop may be somewhat reduced, they must be viewed in the light of the discussion under size of fruit and it must be realized that the economic value of the crop is very likely to be higher from the thinned trees.

102. When to thin.—The time for thinning will vary with the variety, season, latitude, and possibly other factors.

As a rule, the sooner the thinning is done after the June drop, the better will be the results. The apples will be nearly an inch in diameter at that time, some varieties larger and some smaller. This will be the middle of June with peaches and plums, and the last of June to the middle of July (depending on the locality), with apples and pears. When the season is late, it is advisable to begin the work before the June drop is quite over or it will be delayed until late in July in the northern latitudes. When the work is left until late in the season, the beneficial results are often reduced. The reasons for thinning about the time of June drop are:

1. The size will be increased to a greater extent.
2. The development of seeds and "pits" drains the energies of the tree.
3. If done before that time, it is probable that many fruits which were thinned would not have set, thus wasting labor and causing too great a distance between fruits after the natural abscission has taken place.

It is the experience of most growers that if thinning is delayed until late in the season, the size of fruit is not perceptibly increased. The author has seen distinct evidences of this on several occasions, especially with the apple.

In order to establish that early thinning lessens the drain on the resources of the tree, a chemical analysis of the seeds and pits early in the season and later must be considered.

As already referred to in Chapter I, Bigelow and Gore[1] report on the composition of the Triumph, Rivers, Early Crawford, Elberta, Heath, and Smock varieties of the peach, at three periods in the development of the fruit. First, immediately after the time of the June drop; second, when the stone had hardened; and third, when the fruit was

[1] Bigelow, W. D., and H. C. Gore. U. S. Dept. Agr. Bur. Chem. Bull. 97. 1905.

ripe for picking. The average composition of these varieties is shown in the following table:

TABLE XXIII

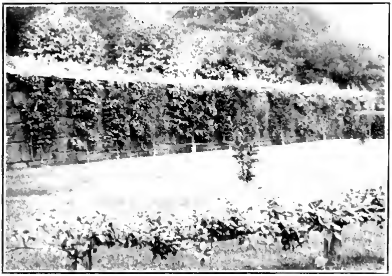
AVERAGE COMPOSITION OF SIX VARIETIES OF PEACHES AT DIFFERENT STAGES OF GROWTH (AFTER BIGELOW AND GORE)

State of growth	*Weight of*				*Total solids in*		
	Peach	*Flesh*	*Stone*	*Kernel*	*Flesh*	*Stone*	*Kernel*
	Grams	%	%	%	%	%	%
June drop.......	9.51	64.55	32.50	2.94	14.77	9.37	6.89
Stone hardened..	16.75	71.54	25.82	2.89	16.97	27.35	7.54
Market ripe.....	73.59	92.49	6.86	0.65	14.04	66.94	44.78

Gould's [1] comments on this table interpret the problem in its relation to early thinning: "The most important feature of this table from the standpoint of thinning is in showing the rapid rate of increase of the solids in the stones while passing from the June drop stage to the hardening stage. The first analyses of the stone-hardened stage were made June 23 and 28, depending on the variety. During the period of fifteen to twenty days, the percentage of solids in the stones nearly trebled. The fact is also brought out that though the average weight of the pit (stone and kernel combined) is only 7 per cent of the weight of the whole fruit, the total solids in the pits comprise more than 25 per cent of the total solids in the whole fruit.

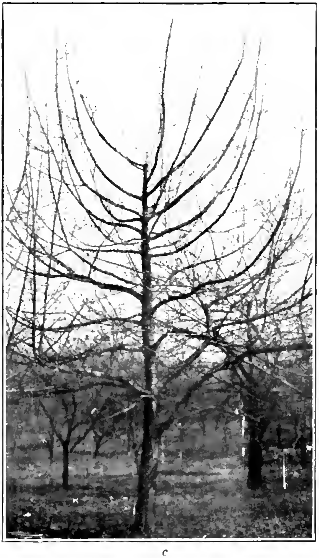
"It is well to observe also that solids in the flesh remained fairly constant throughout the development of the fruit, the variation ranging from a total of 14 to about 17 per cent, a difference of only 3 per cent, while the solids in the stones constantly increased from about 9.3 per cent at

[1] Gould, H. P. *Loco cit.*



a

b



c

d

PLATE III.—*a*, Dwarf apple trees trained in a horizontal cordon, espalier pear trees on wall to rear. *b*, A type of central leader that could now be developed either into a two- or a three-story tree. *c*, An unpruned apple tree that has developed as a central leader; recently the top has been removed. *d*, A two-story tree with four branches at each scaffold; the leader may now be removed.

the June drop period to nearly 67 per cent at the market ripe period.

"These figures, therefore, furnish a scientific basis for early thinning, also for the frequent observation that the development of a large number of pits makes a heavy demand for plant food."

Experience dictates the item listed under 3 and it requires no further explanation.

Some writers suggest that the trees should be thinned twice or thrice, the first time after the June drop, the second about the middle of August, and the third about three weeks before picking, because the operator is not likely to thin sufficiently the first time over the trees. Doubtless it will seem necessary, especially to the beginner, to go over the trees at least twice in order to secure best results, but this is not likely to be possible on large scale orcharding.

With some early varieties such as the Yellow Transparent, it may be desirable to allow all the fruits to develop for a while and gradually thin the crop by making several pickings. The apples can be sold when quite small as this variety is merchantable when only a third or half grown.

103. The June drop referred to above is a natural abscission of the fruit which occurs at the time the permanent fruits are setting. That is, many fruits will start to develop and later fall. The explanation usually offered for this occurrence is that the fruit is imperfectly pollinated; or it has been injured by insect or fungus disease; or the struggle for existence that may operate against a portion of the fruits in a cluster. Often it is greatly increased by adverse weather conditions at bloom time. Usually the central blossom in a cluster opens first and when the fruit is set remains on the tree.

Peach- and plum-growers need no further evidence than they already possess that the curculio is responsible for a large part of the drop many seasons. If the larva works into the soft pit the fruit drops very soon, while if it enters only into the flesh the fruit may develop for a time and then show color as if ripening and drop to the ground.

In some sections, the apple-scab fungus causes a serious non-setting of fruit and early dropping. The fungus girdles the tender stems and prevents the development of the crop.

104. How to thin.—In the operation of thinning the apple and pear, the surplus may be removed by holding the cluster or spur and carefully and quickly giving the fruit an upward twist. A special type of shears is on the market that is convenient in cutting the stems, but usually the operator prefers to thin by hand. With the plum and peach, the operation is still simpler—just pick off the surplus fruits with the thumb and forefinger. Rakes and poles sometimes used to remove the surplus are not to be recommended, although such an operation is much cheaper. The objection is that no discrimination can be made between good and poor fruits. Shaking the tree is also a poor way to accomplish the desired results. The most outstanding warning that can be given is to avoid breaking the fruit-spurs. Varieties vary in the ease with which they are thinned. The Rome apple, for example, because of the long stems, can be removed very rapidly, while the York is difficult and slow to work because of the short stems and ease with which the spurs are broken.

It should be recognized that considerable thinning may result when the trees are pruned, but with such fruits as bear their entire crop from axillary buds, additional thinning must be practiced.

105. Distance to thin.—No definite rule can be given for the distance apart that fruit should be thinned. Usually apples should be from five to eight inches apart and peaches from four to six inches. Beach recommends that apples be thinned to three times the diameter of the largest fruits at maturity while Wickson suggests that two and a half times the diameter of the fruit desired would be the proper distance. Herrick found it desirable to thin Winesap to nine or ten inches apart for the best results. Of course, the smaller the fruit, the more it should be thinned, and conversely the larger the fruit by nature the less it should be thinned, except to prevent the breaking of branches.

In some regions, the recommendation is to remove all fruit from alternate spurs in order to bring about annual bearing. In all cases the thinning should be uniform and the work thoroughly done as the operation progresses, to insure satisfactory results.

106. Cost of thinning versus returns.—The task of thinning a large orchard of mature trees when they have set a heavy crop of fruit seems formidable and the question naturally arises as to whether it will pay. However, if the cost is computed to a tree basis or to a still smaller unit, the barrel or box, it will not seem impracticable. It will depend, of course, largely on how the fruit is to be handled. The cost of thinning reduces itself to a question of time since no particular apparatus is necessary, and this will depend on the size and shape of the tree, the variety, and the person doing the work.

Since the factors are so variable in this regard, it is difficult to average conditions, but the following cases are cited:

New Hampshire. Trees 35 years old. Average 4¾ hours to a tree in one case (4 trees). Average 2¼ hours to a tree in another case (4 trees).

New York. Average 3½ hours to a tree (4 mature trees).

Ohio. Trees 17 years old; 1¾ to 2¾ hours to a tree.

West Virginia. Middle-aged trees bearing 4 to 6 barrels to the tree. Average 2 to 3 hours to a tree.

Colorado. Average a little less than 3 hours to a tree.

Hence, if it requires from two to three hours to thin a tree, the cost can readily be computed.

It is obviously unfair to charge all the cost against thinning, since the same apples would have to be picked in the fall and at a greater expense, and also it would require more handling of inferior fruit and greater grading expense than when thinning is practiced.

107. Thinning the peach.—Peach trees are much inclined to heavy bearing and, as a result, the trees often suffer damage and the fruit runs small. This heavy bearing is largely due to the nature of the fruiting wood. Although a part of the fruit-buds may be removed by pruning, many more fruits are frequently suffered to remain than the tree can properly mature. "There is perhaps no other operation concerning the desirability of which there is a more complete oneness of opinion among peach-growers than in regard to thinning when the trees are overloaded."[1] The principles involved in peach thinning are covered in the treatment preceding.

Close[2] reports on thinning the peach with decided results in increasing the size of the fruit. The trees were five years old (Elberta) and in vigorous condition. He classifies his thinning as follows: "Common thinning means that at maturity the fruit should be four inches apart; 'medium' means six inches apart, and 'severe' eight inches apart when ripe." He also thinned part of the trees early and others late:

[1] Gould, H. P. *Loco cit.*

[2] Close, C. P. Ann. Rept. Del. Agr. Exp. Sta. 1902. p. 89.

TABLE XXIV

RECORD OF RIPE FRUIT FROM THINNED AND UNTHINNED TREES (AFTER CLOSE)

Kind of thinning	*Fancy,*[1] *per cent*	*Firsts,*[2] *per cent*
Unthinned	48	49
Early common	51	47
Early medium	60	39
Early severe	80	20
Late common	47	50
Late medium	80	20
Late severe	73	26

108. Thinning the plum.—Experience has differed in the advantages secured by thinning plums. In some places very good results were obtained in increasing the size of the fruit, while in others the increase was almost nothing. Some varieties fruit so heavily, however, that it would be well to thin to prevent the trees from breaking and to reduce disease and insect injuries.

Garcia's[3] work showed that definite results were obtained by thinning plums to six inches apart and to a less extent to three inches. The trees thinned to six inches produced on the average 84.1 per cent of first-grade fruit, those to three inches 77.6 per cent, and the unthinned trees 50.5 per cent:

[1] Fancy, above 2½ inches in diameter.

[2] First grade, 2½ inches or slightly less in diameter.

[3] Garcia, F. New Mexico Agr. Exp. Sta. Bull. 39. 1901.

Table XXV

THINNING THE PLUM (AFTER GARCIA)

Name	*Distance thinned in inches*	*Percentage of first-class fruit*	*Percentage of second-class fruit*
Wild Goose	6	75.7	24.2
	3	70.1	28.8
	None	67.4	32.5
Clyman	6	93.4	6.5
	3	85.9	14.
	None	53.7	46.2
	6	86.4	13.5
Tragedy	3	96.9	3.
	None	53.7	46.2
	6	81.1	15.9
Yellow Egg	3	57.5	30.6
	None	27.5	53.

On the other hand, Powell reports on thinning trees of the Burbank and Poole's Pride varieties, neither of which was a financial success. It cost ten cents a tree to thin the former and fifteen cents for the latter. "There was some difference in the size of fruit in favor of the thinned trees (Poole's Pride), but the difference was surprisingly small. However, the unthinned trees suffered very heavily from broken branches the latter part of the summer which did not occur with the thinned trees. As far as the crop was concerned the thinning was not a financial success."

109. Thinning the pear.—Not many data are available on the thinning of pears, but there is no reason to suppose that they would not respond if the trees had set a heavy crop. Powell [1] records an experiment with Kieffer pears in which trees, eight years of age, were thinned. The trees had set full and the fruits were removed so that no two were closer than six inches. As a result, 83 per cent of the thinned pears and 61 per cent of the check pears were of the No. 1 grade.

110. Thinning the grape.—Husmann [2] says: "It will sometimes be necessary to thin the grape, in order to more thoroughly develop the remaining bunches. The best thinning is the reduction of bunches and bearing shoots, at the first summer-pruning. If the number of bunches on each fruit-bearing branch is reduced to two, it will do no injury, but make them so much more heavy and perfect."

Bioletti [3] recommends thinning the grape in California as follows: "This excessive compactness can be prevented by thinning before the berries are one-third grown. Thinning, moreover, increases the size of the berries, hastens ripening, promotes coloring, and lessens some forms of sunburn. . . .The bunches are thinned at any time after the berries have set and before they have reached one-third their mature size. No bunches are removed, but only a certain proportion of the berries of each bunch. The number of berries to be removed will depend upon how compact the unthinned bunches usually become. In general it will vary from one-third to one-half of the total number. . . ." This, it will be noted, refers to the European grape (*Vitis vinifera*) as grown in California, and the same recommendations follow when *V. vinifera* is grown under glass in the East.

[1] Powell, G. H. Del. Agr. Exp. Sta. 12th Ann. Rept. 1900. p. 140.

[2] Husmann, George. American Grape Growing and Wine Making. 1883.

[3] Bioletti, F. T. Stand. Cyc. of Hort. III. p. 1385.

CHAPTER VII

ORCHARD SOILS

STUDENTS of every phase of plant production, from the extreme specialist in the greenhouse to the extensive grower of field crops, find a common interest in a study and understanding of the soil. The most casual observation shows that soils vary in their nature or physical make-up and that plants flourish differently on the types. Researches during the past quarter of a century have added greatly to the knowledge of this subject and have opened up numerous new phases which must be considered by the student of soil science. It is not possible nor desirable, however, to enter into a full discussion of the properties of soils in this connection, but a brief outline of the types that commonly occur in the fruit regions should be reviewed.

111. Factors involved.—It is of course true that several factors must enter into consideration when selecting an orchard site. The location of the land as regards market conditions is of such great practical importance that a less valuable soil may be chosen in order to meet this requirement. Also the elevation in order to obviate frosts must be considered. An otherwise good slope may be so "seepy" owing to the geological formation that its use for orcharding is prohibitive without drainage. Also the previous treatment of the land and the supply of humus and calcareous material may greatly affect the desirability of the land for fruit-growing. Aside from these features, however, the mechanical or physical make-up of the soil is fundamental and worthy of careful study. Fortunately most fruit-trees will flourish over a rather wide range of soil types but some are better than others and some types are to be avoided entirely. The classification of soils according to the usual standard should, therefore, be considered first.

112. Soil defined.—Soil has been described as "the broken and weathered fragments of rock that cover in a thin layer the solid part of the earth and that furnish the foothold and, in part, the sustenance for plant life." [1] An understanding of the soil has involved a many-sided and complex investigation, for soils vary in an almost infinite number of ways and the adaptation of various kinds of plants to a given soil is far from constant. These conditions involve on the student of pomology a necessity for study of soil conditions as a basis for orchard production.

113. Soil classification.—As regards origin, soils are classed as either "sedentary" or "transported," depending on their geological history. Soils are composed of minute particles of the various minerals of which the rocks of the earth are made up and the fineness with which they are ground, together with the proportionate mixture of these particles, gives a basis for classification. The method of arriving at this information is called a mechanical analysis.

Four general groups of soil particles are recognized in agriculture as a basis of classification: sand, silt, clay, and humus. The size of the particles composing each of these series has been standardized by the United States Bureau of Soils as follows:

Coarse sand 1/25 to 1/50	of an inch in diameter.
Medium sand 1/50 to 1/100	" " " " "
Fine sand 1/100 to 1/250	" " " " "
Very fine sand 1/250 to 1/500	" " " " "

[1] Lyon, Fippin, Buckman. Soils, Their Properties and Management. New York, 1915. Rural Text-Book Series.

Silt 1/500 to 1/2000	of an inch in diameter.
Fine silt 1/2000 to 1/5000	" " " " "
Clay 1/5000 to 1/250,000	" " " " "

Sand is a valuable component of an orchard soil, although in itself it does not contain plant-food, since the sand particles are largely quartz which weathers very slowly. It is of value because it lightens the soil, gives it natural drainage and has a tendency to make it warm.

Clay is composed of very small particles, microscopic in size, and forms to a considerable extent the body of the soil. It is derived from various rocks and carries considerable of the mineral elements of plant-food. The colloids of the soil, which have recently received considerable attention, are associated with the finer clay particles. If clay is present in abundance, the soil will dry badly, shrink, and crack during very dry periods. On the other hand, clay causes the soil to be heavy and difficult to work when wet.

Silt is much the same as clay in its character but the particles are intermediate in size between the sands and clay. A soil containing large amounts of silt is usually moderately rich, well adapted to the growing of the grain crops.

Humus is a term given to decomposed vegetation and is of signal value in increasing the water-holding capacity of a soil and in causing it to be mellow and easy to work. This term is often used loosely or incorrectly, since vegetation plowed into the soil does not become humus until it is thoroughly decayed. The humic acids produced during decay contribute materially to the setting free of plant-food materials in the soil.

The term loam is used to describe a soil made up of a combination of sand, silt, and clay and it is further defined by the predominance of one or the other, as sandy loam, silt loam, or clay loam. The fruit-grower is interested in the various loam soils, depending on the kind and variety of fruit grown.

When the clay and silt particles predominate, only the fine grades of sand are usually present. If the silt grade is most abundant, the soil is a silt loam. If clay is greatest in amount, the soil is a clay loam. And if the exceedingly fine clay particles constitute more than 30 per cent of the soil mass, the type is a clay, the other 70 per cent being primarily of silt and very fine sand. A soil containing as much as 50 per cent clay is very "heavy," while those containing 60 to 70 per cent, as at Medford, Oregon, are exceedingly stiff and hard to work.[1]

114. Soils and subsoils.—Most soils consist of a surface layer which is more fertile and usually darker colored than those lying beneath it. It may be very shallow or a foot to many feet in thickness. This surface soil determines the richness of the land, since the roots of most crops penetrate but little below it. Its fertility is due to the larger amounts of organic matter and the accumulation of the more readily available plant-foods, together with the activity of the beneficial soil flora. The subsoil, or that which lies immediately beneath the surface, is of great importance to the fruit-grower and its character may vary from a sand to an impervious clay known as hardpan. The tree roots should have a wide range and penetrate the subsoil with ease as well as be free from standing water. While the subsoil must not be too well drained and devoid of plant-food, yet an open gravelly loam is usually considered best. If this does not obtain, it may be necessary to tile drain and plow or break up the subsoil for best results. The time to solve this problem or rather to avoid difficulty is when the orchard land is selected.

The necessity for good depth of subsoil cannot be empha-

[1] Wilder, H. J. U. S. Dept. Agr. Bull. 140. 1915.

sized too strongly. This applies to every variety of apple or other tree-fruit and to every type of soil. Shallow soils should be assiduously avoided for orchard purposes wherever they occur. The presence of unbroken rock, large ledges, or hardpan within three feet of the surface should be considered prohibitive. A soil depth of at least six feet should be insisted on wherever possible and an even greater depth is highly desirable.

Most of the fruit sections in America contain some soils adapted to fruit-growing and others that give indifferent or poor results. Not infrequently the nature of the subsoil is the cause of the failures, for it must be remembered that trees are comparatively deep-rooted.

While many sections might be taken for illustration, the extensive fruit region known as the "Ozarks" may be cited or a certain part of it which lies in the Arkansas Valley. Three types of subsoils are found through that general section. The good fruit subsoils vary from dark brown to a light reddish brown in color and are formed from broken granite. The deposit of this material varies from a few inches to several feet in depth, holds moisture well, but also drains well, and hence is good fruit land. Another type is a gravel subsoil which leaches badly and is likely to suffer in dry weather unless irrigated. A third type, on which many orchards have been inadvertently set, consists of the finest of soil particles and hence affords poor drainage. The roots seem unable to penetrate this soil and the trees suffer from droughts, root-rot, and widespread winter-injury. Incidentally, much of the difficulty can be avoided if alfalfa is planted, as the roots of this plant penetrate the subsoil.

115. Mechanical analysis of fruit soils.—The texture of a few typical fruit soils may now be examined. No one type of soil is essential, since fortunately most fruit-trees have a fairly wide range of adaptability, but it will be seen that in general the loam or gravelly soils when underlaid by one not too heavy are frequently best adapted to fruit-growing. The kind and variety of fruit to be grown must be considered in determining whether the heavier or lighter types of soils should be selected. The light sandy soils are ideal to work, but they do not hold the soluble plant-foods so well and are likely to suffer in times of drought.

In western New York, the apple soils are a little heavier than those in many other sections. The trees attain very large size and give high yields. In Niagara County, which produces a large amount of fruit, the Dunkirk loam is typical of the best fruit-soils. "Besides general crops, a very large acreage of this type (of soil) is devoted to fruit production. Throughout the county it (the Dunkirk loam) is distinguished by the prevalence of apple orchards. In the southern part the small area may almost universally be recognized by the presence and condition of the orchards. The trees have made a good growth and are regular in form and thrifty in appearance. While other types may produce good apples, the opinion of a large number of apple buyers and packers is that apples grown on this soil are of superior flavor, color, and keeping quality. . . While the peach thrives on a soil much lighter than is suitable for the apple, it is said by a number of practical men that on this soil is obtained fruit superior in flavor, color, and keeping quality. Pears, plums, and quinces are grown and west of Lockport there is a large acreage of grapes."[1]

The following table gives the mechanical analysis of this soil:

[1] U. S. Bureau Soils. 1906.

Table XXVI

DUNKIRK LOAM, NIAGARA COUNTY, NEW YORK

	Fine gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Clay*
Soil	0.9	4.2	3.3	6.4	13.5	52.9	18.4
Subsoil	.0	1.7	1.4	5.5	4.3	54.9	32.1

In Ontario County, which is also in the fruit belt of western New York, the best fruit is grown on the Ontario loam which is somewhat lighter and has the following mechanical analysis:

Table XXVII

ONTARIO LOAM, ONTARIO COUNTY, NEW YORK

	Fine gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Clay*
Soil	1.0	3.0	4.5	12.8	14.6	47.5	16.1
Subsoil	1.1	4.0	5.4	14.5	19.0	39.6	16.3

Fort Valley is the center of the peach industry of Georgia and one of the best known peach sections of the country. The soils best adapted to the production of this fruit are the Orangeburg sandy loam and the Orangeburg fine sandy loam. The fruit grown on these soils is superior to that on any of the other soils of that area. The latter is ranked as the best peach soil of the whole Gulf Coastal Plain region, owing to "the inherent characteristics of the soil itself and to the elevated and well drained position it normally occupies." Elberta is the variety typically grown.

Table XXVIII

ORANGEBURG SANDY LOAM

	Fine gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Clay*
Soil..........	1.90	6.90	6.68	27.10	40.40	10.28	6.28
Subsoil.......	.52	3.42	4.44	21.86	29.56	9.00	30.50

In comparison with the lighter types, the very heavy dark soils of the Rogue River Valley near Medford, Oregon, on which the pear is being grown very extensively, should be considered. A number of types of soil occur in the valley and foothills which are adapted to the growing of pears and apples, the Phœnix clay adobe being one of the heavier kinds. Some of the most valuable orchards in the valley are on this soil.

Table XXIX

PHŒNIX CLAY ADOBE

	Fine gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Clay*
Soil.............	0.9	2.4	2.2	4.1	5.7	21.4	63.1

This soil is 12 inches to six feet or more in depth, of a dark reddish brown to nearly black, sticky, and of a pronounced adobe structure.

The soil in the Hood River (Oregon) district is much lighter and well adapted to apples. It is essentially a loam with a high percentage of very fine sand. The subsoil is much the same in character except in places where it becomes very compact and not suited to orcharding.

Table XXX

HOOD SILT LOAM

	Fine gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Clay*
Soil	0.4	2.4	4.8	9.6	20.3	48.8	13.6
Subsoil	.1	.8	1.9	7.8	26.6	42.8	19.8

From these examples it will be seen that there is a rather wide range of fruit soils, although as a rule those which approximate the following analysis are best adapted to most fruits:

	Per cent
Aggregate of all sands	20–50
Silt	20–50
Clay	10–30

Hall and Russell give the following as an ideal fruit soil:

	Per cent
Fine gravel	1.0
Coarse sand	6.8
Fine sand	42.0
Silt	23.3
Fine silt	7.3
Clay	10.9

116. Orchard soils.—Since an orchard soil is judged more from its mechanical make-up than from its chemical constitution, it may be well to define further the types best adapted to the several fruits. It is impossible to state within narrow limits just what may be termed an orchard soil. Indeed, perhaps a fourth or a third of the arable land of this country might be used with considerable success for orcharding if other factors were favorable. While analyses have been given of a few typical orchard soils, the list might be greatly extended. In a very general way the following are usually requisites:

(1) The soil should be sufficiently retentive of moisture so that the trees and crop will not suffer from lack of water throughout the growing season, or else irrigation should be available.

(2) Fruit soils should usually be of a rather open nature so that ample drainage is provided; the texture being porous and friable.

(3) The soil should not be low in organic matter.

(4) Extremes of acidity and alkalinity should be avoided.

(5) A depth of not less than six feet is highly desirable.

The apple in general thrives on an open gravelly or light clay loam, although it succeeds on both heavy and quite light soils. Varieties differ in their requirements.

Pears as a class prefer a heavier type of soil than the apple, but the "adobe" soils of southern Oregon represent an extreme rather than the usual type. On a heavy silt or clay loam they are at their best.

The peach and cherry prefer a gravelly or heavy sandy loam, but in some sections the soil runs to a heavier type, even approaching a clay. The one requisite in all cases is good drainage.

The domestica plums should be grown on a moderately rich loamy soil, and the salicina varieties on a somewhat lighter type.

Much has been said in literature regarding the value of stony land for orchard purposes. This idea doubtless has its origin in the fact that well-drained soils are preferable and also that orchards are frequently successful on stony or rocky hillsides. There can be no virtue in such land other than the fact that an abundance of stones may give ample drainage and produce a loose type of soil and perhaps that a quantity of stones may serve as a mulch and conserve moisture. If a stony soil is selected, and it frequently is very satisfactory, it should be fertile and productive.

117. Chemical nature of fruit soils.—It is generally agreed that the mechanical make-up or texture of the soil is even more important than its fertility, since it is more difficult to change materially. However, it is a mistaken notion that the poorest soils should be selected for fruit-trees. This is true in spite of the fact that some kinds of fruit can usually be grown on the poorer soils with more success than most agricultural crops. It must also be recognized that it is not entirely the percentage of mineral elements in the soil in available form that makes for its fertility, but of great importance are the organic or humus content and its consequent soil flora together with a proper water relation and the absence of toxic materials or "unsanitary" conditions.

A chemical analysis of agricultural soils shows that the following elements are usually present: Silicon, aluminum, iron, phosphorus, calcium, magnesium, sodium, and potassium. Sulfur and chlorine are also found in small quantities. The nitrogen of the soil, which is so important to plant growth, is almost entirely in the form of organic matter, although the soil-air contains small amounts of the atmospheric nitrogen and also more or less ammonia. Nitrogen occurs in mineral form in some places or is obtained by manufacture and purchased as nitrate of soda, potassium nitrate, and sulfate of ammonia for agricultural purposes. If the silicon, aluminum, and sodium are eliminated as unessential plant-foods, it leaves but 15 per cent of the soil as the source of the mineral constitutents of plants.

118. Soil color.—While the question of soil color may be over-emphasized, nevertheless certain characteristics are correlated with it. A dark color usually indicates the presence of considerable percentage of organic material and this is usually associated with a rich soil.

The Porters black loam of Virginia and the Phœnix adobe clay of Medford, Oregon, are examples of black soils especially valuable for fruit-growing. Most fruit soils are not so dark in color. A reddish or yellowish soil usually indicates the presence of a large amount of oxidized iron. Some of the clays are very red as also are some of the soils derived from sandstone formation. Some of these are rich and productive, but ordinarily the red color would not indicate a well aërated and rich soil.

119. Limestone soils.—The question as to whether limestone soils are preferable for fruit is frequently raised. In order to form an opinion, the function of lime in the soil may be briefly reviewed.

The function of lime in the soil is two-fold: (1) to prevent "sourness" and neutralize the aluminum compounds; and (2) to flocculate clay soils and tend to hold together the sandy ones. Lime is looked on as a soil "improver" but it is of course a plant-food, for it is present in the ash of all plants and has a definite function to perform. However, it is rarely necessary to apply it for that purpose since all soils contain some calcium oxide. The exact percentage of lime necessary varies with the nature of the soil and hence is relative. "The greater the clay percentage in a soil, the more lime carbonate it must contain in order to possess the advantages of a calcareous soil; and that while in sandy lands lime growth may follow the presence of only .10 per cent of lime, in heavy clay soils not less than about .6 percent should be present to bring about the same result." [1]

The adaptation of plants to soils is a well-known phenomenon and one which has frequently guided the agricultur-

[1] Hilgard, E. W. Soils, p. 369. New York. 1906.

ist in determining cultural requirements. Some plants are distinctly "lime-loving," such as most of the legumes (alfalfa, clovers), others are equally "acid-loving," as the Heath family and the chestnut (*Castanea dentata*), while others are cosmopolitan so far as the soil requirement is concerned. Among the fruits, the following are adapted to sour soils: blueberry, cranberry, strawberry, blackberry, and red and blackcap raspberries; while the currant is listed as injured by sour soils.[1] It would seem from observation that most fruit-trees, especially the apple, stand on middle ground so far as the lime requirement is concerned. They are neither distinctly lime- nor acid-loving (as these terms are commonly used) but flourish in both types until the distinctly alkaline soils are reached on the one hand and the bog soils on the other. There is a popular belief that the apple does best on a limestone soil, but this would be difficult to establish. The idea doubtless has its source in the fact that a limestone soil is frequently fertile and that many very fine orchards happen to be located in limestone districts. As a matter of fact, the non-calcareous soils are often preferred, even when either would be available. This is particularly true for the peach.

Thus it is difficult to find evidence to answer this question in the affirmative since the eye does not detect any outstanding differences and, generally speaking, fruit-trees do as well in the non-calcareous regions as in the limestone areas. It would seem that Hilgard has put the matter too strongly so far as orchard fruits are concerned when he says, "The abundant fruiting of oaks on such lands as compared with the same species on non-calcareous soils is a matter of common note in the Mississippi Valley states; and the same is true of other trees, and of herbaceous plants as well." [2]

[1] Lyon, Fippin, Buckman. Soils, p. 384. New York. 1915.

[2] *Loco cit.* p. 503.

There is also little evidence in this country to show that the application of lime to orchard land has any appreciable effect on the trees or the quality of the fruit. Its effect in increasing the growth of cover-crops on certain soils is quite another question and must at once be recognized. Indirectly this may bring about an increase in the growth and yield of the trees as is discussed in a later chapter.

120. Alkaline soils.—An alkali soil is one which is strongly impregnated with various salts, such as sulfate, chlorid, and carbonate of sodium, magnesium sulfate, calcium sulfate, calcium chlorid, and others. In some sections

TABLE XXXI

ALKALI IN SOILS OF ORCHARDS (AFTER LOUGHBRIDGE)

Trees	*Condition*	*Percentage in soil. Total sulfate carbonate chlorid*
Apples		
Red Bietigheimer	Good	.101
Duchess	Poor	.146
Jonathan	Poor	.041
Apricots	Good	.063
	Affected	.246
Peaches	Best	.070
	Poor	.106
	Poor	.160
Pears	Best	.131
	Poor	.261
Plums	Very poor	.165

of the country, this type of soil constitutes a serious handicap to fruit-growing as well as to the production of other crops. Fruit plants vary considerably in their susceptibility to alkali conditions. Loughbridge[1] has made a careful study of this problem as shown in the table on page 137.

"The (apple) tree is quite sensitive to alkali salts, and their effects on the foliage of the tree were very marked. The Jonathan seems to be more sensitive than the Duchess."

The other fruits observed showed that when the trees are affected by alkali soil conditions, the newer limbs are more or less bare except for a tuft of leaves on the terminal, the leaves are small, yellowish or blackish in appearance, and the trees are barren of fruit.

Observations and data cited show that "the susceptibility of the wine (grape) varies according to variety, and that while some are tolerant of very large amounts of carbonate of soda and common salt, others succumb to the effect of far less of each."

Hilgard[2] says, in discussing deciduous orchard trees, "Of these, strangely enough, the almond seems to resist best. The peach is more sensitive, the apricot does fairly well. Plum trees are nearly as resistant as peaches, but sometimes suddenly begin to fail when beginning to bear; the fruit appears normal on the outside for a time, but the pit fails to form, being sometimes flattened out like a piece of pasteboard; and the fruit fails to mature. Apples are rather sensitive; pears considerably less so, doing well even when the outside bark around the root crown is blackened by alkali. The olive is quite resistant, the fig less so."

121. Drainage.—As stated in paragraph 114, the natural drainage of the orchard land is of the greatest importance in maintaining a healthy and long-lived tree. If the soil is

[1] Loughbridge, R. H. Calif. Agr. Exp. Sta. Bull. 133. 1901.

[2] Calif. Agr. Exp. Sta. Bull. 128. 1900.

not naturally well drained, artificial drainage may be very desirable if not necessary. While kinds and varieties of fruit will vary in their susceptibility to "wet feet," yet practically all fruit-trees do poorly if the land is regularly soggy or springy during any extended period of the growing season.

When artificial drainage is resorted to, the depth of the tiles and the distance apart the lines are placed will vary with the nature of the soil and the amount of water which must be drained. In a heavy soil the lines of tile are commonly placed at 2 to $2\frac{1}{2}$ feet deep, and about 2 rods apart, while in a sandy or gravelly soil the depth would be greater—from 3 to $3\frac{1}{2}$ feet. That is, the more open the soil the greater the distance the drainage water may be drawn.

122. Organic matter.—Probably any system of permanent agriculture should involve the returning to the soil of a plant residue or vegetative matter. This seems fundamental because investigation has entirely established the existence of a large soil flora and the necessity of bacterial action for the continuous availability of plant-food materials. A soil very low in organic matter is usually of poor tilth and supports a stunted tree growth. Also the returning of vegetation, especially legumes, to the soil maintains a much better supply of nitrates than when the soil receives "clean" tillage or is entirely untilled. Many orchard soils are materially improved in texture by plowing in a rank or heavy growing crop. This may be replaced after a few years by a nitrogenous crop.

The student should appreciate, however, that it is often a long and expensive process to reconstruct a soil devoid of humus, or a heavy intractable clay into one which is well adapted to orcharding. From an economic standpoint, it is better to select soil that is already adapted to the crop to be grown and then by reasonable amendments maintain its fertility.

123. Adaptation of fruit to soil types.—As indicated in a foregoing paragraph, there is in nature a definite adaptation of given plants to certain soils, some preferring an acid soil, others a calcareous one, some a wet soil, others an arid one. The different kinds of fruit-trees also manifest to a less degree some soil preferences, or rather they thrive better on one kind than on another.

The knowledge in regard to varietal adaptation to soils is not extensive, although certain outstanding cases have been repeatedly observed. The work of Wilder [1] along this line is the most complete in American literature.

The previous conception that the Baldwin apple thrives best on a rather light type of orchard land is confirmed by his observations. The subsoil should be somewhat heavier but not so clayey as to be termed stiff. The Rhode Island Greening, on the other hand, produces better fruit if the soil is of a heavy silty loam or light silty clay loam, underlain by silty clay loam. The soil should be moderately rich in organic matter and retain sufficient moisture to be classed as a moist soil and yet must not be poorly drained. The "blushed" Greening is produced on soil which approaches more nearly the Baldwin type. The Northern Spy is very exacting in regard to the type of soil on which it does best and the one suited to it seems to be a medium loam underlain by a heavy loam or light clay loam, *i. e.*, a soil as heavy as can be selected without incurring danger of inferior drainage. Much the same type of soil is desirable for the Wagener. The heavier of the Baldwin soils is recommended for the McIntosh but if experience is to be taken as a guide, this variety must be considered rather more cosmopolitan than many others, for it is successfully grown on soils ranging from rather light to fairly heavy and even on those which are not very well drained. Much the

[1] See Wilder, H. J. *Loco cit.*

same is true of the Stayman. The Tompkins King, Gravenstein, and Ben Davis do well on an open-textured rather than a fine loam, with subsoil of the same or only slightly heavier texture.

For peach varieties the following soil types have been suggested: Champion succeeds best on soils of only medium productivity, but they should be deep and well drained. Medium to heavy friable sandy loams, underlain by material not heavier than a friable loam and preferably a heavy sandy loam, are very desirable. Carman and Mountain Rose succeed best on soils somewhat less pervious than the Champion, yet deep and well drained. The Elberta and the Belle prefer stronger soils than the Carman and the Mountain Rose. Loams, silty loams, and silt loams, with subsoils of similar material seem best to meet these requirements. For Late Crawford, a fairly strong soil, such as a light porous loam somewhat less retentive of moisture than the heaviest of the Elberta soils, is desirable.

Some of the early varieties, such as Greensboro, are less sensitive to shallow soil conditions than the sorts mentioned above.

CHAPTER VIII

CULTURAL METHODS IN ORCHARDS

THE kinds of fruits vary in their requirements as regards culture, some bring tolerant of widely different methods while others are specific. Varieties also differ in this regard, some requiring thorough and annual cultivation while others may produce a satisfactory growth and yield with less stimulation. In general, however, it may be said that fruit-trees are vigorous and productive largely in proportion to the soil treatment that they receive. Young orchards in particular suffer readily from lack of good growing conditions and hence delayed bearing of commercial crops is the result. Older trees, while more tolerant of neglect, owing to the greater ramification of their root systems and also because of their greater reserve food materials will, nevertheless, usually respond readily to good soil treatment.

Unfortunately, authorities do not entirely agree as to the best methods of orchard culture. Certainly there is no one best system for all orchards under all conditions. However there are principles underlying the cultural problems which should guide the student in deciding what system to use.

While the use of manures and artificial fertilizers is intimately related to cultural problems, a full discussion of them must be considered later, except as general statements require mention.

124. Systems of cultivation.—Broadly speaking, two general systems of cultivation are followed in orchard practice, one in which the land or a part of it is tilled and the other in which the land remains permanently in sod. A number of variations of both these methods are in use. If a grower has achieved success with one or the other, he often becomes prejudiced against the other systems.

125. Terms defined.—*Sod culture* describes any system of soil management wherein the trees are grown in sod without tillage of any kind, or without mulching the trees with litter. The grass may remain without cutting or it may be cut and removed from the orchard or left lying on the ground. If the grass or litter is insufficient at least partially to kill out the growth beneath the trees, it must still be termed sod culture. This system, like all the following, may or may not involve the use of manure or artificial fertilizers and pasturing with stock. The *grass mulch* system consists in placing a mulch of litter (grass, straw, hay, corn-stalks, or other material) beneath the trees, usually extending it a little beyond the drip of the branches. As the trees become large, material must be brought in from outside the orchard in order properly to mulch them. A cleared or bare area should be maintained immediately about the tree trunks as a fire break and to lessen injury from rodents. *Clean tillage* involves the plowing or disking of the land in the late fall or spring and tilling at intervals of about two weeks throughout the early summer, usually until the first or middle of July. After tillage is stopped, the ground lies bare until the following spring, hence no vegetation is turned into the soil. The *tillage and cover-crops* system is similar to the former, but in addition to the tillage a cover-crop is sown at the time of the last cultivation and the crop is plowed under in the late fall or spring. Instead of sowing a crop, the land may be allowed to grow up to weeds. *Inter-cropping,* which is often followed in young orchards, refers to the growing of any crop (usually a cultivated one) between the tree rows for the purpose of harvesting it and thus utilizing more fully the land not yet occupied by the trees. The system of *alternate-row cultivation* is in use in some regions and involves the tillage and perhaps cropping of every other "land" or area between alternate rows of trees.

126. Sod culture.—In the first half or perhaps three-quarters of the nineteenth century, the prevailing practice in this country was to grow fruit-trees in sod land and along fence-rows; especially was this true of the apple. This was before the western orchard sections had come into existence and before the rise of commercial orcharding in the East. In the last quarter of the past century, the cultivation of orchards, wherever possible, was advocated by the progressive growers. Both experiment and experience in this country prove that sod culture is the poorest way of handling an orchard, although there are some outstanding cases to the contrary.[1]

The chief objection to the sod system is that, on the average, fruit-trees do not thrive so well as when they are at least partially cultivated, as is shown by the growth of trees, color, size, and amount of foliage, and yield of fruit. This objection may be entirely or partially overcome, however, by proper fertilization and mulching with litter. The reasons for these effects on the trees are discussed later.

On the other hand, certain advantages of growing trees in grass land may be cited as follows:

1. It prevents the washing and erosion of the soil. This is not so true in New England and other northern sections, because the ground is likely to be frozen during the so-called "soft" weather in winter or early spring that occurs farther south.

[1] The student should not confuse sod culture and grass mulch, for they are distinct systems if properly carried out, although it is not uncommon to find a mulch system soon degenerate into a sod culture, and thus they may be confusing.

2. The color of the fruit is usually higher and, therefore, it has greater commercial value than when grown under cultivation. Not all varieties are affected alike, however, for some will develop a high color under tillage.

3. The land is in better condition for spring operations than when it has been plowed. This applies particularly to heavy soils which do not drain readily. Also there may be less winter-injury in the sod orchard.

4. The dropped fruit is of higher market value.

5. Land too rocky to plow or to permit tillage may be ulitized by following some type of the sod system.

6. The expense of caring for the soil is reduced to little or nothing, in some cases only the loss of the land for pasturage and many times not that.

127. Grass mulch.—This method of handling an orchard is an attempt to follow nature and allow litter to accumulate in increasing proportion beneath the trees and thus conserve moisture and add plant-food to the soil. It seems to have been worked out simultaneously by F. P. Vergon of Delaware, Ohio, and Grant Hitchings of Syracuse, New York. Both of their orchards are commercially successful and many have emulated the practice.

As stated in the definition, the mulch system is limited to the practice of placing sufficient mulch about the trees partially or entirely to kill out the growth of grass beneath them. This would not include the practice of mowing the grass of the orchard and letting it lie where it falls, although a partial mulch is thus accumulated after a few years, but the grass still grows beneath the trees and thus the evil effects of it are not obviated. This latter system has been termed the "sod mulch" to distinguish it from grass mulch.

After the mulch system has been maintained for a few years, the soil beneath the mulch becomes loose and friable, retains moisture, is cooler in summer and freezes less in winter, and nitrates may be more abundant than when trees are grown in sod, but this latter is not always true. The growth of the trees is usually vigorous, the foliage abundant, and the yield much improved as compared with sod-grown trees. Under most conditions, it is desirable to add artificial fertilizers or animal manures, but sometimes this does not appear necessary.

It is usually desirable to plow the land before setting the trees. It may then be seeded down and the mulch system put in operation. When conditions will permit, it is still better to cultivate the orchard for four to six years. However, some very successful orchards have been planted in grass land that had not been previously plowed for a number of years and no ill effects appeared after the system had been followed for a long period of time. Its success under such conditions may be largely attributed to an abundant supply of moisture. The great difficulty is that neglect may result and the orchard soon show ill effects, as indicated by sparser foliage, smaller and yellowish leaves, and small fruits. If faithfully prosecuted, however, it is a practical system of orchard management, and well adapted to many conditions.

On hillsides that wash badly it is not desirable to plow much and yet the sod system is not desirable; hence the mulch finds a very desirable use. The same may be said of rocky land. Under many such conditions, it is not a question whether grass mulch is as good as cultivation but whether it is better than nothing.

The mulch system is perhaps better adapted to the apple than other fruits, although the pear, quince, and small-fruits may be grown in this way. Under few conditions should the peach, cherry, or plum be so treated, as the results of tillage methods produce much better results and longer-lived trees.

Among the precautions to be observed with mulched trees are:

1. Protection from mice, rabbits, and other rodents. The trees should be safeguarded by either a mechanical device or by means of a protective wash, but the former is much more reliable. Rodents are more likely to do damage in a mulch or sod orchard than in a cultivated one because of the harboring places.

2. Fire is another ever-present danger and provision should be made for fire breaks by having a bare space between the bole of the tree and the mulching material. On a young tree this area should be about a foot in radius and as the tree becomes older it should gradually be increased to three feet. A mound of coal cinders about the tree is also advisable for this same purpose.

128. Production of mulch material.—One of the problems in a large grass mulch orchard is to secure sufficient material for mulching. As much as possible is secured in the orchard, but as the trees become older the amount available becomes less. In some sections oats and wheat stubble is mowed about two or three weeks following the cutting of the grain and in this way a large amount of material is secured. Others procure hay, straw, or the like for the purpose.

One of the striking results secured by the Ohio Experiment Station [1] was the effect of fertilizers on the increased growth of grass in the orchard, which solved the mulch problem. It was found that when acid phosphate was used, alone or in combination with potash, a striking increase in growth of the clovers resulted without any seeding whatever. When nitrogen was used alone or in combination, the clovers were crowded out by the timothy, blue-grass, red-top, and in some cases orchard-grass, which took possession of the land.

[1] Ballou, F. H. Ohio Agr. Exp. Sta. Bull. 301, 1916. Also Bull 339. 1920. p. 16.

(See Plate VI.) The following figures show the results obtained in one orchard:

TABLE XXXII

RESULTS OF FERTILIZERS ON YIELD OF MULCH (AFTER BALLOU)

Annual fertilizer treatment to an acre	*Yield*	*Kind of grass*
	lbs.	
Acid phosphate, 350 lbs.	2,716	Red clover
Acid phosphate, 350 lbs.; muriate of potash, 175 lbs.	2,884	Red clover
Acid phosphate, 350 lbs.; muriate of potash, 175 lbs.; nitrate of soda, 350 lbs.	3,458	Timothy, red-top, blue-grass, orchard-grass.
Unfertilized	840	Poverty-grass, weeds

129. Clean cultivation has never been widely used in the eastern United States, but in sections of the Northwest and in California it has been followed extensively. The danger of clean tillage seems to be in its ultimate effect on the soil itself. Especially is this true in sections in which there is a long growing season and the summer sun is intense.[1] In the West it has been found that shade or cover-crops are desirable to shade the ground, thus protecting the soil flora and also maintaining the organic matter in the soil. While this system may and often does give satisfactory results for a period of years, it is likely to end in a premature decline of the trees and a decrease in size of the fruit. This would depend on the climate, the nature of the soil, and its fertility.

130. Tillage and cover-crop system.—From the standpoint of growth and yield of the trees, this system doubtless

[1] Paddock, W., and O. B. Whipple. Fruit-Growing in Arid Regions. New York. 1910. Ch. 11.

stands preëminent for most orchard lands in this country. Except for economic reasons or because of topography of land or nature of its surface, it would usually be safe to follow this practice. While the chief benefits of tillage are to the soil itself, yet certain orchard pests are better controlled when grass or weeds do not occupy the land between the trees. Rodents and some of the injurious diseases and insects are less prevalent in a cultivated orchard, for the stirring of the ground destroys their natural harboring places. Weeds likewise are kept under control, avoiding a loss of soil-moisture and plant-food materials to the trees. Tillage benefits the soil for orchard production in the following ways:

1. Maintains a better medium for the more desirable soil flora.
2. Increases nitrification.
3. Makes more available the plant-food materials of the soil.
4. Creates and preserves a surface mulch which conserves moisture.[1]

131. Cover-crops.—This term was first used in this connection by L. H. Bailey in 1893 in Bulletin 61 of the New York (Cornell) Experiment Station. It has its origin from the fact that such crops are planted in middle or late summer and are designed to make a cover over the land as well as a winter protection and to recover from the soil surplus moisture, as well as readily available plant-food materials and thus augment the maturity of the trees; also to produce on the land itself a green-manure crop for maintaining fertility.

The value of cover-crops in an orchard has been questioned by some authorities on the grounds that no special benefit could be observed where they had been used. This

[1] See also Bailey, L. H. Principles of Fruit-Growing. 20th Ed. p. 76. 1915.

is one of the oldest practices in agriculture and it would indeed be unfortunate to advocate the discontinuance of it unless there is adequate data to warrant the position. This the author believes is not the case, but rather that in the past few years it has been demonstrated beyond question that the practice is valuable both in the orchard and on the farm. To test the soil for the presence of organic matter (carbon) and to find an immaterial gain where abundant organic matter has been returned to the soil for a long period of time is hardly sufficient evidence on which to rest the case. It is of more value to the orchardist to know that where clean tillage has been followed in both citrus and deciduous orchards, the soil failed properly to support the trees within a relatively short time. When cover-crops were again included in the orchard management, the trees became vigorous and productive, even without the use of fertilizers. As is pointed out elsewhere, the hotter the climate and the longer the season, the quicker will the humus and also the nitrogen disappear from the soil through tillage methods. True, there may not be sufficient material raised to maintain an increasing ratio of organic matter as the trees become mature and shade a large portion of the ground. Then outside material may be resorted to, to supplement the loss. Hence the present teaching must be that abundant cover-crops are the safest way of preventing depletion of the soil where tillage methods are followed.

132. Nitrification.—The student should not confuse the two groups of bacteria that have to do with the nitrogen transformations in the soil. Where legumes are grown, the symbiotic organisms living in the nodules on the roots fix nitrogen of the soil-air and leave it behind in combined forms in their remains and in the tissues of the host. Among the organisms concerned in the decay of legumes as well as of other plants are those which break down the complex nitrogen compounds and change the nitrogen to available forms. This process is known as nitrification, and the nitrogen which the legume organisms took from the air is not available to other plants until these nitrifying organisms have had an opportunity to do their work. Incidentally it should be mentioned that there are other groups of nitrogen-fixing organisms in the soil capable of taking nitrogen from the soil-air in considerable quantities when supplied

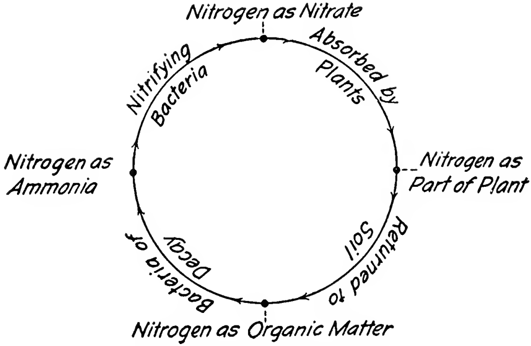


FIG. 26.—A graphic representation of the cycle of nitrogen through the plant and the soil.

with an abundance of phosphate, limestone, and organic matter. These organisms are not related to legumes but are present in all normal soils. The nitrogen left behind in their bodies also becomes available to plants in the process of nitrification. The nitrification process is graphically illustrated in Fig. 26.

133. Value of cover-crops in California.—In semi-arid regions, such as are found within the agricultural section of California, there is a notable deficiency in the organic matter of the soil, and, as has already been pointed out, where there is a lack of organic matter there is also likely to be a lack of nitrogen. Under those conditions, legumes proved to be far superior for green-manures as evidenced by their effect on the succeeding crops. The yield of a number of crops following legume green-manures when compared with those following non-legumes showed the following increases: An average increase with potatoes of 39 per cent; with corn, 45; with cabbage, 44; with sugar-beets, 43 per cent, respectively. Legumes alone gave as good or better results than non-leguminous green-manure crops plus an annual application of 540 pounds of nitrate of soda to the acre.

Of more direct interest in this connection is the measurable effect of green-manuring on citrus fruit-trees. The trees on plots where legumes have been turned in annually were superior in every way to those similarly fertilized but where no leguminous green-manure crops had been used. Green-manuring resulted in a 30 per cent increase in size of tree and a 68 per cent increase in yield at the age of ten years.[1]

134. Effects of the cultural methods on the soil.—Before examining the effect of these cultural systems on the trees, it would be well to follow the investigations as they affect the soil itself. While the student must consult works on soil science for a fuller treatment of this subject, yet some reference to it is necessary in order to secure a basis for the cultural methods used in orchards.

It is axiomatic that an abundance of available inorganic plant-food materials and moisture will give a better development of the trees and production of fruit than when these are deficient at the critical period of development. It is, of course, equally detrimental to have excesses of moisture

[1] Mertz, W. M. Calif. Agr. Exp. Sta. Bull. 292. 1918.

and in some instances of plant-food materials, and this should be avoided.

135. Effect of moisture.—Hilgard,[1] in discussing the effect of moisture on crop production, says: "Production is almost directly proportional to rainfall during the period of active vegetation." In studying the moisture relation, it is important to consider the type of soil. A clay by its nature holds more moisture than a light soil, so that when a heavy soil contains 12 per cent of moisture, a light one under the same conditions may only have about 7 to 9 per cent, and the consequent effect on the trees would be as detrimental under the one as under the other condition, because of the factor of availability. It has usually been observed that the soil-moisture in an orchard standing in sod is less than when the soil is tilled, but under some conditions this has not held true.

Woodbury[2] shows from an orchard experiment that moisture was less under sod culture than under tillage. "During the season of 1913 and 1914 we have a positive indication of the effects of different treatments on soil moisture. In both of these seasons, the rain-fall during the active growing period of the trees (May, June, and July) was considerably below the five-year average for those months. Inasmuch as the cultural practices are conservation measures, preventing the loss of water after it enters the soil, it is largely in such dry periods that the value of certain systems of management in conserving soil moisture are made manifest.

"In both of these years, during the month of June, the upland plots either where the grass was cut and let lie or piled under the trees, were low in soil moisture. Where an adequate mulch was maintained on the surface of the soil

[1] Soils. p. 193.

[2] Purdue Agr. Exp. Sta. Bull. 205. 1917.

either through the agency of cultivation or by a heavy straw covering, the percentage of moisture was more than twice that in straight grass land."

TABLE XXXIII

MOISTURE (TOTAL) IN SOIL (AFTER WOODBURY ET AL.)

	Clean culture cover-crop		*Straw mulch, grass cut, let lie*	*Grass cut, let lie*	*Grass cut, piled*	
	A *per cent*	*B* *per cent*	*C* *per cent*	*D* *per cent*	*E* *per cent*	*F* *per cent*
1913						
Apr. 29....	18.9	19.1	19.2	19.6	18.5	19.5
June 17....	14.6	15.0	18.8	7.2	6.1	6.5
Sept. 4....	14.0	13.8	15.6	9.4	9.4	9.4
Nov. 25.....	20.4	20.1	21.3	21.2	20.3	20.2
1914						
May 6....	19.9	19.8	22.2	21.6	20.0	21.0
June 17....	15.3	15.0	17.6	6.5	6.1	6.0
Aug. 13....	11.4	10.4	10.9	7.2	7.1	7.9
Nov. 25.....	14.3	14.7	18.6	16.1	15.9	17.3

Data obtained at the New York State Experiment Station are in accord with those cited from Indiana. The soil in the latter experiment is described as follows: "The character of the soil changes somewhat with the topographical outlines of the orchard. On the ridge and high ground the soil is a fertile Dunkirk sandy loam to a depth of nine or ten inches, underlain by a compact sandy subsoil. In the depression the type changes to a dark colored Dunkirk loam, ten to twelve inches deep, and underlain by a very fine compact sand." [1]

[1] N. Y. [Geneva] Agr. Exp. Sta. Bull. 314. 1909.

a

b

c

d

PLATE IV.—Six-year old sour cherry trees. *a*, Unpruned; *b*, moderately pruned; *c*, heavily pruned; *d*, summer pruned.

It is concluded from an experiment in the above orchard that, "The results of 120 moisture determinations in the Auchter orchard show that the differences in tree growth and crop in the two plots of this experiment are mainly due to differences in moisture, the tilled plot having most moisture. As a consequence of the reduced water supply in the sod plot, there is a reduced food supply, for it is only through the medium of free water that plants can take in food. Analyses show that the difference between the actual amount of plant food in the two plots are very small."

TABLE XXXIV

MOISTURE TO THE ACRE IN TILLED AND SOD PLOTS (AFTER HEDRICK)

Soil, depth	*Plot*	*1907*	*1908*
		Amount of moisture	*Amount of moisture*
		Per cent	Per cent
1–6 in.	Tillage	12.20	14.04
	Sod	7.30	10.06
	Difference	4.90	3.98
1–12 in.	Tillage	11.53	13.57
	Sod	6.52	9.37
	Difference	5.01	4.20

Thus, from these figures, it is concluded that moisture is the limiting factor in fruit production and tree growth in this orchard.

On the other hand, the New Hampshire Station [1] describes an orchard in which moisture was as abundant in the sod plot as in the adjoining tilled one, and hence was not

[1] N. H. Agr. Exp. Sta. Tech. Bull. 11. 1916.

the limiting factor. This condition is not the usual one, however, although the same conditions obtained in southern Illinois. The average difference in favor of the sod plot is shown below.

TABLE XXXV

SUMMARY OF MOISTURE DETERMINATIONS

AVERAGE TO A PLOT. PERCENTAGE

Year	*Plot 1, sod*	*Plot 4, tillage*	*Plot 5, tillage with cover-crops*
Surface soil			
1913	16.02	13.69	14.20
1914	18.87	13.39	15.03
1915	25.63	19.29	20.82
1916	20.48	16.45	21.31
Average	20.25	15.70	17.84
Subsoil			
1913	10.98	9.06	8.93
1914	14.14	9.78	10.26
1915	14.26	14.03	13.33
1916	14.82	12.74	13.24
Average	13.55	11.40	11.44

Much the same results were obtained at the Woburn Experimental Fruit Farms (England), as indicated in the following summary of the data:

TABLE XXXVI

SUMMARY OF MOISTURE DETERMINATIONS (WOBURN)

UPPER 9 INCHES

Date	*Tilled soil*			*Grassed soil*			*Average diff.*
	Plot 13	*Plot 14*	*Plot 18*	*Plot 15*	*Plot 16*	*Plot 17*	
1907							
B. Aug. 7..	13.50	13.95	12.13	14.30	14.86	17.76	+2.45
C. Aug. 16..	12.54	12.54	10.20	10.00	9.75	12.15	—1.13
P. Aug. 27..	11.30	11.79	11.40	12.73	11.43	11.05	+0.24
Mean......	12.45	12.76 12.15	11.24	12.34	12.01 12.67	13.54	+0.52
1910 B. Sept. 9	13.25	12.60 12.74	12.38	14.07	14.72 14.84	15.73	+2.10
1910	Farmers A	Farmers B		A	B		
Sept. 9...	14.60	13.03 13.82		19.70	13.72 16.71		+2.89

136. Effect of temperature.—The temperature of the surface soil can be affected somewhat by the soil treatment and the nature of the soil covering. To what extent a few degrees difference in temperature may affect the activity of the soil flora cannot be stated definitely, but it is possible that the effects are greater than the small differences of temperature would indicate. Many factors are involved in affecting the soil temperature, but the greatest are the temperature of the air and the absorption of the sun's rays. (Fig. 27). The work of Bouyoucos[1] shows that a difference of as much as five degrees of temperature may obtain between a soil which is tilled and one which lies bare or is in sod. The following table shows the data as a monthly average:

[1] Bouyoucos, G. J. Mich. Agr. Exp. Sta. Tech. Bull. 17. 1913.

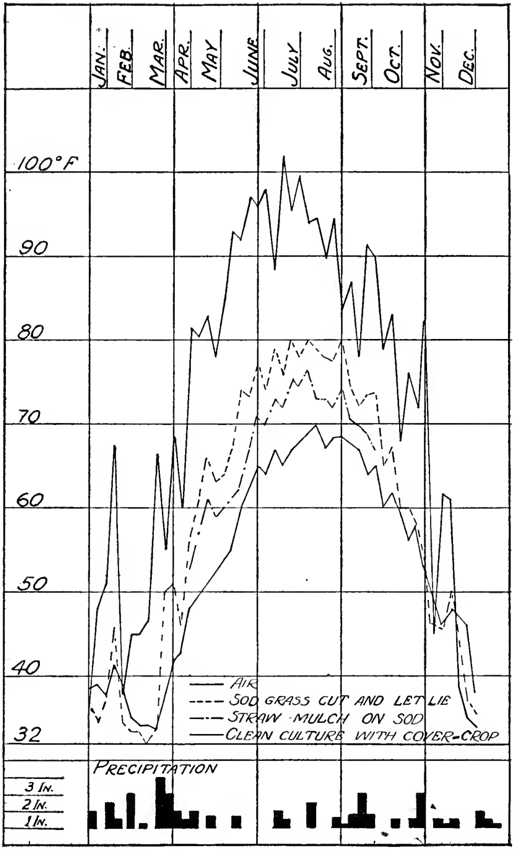


FIG. 27.—Curves showing the maximum soil temperatures under the different soil treatments in an orchard.

Table XXXVII

AVERAGE MONTHLY TEMPERATURE OF UNCULTIVATED, CULTIVATED, AND SOD LAND. (AFTER WOODBURY, NOYES AND OSKAMP)

Name of month	*Uncultivated*		*Cultivated*		*Sod*	
	7″	20″	7″	20″	7″	20″
December.....	34.5°F	36.62°F	34.84°F	35.94°F	34.38°F	37.07°F
January.......	27.73	....	27.79	30.92	29.22	....
February......	30.73	....	29.42	30.06	30.07	....
March........	31.81	....	30.60	30.67	30.81	....
April.........	42.24	....	39.63	37.10	41.93	....
May.........	....	....	54.12	50.88	....	....
June.........	65.25	62.00	64.4	60.64	61.97	....
July..........	71.09	66.94	70.04	66.61	65.55	64.0
August........	66.60	63.80	66.24	63.75	63.39	63.74
September.....	63.48	61.90	62.80	61.84	59.60	61.40
October.......	50.24	50.89	50.46	50.90	48.46	52.43
November.....	39.77	41.20	39.50	41.27	39.85	45.07

Orchard experiments confirm these figures as shown by the following data:

Table XXXVIII

SOIL TEMPERATURE IN TILLED AND SODDED LAND. N. Y. STATE EXP. STA. DAILY—JUNE 28 TO JULY 29

Depth of 6 inches				*Depth of 12 inches*			
7 a. m.		*6 p. m.*		*7 a. m.*		*6 p. m.*	
Sod	*Tilled*	*Sod*	*Tilled*	*Sod*	*Tilled*	*Sod*	*Tilled*
66.3	67.4	71.	73.3	64.5	66.6	65.4	67.2

This work has been repeated in orchards under the various systems of soil management with much the same results. In one orchard [1] in which these observations were made, it was found that the soil temperature was lowest under the heaviest vegetation and highest under clean tillage during the summer and the reverse in winter; also the heavier the vegetation, the cooler the soil during the summer and the warmer in the winter. The following figures show the effect of the soil treatment during the growing season:

Table XXXIX

AVERAGE SOIL TEMPERATURE

TILLED AND COVER-CROP PLOTS AT 8 INCHES. N. H. EXP. STA.

Monthly average, April to September. Records made at 2 p. m. daily

	Sod	*Tilled*	*Tilled and cover-crops*
April	38.3	43.0	42.5
May	52.3	55.5	54.7
June	59.3	61.1	57.9
July	66.8	69.7	65.7
Aug	66.6	69.6	65.2
Sept	61.9	64.5	61.1
Average	57.5	60.5	57.8

The depth of freezing in these same plots is shown at a time when the soil was supposedly frozen to the greatest depth of the winter.

Table XL

DEPTH OF FREEZING IN INCHES

Sod	*Bare*	*Light cover-crop*	*Heavier cover-crops, especially in last three plots*				
			Cover-crop	*Cover-crop*	*Cover-crop*	*Cover-crop*	*Cover-crop*
12	16	15	12	10	8	7	7

[1] N. H. Agr. Exp. Sta. Tech. Bull. 12. 1917.

In another investigation[1] it was found that the "clean cultivation with cover-crop and the straw mulch occupy the extreme positions in soil temperature behavior." The bare soil will respond very quickly to a change in the air temperature, rising rapidly during warm weather and conversely showing the lowest temperature in the winter. By examining Fig. 27 it will be seen how closely the soil temperature follows that of the air. (Maximum air temperature.)

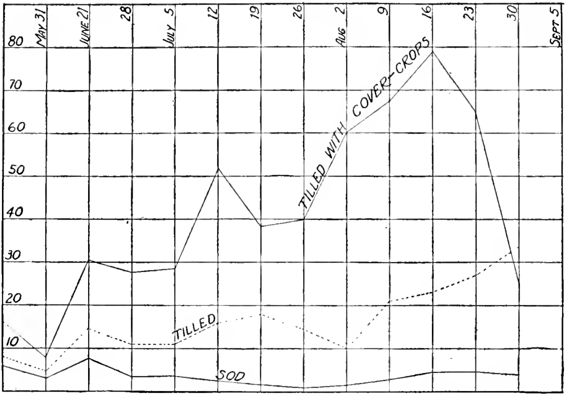


FIG. 28.—Curves showing the relative formation of nitrates under sod, tillage, and tillage cover-crop systems of orcharding. Parts per million, dry soil.

137. Nitrates.—The nitrogen problem is of paramount importance in discussing the fertility of an orchard. This is because in many cases nitrogen is the limiting factor, and also because it is a very expensive element to purchase in the form of artificial fertilizer. Hence, the bacterial activities in the soil, particularly nitrification, become of great im-

[1] Ind. Agr. Exp. Sta. Bull. 205. 1917.

portance to the orchardist. A system of cultivation which will maintain a sufficient supply of nitrates and produce a good growth of the trees together with high yield is to be sought. The effect of the standard cultural methods in this regard seems to be marked. (Fig. 28.)

In several investigations in both young and mature orchards, it has been found that the amount of nitrates under sod is likely to be very low, in fact so low as to be the limiting factor in production. However, Lyon and Bizzell have shown that nitrification is not depressed when leguminous crops are grown, in contrast to the conditions under rye and the grasses. When the soil on which grass has been growing is stirred by cultivation, the nitrates are greatly increased, especially when a leguminous crop is plowed into the soil annually. In cases in which the moisture is conserved also, the results of cultivation on the orchard are likely to be very beneficial; in fact, this practice is usually one of the first steps in orchard renovation.

The following data indicate the results of the investigations along this line:

TABLE XLI

NITRATES IN LAUREL SOIL [PARTS (NO_3) PER MILLION PARTS SOIL] AVERAGE OF 8 DETERMINATIONS MADE DURING GROWING SEASONS OF 1914, '15, '16. (ADAPTED FROM WOODBURY ET AL.)

Clean culture cover-crop (2 plots)	*Straw mulch grass cut, let lie*	*Grass cut, let lie*	*Grass cut, piled (3 plots)*	*Hillside grass cut, piled*
82 [1]	53	14	17	36

Here, as in the experiments that follow, it was found that nitrates were reduced under grass land and also under rye as a cover-crop. The highest nitrates were present

[1] Seven determinations only.

where the system of tillage and cover-crops was practiced, and the straw mulch ranked second to the tillage plots. While not indicated in the data in the above table, very little nitrate was found in late fall and winter, but nitrification continued later in the fall in the warmer soil under the straw mulch than elsewhere. The gains made by the trees in this experiment were roughly proportional to the nitrate-content of the soil.

The New Hampshire Station reports the same results, although the averages are lower in all cases. The averages include samples taken each week throughout the growing season for the four years and this may account at least in part for the difference. The following table and Fig. 28 epitomize this work:

TABLE XLII

SUMMARY OF NITRATE DETERMINATIONS, WATER SOLUBLE PARTS TO THE MILLION OF DRY SOIL

AVERAGE TO A PLOT

Year	Plot 1, sod	Plot 4, tillage	Plot 5, tillage with cover-crop
Surface soil			
1913	2.64	18.25	38.37
1914	4.41	14.01	37.27
1915	2.09	21.05	18.75
1916	3.58	16.29	41.26
Average	3.18	17.40	33.91
Subsoil			
1913	1.55	6.90	6.87
1914	3.56	6.62	10.81
1915	1.51	10.76	6.88
1916	2.18	5.05	8.05
Average	2.20	7.33	8.15

It is further stated that at no time during the four years in which the investigation was in progress did the soil samples in the sod plots show more than 14.78 parts nitrates per million of dry soil, while under clean tillage they were as high as 63 in some cases, and where a cover-crop was plowed in they occurred as high as 132, although the average for the plots is not in this proportion.

138. Is nitrification retarded under sod?—Since the grass is making use of large amounts of nitrates in a sod plot, it is but reasonable to concede that the quantity, as determined by analysis, would be low, although nitrates may be formed as readily there as when the soil is cultivated.

In order to arrive at some conclusion on this point, observations were taken on the sod plot in the above experiment. A small plot three feet square was selected very near to the point where the soil samples had been taken each year previously and the sod was carefully removed without stirring the soil beneath. Another plot of equal size was selected close to the first and after the sod was removed it was spaded to the depth of the surface soil and subsequently cultivated with a hoe weekly. This gave three conditions within the original sod plot: (1) sod; (2) bare unshaded soil; (3) cultivated soil. While the bare soil would not represent the exact conditions under sod, yet it seems to be as near as is practical to obtain in the field. There was practically no difference in soil-moisture at the time these observations were made. The results would seem to indicate that, under the conditions obtaining in this experiment, nitrification progressed much more rapidly under tillage than when the land is in sod or bare and uncultivated.

Table XLIII

NITRATES, PARTS TO THE MILLION OF DRY SOIL

SURFACE SOIL

	July 24	*July 31*	*Aug. 7*	*Aug. 14*	*Aug. 21*	*Aug. 28*	*Sept. 4*	*Sept. 16*	*Sept. 23*	*Average Aug. 7 to Sept. 23*
Sod . . .	2.599	1.871	2.800	2.668	3.748	3.075	4.27	.568	1.464	2.656
Bare .	2.575	2.615	4.717	3.330	11.112	10.755	7.856	1.923	2.380	6.010
Tilled . .	. . . .	. . . .	10.575	16.002	24.969	51.021	65.553	8.332	8.820	26.469

These results are not in accord with the findings of some writers [1] who state that neither moisture nor nitrates are influenced by cultivation. The chief reason given for loss of moisture and nitrates is the weeds that utilize them, and if the weeds are removed, it is contended, the nitrates will be found as abundantly with no tillage as with it. An explanation of these observations in regard to moisture is suggested by Lyon [2] as follows: "It seems possible that the latter result may occur only in those regions in which conditions are such that a natural mulch is formed by a rapid drying of the surface soil in which process moisture is removed so rapidly that the capillary column is broken and further loss of moisture is stopped. This would confine it to semi-arid and arid regions of high summer temperatures."

139. The toxic theory.—It is accepted at the present time that toxic substances are found in certain soils, *i. e.*, compounds poisonous to certain plants. Lack of soil aëration, proper "sanitary" conditions, or poor drainage seems to explain their existence. Some writers hold that the whole problem of soil fertility is largely one of toxicity, and that the application of the various fertilizers merely results in neutralizing the toxic effect. This theory has been used

[1] Call, L. E., and M. C. Sewell. Jour. Amer. Soc. Agron. Vol. 10, No. 1, Jan., 1918.

[2] Lyon, T. L. Soils and Fertilizers. Rural Text-Book Series.

by some to explain the cause of trees doing poorly in sod and, conversely, why they thrive when the soil is cultivated. The work of Bedford and Pickering along this line is discussed later in the chapter.

140. Effect of cultural systems on the growth of the trees. —(For convenience of study and to avoid complications, the data are given from unfertilized orchards only.) The results of an experiment to determine the effects of tillage and sod mulch in a Baldwin apple orchard have been reported by Hedrick.[1] The experiment was continued for ten years and the trees were twenty-six years old at the beginning. While the type of mulching given these trees would not agree with our definition, yet more than two tons of grass to the acre were allowed to remain, thus giving more mulching material than is ordinarily used when placed beneath the trees. The results are very striking, as they show that the tilled trees made much greater diameter growth than those not tilled.

Table XLIV

GAIN IN DIAMETER OF TREE TRUNKS ON SOD AND TILLAGE PLOTS (AFTER HEDRICK.)

	Sod (average 61 trees), inches	*Tilled (average 60 trees), inches*
1913	16.08	17.15
1903	13.70	13.25
Gain	2.38	3.90

It is further recorded that the sodded trees showed inferiority in all respects when compared with the tilled ones.

Such results as these are very common in orchards growing in sod alone and the sparse yellowish foliage is familiar to all observers. However, when mulching material is added in sufficient amounts (about 50 to 100 pounds dry matter

[1] N. Y. (Geneva). Agr. Exp. Sta. Bull. 314 and 383.

to a tree annually), the trees often show considerable gain, and when nitrate of soda is also used the orchard will not infrequently do as well as when tilled. It then becomes largely a question of soil and amount of available moisture during the critical season of growth.

Woodbury and associates report that "Trees grown under a clean culture cover-crop system or under a heavy mulch made 44.5 per cent greater average yearly gains in trunk girth than trees grown in grass with a light mulch or no mulch at all. There has been no significant difference between the three varieties in their response to soil management treatments. The Stayman variety made slightly greater gains in girth of trunk on all plots than did Grimes or Jonathan."

In support of this conclusion, the following data are submitted:

TABLE XLV

DETAILED GROWTH RECORD OF PERMANENT TREES FOR FIVE-YEAR PERIOD (AFTER WOODBURY ET AL.)

Systems of management	*Plot*	*Number trees included in averages*	*Average girth*			*Yearly gain cm.*
			1916 cm.	*1911 cm.*	*1912–1916 cm.*	
Clean culture cover-crop	A	90	33.88	8.02	25.86	5.17
	B	62	32.68	7.54	25.14	5.03
Straw mulch grass cut, let lie	C	61	33.24	7.30	25.94	5.19
Grass cut, let lie	D	84	24.32	7.17	17.15	3.43
Grass cut, piled	E	47	26.00	7.90	18.10	3.62
	F	79	25.31	7.25	18.06	3.61
Hillside grass cut, piled	O	53	28.93	15.15 [1]	13.78 [2]	4.59
	H	89	30.71	8.41	22.30	4.46

[1] Girth, 1913. [2] Gain in girth, 1914 to 1916.

They also report that, "The terminal twig growth has been measured and found to correlate satisfactorily with girth increase."

At the Pennsylvania Experiment Station, a series of cultural experiments was conducted in various parts of the state, thus including various soil types. Table XLVI gives the results of the treatment on the growth of the trees only, as the effect on the yield is considered later. In two cases the sod mulch system gave decidedly the best results in growth, with tillage and cover-crops ranking second, tillage (clean cultivation) third, and sod poorest. In the other ten, the order of the first two is reversed and tillage and cover-crops gave the best results by a very decided margin. It seems that the younger trees respond best to the mulch system and the older ones to tillage methods, while sod gives poor results on all trees.

The New Hampshire experiments again show the superiority of tillage over sod. After ten years' work in renovating a declining Baldwin orchard, it was found that the trees growing in sod made such inferior growth most seasons as to make them less able to withstand the destructive influences of weather and parasites. On the other hand, tillage every other year resulted in a decided benefit to the trees, but better results were obtained when tillage was followed annually, amounting to 43 per cent greater than when trees were grown in sod. However, the results of this work are significant as they point to the conclusion that this system (clean culture) could not be continued over a long period of time on the soil involved, since at the end of ten years the trees were not making so good an average growth as at the end of the first five-year period, which is interpreted as a decline.

When cover-crops were plowed in annually, there was an additional 18 per cent increase in growth. However, under

TABLE XLVI

INFLUENCE OF CULTURAL TREATMENTS ON THE GROWTH OF TREES

AVERAGE GAIN IN TRUNK-GIRTH TO A TREE. NO FERTILIZERS OR MANURES USED.[1] (AFTER STEWART)

Varieties	*Trees planted*	*Duration of experiment*	*Number trees to a plot*	*Tillage, inches*	*Tillage and cover-crops, inches*	*Sod mulch, inches*	*Sod, inches*
Jonathan York, Gano.... Ben Davis	1902	1907–1915	40	14.39	14.46	15.64	12.32
York......... Yellow Newton	1900 1893	1907–1915	40	13.52	16.07	16.87	13.36
Smokehouse, Stayman......	1901	1908–1915	40		20.03	17.50	13.92
Baldwin, Northern Spy..	1873	1907–1915	40		9.09	6.46	

the conditions obtaining in this experiment, the growth was not being maintained by this treatment, as is shown by the data at the end of the first and second five-year periods. On stronger soils, the time would be delayed when such a decline would begin to be evident. When fertilizers were added, both the cover-crop and trees showed the growth to be in an increasing ratio rather than in a decreasing one. This means that tillage with cover-crops is somewhat superior to tillage alone, but a lighter soil will show the lack of green-manuring before a stronger one, the length of time depending on the original fertility of the soil.

[1] Penn. Agr. Exp. Sta. Bull. 141. 1916.

Table XLVII

AVERAGE ANNUAL TWIG GROWTH TO A TREE IN INCHES

	Sod	*Tilled in alternate years*		*Clean tillage*	*Tillage and cover-crops*
	Plot 1	*Plot* 2	3	*Plot* 4	*Plot* 5
10-yr. ave.	5.09	5.41	6.82	7.31	8.21
Percentage increase over plot 1		6	34	43	61

141. Leaf area.—In all these experiments the foliage is a notable index to the vigorous condition of the trees or the reverse, both in the abundance of leaves and in their size and color. As an illustration, the following figures may be cited:

Table XLVIII

EFFECT OF CULTURAL METHODS ON LEAF SIZE

	Average area of leaves in square inches
Trees in sod	4.24
Clean tillage	5.07
Tillage-cover-crops	5.28

Not only are the area and abundance of the leaves reduced under sod culture, but the foliage often turns yellow and drops prematurely. A cross-section of such leaves shows that there is one layer of palisade cells and another layer about half the length of the surface or first layer. In contrast with this structure, the leaves on trees in a high state of vigor show three and sometimes a partial fourth layer of palisade cells and a denser structure of the mesophyll.

142. The Woburn experiments.[1]—The work of the Woburn Experimental Fruit Station on the effect of sod on the growth of trees is of special interest, since it is viewed from the standpoint of the toxicity of the soil. The results there are not paralleled in this country so far as the extreme effect of sod on trees is concerned. It was found that young orchards planted in sod made a feeble growth and soon reached the point of death if not tilled. No form of ill-treatment would produce such enfeebling results with the exception of transplanting the trees each year. Not only did trees planted in sod show this effect, but those which had made a vigorous growth in tilled land for a period of four years showed the ill effects at once when the land was laid down to grass. Within five years most of the trees of the weaker varieties were entirely dead. The work was repeated under varying conditions, with different varieties and with both standard and dwarf kinds. Some varieties proved resistant to the effect of the grass, but mostly they suffered extensively. Different kinds of fruits varied in their behavior toward the sod as is seen by the following data:

Table XLIX

VALUES COMPARED WITH UNGRASSED TREES = 100
(AFTER BEDFORD AND PICKERING)

	Leaf-size	*Prunings*	*Crops*
Cherries	88	32	8
Pears	72	21	0
Plums	72	7	1.5
Apples	68	—	6

When grassed trees in low vitality were again tilled, they made an immediate response to the culture. (This was also the experience of Hedrick in the Auchter orchard.) Con-

[1] Woburn Exp. Fruit Farm Rept., 1, 2, 3, 13, 14.

versely, when tilled trees were gradually grassed over, they showed the deleterious effect so common to this form of treatment. In one block of standard apples, the sod was replaced immediately after planting, and when they were compared with a block of similar trees under tillage but which were gradually allowed to grass over, the following significant results were obtained:

TABLE L

ANNUAL GROWTH OF TILLED TREES = 100
(AFTER BEDFORD AND PICKERING)

	1910	*1911*	*1912*	*1913*	*1914*	*1915*	*Mean 1911–15*
Turf replaced.......	76	30	6	5	11	7	12
Grassed gradually....	101	38	12	10	33	28	24

These results are explained entirely on the ground that some toxic influence is interfering with the normal functioning of the plant and preventing it from utilizing the food present. Somewhat similar results in this country have been explained largely by the low rate of nitrification and often the reduction in soil-moisture, but toxic substances, perhaps due to lack of oxidation, may be involved in the low nitrification which occurs.

In general, these various experiments would seem to bear out fully the results that might be anticipated from a study of the effects of culture on the soil. Sod has practically always inhibited the growth, size, color, and amount of foliage on the trees. Toxicity and lack of available nitrogen and moisture may all play important parts in the effects secured. Tillage has universally increased growth and general vigor of the trees and the same is often true when a mulch of litter is placed about the trees to such a depth as will destroy the growth of grass. Even partial tillage or only one cultivation for the season will produce markedly increased results as compared with sod.

143. Yield of fruit.—As previously stated, the soil treatment is largely responsible for the amount of bloom and hence for the possibilities of a crop of fruit. Therefore, it becomes of the first importance to study the cultural treatments that are most likely to give a maximum crop, so long as this is not inconsistent with the health and vigor of the trees.

A fundamental principle established by all the experimental evidence at hand may be stated as follows: The growth of the tree and yield of fruit proceed in the same direction and are not antagonistic. This of course is within reasonable limits, for a point may be reached when the growth is so excessive as to suppress flower-bud formation. An extreme of such a condition is reported from the tropics.[1] "Of our apple trees it is well known that in warm insular climates they grow into magnificent foliage trees, but remain unproductive."

In keeping with this principle, it may be said that the above data on the growth of the trees applies with much the same force to the yield. In regard to yield no one system is always best, but the one most suitable to the conditions should be adopted.

As seen above, the purposes of adopting a cultural system are to conserve sufficient moisture for maximum results, to increase nitrification in the soil, and to set free plant-food materials, as well as to control weed growth. This, interpreted in terms of the plant, results in increased growth and fruitfulness.

144. Sod, tillage, and mulch for the apple.—The work with the apple shows that, as a rule, the trees growing in sod land are lower in yield and the fruit smaller but higher in

[1] Sorauer, P. A Treatise on Physiology of Plants. p. 222.

color than when cultivated. If the trees are in sod mulch, the yield is somewhat higher than in sod alone, although as a rule fertilizers or manures are necessary to obtain best results.

Some of the best-known experiments in this country have been conducted by the New York Experiment Station and have been referred to in the discussion of "growth." To recapitulate and state in more detail: The experiment was conducted as follows (Auchter orchard). The soil was a fertile Dunkirk loam, about ten inches in depth and underlaid by a sandy subsoil. The orchard of nine and one-half acres of Baldwin trees was divided in half in the first five years, so that 118 were left in sod and 121 under tillage. In the second five-year period, the orchard was divided into quarters so that one quarter was in sod for ten years and another in tillage for ten years, a third quarter was in sod for five years and under tillage the latter five years, while the other fourth was in tillage the first five years and in sod five years. While potash and phosphoric acid were used for the first three years in this experiment, no results were noted where they were applied and this fact need not come into the present discussion.

The plot which was tilled for ten consecutive years resulted in an average yield to a tree of 4.29 barrels; the plot in sod for ten years yielded 2.54 barrels to the tree; the plot which was tilled for five years and in sod five years averaged for the second five-year period 2 barrels to the tree; while the plot which was first in sod for five years and then tilled for five, gave an average of 5.17 barrels during the second period. These figures are very striking and emphasize the value of tillage under the conditions of this orchard.

Another experiment by the New York Experiment Station was conducted for a ten-year period to determine the value of tillage and mulch in an apple orchard (Hitchings orchard). In this case, the land was deep, fertile, and well supplied with moisture, which factors favor the mulch system of orcharding. At the end of the period, the four varieties (Alexander, Fameuse, Northern Spy, and Wealthy) averaged 3.18 bushels of apples to the tree on the tillage block and 3.95 bushels on the sod mulch plot.

The Pennsylvania experiments show the same general results in yield as in growth. The statement of Stewart is that "In general the mulch treatment, reinforced by outside materials, has been most efficient in improving the yield, growth, and average size of fruit in orchards up to about 20 years of age. In older orchards, it has been surpassed slightly by tillage and cover-crops, unless accompanied by adequate fertilization. It has also been most efficient in conserving moisture, in all cases that have been determined."

TABLE LI

INFLUENCE OF CULTURAL TREATMENTS ON THE YIELD OF TREES

AVERAGE ANNUAL YIELD TO THE ACRE (AFTER STEWART)

Varieties	*Trees planted*	*Duration of experiment*	*Number trees to a plot*	*Tillage*	*Tillage and cover-crops*	*Sod mulch*	*Sod*
				Bu.	Bu.	Bu.	Bu.
Jonathan York, Gano, Ben Davis	1902	1907–1915	40	78.4	85.7	152.6	78.1
Smokehouse, Stayman	1901	1908–1915	40	....	127.9	147.5	43.7
Baldwin, Northern Spy	1873	1907–1915	40	....	398.0	385.2	....

The New Hampshire experiments show again the value of tillage over sod culture of the trees. The conclusions from the work are as follows: The trees growing in sod have not yielded sufficiently well to warrant the use of the land for orcharding. Tillage every other year resulted in decided benefit to the trees. Clean cultivation, without the use of green-crops, has proved successful in the reclamation of a run-down orchard, increasing the yield nearly 100 per cent. It has shown evidence, however, that it could not be continued for a long period of time as the trees were not quite so vigorous at the end of a ten-year period as at the completion of the first five years. Tillage with cover-crops has proved to be a slightly better system than clean tillage alone. For yields of these plots see page 206.

145. Cultivation for the peach.—What has been said in regard to tillage applies with particular force to the peach. In fact, it is doubtful whether the peach will ever do as well under any other system as under cultivation. Most soil experiments with this fruit include fertilizers and are hence treated in the next chapter. Ralston [1] cites some work, however, confirming the value of tillage for the peach. There were 288 trees to the plot equally divided between Early Crawford and Elberta. The trees were planted in 1911 and the data taken 1915–17, inclusive. The soil is described as a "very poor Cecil Clay which contains an abundance of small pebbles and a small amount of loose shale, and is fairly uniform throughout."

TABLE LII

RESULTS OF CULTURAL TREATMENTS

YIELD OF FRUIT IN POUNDS TO A TREE FOR 3 YEARS. (AFTER RALSTON)

Intense cultivation (7 to 9 times annually)	*Commercial cultivation (3 to 4 times annually)*	*Sod (in sod since spring of 1913)*
1,943 lbs.	1,285 lbs.	712 lbs.

[1] Ralston, G. S. 23d Ann. Rept. Va. Hort. Soc. 1918.

146. Fall plowing the orchard.—If the orchard can be safely plowed in the fall, it will result in a saving of time in the spring when a great demand exists for teams and men. This practice has been put to the test in many of the fruit-growing regions and without resultant injury to the trees. Fall plowing can be followed in both the North and South, and with tender fruits such as the peach as well as with the apple provided the soil will not erode. The land is usually allowed to lie in the rough (without harrowing) over winter and is harrowed down in the spring.

147. Use of explosives for tillage purposes.[1]—Much has recently been written in regard to the use of explosives in the planting of young trees and also in the tillage of mature ones. The experimental work on this subject is not extensive, although these agencies have been extensively used both as demonstrations and in commercial work.

That a well-developed, extensive root system is correlated with a vigorous productive top of a fruit-tree goes without saying, and the theory of the use of explosives for this purpose is well founded. Whether such extraordinary means are necessary will depend on the nature of the soil, for if it is hard and impervious, rocky or underlaid with hard-pan or other resistant material, the use of an explosive should be most helpful. There is, however, no virtue in the use of dynamite other than what is gained by a better mechanical soil condition, or else in the cost of the operation. The soil should not be wet at the time of the operation or a pot-hole is likely to be blown out which makes a basin for water and is hence more harmful than other methods. It is usually advisable to blow the holes some time before setting in order to allow the soil to settle; otherwise, the trees are likely to sink a few inches which is quite undesirable.

[1] "The Use of Explosives in the Tillage of Trees." Pub. by Institute of Makers of Explosives, New York. 1918.

Farley [1] conducted some experiments with peaches in which he found that there was usually an increase in growth of the trees during the first summer when they were planted with dynamite as compared with trees set in the usual way. In one experiment this increase was not maintained during the second and third season. "The crop of peaches produced by the New Brunswick and Vineland trees during the third summer show a noticeable advantage in favor of dynamiting in the case of the variety Carman, the only variety which produced what could be termed a profitable crop."

In general, however, he concludes, that, "The results of our experiments indicate that in the majority of cases the increased growth and fruit production recorded on dynamited trees is not great enough to make up for the increased cost and danger involved in planting. Furthermore, the use of dynamite is not recommended for tree planting on those soils that are naturally adapted to orcharding."

[1] Farley, A. J. Proc. Amer. Soc. Hort. Sci. 1914.

CHAPTER IX

FERTILIZERS AND MANURES FOR THE ORCHARD

The supplying of artificial plant-food materials to fruit-trees introduces a problem on which there is some difference of opinion among authorities. However, much experimental evidence is available and in many sections the results of proper fertilization can be predicted with considerable certainty. The original conceptions of this problem were based largely on the findings of the chemists, for it seemed logical to conclude that the elements found in the plant and its products in greatest amounts were the ones to return to the soil in like proportions. This doctrine led the horticulturists somewhat astray for a time, for valuable as it is, such a theory does not take into consideration the mechanical or physical condition of the soil or the important rôle of micro-organisms to soil fertility and the associated factors of heat, moisture, and soil sanitation. Obviously, the amount of artificial "feeding" that trees will require depends basicly on the original or native fertility of the soil together with its physical condition and moisture-content. Hence a wide variation in the practical results of fertilizing orchards is to be anticipated, especially in the relative length of time that will be necessary to produce like results. The problem should be studied from the standpoint of several generations of trees on the same land, yet the longest experiments have been in progress scarcely a quarter of a century.

148. Criticisms of orchard experiments.—The field tests of orchard fertilizing have been seriously criticised from several points of view, viz.: (1) The soil in some of the experimental orchards has been exceedingly variable and yet no account has been taken of that fact in recording the effects of the various fertilizer treatments. (2) Fruit-trees, particularly large apple trees, vary exceedingly in the size of the crop they produce, and averages for any given plot may be misleading. (3) When buffer rows have not been maintained between the plots, there has not infrequently been cross feeding which would seriously modify the results. (4) Missing trees in an orchard may give certain advantages to those adjacent to the open spaces, and also diseased or subnormal individuals may not give a representative result of the treatments used in an orchard. (5) Differences of topography which may give an advantage to certain plots over others because of unequal frost action and drainage have often played a large part in results secured, without allowances being made for the inequalities, often without mention of them. (6) Unwarranted conclusions have been drawn of the value of a single element by subtracting the performance of a two-element plot from that of a three-element plot. Many other suggestions or criticisms might be enumerated, all of which would be justifiable in critically examining this problem.

Without question it is more difficult to select uniform conditions for an orchard experiment than for field tests of the farm crops, and the available data are open to criticism on many grounds. Nevertheless, this field work has been a valuable, if not a necessary, forerunner of the more technical studies of a physiological nature that must follow. A number of valuable economic questions have already been settled and much of the previous confusion in regard to orchard fertilization has been cleared up.

149. Fertility removed by fruit-trees.—Proceeding from a chemical view-point, the amount of fertility removed by fruit-trees from the soil will give a basis on which to study the plant-food requirements of an orchard. Such modifications as are suggested in the introductory paragraph will be considered later. There are marked variations in the analyses reported by chemists, due probably to a difference in methods and to the varying material analyzed. In order to obtain a satisfactory set of figures, Stewart has averaged a large number of analyses of the apple that were made in both America and Europe and reports them in the form of percentage of dry matter, instead of on the basis of ash constituents as they are given in Chapter I. The following table summarizes this information:

TABLE LIII

THE COMPOSITION OF APPLE WOOD, LEAVES, AND FRUIT

Plant part	*Dry substance*	*Nitrogen* (N)	*Phos. acid* (P_2O_5)	*Potash* (K_2O)	*Lime* (CaO)	*Magnesia* (MgO)	*Iron* (Fe_2O_3)
	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Wood .	52.25	.62	.20	.36	1.6	.24	.03
Leaves	34.45	2.15	.44	1.34	2.48	.75	.125
Fruit . .	15.39	.43	.17	1.10	.08	.09	.02

The same writer has made a comparison of the total draft of an apple and a wheat crop to the acre, assuming vigorous and productive plants in each case. Such a collation is of interest, for it has usually been assumed that the apple makes a lighter draft on the soil in comparison with a grain crop. Table LIV compares the plant-food materials utilized by the two crops.

Table LIV

RELATIVE AMOUNTS OF PLANT-FOOD MATERIALS REMOVED BY APPLES AND WHEAT

IN POUNDS TO THE ACRE ANNUALLY, BASED ON THE COMPOSITION INDICATED IN TABLE LIII

	Wood	*Leaves*	*Fruit*	*Apple (total)*	*Wheat grain*	*Wheat (total)*
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Estimated annual weights	3,500	3,500	24,500	31,500	1,500	4,200
Nitrogen (N)	11.3	25.6	16.2	53.1	30.0	43.7
Phosphoric acid (P_2O_5)	3.6	5.3	6.4	15.3	10.0	15.8
Potash (K_2O)	6.6	15.9	41.5	64.0	9.8	26.8
Lime (CaO)	29.1	29.5	3.0	61.6	0.84	8.0
Magnesia (MgO)	4.4	8.9	3.4	16.7	3.0	6.1
Iron (Fe_2O_3)	0.5	1.5	0.8	2.8	....	....

Van Slyke has summarized his data for the several tree-fruits and observes that the quantity of nitrogen and potash is about the same in any one kind of tree, while the amount of phosphoric acid is only about one-fourth that of the other two materials.[1]

Nitrogen	30	to	75	pounds
Phosphoric acid	7	"	18	"
Potash	33	"	72	"
Calcium oxide (lime)	38	"	114	"

However, the amounts used by different kinds of fruit-trees vary greatly, as is shown by the table on opposite page.

According to studies by Thompson,[2] "fruit-trees demand plant food more nearly in the proportion in which it exists in the soil than does corn or almost any other crop."

[1] Fertilizers and Crops. New York. 1912.

[2] Thompson, R. C. Ark. Agr. Exp. Sta. Bull. 123 (Tech.). 1916.

TABLE LV

AMOUNT OF MINERAL PLANT-FOOD MATERIAL USED TO THE ACRE (AFTER VAN SLYKE)

Variety	*Number of trees to the acre*	*Nitrogen* (N)	*Phosphoric acid* (P_2O_5)	*Potash* (K_2O)	*Lime* (CaO)	*Magnesia* (MgO)
		lbs.	lbs.	lbs.	lbs.	lbs.
Apple....	35	51.5	14.0	55.0	57.0	23
Peach....	120	74.5	18.0	72.0	114.0	35
Pear.....	120	29.5	7.0	33.0	38.0	11
Plum....	120	29.5	8.5	38.0	41.0	13
Quince...	240	45.5	15.5	57.0	65.5	19

150. Fruit-trees essentially different from other crops.— It must be recognized in dealing with the fertility problem that fruit-trees are essentially different from other crops because of their greater root area and the fact that a large part of the roots may be found in the subsoil. This means that the soil will support a fruit-tree better than a plant with a restricted root system. Also the orchard occupies the land for many years, and hence the problem is different from that in which a rotation of crops is practiced. The situation is also more complex because of the material that is returned to the soil from the leaves.

151. Amount of food materials found in plants not a guide.—The relative amounts of the various "essential" elements in the tissues of the plant cannot be taken as an actual guide, because the soil may contain an abundance of the element which would seem to be most necessary to apply. This is particularly conspicuous with regard to potash. According to the data, the tree uses four times as much potash and nitrogen as phosphoric acid. It is usual to find that most fruit soils are relatively rich in potash which appears to become available sufficiently rapidly by good tillage methods. Therefore, instead of being first, potash usually is of the least importance of the three. Similarly nothing in the analysis indicates that nitrogen is usually of first importance, yet this is commonly preëminent. Furthermore, it must be recognized that more food may be taken into the plant than is necessary for complete functioning, if such material is present in the soil in abundance and in an available form.

Jordan [1] conducted a series of experiments with such crops as barley, peas, tomatoes, tobacco, buckwheat, rape, and turnips, and concludes that "the results secured indicate that what a grain crop contains of certain elements is not necessarily to be regarded as a measure of what must be supplied in order to meet the needs for maximum growth."

152. Analysis of the soil as a guide to fertilizing.—The question naturally arises as to whether a chemical analysis of the soil would be a guide to the fertilizing of the orchard, and if so, what element in particular should be applied and at what probable rate. While it would seem but reasonable to make the assumption that such is the case, yet experience shows that the plants' requirements can be only roughly approximated in this way and that errors will often result if dependence is placed in such a procedure.

While it is true that trees on poor impoverished land will usually be notable for their paucity of both growth and yield, yet if the physical condition of the soil is congenial, a good growth may be secured out of all proportion to what would be expected from ordinary farm crops on the same soil. This is doubtless accounted for at least in part by the greater feeding area of the root systems of fruit-trees.

153. Necessity of fertilizing orchards.—Whether it is necessary to fertilize an orchard is a question not easily answered, since so many factors are involved. The prob-

[1] N. Y. Agr. Exp. Sta. Bull. 360, 1913, also F. R. Pemper, R. I. Agr. Exp. Sta. Bull. 169. 1917.

lem should be viewed without prejudice from the standpoint of discovering any limiting factor to maximum results. If insufficient plant-food is available, this situation should be sensed as soon as possible and the condition relieved. It will depend, however, on the kind of trees, the soil, the system of culture followed, the age of the trees, and finally on the results of these conditions as manifested in the trees themselves. This is not so unsatisfactory as it at first seems. An experienced grower should have a sufficiently accurate knowledge of what the possibilities of trees are, to determine whether they need additional fertility. In general, the stone-fruits, particularly the peach, should be fertilized each year after they come into bearing. The apple and pear, when grown in the sod or mulch system, should usually be fertilized. However, exceptions will present themselves; and when these fruits are well tilled they may continue for many years without need for additional plant-food materials, unless they are inter-cropped. When trees are not making an average terminal growth of at least several inches (6 to 12), when the foliage is not a rich green color and held well into the fall, and when they are not bearing good crops practically every year, it would be well to introduce additional fertility either in the form of artificial fertilizers or manures or both. However, the varietal factor enters here strongly; also it should be determined whether the orchard is well drained and free from other conditions known to be injurious. All this, of course, means that in the case of doubt the only definite answer can be obtained by the local test. If a response is secured by any of the fertilizer elements or a combination of them, their use should at once be extended to the remainder of the orchard. Under many conditions, very large financial returns may be secured from the use of fertilizers; it is not wise to delay applying them until such marked results are secured as on some of the impoverished soils, but rather to maintain continuously a vigorous condition of the trees.

154. Fertilizing tilled and non-tilled apple orchards.—The source of much error in studying the fertilizer problem in the apple orchard lies in a failure to recognize the all but universal experience in fertilizing a tilled and a sodded plantation. The fundamental or underlying reasons for this difference lie in the effects of stirring the soil on its nitrate and moisture-content. As a general rule, a well-cultivated apple orchard (including the use of cover-crops) will respond slowly to the use of chemical fertilizers, and one which is not tilled will give prompt returns. An outstanding exception is in the impoverished soils of southern Ohio where the fertilizers gave as great and as prompt results in tilled as in sod orchards. The author believes this is of such importance that the fertilization of tilled and untilled orchards are considered separately.

155. Moisture and fertility intimately related.—Moisture is of first importance in the proper growth and development of plant and fruit, and when it is lacking the elements of fertility are not available. If the soil is too dry at a critical period, the foliage suffers and the fruit is small and of poor quality. On the other hand, too much water in the soil is equally serious, resulting in stunted growth, yellow foliage, and eventually death of the trees. Of the ten or more chemical elements that enter into the composition of the plant, only four are likely to require special attention in the way of amendments to the soil. These are nitrogen, phosphorus, potassium, and calcium. Of these most of the calcium (lime) remains in the wood and leaves, while a large proportion of the potassium (potash) finds its way to the leaves and fruit.

156. Relative importance of the different essential elements.—While each of these so-called essential elements is necessary for tree growth, the relative necessity of their application to the soil will depend on the amount already available and the quantity taken up by any given kind of plant. There has been much misunderstanding and erroneous teaching regarding this question in pomology. However, the field experiments have done much to clear up the situation, although there is still a lack of conclusive information.

157. Organic versus inorganic fertilizers.—In comparative tests on the use of organic fertilizers, such as dried blood, tankage, and cotton-seed meal, and such inorganic materials as nitrate of soda, acid phosphate, basic slag, and muriate or sulfate of potash, the conclusion is reached that the inorganic materials are usually to be preferred.

In an Ohio experiment [1] two orchards badly in need of nitrogen show the following results as a five-year average in pounds of fruit to a tree:

TABLE LVI

COMPARATIVE VALUE OF INORGANIC AND ORGANIC FORMS OF FERTILIZER (AFTER BALLOU)

Application to a tree	*1st orchard*	*2d orchard*
5 pounds nitrate of soda 5 pounds acid phosphate 2½ pounds muriate of potash	Lbs. 205.8	Lbs. 317.6
5 pounds tankage 5 pounds bone-meal 2½ pounds muriate of potash	Lbs. 93.8	Lbs. 163.9

158. Value of nitrogen.—One of the most outstanding results of the various fertilizer experiments conducted throughout the country is the importance of applying ni-

[1] Ohio Agr. Exp. Sta. Bull. 301. 1916.

trogen in a soluble form when an orchard is low in vitality. Such a treatment is of much more importance to an orchard which is not tilled since it has been shown that the soil nitrates are likely to be greatly reduced under those circumstances. This, of course, will depend on the conditions of the soil and perhaps on the climate, for some notable cases are on record in which an application of nitrogen to a cultivated orchard gave immediate and striking results. If an orchard experiment is continued for a very long period, the time is likely to come when nitrogen may be applied with profit whatever the cultural system followed.

In point of efficiency in maintaining the growth and yield of the trees, nitrogen stands alone among the artificial fertilizers.

159. Nitrate of soda.—This carrier of nitrogen is more commonly used than any other because of its solubility. The results are usually prompt and marked. When this fertilizer is used alone, it often gives as good results for the first few years as when in combination with carriers of phosphoric acid and potash. However, over a series of years, a complete fertilizer is considered best. The amount necessary varies with the age of the trees, their condition, and the type of soil involved. Nitrate of soda is also used as a special "stimulant" for trees that are sub-normal as a result of injury, having been employed with success on winter-injured trees, those hurt by fire or other agencies.

For mature apple trees, the usual application is from 4 to 6 pounds to a tree or approximately 150 to 200 pounds to an acre. Smaller trees receive proportionately less unless the application is made over the entire orchard surface. For the peach, an application of 2½ to 3½ pounds to a tree is usually sufficient.

160. Sulfate of ammonia is also a readily available form of nitrogen and from a knowledge of its effects on other crops, it would seem to be adapted to orchard use. Unfortunately, sufficient data are not as yet available to warrant a definite statement of its value, but in demonstration tests the results have fully equaled those of nitrate of soda. Reimer[1] used sulfate of ammonia in an experiment with Winter Nelis pears in the Rogue River Valley, Oregon, and finds that "The plot which received 5 pounds of sulfate of ammonia produced a notable increase in yield, almost equaling the yield produced by 10 pounds of nitrate of soda. The 5 pounds of sulfate of ammonia contains as much nitrogen as 6½ pounds of nitrate of soda." Other experimental work in Oregon with both the peach and apple demonstrate that this material is of increasing importance in orchard work. With certain of the field crops, however, it has been found that this source of nitrogen is not quite equal to the same units of nitrogen in nitrate of soda. Also the chemical changes which take place will ultimately exhaust the bases of the soil unless the land is well supplied with calcium or else lime is applied to offset the loss.

161. Time of application.—So far as is now known, the quickly available forms of fertilizers should be applied not later than blossom time to secure the best results, and it is convenient to add all materials at the same time whether they are readily soluble in water or not. They may be broadcast on top of the grass or mulch or sown with a fertilizer drill in the case of a tilled orchard.

There seems to be some definite evidence to show that an application of nitrate of soda about two weeks before the blossoms open will greatly stimulate the "set" of fruits of the apple, this being particularly noticeable on weak trees. This seems to have been reported first by Ballou[2] from work in southern Ohio. An orchard of twenty-year-old Rome

[1] Ore. Agr. Exp. Sta. Bull. 166. 1920.

[2] Ohio Agr. Exp. Sta. Bull. 301. 1916.

apples which had produced but one crop of fruit because of its extremely low vitality, was fertilized in part about the middle of April. "The trees bloomed rather uniformly over the entire orchard, but the blossoms were unusually small and apparently lacking in vitality. However, after the petals of the blossoms had fallen, the little apples on the fertilized plots where nitrate of soda had been included clung to the fruit spurs and began to grow in a perfectly normal manner, while most of the embryo fruits on the adjoining unfertilized plots withered and dropped from the tree just as the apples had been doing throughout the past life of the orchard." At picking time of this first year one row of eight trees which was fertilized with a 5-5 nitrate-phosphate combination produced twenty-one barrels of fruit, while the adjoining untreated row yielded nine barrels.

The same effect of an early application of nitrate on the set of blossoms is reported by Lewis. He finds that as a result they secured a higher percentage of "set," an immediate change in character of foliage, and a stimulation of wood growth.

162. Phosphorus is rather low in many soils and in animal manures, but is required in less amounts by fruit-trees than either nitrogen or potassium (in the relation of 4N, 1 P_2O_5, 4K_2O) as was seen above. However, the data in regard to this element are rather unsatisfactory and inconsistent in the orchard experiments. It would seem to rank next to nitrogen in its requirement as an amendment to the soil, although when applied alone the results are frequently meager or negative. An exception is found in certain sections where phosphoric acid has had a positive result in encouraging the growth of clover in a sod orchard (see Ohio experiments) which in turn is beneficial to the soil.

163. Acid phosphate.—As a carrier of phosphoric acid, this material seems to give the most satisfactory results because of its availability. It is commonly used at the rate of 350 to 400 pounds to the acre.

Both floats and basic slag have been used in orchard experiments with varying results, but neither has been so efficient as acid phosphate. Bone-meal has not proved valuable in securing results within a reasonable length of time and it is not so widely used in orchards as formerly.

164. Potash is used by fruit-trees in relatively large amounts. This led to the earlier teachings that potash was the first essential in fertilizing fruit-trees. This theory ignored the fact that many fruit soils are comparatively rich in potash and hence obviated the necessity of adding it in an artificial form. The statements that potash fertilizers make better color, better shipping quality and flavor of fruits are without apparent foundation in experimental results. When potash is applied alone or in combination, the data show few instances in which outstanding results are secured from it.

165. Muriate versus sulfate of potash.—Some difference of opinion exists as to the relative value of muriate and sulfate of potash for orchard use. Both have given satisfactory results where there was need for a potash fertilizer. Therefore, since the muriate is cheaper, it would seem good practice to apply it until further research shows a superiority of the sulfate.

166. Hardwood-ashes.—Wood-ashes have long been used for fruit-trees and were highly valued a half century ago, but their scarcity at the present time has greatly restricted their use. Wood-ashes will vary markedly in their composition; if they are unleached they will analyze about 4 to 6 per cent potash, 1.5 to 2 phosphoric acid, and 25 to 30 per cent lime. Potash salts have largely replaced wood-ashes as a source of potassium in orchard fertilization.

167. Common salt.—Sodium chloride has been advocated for orchards (at the rate of about 150 pounds to the acre) to release the potash in the soil and thus furnish the trees with that element. Since potash is not often the limiting factor, this practice is not of importance to the orchardist. Some such reaction as the following is believed to take place in the soil:

$$NaCl + KAlSi_3O_8 = NaAlSi_3O_8 + KCl.$$

168. Animal manures in the orchard.—In several of the fertilizer experiments already cited, the value of manure for the orchard has been shown. When it is used on a sodded or mulched orchard, it not only furnishes plant-food but, what is often quite as valuable, it conserves the moisture. As a top dressing in a sod orchard it is slower acting, however, and on the whole less effective than nitrate of soda, when nitrogen is badly needed. In a tilled orchard it is valuable as a source of organic matter as well as of plant-food.

That the experimental results from its use are variable is shown by results in two orchards which seemed similar.[1] In one was obtained an annual cash gain to the acre for five years of $20.75, while in another the gain was $110.75, or $2.00 an acre less than the adjoining plot treated with nitrate of soda alone. Unfortunately, these data are not given in terms of yield.

From work conducted in Pennsylvania [2], it is reported that "in ten similar experiments, the gains from stable manure in both tilled and untilled treatments have averaged 79.3 bushels per acre annually, while those from commercial fertilizer averaged 73.0 bushels. In five cases involving tillage, however, the gains from the fertilizer have averaged 99.6 bushels per acre annually, while those from the manure

[1] Ohio Agr. Exp. Sta. Bull. 301. 1916.
[2] Penn. Agr. Exp. Sta. Bull. 141. 1916.

have averaged only 83.4 bushels. In general, therefore, the manure has surpassed the fertilizer on untilled trees and has been surpassed by it on those receiving tillage. The extra mulching effect of the manures has doubtless contributed to this result."

EXPERIMENTS IN UNTILLED ORCHARDS

As stated in the foregoing paragraphs, the most marked results from fertilizing have been secured in orchards that are not cultivated, and some typical cases may be cited to show the results attained.

169. The Massachusetts experiment.[1]—In Massachusetts a fertilizer test was conducted in an orchard of Gravenstein, Baldwin, Roxbury Russet, and Rhode Island Greening apples for a period of fifteen years. Three trees of each of these varieties were included to a plot. They were planted in 1890 and cultivated for five years. From 1895 until 1910, the trees were in sod, and the following list of treatments together with the total yield of fruit for this period summarizes the results:

Table LVII

RESULTS OF ORCHARD FERTILIZATION—MASSACHUSETTS. (AFTER BROOKS)

Plot	*Fertilizer*	*Annual rate to the acre —pounds*	*Total yield for 15 years—pounds*
1	Barnyard manure	20,000	24,934
2	Wood-ashes	2,000	12,841
3	Nothing		3,940
4	Bone-meal	600	
	Muriate of potash	200	14,453
5	Bone-meal	600	
	Low-grade sulfate of potash	400	21,863

[1] Mass. Agr. Exp. Sta., 22d Ann. Rept., Part 2. 1910.

This experiment shows the superiority of any of the treatments over the untreated plot. The striking point, in the light of later investigations, is the absence of an application of quickly available nitrogen for this orchard. The manure has given outstanding results in yield and growth, no doubt due to the supply of nitrogen it carried as well as to the organic matter added to the soil. Brooks states that too much manure was used, for the trees made too heavy a growth and the fruit was green and coarse. This is a common experience when trees are over-fertilized with animal manures. Perhaps the most outstanding result of this experiment is the apparent superiority of the low-grade sulfate of potash, which contains a large amount of magnesia, over the bone-meal-muriate-of-potash treatment. The differences in the two plots may have been due to the presence of magnesium as the sulfate or chlorid or to the sulfur itself in the sulfates of potassium and magnesium, but the cause or causes for the difference in behavior have not been clearly established. The effect of wood-ashes, which contain about 1 to 2 per cent of phosphoric acid (P_2O_5) and 4 to 6 per cent of potash (K_2O), is of interest since the common recommendation of the older horticulturists was to use wood-ashes for fruit-trees.

170. The Ohio experiments.—Further light is thrown on this problem by the Ohio experiments in which a mulch is usually included. This work was conducted in the southern part of the state on land low in native fertility, and where the surface soil is very thin, usually supporting a cover of poverty-grass (*Danthonia spicata*) and weeds. The land washes or erodes badly and hence it is not deemed wise to cultivate it.

This experiment gave immediate results when nitrogen was used alone or in combination with fertilizers carrying phosphoric acid or potash. The beneficial effects continued each year, and demonstrated beyond question that the first and most important need for these orchards was a quickly available form of nitrogen. Nitrate of soda proved to be the best carrier of nitrogen. When phosphoric acid was used in combination with nitrate of soda or in a complete fertilizer, there was little or no evidence that it was a limiting factor, although the soil is naturally low in phosphorus. However, it proved of great value in securing a stand of better grasses as is discussed in connection with producing mulch material. Neither did potash have any apparent effect in increasing the vigor or yield of the trees during the five-year test. These conclusions are supported by the following summary of the data:

TABLE LVIII

AVERAGE YIELD TO A TREE IN 3 ORCHARDS OF ROME BEAUTY APPLES, 22–25 YEARS OLD.[1] GRASS-MULCH

5-YEAR AVERAGE. (AFTER BALLOU)

Treatment [2]	*1st Orchard*	*2d Orchard*	*3d Orchard*
	Lbs.	Lbs.	Lbs.
Checks	69.9	124.1	122.6
Nitrate	315.6	296.3	378.9
Nitrate—phosphorus—potash	205.8	317.6	348.4
Duplicate			315.9
Tankage—bone—potash	93.8	163.9	
Nitrate—phosphorus	214.2		
Potash	96.0	133.7	
Manure	100.1	124.1	

[1] *Loc. cit.*

[2] The following amounts of fertilizer were used in each case:

Nitrate of soda, 5 lbs.	Stable manure 250 lbs.
Acid phosphate, 5 lbs.	Tankage 5 lbs.
Muriate of potash 2½ lbs.	Bone 5 lbs.

In a later report,[1] an additional experiment is recorded which confirms the earlier findings on the type of soil in southern Ohio. Other features of interest are also included.

In 1914, a twenty-year-old orchard of Rome Beauty and Ben Davis apples which were very low in vitality and entirely non-productive was secured for the purpose of experimentation. Two rows of twelve trees each constituted a plot, the one having the fertilizer distributed in a circle beneath the tree, and the other having it applied over the entire tree square ("all-over method"). A check or buffer row was maintained between each two plots. Half the orchard was cultivated and a cover-crop sown annually, and the other half was put under the grass-mulch system, the fertilizer treatments being the same on both sections. There was no material difference in yield between the "circle" and the "all-over," method of distributing the fertilizer, but the latter encouraged a strong growth of vegetation for mulching purposes.

The conclusions of this experiment are striking in several particulars, notably in showing that fertilizer will produce equally prompt and valuable results in both tilled and mulched orchards in that section, an end not secured, under a number of other conditions, as discussed later in this chapter. Also tillage alone will not suffice to produce maximum crops on the soil in question.

If the unfertilized grass-mulch plot is taken as the check, the following increases obtain for a five-year average:

[1] Ohio Agr. Exp. Sta. Bull. 339. 1920.

Table LIX

RESULTS FROM FERTILIZING TILLED AND MULCHED ORCHARDS—SOUTHERN OHIO. (ADAPTED FROM BALLOU AND LEWIS)

	Percentage increase	*Average yield to the acre, 5-yr. period*
		Barrels
Grass mulch—unfertilized	0	37.6
Cultivation—cover-crops unfertilized	41	53.2
Grass mulch—fertilized	100	75.4
Cultivation—cover-crops fertilized	95	73.5

The more complete data are given in the following table:

Table LX

EFFECT OF FERTILIZATION ON TILLED AND GRASS-MULCH ORCHARD—OHIO. (AFTER BALLOU AND LEWIS)

Row No.	*Cultivated plot*	*5-year average, 1914–18*
		Lbs.
1	Nitrate of soda, 5 lbs. on tree circle	3,220.1
2	Nitrate of soda, 5 lbs. on tree square	3,017.2
3	No fertilizer	2,270.8
4	Nitrate of soda, 5 lbs.; acid phosphate, 5 lbs. on tree circle	3,081.6
5	Nitrate of soda, 5 lbs.; acid phosphate, 5 lbs. on tree square	2,950.6
6	No fertilizer	2,308.0
7	Nitrate of soda, 5 lbs.; acid phosphate, 5 lbs.; muriate of potash, 5 lbs. on tree circle	2,935.7
8	Nitrate of soda, 5 lbs.; acid phosphate, 5 lbs.; muriate of potash, 5 lbs. on tree square	3,407.5
	Totals for cultivated plot	23,191.5

TABLE LX—*Continued.*

Row No.	*Grass-mulch plot*	*5-year average 1914–18*
		Lbs.
9	Nitrate of soda, 5 lbs. on tree circle	2,817.9
10	Nitrate of soda, 5 lbs. on tree square	2,295.5
11	No fertilizer	1,503.7
12	Nitrate of soda, 5 lbs.; acid phosphate, 5 lbs. on tree circle	3,799.7
13	Nitrate of soda, 5 lbs.; acid phosphate, 5 lbs. on tree square	3,641.3
14	No fertilizer	1,773.5
15	Nitrate of soda, 5 lbs.; acid phosphate, 5 lbs.; muriate of potash, 5 lbs. on tree circle	3,287.6
16	Nitrate of soda, 5 lbs.; acid phosphate, 5 lbs.; muriate of potash, 5 lbs. on tree square	3,851.1
	Totals for grass-mulch plot	22,970.3

171. The Pennsylvania experiments [1] confirm the above results in general, with some modifications. Again nitrogen has proved the most important element in increasing the growth and yield of apple trees in sod, although the other elements have seemed to be of greater importance here than in the Ohio work. In a summary statement Stewart says, "The addition of phosphorus or potassium to nitrogen applications has usually given larger returns than nitrogen alone. The nitrogen and phosphorus combination has produced an average increase over the normal yields in two experiments of 265 and 308 bushels per acre annually during 9- and 10-year periods. This combination is also proving important in one of the experiments in young orchards. In at least three of the other bearing orchards,

[1] *Loc. cit.*

a

b

PLATE V.—*a*, Fruit from an unthinned Baldwin apple tree; 7 bushels No. 1 fruit and 17 bushels No. 2 fruit. *b*, Fruit from a thinned Baldwin tree; 19 bushels No. 1 fruit and $1\frac{1}{2}$ bushels No. 2 fruit.

however, the addition of phosphorus has resulted in no important benefit." Also, "Potash has increased the yields materially in three of the experiments in bearing orchards and apparently has shown some value in increasing the size of the fruit. It has also apparently had an injurious effect in two of the eight experiments. It would seem advisable therefore, to defer its general use in any particular orchard until definite evidence of its value is secured." Manure has usually had a beneficial effect, although it is slower acting than nitrate of soda. These conclusions are supported by the following data:

Table LXI

10-YEAR SUMMARY OF RESULTS IN FERTILIZING APPLE ORCHARDS IN PENNSYLVANIA. YIELD TO THE ACRE IN BUSHELS (AFTER STEWART)

Treatment *Trees in sod or grass mulch*	*Baldwin, mature orchard*	*York, Baldwin, mature orchard*
	Bu.	Bu.
Average of checks	228	111
Nitrogen and phosphoric acid	488.6	486.1
Nitrogen and potash as muriate	450.9	318.2
Phosphorus and potash as muriate	291.8	113.1
Phosphorus and potash as sulfate	.....	91.3
Nitrogen, phosphorus, and potash	479.9	292.2
Nitrogen	.....	186.2
Manure	519.	405.1

The kind and amounts of fertilizer commonly used in the Pennsylvania experiments are shown in table on page 200.

Table LXII

AMOUNT OF FERTILIZER TO THE ACRE FOR BEARING TREES (AFTER STEWART)

Nitrogen *30 lbs.* (N)	*Phosphoric acid* *50 lbs.* (P_2O_5)	*Potash* *25 to 50 lbs.* (K_2O)
Carried in:	Carried in:	Carried in:
100 lbs. nitrate of soda	350 lbs. acid phosphate	50 to 100 lbs. muriate
and	or in	of potash
150 lbs. dried blood	200 lbs. bone-meal	or in
or in	or in	100 to 200 lbs. of low-
150 lbs. ammonium sulfate	300 lbs. basic slag	grade sulfate

172. New Hampshire experiments.—In order to determine to what extent the results from grass-mulch orchards could be duplicated under the conditions existing

Fig. 29.—Row of trees to left were fertilized with 5 pounds nitrate of soda each. Those to right were untreated.

in New Hampshire, a test was arranged in a mature Baldwin orchard which was producing low yields. It had not been cultivated for several years, the grass being cut for hay and removed annually. The results secured by the treatments were quite similar to those obtained from the experiments just reviewed and demonstrate that the grass-mulch system of orcharding has wide application. Table LXIII gives the treatments and the results secured for three years.

TABLE LXIII

YIELD OF BALDWIN APPLES IN A RENOVATED ORCHARD (NEW HAMPSHIRE)
ALL TREES MULCHED WITH 200 POUNDS SWAMP HAY TO A TREE
YIELD A ROW (8 TREES) IN BARRELS

Row No.	*Treatment*	*1916 Barrels*	*1917 Barrels* [1]	*1918 Barrels*	*Average 3 years*	*Barrels to the acre*
1	7 lbs. basic slag to a tree. .	13.50	4.50	31.3	16.43	71.75
2	5 lbs. nitrate of soda.	20.63	5.33	27.8	17.92	77.35
3	3 lbs. sulfate of potash. . . .	13.92	3.29	19.2	12.13	52.85
4	Check.	9.48	3.30	24.1	12.29	53.55
5	7 lbs. basic slag. . . . . 5 lbs. nitrate soda.	28.88	6.97	35.36	23.73	103.60
6	5 lbs. acid phosphate. . . . . 3 lbs. sulfate potash.	8.91	4.50	35.60	16.33	71.40
7	7 lbs. basic slag. . . . . 3 lbs. sulfate potash.	7.52	2.90	19.04	9.82	43.05
8	Check.	12.12	2.89	16.32	10.54	45.85
9	5 lbs. nitrate soda. . . . . 3 lbs. sulfate potash	21.08	4.51	20.24	15.27	66.85
10	5 lbs. acid phosphate.	4.76	2.46	16.0	7.74	33.95
	Ave. check rows, 4 and 8	10.95	3.09	20.21	11.41	49.70
	Ave. nitrogen rows, 2, 5, 9	23.53	5.60	27.80	18.97	82.73
	Ave. potash and phosphoric acid rows, 1, 3, 6, 7, 10. . .	9.72	3.53	24.23	12.49	54.60

EXPERIMENTS IN TILLED ORCHARDS

It has been stated that a cultivated apple orchard usually responds much more slowly to the use of fertilizers than a sodded or mulched one, although there are conditions in which the response is as immediate as in the latter case. While the former cases predominate, some standard experiments will be cited in which the trees have not responded to fertilization and others in which results were obtained.

[1] Computed in part from total yield, approximately correct.

173. The Woburn experiment.[1]—At the Woburn Experimental Fruit Farm (England), a cultivated orchard was treated annually for fourteen years and at the completion of the work the following conclusion was drawn: "Neither moderate nor heavy dressings of dung or artificial fertilizers, nor of both combined, had any appreciable effect on any feature of the trees nor on the crops from them. The total effect did not amount to 5 per cent and even that effect was doubtful. The only exception was in the case of nitrate applied in the early summer which in several seasons produced a good effect."

Later Pickering reports the following:[2] "The results obtained at Ridgmont during twenty-two years lead to the conclusion that the apple trees which have been dressed every year throughout that period with various dressings of artificial or natural manure have shown no appreciable advantage over similar trees which received no dressing whatever. Whilst this, however, has been the case with dwarf and standard apple trees, and also mixed with plantations of apples, pears, and plums, the reverse has proved to be the case with bush fruits, such as currants, gooseberries, and raspberries: those which were left unmanured have been practically exterminated, whilst those which were manured flourished. But the manure which was essential in these cases was a bulky organic manure, such as dung, since artificial manures produced but little more effect than no manure at all."

174. The New York experiments.—Hedrick reports on a twelve-year experiment[3] in a mature orchard in New York, showing that neither lime, potash, nor phosphoric acid had any practical effect on the growth or yield of the trees.

[1] Woburn Expt. Fruit Farm. 4th and 5th Rept. 1904–05.

[2] Science and Fruit Growing. London. 1919. pp. 89–90.

[3] N. Y. Agr. Exp. Sta. Bull. 289. 1907.

The varieties involved were Baldwin, Fall Pippin, Rhode Island Greening, Roxbury Russet, and Northern Spy. Clean culture was followed annually until August 1, when a cover-crop of oats, barley, or clover was sown. Wood-ashes were applied at the rate of 100 pounds to a tree and also in the last seven years 8½ pounds of acid phosphate to a tree. The conclusion drawn is that: "The returns obtained in this twelve-year experiment are negative from a practical standpoint. The experiment shows that it is not profitable to apply potash, phosphoric acid, or lime to the soil of this orchard. Fifty-seven years of orchard cropping has not reduced this soil to the condition where it needs a 'complete' fertilizer, yet the leguminous cover crops plowed under in the orchard have usually produced beneficial effects the same or the next season. . . . An interesting fact is that both treated and untreated plots increased markedly in yield from 1893 to 1904. The probable explanation is that prior to 1893 the orchard was in sod but during the experiment it was kept under cultivation and grew more productive under the treatment."

In another experiment [1] conducted in a younger orchard, a similar lack of response from the use of fertilizers is reported after fifteen years' work. The variety was Rome Beauty top-worked on Ben Davis. The following results were secured from the treatments:

[1] N. Y. Agr. Exp. Sta. Bull. 339. 1911.

TABLE LXIV

YIELD AND GROWTH FROM FERTILIZER TREATMENTS (AFTER HEDRICK)

Treatment		*Average yield to a tree, 7-yr. average*	*Average diameter of trunk at end of experiment (1910)*
		Lbs.	In.
Stable manure	415.15	90.47	6.26
Acid phosphate	12.66	87.57	5.98
Muriate of potash	7.26		
Acid phosphate	12.6	103.34	6.35
Muriate of potash	7.26		
Acid phosphate	12.60		
Nitrate of soda	3.67	99.10	6.18
Dried blood	12.84		
Check	92.25	92.25	6.14

It will be seen from these data that the fertilizers have resulted in practically no increases in growth or yield of the trees. Neither was there a difference in the uniformity of the crops or in the maturity, keeping quality, texture, or flavor of the fruit. It is recorded that the size of the apples was slightly increased by the treatments and that the foliage was greener during the last season of the experiment where nitrogen had been applied. But the conclusion was drawn that "The trees in this experiment would have been practically as well off had not an ounce of fertilizer been applied to them."

After twenty years' work in this same orchard, the conclusions are drawn that, "In general there are so many inconclusive or contradictory results that no conclusion of practical value can be drawn from the yields. Heavy applications of nitrogen in a complete fertilizer and in manure have not increased tree growth. When the costs are considered, certain plats have given increases sufficient to equal the costs, or even to show a profit, but in other plats the same plant food elements have shown a financial loss." [1]

175. The New Hampshire experiments.—A somewhat similar experiment [2] was conducted by the New Hampshire Station. The orchard, which consisted of about 300 mature Baldwin trees, was situated on a light soil. It was found, after ten years, that the use of a complete fertilizer had decidedly increased the growth of the trees and that after the sixth year a better general appearance and darker green color was evident. This is in contrast with the New York experiment involving a heavier and richer soil, where such a difference was not evident until the fifteenth year. However, after twelve years' treatment, the fertilized plots failed to respond in yield of fruit, as they had made very slight gains and in some cases none over the first stimulus of the cultivation. An increase in size of the fruit, however, was distinctly noticeable, especially in the plot receiving the following treatment high in potash: 2 pounds nitrate of soda, 10 pounds sulfate of potash, and $8\frac{1}{2}$ pounds acid phosphate to a tree (Plot 10). It was observed, however, that an increase in yield of fruit was to be expected in the near future because of the greater size of trees, and hence bearing surface. This is in accord with much of the work conducted in well-tilled orchards, some requiring, however, much longer to show the need of artificial "feeding" than others. In fact, some may never reach the point at which it would be economical to apply fertilizers. The following table shows not only the effect of the fertilizers but also other cultural treatments as discussed in the previous chapter:

[1] Hedrick, U. P., and R. D. Anthony. Twenty years of fertilizers in an apple orchard. N. Y. (Geneva) Agr. Exp. Sta. Bull. 460. 1919.

[2] Gourley, J. H. Sod, tillage and fertilizers for the apple orchard. A ten-year summary. N. H. Agr. Exp. Sta. Bull. 190. 1919.

TABLE LXV

AVERAGE ANNUAL YIELD TO THE ACRE IN BUSHELS (1909–1918)

Plot		
1	Sod	99
4	Clean tillage	191
5	Tillage cover-crops	196
6	To the acre: 70 lbs. nitrate 245 lbs. basic slag 140 lbs. sul. potash	188
7	To the acre: 70 lbs. nitrate 298 lbs. acid phos. 140 lbs. sul. potash	154
8	To the acre: 70 lbs. nitrate 595 lbs. acid phos. 140 lbs. sul. potash	145
9	To the acre: 210 lbs. nitrate 298 lbs. acid phos. 140 lbs. sul. potash	160
10	To the acre: 70 lbs. nitrate 298 lbs. acid phos. 350 lbs. sul. potash	176

176. The Maine experiment.—Much the same result has been obtained in the Maine experiments. A mature Ben Davis orchard of 400 trees was divided into three plots and the following treatments given: Plot A has had no fertilizer since 1912; plot B has received annually since 1912, 500 pounds to the acre of a fertilizer carrying 4 per cent nitrogen, 8 per cent available phosphoric acid, and 7 per cent potash; plot C has been given annually since 1912, 1000 pounds to the acre of a 4-8-7 fertilizer. For three years prior to 1912 the entire orchard was cultivated and fertilized at the rate of 1000 pounds to the acre of a 4-8-7 fertilizer which of course complicates the matter but the results after eight years may be summarized as follows: "Exact records of yields and measurements of growth have been taken since the experiment was begun. No differences that could be attributed to the additional nitrogen (or other ingredients) in the fertilizer have been noticed." [1]

177. The Oregon experiments.—An interesting example of the influence of commercial fertilizers on a cultivated orchard of bearing apple trees is shown by the work of Lewis and Brown in Oregon.[2] The soils were exhausted by continual clean cultivation without the use of green-crops to maintain the supply of organic matter. Neither was irrigation practiced in order to supply the necessary moisture. As a result, the soils "lacked water-holding capacity, they baked or puddled early, and on hillsides were given to erosion." Two years' work demonstrated that no response of a practical nature could be expected from the use of potash or phosphoric acid, but when nitrogen was supplied the effect was immediate. This would seem to be a special case in which the soil had reached the point of exhaustion of available nitrogen, and hence would no longer support the trees satisfactorily. Even though all these soils were cultivated frequently and part of them continually, the application of nitrogenous fertilizer gave as quick returns as when it is added to a run-down sodded orchard. The apparent exception here to the general premise in this text is probably largely explained by the authors of the work as follows: "We are all familiar with the fact that shade crops induce bacterial action and by liberating nitrogen, stimulate tree growth. There are many evidences to show that alfalfa, left permanently in the orchard, does not stimulate wood growth as rapidly as where placed in a shorter rotation with

[1] Me. Agr. Exp. Sta. Bull. 236, 260.

[2] Rept. 1916. Hood River Branch Exp. Sta., p. 37.

clean tillage. The same rule to some extent applies to clover. In the former case, unless receiving an abundance of water, often not the case, and care such as renovation and cultivation in its somewhat unnatural environment, this shade crop does not make its best growth, and becomes soddy, a condition not only inimical to its own welfare, but to that of the trees as well. On the other hand, when organic matter such as clover or alfalfa is turned under frequently, say once in every three or four years, and followed by clean tillage, disintegration of organic matter and bacterial action are greatly accelerated, inducing great vigor of tree, especially in 'off' years when the crop is light." It is, therefore, recognized that on the soils in question the nitrate was applied as a special measure and gave excellent results, but that such a treatment would probably not have been necessary had a better system of soil management been followed. It should also be stated in this connection that alfalfa may remain in the orchard for a period of years when properly handled without injury to the trees.

The data in Table LXVI give a summary of this work.

178. West Virginia experiment.[1]—The experiments conducted in the Ohio Valley on impoverished soils, which were under cultivation, corroborates the results secured in southern Ohio. Nitrogen proved to be of first importance in obtaining a vigorous growth of trees and maximum yield of fruit. When phosphorus was used in connection with nitrogen, the results were somewhat greater than was secured from the latter alone, but the chief value of the phosphorus seems to have been in promoting a greater growth of cover-crops and sod coverings. Potash apparently gave no response in these orchards.

[1] Alderman, W. H., and H. L. Crane. W. Va. Agr. Exp. Sta. Bull. 174. 1920.

Table LXVI

RESULTS ON SPITZENBURG APPLE TREES FROM USE OF NITRATE OF SODA (AFTER LEWIS AND BROWN)

Orchard[1] *number*	*Plot number*	*Pounds to a tree, Nitrate of soda*		*Treatment, 1916*	*3-yr. ave. to a tree 1914–1916. Yield loose boxes*	*Ave. terminal growth, inches, 1914–1916*
		1914	*1915*			
1	1. a	5.2	5.2	Clover	8.4	20.1
	2. b	5.2	5.2	Green-manure	7.8	17.1
	3. c	5.2	5.2	" "	5.3	16.1
	4.	No fertilizer		Check	3.1	19.9
2	1. a	6.75	6.75	Alfalfa sod	8.8	15.4
	2. b	6.75	6.75	" "	9.2	8.4
	3. c	6.75	6.75	" "	11.8	14.7
	4.	No fertilizer		Check	2.9	5.2
				Lbs. nitrate to a tree		
3	1.			7.3	16.1	11.7
	2.	No treatment		5.0	13.44	9.9
	3.			None	8.56	4.1
	4.			3.0	12.61	14.1
4	1.			7.3	6.08	17.4
	2.			5.0	4.72	20.1
	3.			None	1.77	4.7
	4.			3.0	5.78	17.7

In cultivated orchards in the eastern part of West Virginia where the soil is more fertile, the response from fertilization was practically negligible after eight years' work.

179. The Pennsylvania experiments.—The Pennsylvania Station[2] reports a set of experiments in tilled orchards which is not in harmony with several of the others considered. It was found that under the conditions of their experiments, both manure and artificial fertilizers have given as good results in a cultivated as in a sod orchard. "In six cases with tillage, the gains from commercial ferti-

[1] Orchards Nos. 1 and 2.

a. Fertilizer broadcast on ground.

b. Fertilizer sprayed on ground as liquid.

c. Fertilizer sprayed on ground and tree as liquid.

Orchards Nos. 3 and 4.

Treatment began in 1916. All broadcast on ground.

[2] Penn. Agr. Exp. Sta. Bull. 153.

lizer have averaged 90.3 bushels per acre, and only 69.1 bushels in the six corresponding cases without. Tillage, therefore, has increased the efficiency of the fertilization in most cases. There were several important exceptions, however, and tillage excesses, either in depth or frequency, may actually reduce the gains from fertilization." These conclusions are supported with the following data:

TABLE LXVII

TEN-YEAR SUMMARY OF RESULTS IN FERTILIZING TILLED APPLE ORCHARDS (AFTER STEWART)

Treatment	*Grimes, Smokehouse, Stayman, Young orchard*	*York, Stayman, Young orchard*
Ave. of checks	221.4	225.7
Nitrogen and phosphorus	282.2	279.1
Nitrogen and potash	273.1	350.4
Phosphorus and muriate	225.1	292.4
Phosphorus and sulfate		293.4
Nitrogen, phosphorus, and potash	239.6	298.5
Nitrogen		236.8
Manure	290.2	304.2

180. The Ohio experiments.—A discussion of these experiments was included under the section on "untilled orchards," since a comparative statement in that place seemed more desirable.

181. Results compared.—It is confusing to find such contradictory statements from a similar type of experiment, but the student should understand that it is the duty of the experimenter to report faithfully the results of his work without prejudice in regard to the results. When it becomes evident that the worker is endeavoring to prove instead of to find out something, the interpretation of his work is weakened proportionately.

It is possible that the difference in results is due largely to the organic matter in the soil. In a climate where the season is long and the summer heat intense, cultivation would "burn out" the organic matter or source of nitrogen much more quickly than where the opposite conditions obtain. Also a soil already devoid of organic material would probably produce the same results. It is at least worthy of notice that three of the experiments here considered in which fertilizers in a cultivated apple orchard were very slow in producing results were in the North (Maine, New Hampshire, and New York).

OTHER RESULTS OF FERTILIZING

182. Color of fruit.—In general, it may be stated that no fertilizer combination yet tried will increase the color of fruit appreciably. In some apple experiments there seemed to be a slight advantage to color from potash but not sufficient to warrant its use for this purpose. Alderman [1] gave double and triple applications of potash to plots of peaches and reports that there is "absolutely no effect upon color of fruit, a fact which indicates the worthlessness of this material as a coloring agent." In the case of a number of crops, phosphoric acid will hasten maturity, but this has not been observed with the apple.

It has not infrequently been stated that iron salts will heighten the red color of fruits, and several well-planned experiments have been prosecuted to determine this point. At the Woburn Experimental Fruit Farm [2] where such a test was made, it was concluded after twenty-two years' work that where 2.8 grains of iron sulfate to a square meter or a similar amount of manganese sulfate was used, no effect had been noticed on fruit color with the exception of

[1] W. Va. Agr. Exp. Sta. Bull. 150. 1915.

[2] Woburn Exp. Fruit Farm. 16th Rept. 1917.

one year, and this was attributed to chance. Conversely, tillage or the use of nitrogen fertilizers or manure commonly cause a profusion of foliage which shades the fruit and reduces coloring; it also delays maturity and hence may lessen the red color of fruit.

In other words, the development of color in fruit is largely dependent on maturity and the free action of sunlight. If fruits are bagged while green, they will not develop red color unless the bag itself is translucent to the extent of letting some light pass through when some proportionate color will develop.[1] Where fogs occur and the intensity of the light is decreased, the color of the fruit is lower, and the converse holds true.

183. Fertilizing the peach.—It is not necessary to consider separately the fertilization of tilled and untilled peach orchards, since rarely is this fruit grown without cultivation. The outstanding fact to be considered here is that, unlike the cultivated apple orchard, the peach will usually respond readily to proper fertilization, particularly after the trees reach bearing age.

Chemical data show that the peach is a heavy feeder and removes large quantities of plant-food from the soil. It is particularly striking that this fruit removes nitrogen and potash in great excess over phosphorus. This fact is well illustrated in Table LXVIII adapted from Alderman:[2]

Since it has been shown that the peach uses large quantities of the soil ingredients in comparison with most other fruits, it might be anticipated that it should require rather heavy fertilization for best results. That the growth of the trees and yield of fruit are affected by proper fertilizing is shown by the following condensed table of the results secured by the West Virginia Experiment Station:

[1] Blake, M. A. Rept. Soc. Hort. Sci. 1913.
[2] W. Va. Agr. Exp. Sta. Bull. 150. 1915.

TABLE LXVIII

PLANT-FOOD REMOVED TO THE ACRE A YEAR BY THE PEACH

	Nitrogen	*Phosphoric acid*	*Potash*
New Jersey (173 trees)	64 lbs.	18 lbs.	40 lbs.
New York (120 trees)	75 "	18 "	72 "
Average	69.5 "	18 "	56 "
	Nitrate of soda	*16% acid phosphate*	*Muriate of potash*
Equivalent amounts	463	112.5	112

TABLE LXIX

EFFECT OF FERTILIZERS ON PEACH TREES (ADAPTED FROM ALDERMAN)

Treatment [1]	*Ave. yield 1911–'13, '14*	*Effect on set of buds, ave. '12–'15*	*Area to a leaf, 3-yr. ave.*	*Terminal growth, 4-yr. ave.*
	Lbs. to the tree	Per cent	Sq. in.	Inches
Nitrogen and phosphoric acid	69.95	80.6	4.28	16.1
Nitrogen and potassium	71.93	75.5	4.26	14.47
Complete	72.06	74.0	4.06	15.0
Check	49.48	58.0	2.63	8.16
Potash and acid phosphate	42.42	57.9	2.89	7.28
Complete	82.29	76.6	4.12	14.40
Complete with double potash	82.09	75.2	4.39	15.59
Complete with potash tripled	82.59	76.2	4.26	15.0
Lime	60.82	64.4	3.26	7.84

[1] N = 200 lbs. nitrate of soda to the acre.
P_2O_5 = 335 lbs. acid phosphate (16%) to the acre.
K = 135 lbs. muriate of potash to the acre.

The above experiment with bearing peach trees was conducted for four years. The soil in question was a shale loam and "low in fertility," and each plot contained twenty trees of Carman and Waddell varieties. As a result of the treatments with nitrate of soda, the annual growth of the trees was double that of the untreated ones. The yield was nearly doubled also by the use of nitrogen but it delayed maturity by several days, which in some cases was advantageous from a commercial standpoint. Neither the element phosphorus nor potassium produced any beneficial effects and some injurious consequences followed the use of the latter.

The influence of lime could not be definitely determined and was regarded as largely negative, although the production was somewhat increased.

The trees which did not receive nitrogen produced fruit of higher color, but the cause was attributed to the extra sunshine which reached the fruit, owing to the sparse and sickly foilage.

It is commonly stated that a limestone soil is markedly better than a non-calcareous one, but this statement is open to question, depending on what shall be considered such a soil and what is to be grown. Fruit-trees use lime in considerable quantities and would not thrive if the supply of carbonate of lime in the soil was very low, any more than other plants. However, as indicated before, it is not necessary to have a so-called limestone soil for the production of any of the common fruits. It is claimed that the "stone" fruits require more lime than the pome-fruit, although data are lacking to establish this statement. Lewis[1] reports that his work with lime on stone-fruits has given no benefits to the trees. On the other hand, lime seems to have been of some benefit to peach trees in the "Eastern Pan-handle" of West Virginia but no effect was noticed on the fruit itself.

[1] Ore. Agr. Exp. Sta. Bull. 166. 1920.

It is of course well established that lime will increase nitrification in the soil, but orchard experiments, and many are on record, do not show much benefit from its use. The inter-crops and cover-crops, on the other hand, may require it and as soon as this can be determined, lime should be applied.

184. Effect of fertilizing on regular bearing.—It is usually found that, unless weather or other external causes interfere, fruit-trees that respond to tillage, fertilizer, or both will be more regular in their bearing than those that are somewhat below normal. It has been observed that well-fertilized trees are noticeably more productive in a season unfavorable for setting fruit or following a severe winter than untreated individuals.[1]

185. Application of fertilizers.—When fertilizers are applied to a mulched or sodded orchard, they are merely broadcasted on the mulch or over the entire orchard area as the case may be, and the succeeding rains dissolve and carry them into the soil. This is usually done about the time the blossoms are ready to open, although in the case of nitrate of soda it may be applied earlier. When fertilizers are added to a tilled orchard, they are usually applied after it is plowed and perhaps harrowed once in the spring, thus incorporating them with the soil early in the growing season.

186. Size of fruit is influenced largely by the amount which a tree has set. Good cultural methods will increase the size provided they do not result in an overload of the trees, in which case the size may not be maintained. Fertilizers, especially those containing a liberal amount of potash, seem to have some effect in increasing size. Whenever moisture is well maintained, the size is increased. Manure will often produce excessively large and coarse fruits.

Young trees are likely to produce over-sized fruit, even to the point of losing some of the normal characteristics of

[1] N. J. Agr. Exp. Sta. Ann. Rept. 1884–94.

the variety. Thinning has a greater effect on increasing size on a heavily ladened tree than any other practice.

187. Summary.[1]—The following statements summarize the general conclusions which may be drawn from the foregoing discussion:

1. The most fundamental difficulty in interpreting the experiments in orchard fertilization is due to failure to recognize whether or not an orchard is tilled.

2. Apple orchards in sod or grass mulch usually require fertilization to maintain the growth and yield of the trees.

3. Orchards which are being well cultivated, involving the use of some cover-crop, are likely to respond rather slowly to the use of chemical fertilizers, and when such benefit appears it is usually first seen in growth rather than in yield.

4. The length of time which an orchard under cultivation can be operated without supplying additional fertility will depend on the initial fertility of the soil.

5. Nitrogen is likely to be the first limiting factor so far as soil fertility is concerned. This one element is likely to give as good results for a few years as a complete fertilizer, although on some soils the latter would be more desirable in the end.

6. This element (nitrogen) then may be supplied in either of two ways, by the use of the plow and harrow or from the fertilizer bag.

7. A peach orchard (which should always be cultivated) will respond generously to the use of fertilizers unless it is for the first two or three years after planting.

8. Red color of fruit is apparently not affected except adversely by fertilizing.

9. Size of fruit is variously affected by fertilizing. A

[1] Author's statement. Proc. N. Y. State Hort. Soc., 2nd Ann. Meeting. 1920. pp. 92–93.

very heavy crop, due to the treatment, may result in a decrease in the size of the individual fruits, or if a moderate crop is produced the fruits may be markedly increased in size. Potash appears to be of some importance in increasing size.

10. An orchard which is inter-cropped should usually be manured or fertilized.

11. So far as apple trees are concerned, the addition of lime is rarely necessary, but it may be very desirable for the cover- or inter-crop grown. Peach trees have occasionally responded to applications of lime.

12. Inorganic forms of artificial fertilizers seem to give prompter results than the organic ones.

13. Yield and growth go "hand in hand" and are not antagonistic.

14. An early application of nitrogen (in a quickly available form) will often stimulate the "set" of fruit the same season and hence give immediate results.

CHAPTER X

THE RELATION OF CLIMATE TO POMOLOGY

The relation of climate to horticulture and agriculture is very intimate and is almost the ultimate determinant of what shall be grown. The orchardist feels that he has reached the frontier of his knowledge and ingenuity in attempting to combat the elements and overcome their devastating effects. Other factors, of course, determine where and what crops can be grown, but climate becomes the actual determinant as the northern and southern limits for special crops are reached.

While the forester studies the climatic conditions best adapted to certain types of tree growth and then does his planting accordingly, the horticulturist must consider the climatic peculiarities and causes of failure and then determine means of overcoming them. It is also true that insect and disease pests are more abundant and more destructive some seasons than others, owing to favorable weather conditions, and the grower must accordingly modify his plans to combat them successfully.

188. Terms defined.—Climate has been defined as the average condition of the atmosphere, while weather denotes a single occurrence, or event, in the series of conditions that make up climate. The climate of a place is, then, in a sense its average weather. Phenology is the science of the relations between climate and periodic biological phenomena, such as the flowering, leafing, and fruiting of plants.

The particular natural phenomena constituting climate that are of special interest in this connection are, temperature, rainfall, wind, sunlight, frost, hail, and humidity.

189. Relation of weather to the fruit crops.—The weather may specifically affect the fruit crop for any given season in two general ways: (1) it may govern largely the potential possibilities of the trees to form fruit-buds; and (2) it may partially or entirely destroy the buds, blossoms, or crop in the process of development. These effects of weather on the fruit-crop may be subdivided as follows: (a) the nature of the growing season may be favorable or unfavorable to a set of fruit-buds for the ensuing season; (b) the winter may be favorable to or may destroy the fruit-buds previously formed; (c) the spring weather may be responsible for the partial or entire loss of the fruit crop due to frosts at blooming time or shortly thereafter; (d) special agencies such as hail or wind may partially or entirely destroy the maturing crop; (e) rainy weather or heavy winds may prevent pollination of the blossoms in whole or in part; (f) low temperatures may check pollen-tube growth; (g) the quality of a crop and the size of the individual fruits, as well as their early or late maturity, is often governed largely by the weather.

190. Temperature is the most important climatic element affecting vegetation and the total effect of the warmth of the air must be observed in studying it. There is a minimum and maxumim temperature, below or above which the plant does not function, and there is for each kind an optimum temperature at which it grows or functions best. The minimum for most higher plants is around 40° to 43° F. and the maximum is from 85° to 114° F., while the optima range from 75° to 85° F., depending in all cases on the species in question. Since the various phases of the plants' functions may have different optima and since it is also difficult to define closely these terms, the above temperatures should be considered as applying particularly to the more manifest growth activities. The student of pomology is interested in both the temperatures of the growing season and those of winter, for much damage may occur from too low or too high temperatures during the winter rest. The latter are treated in Chapter XI.

Many fruit sections are accumulating data on which future plantings may be based with greater intelligence. The mean annual temperature or the mean of the 365 successive daily means is a figure of importance for any given place, as is also the mean temperature of the hottest six weeks. The annual mean is frequently computed from the twelve monthly means which is practically the same as when calculated on the daily basis. The average dates of the last frost in spring and the first frost in autumn are also of great importance to the pomologist and vegetable-gardener. From these figures is calculated the average number of days free from frost at any particular point, and hence the length of the average growing season.

The total temperature necessary for the development of plants or for the accomplishment of any phase of their growth has been a question of interesting speculation for many years and has resulted in an attempt to secure the "physiological constant" for a plant, which is discussed in a later paragraph. The general temperature conditions for the larger regions of this country are indicated in paragraph 198.

From the standpoint of the pollination and "setting" of fruit, temperature is of vital importance and this is treated more fully in connection with pollination of fruits (Chapter XII). Aside from actual injury to the floral parts, particularly the pistils from frosts and low temperatures, the development of the pollen-tube may be checked materially when the temperature falls below 50° F. The bees are not active much below 65° F. and hence the opportunity for pollination of the flowers is greatly reduced when the temperature remains constantly below that point during the period of blossoming.

191. Rainfall.—The rainfall situation is indicated for the larger districts under paragraph 199. Most sections are likely to suffer at times from droughty conditions but a large part of the United States is well supplied with rainfall. The distribution of the rainfall throughout the twelve months has much to do with its efficacy in crop production, for even though a heavy annual rainfall is recorded for a region, it will avail little if a large proportion of it falls in the non-growing period.

Rain at the blossoming period of fruit-trees is particularly injurious to the crop from both direct and indirect causes. It is primarily injurious because it prevents pollination, especially when the rain is accompanied by cold weather and gales of wind. Injury to the floral parts may result from such weather conditions, but more particularly the insects instrumental in effecting pollination are not active. In the twenty-five years between 1881 to 1905, inclusive, Hedrick reports fourteen seasons in which rain or snow at blossom time was destructive or partially so to the fruit crop in some sections of New York state.[1] The effect of such inclement weather is probably more pronounced with self-sterile varieties of fruits than with the self-fertile ones.

According to the investigations of Dorsey, rain operates against pollination and fruit-setting by causing the anthers to close or by preventing them from opening, but it does not burst the pollen-grains nor kill them. Neither does rain wash pollen from the stigmas to any great extent as has been reported, since there is a strong adhesive action between stigmas and pollen. In general, however, no factors of weather are so effective in preventing the setting of fruit as rain and low temperatures.[2]

[1] N. Y. (Geneva) Agr. Exp. Sta. Bull. 407. 1915.

[2] Dorsey, M. J. Relation of weather to fruitfulness in the plum. Jour. Agr. Res., Vol. 17, No. 3. 1919.

192. Spring frosts.—Frosts in autumn are of some economic importance to the pomologist, but those occurring in the spring are usually much more disastrous to the fruit crop, and are considered here more in detail. The destruction of blossoms and hence the prospective crop by spring frosts either locally or over rather large areas is a common occurrence and one of the most ruinous phases of fruit-growing.

The United States Weather Bureau distinguishes three types of frost, based on the degree or severity of it, namely: "light," "heavy," and "killing." The latter two are usually distinguished by the extent of injury to vegetation rather than to the actual amount of deposit. The term "killing frost" is described as one which is generally destructive to the staple products of the locality. Vegetation may also be damaged by low temperature without an actual deposit of frost, a condition due usually to cloudiness. The probable dates of killing frosts for any locality are a valuable guide to the fruit-grower and gardener and some maps have been prepared by the Weather Bureau showing the dates of the last killing frosts in spring for the different regions of the United States. The same sort of map is given for the last killing frosts in the fall and for the average number of days without killing frosts.[1] These maps are based on a very large number of records from many regular and coöperative stations of the Weather Bureau. There is great irregularity in the dates of the last frosts in the spring and the first ones in the fall for any given place, and usually the arithmetical average of these dates is used in constructing the maps but such a date entails a large amount of risk, one year with another. On the other hand, if the latest frost date recorded in the spring and the earliest in the fall

[1] Reed, William Gardner. Frosts and the growing season. U. S. Dept. Agr. Off. Farm Manag. 1918.

are used for calculating crop risks, then many years the grower limits his season much more than would have been necessary.

While a fruit-grower may attempt to determine places that are safe for fruits by computing the average date of the last killing frost, yet it must be expected that in the most favorable locations there will occasionally be destructive frosts. For New York state Hedrick has recorded a surprising frequency of frost damage in the fruit-growing regions, stating that "Fruits were injured at blossoming time by frosts in thirteen out of the twenty-five years under consideration." [1] Frost injury may take the form of russeting the fruit, occurring either in bands, in patches about the basin or cavity, or in spots on the surface of the skin. It may also cause blistering of the young leaves when they first expand, in which case they do not fully develop and often fall prematurely. In addition to the destruction of the pistils and ovaries of the flowers, the stems may be injured and the flower-cluster base may also be discolored, which often results in a heavy drop of the fruit.

193. Winds.—Heavy winds also play a part in the weather conditions that affect fruit-growing. They are by no means such destructive agents as temperature and rainfall may be, but they may reduce the number of blossoms which set fruit and prove ruinous to the crop as it approaches the harvesting season. Just as rain or humid conditions may prevent bees and other pollen-carrying insects from working during the blossoming season, so winds may also greatly reduce their activity and consequently reduce pol-

[1] N. Y. (Geneva) Agr. Exp. Sta. Bull. 299. See also Wilson, W. M. Frosts in New York. N. Y. (Cornell) Agr. Exp. Sta. Bull. 316. 1912. U. S. Dept. Agr. Farmers' Bull. 1096. 1920. Paddock, Wendell, and Orville B. Whipple. Fruit-Growing in Arid Regions. New York, 1910.

lination. To what extent the floral parts, particularly the stigmatic fluid, of fruits in general are affected by the drying action of wind cannot be stated definitely, but in the plum Dorsey noted that dehiscence was quickened as a result of wind action and petals dropped earlier, but a drying of the stigmatic fluid was more critical late in the receptive period than in the earlier stage.

The effect of wind on the maturing crop of fruit is a constant source of economic loss, as more or less fruit is blown from the trees every year and some seasons it assumes serious proportions. Windbreaks and close planting of trees on the windward side are often used to reduce the damage.

Winds, in some sections, cause young trees to grow one-sided and to lean to the leeward, but it would be difficult to estimate the actual damage which results.

One of the most serious effects of wind in fruit-growing is that encountered during the spraying (or dusting) season. Not infrequently that work must be delayed on account of high winds until the fruit crop is jeopardized.

194. Sunshine.—Just as rain is the most unfavorable element in preventing the pollination and setting of fruit blossoms, so conversely is sunshine most favorable to its setting, especially when accompanied by a relatively low percentage of humidity. This condition affords the best opportunity for the agencies of pollination and also the growth of the pollen-tube. When the period of blossoming is bright, the flowers are usually in bloom for a shorter period, as would be expected. The absence of sunshine does not mean, however, that pollination may not take place freely. Sunlight is of first importance, of course, for the growth of plants in general and in the development and coloring of the fruit.

195. Hail usually occurs during the summer and may cause serious loss in the orchard as well as to farm crops.

The hail marks on the fruit injure its selling quality and indeed may break open the skin, thus encouraging rapid deterioration. In some sections it is not uncommon to find an entire fruit crop destroyed. (Fig 30).

Serious injury may also occur to the tree itself, the healed scars often resembling somewhat the work of the tree cricket (*Oecanthus* sp.) or cicada (*Tibicen septendecim*).

196. Continental versus marine climates.—The climate of the interior of the northern sections of the United States and Canada is much more severe than is the marine climate on the same parallel. This difference is primarily due to the fact that the specific heat of water is much higher than the materials of which the earth's sur-

Fig. 30.—Apple tree injured by hail storm. Note abrasions of bark and partial defoliation.

face is composed. According to Hann,[1] if the specific heats of equal weights of water and dry soil are compared, the latter would be 0.2 of the former, but when equal volumes are compared, the specific heat of the land is about 0.6 that of water. In other words, if equal quantities of heat are received by equal areas of land and of water, the land will have its temperature increased almost twice as much as the water. Therefore, this slowness with which water takes up and gives up its heat accounts for the more equable temperature of land adjacent to large bodies of water, particularly on the leeward side. The more exposed the land area is to the influence of ocean winds, the more uniform is its temperature.

The case cited later of the western section of the state of Michigan illustrates this fact as it pertains to pomology. Just as marine climates are more equable, so continental climates are characterized by a great range of temperature.

197. Mountain versus valley climates.—One of the teachings that has become axiomatic in fruit-growing is to plant orchards on elevations and avoid valleys, coves, or other places where the movement of the air is restricted. This doctrine is based on the fact that the cold air drains from the high lands into the valleys and often results in damage to the crops in the latter places when those on the higher elevations may escape injury. Other factors, such as humidity of the atmosphere, also play an important part in the behavior of plants in valleys and on mountains. In general, a climate characterized by low humidity and bright sunshine throughout the growing season will usually produce a fruit which has a clear skin and is comparatively free from such diseases as scab and sooty fungus. Such a climatic

[1] Hann, Dr. Julius. Handbook of Climatology. Eng. Trans. The Macmillan Company, New York. 1903.

condition usually obtains at high altitudes and the reverse in valleys. High altitudes, especially in the East, may be humid and, therefore, the greater freedom from disease would not be found as indicated in the above statement. Aside from the presence of large bodies of water, no factor is so potent in causing differences in climate along any parallel of latitude as elevation above sea level.

The facts here would seem to be contradictory, for there is a vertical decrease of temperature with the increase in elevation, amounting to about 1° F. for every 300 feet. The amount of decrease of temperature will vary with the latitude, exposure, season, and local conditions. But what is termed "inversions of temperature" occur in clear cool nights up to a certain elevation which results in the higher lands being warmer than the valleys. According to Hann,[1] "This increase of temperature upward reaches altitudes of at least 300 m., and is rapid in the lower strata, but slower farther up." In this country the effects of these inversions of temperature are experienced at practically all elevations at which fruit is grown, except as noted elsewhere, in certain canyons in the western United States.

The occurrence of the colder temperatures in valleys is explained by the fact that there is a radiation of heat from the earth during the night and as a result the earth is cooled. The stratum of air which lies next to the earth is cooled, and, as cold air is heavier than warm, it results in its flowing downward, and the warmer air of the valley rising. Air will also lie in strata of somewhat equal temperatures, which phenomenon is experienced in traveling over undulating country, particularly at night. As a result of the above facts, it is frequently noted that fruit blossoms (and other vegetation) are injured or destroyed at lower elevations and those higher up escape damage. Even the blossoms on the

[1] *Loc. cit.*, p. 252.

lower part of a tree may be entirely destroyed and those above be unhurt and develop a crop.

Paddock and Whipple discuss fruit-growing at high altitudes as follows: "In a few favored localities peaches are successfully grown at an altitude above 6000 feet. But on the Eastern slope of the (Rocky) mountains no peaches are grown commercially without winter protection where the altitude is only 5000 feet. . . . In general it may be said that as a rule, fruit cannot be grown to any extent at an altitude much above 5000 feet, and at this height much depends on the protection afforded by the mountains."

198. Climate of United States.—Due to the extent of territory comprised within the United States, there is a great variety of climate, from the Arctic region on the northwest to the semi-tropical climate of the south; yet the great proportion of this country lies within the temperate zone. However, as has been shown by Henry,[1] a great difference exists in the length of the growing season as latitude and elevation are changed and that this can be reduced to definite laws will be seen later. The map in Fig. 31 shows this variation from a five months' season in the North to a twelve month in the South. Such a condition makes evident that climate will limit fruit-growing in certain sections except as artificial means and certain cultural practices are employed that will overcome the natural barriers.

Any statistical statement of meteorological data would be too extensive for use here, but the student should familiarize himself with local conditions. The extremes of rainfall and temperature will serve to emphasize the wide diversity within the borders of the United States. These data may best be examined in connection with the several so-called climatic provinces of the United States.

[1] Henry, A. J. Weather Bur. Bull. Q. Washington, D. C. 1906.

199. Climatic provinces of the United States.[1]—While climate frequently varies markedly within comparatively short distances, yet there are several grand divisions within

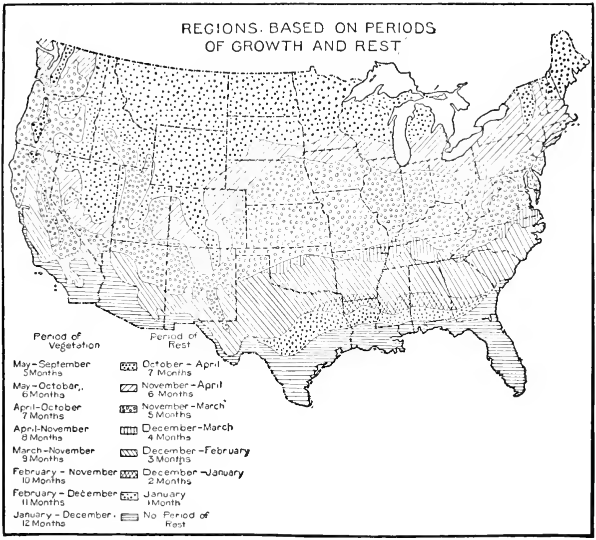


FIG. 31.—Length of growing season in different parts of the United States.

the country which represent regions of similar climate. These have been described as "climatic provinces," being five in number. The largest, or *Eastern*, extends from the

[1] Adapted from Ward, Robert DeC. The essential characteristics of U. S. climates. Sci. Month., Vol. II, No. 6. Dec., 1920. See also Bailey, L. H. Principles of Fruit-Growing, New York. 20th Ed. 1915. p. 11.

eastern margin of the Great Plains, which roughly coincides with the 20-inch annual rainfall line and also with the 100th meridian, to the Atlantic Ocean, and southward nearly to the Gulf of Mexico. The strip bordering on the Gulf may be set apart as a subordinate district, the *Gulf* province. The *Plains* province includes the Great Plains proper, and extends westward to the Rocky Mountains. Between the Rocky Mountains and the Sierra Nevada-Cascade ranges comes the *Plateau* province. The Pacific slope constitutes a natural climatic region which may be called the *Pacific* province.

"The differences between north and south, resulting from differences in latitude, suggest a further subdivision of the Plains, Plateau, and Pacific provinces into northern and southern sections. Similarly, the Gulf province occupies the more southern latitudes of the Eastern province."

200. The Eastern province.—This extensive area is characterized by great uniformity in its climatic conditions and weather types. Over most of it the seasons are strongly contrasted. The summers are very warm and the winters cold. The rainfall is abundant or at least sufficient for agriculture and nowhere in this district is there permanent necessity of irrigation. There are only relatively slight and unimportant differences of topography, the whole area being freely open from Canada on the north to the Atlantic Ocean on the east, and to the Gulf of Mexico on the south.

In January, the isotherms over the eastern United States are very closely crowded together. The temperature then decreases northward at the rate of 2.7° F. in each degree of latitude, both on the Atlantic coast and in the Mississippi Valley, which is an extraordinarily rapid temperature-gradient. There is, however, much less difference of temperature between South and North in summer. It becomes 1.1° along the eastern coast and 0.7° in the Mississippi Valley.

The temperature conditions have been briefly generalized as follows:

TABLE LXX

TEMPERATURE CONDITIONS OF THE EASTERN PROVINCE

District	*Mean annual*	*Jan.*	*July*	*Abs. max.*	*Abs. min.*
N	40°	5°–10°	65°	100°–105°	—40° to —50°
S	65°–70°	50°–55°+	80°+	105°	zero–10°

The average dates of first and last frost, broadly generalized, are as follows:

TABLE LXXI

LENGTH OF GROWING SEASON, EASTERN PROVINCE

District	*Last Spring*	*First Autumn*	*Average length of growing season*
N	After June 1 (extreme N)	Sept. (extreme N)	3–4 months
S	Before March 1	November	7 months and over

As indicated above, the rainfall is usually sufficient for vegetation over this province and well distributed throughout the year. Disregarding local areas on the mountains, the annual rainfall is greatest (50+ inches) towards the Gulf, and on the South Atlantic coast and decreases from about 40–45 inches over much of the north and central Atlantic coast and Ohio Valley to 30–40 inches over the prairies and 20 inches at about the 100th meridian.

201. The Gulf province.—Over the southern tier of states bordering on the Gulf of Mexico, the temperatures are higher; the winters are much milder; the summers are longer and hotter; the rainfall is heavier; and there is a late summer or early autumn maximum.

202. The Plains province.—The essential difference between the climate of the Great Plains and that of the Eastern province is not so much one of general temperature conditions as of rainfall. The similarity of temperature may be seen by comparing the summary below with that given under the Eastern province.

Table LXXII

TEMPERATURE CONDITIONS OF THE PLAINS PROVINCE

District	*Mean annual*	*January*	*July*	*Abs. max.*	*Abs. min.*
N	40°	0°–10°	65°–70°	105°–110°	—50° to —60°
S	65°	40°–50°	80°–85°	110°	zero

As compared with the eastern states, the Plains have larger diurnal ranges of temperature; more abundant sunshine; drier air; greater evaporation; smaller rain probability; less rain; more wind. The contrast in rainfall between the Eastern and Plains provinces is striking. From a 20-inch rainfall on the eastern margin of the Plains, it decreases to below 15 inches on the western margin, and where the rainfall is below 20 inches it is insufficient for successful agriculture, and irrigation must be practiced.

203. The Plateau province is a great interior region of very diversified topography. It has a wide range of mountain, high plateau, and arid lowland climate, superposed on and causing local modifications of the general dry continental climate of the province as a whole. The outstanding characteristic is the small rainfall, which, however, shows marked increase with altitude. With the exception of local areas in the mountains, the mean annual rainfall is everywhere less than 20 inches; it is mostly below 10 inches, and over no insignificant portion of the Southwest it is even below 5 inches.

204. The Pacific province.—Over the narrow Pacific coastal belt climatic conditions are quite unlike those elsewhere in the country, and in many respects resemble those of northwestern and western Europe, including the Mediterranean area. The wide range of latitude between north and south, together with the varying topographic controls and the differences of exposure to the ocean influences, explain the great variety of climate in this province. These range from those of the rainy and densely forested slopes of Washington to those of semi-arid southern California; from those of the lowlands to the snow-covered mountain tops; from the cool summer of the coast to the hot summers of the Great Valley. The climate, in general, is mild and equable, with slight diurnal and seasonal ranges.

The following table summarizes, in a very general way, the essential temperature characteristics of the Pacific province:

Table LXXIII

TEMPERATURE CONDITIONS OF THE PACIFIC PROVINCE

District	*Mean annual*	*Jan.*	*July*	*Abs. max.*	*Abs. min.*
N	50°–55°	35°–40°	60°–65°+	95°–105°	10°– 0°
S	65° ±	50°–55°	65°–75°+	110°–115°	20°–10°

The rainfall is heavy (over 100 inches) on the northwestern coast of Washington, and decreases rapidly to the south, to about 10 inches in the San Joaquin Valley.

205. Natural guides to horticultural practices.—From earliest times the grower of crops has made use of certain natural guides to determine when he would plant and harvest his crops as well as for other activities about the farm. Such an expression as "it is time to plant corn when white oak leaves are the size of squirrels' ears" is familiar. Others use the time of the arrival or migration of certain birds, the unfolding of the leaves or flowering of certain plants, or the appearance of certain insects as an index to farm and orchard practice. Such a method, if well observed, should be a very accurate guide, as it represents the sum of all the complex factors involved and no instrument can do this.

206. Bioclimatic law of latitude, longitude, and altitude.[1]— A large number of observations made at many points and over a period of years has resulted in the deduction of a set of laws in regard to the response of plant and animal life to climate. Howard reports the following laws:

1. The periodical phenomena of plants and animals are in response to the influence of all the complex factors and elements of the climate as controlled, primarily, by the motions of the earth and its position relative to the influences of solar radiation.

2. The variations in the climate and consequent variations in the geographical distribution and periodical activities of the plants and animals of a continent are controlled by the modifying influences of topography, oceans, lakes, large rivers, and of other regional and local conditions, and the amount and character of daylight, sunshine, rain, snow, humidity, and other elements and factors of a general and local nature.

3. There is a tendency toward a constant rate of variation in the climatic and biological conditions of a continent as a whole in direct proportion to variation in geographical position as defined by the three geographical coördinates, latitude, longitude, and altitude.

[1] U. S. Dept. Agr. Monthly Weather Review. Suppl. No. 9, 1918. A. D. Hopkins. Periodical events and natural law as guides to agricultural research and practice.

4. Other conditions being equal, the variation in the time of occurrence of a given periodical event in life activity in temperate North America is at the general average rate of 4 days to each 1 degree of latitude, 5 degrees of longitude, and 400 feet of altitude, later northward, eastward and upward in the spring and early summer, and the reverse in late summer and autumn.

5. Owing to the fact that all conditions are never exactly equal in two or more biological or climatic regions of the continent, and rarely alike in two or more places within the same region or locality, there are always departures from the theoretical time constant.

6. The departures, in number of days from a theoretical time constant, are in direct relation to the intensity of the controlling influences. Therefore, the constant, as expressed in the time coördinates of the law, is a measure of the intensity of the influences.

Fig. 32 shows the working of this law as adapted to North America. "Taking base maps of North America and of the major and minor political divisions, parallel lines (designated as isophanes [1]) are drawn on them to define, according to the bioclimatic law, theoretical lines and zones of equal phenomena as to time of occurrence and equal bioclimatic conditions, at the same level."[2]

"The isophanes, instead of following the parallels of north latitude in North America, proceed from the Atlantic to the Pacific in a northwestward curve at the rate of 1 degree of latitude to 5 degrees of longitude (Fig. 32), so

[1] *Isophane.* In phenology, an isochrone of the first blossoming of a specified plant.

Isochrone. Phenological isochrone is a line drawn between points at which plants of the same species attain the same degree of development simultaneously. (Standard Dictionary.)

[2] For full explanation, see original text.

that they serve as a diagrammatic expression of the average rate of four days' variation for 1 degree of latitude and 5

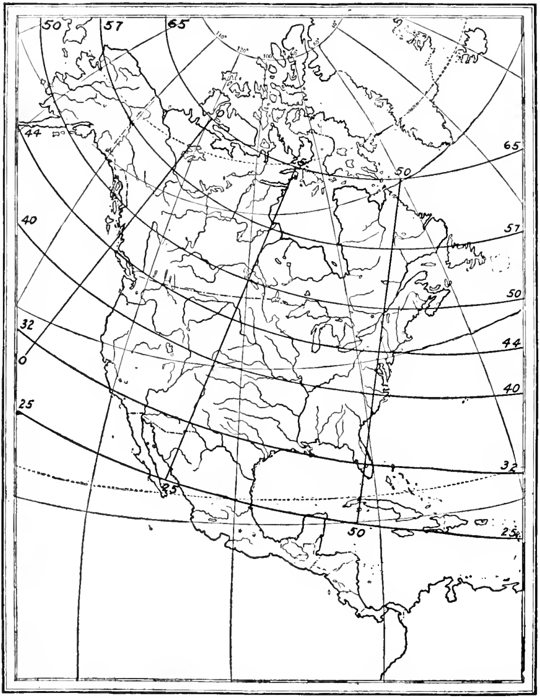


FIG. 32.—Isophanal map of North America.

degrees of longitude. Therefore one of these lines across the continent at any given level of land surface represents the same average phenological constant date of a seasonal event and the same average climatic and biological conditions."

In other words, if 1 degree of latitude is assumed to be equal to about 70 miles and 1 degree of longitude equal to 50 miles, then, other things being equal, there are 4 days variation for every 70 miles north or south and for every 250 miles east or west from a given point, and for every 400 feet altitude. Or if any given isophane is followed, there would be no variation in time of occurrence of the natural phenomena. Variations from these rules will occur, depending on such modifying influences as are mentioned in rule 2.

A fuller appreciation of this subject means that spray calendars must be made up for conditions of similar climatic conditions; a study of insect and disease control must consider the local conditions; and so for many agricultural practices and researches.

207. Species adaptation.—It is not a settled question as to how far a species native to one set of climatic conditions can become adapted to an entirely different climate. That is, can a plant from a warm region gradually become acclimated to a cold one and hence secure hardier strains or races of tender plants? Can a plant which requires a moist growing season gradually become adapted to xerophytic conditions or *vice versa?* These questions are of great importance in the science of pomology and much difference of opinion is recorded in literature. It is now usually accepted, however, that a plant is not gradually changed to suit its environment but that it is necessary to secure individuals which possess the character desired and from this stock so breed a new strain as to combine other desirable qualities. At least this would seem to be the shortest and surest method of securing better fruits for extreme conditions of soil and climate.

It is, of course, well known that a given variety or species becomes somewhat adapted to the length of growing season in widely differing sections of the country, but this is not to be interpreted as meaning that a variety of peach, apple, or other fruit having the capacity to withstand a certain minimum degree of temperature may be acclimated to a still lower one by adaptation. The work of Whitten, Dorsey, Macoun, and others show adaptation within certain limits.

208. Temperatures which injure setting of fruits.—It is well known, as stated above, that frosts destroy fruit blossoms frequently, but it is also true that injury may occur without apparently killing the tender tissues. The after effects of the latter are seen in the heavy fall of fruit during about three weeks following the blossom period.

The following figures give the temperatures at which the various fruits may be injured at blossom time:

TABLE LXXIV

TEMPERATURES WHICH INJURE SETTING OF FRUITS [1]

Fruits	*In bud*	*In blossom*	*In setting fruit*
	Degrees F	*Degrees F*	*Degrees F*
Almonds	28	30	30
Apples	27	29	30
Apricots	30	31	32
Cherries	22–29	28–30	28–30
Grapes	31	31	30
Peaches	29	30	30
Pears	28	29	29
Plums	30	31	31
Strawberries	28	28	28
Raspberries	28	28	28
Blackberries	28	28	28

[1] See West, Frank L., and N. E. Edlefsen. Freezing of fruit buds. Jour. Agr. Res., Vol. 20, No. 8. 1921.

Several factors determine at what temperature such injury occurs, for it is well known that it is not consistent. The amount of moisture in the atmosphere at the time of frost is commonly cited as of the greatest importance, the greater the humidity the less likely will there be injury. Also the individuality of the plant may enter into the problem.

West and Edlefsen comment as follows in regard to this phenomenon: "The fact that the same branch of buds will on one occasion experience 27° F. with 25 per cent injury and on another occasion take the same temperature with no injury is no doubt due to the fact that the juice is contained in capillary cells and supercooling results—that is, the buds are cooled below the freezing point of the juice without the freezing taking place. The great difficulty of killing all the buds even at extremely low temperatures is due to the same cause together with the fact that the cell sap may be very concentrated. Differences in the hardiness of the different kinds of buds and also of the same buds at different stages of development is due to differences in quality and concentration of the cell sap."

It is easy to overestimate the damage at the time of the low temperatures, for no means are available for determining the extent of injury unless the floral parts (usually the pistils first) are blackened or withered. Orchards in which the blossoms seemed entirely destroyed may still set a fair crop of fruit.

209. Averting injury from frosts and freezes.[1]—Attempts are sometimes made to avert injury to the fruit crop from spring frosts by various devices. Whitten [2] whitewashed peach trees to delay their blossoming, with some success. The principle made use of here is that a white surface will

[1] See papers on frosts and frost protection in U. S. U. S. Dept. Agr. The Monthly Weather Review, 42: 562–592. 1914.

[2] Mo. Agr. Exp. Sta. Bull. 38. 1897.

reflect light and heat, while a dark one absorbs it. Thus the whitewashed trees were delayed a few days in their time of blooming. He also shifted the resting period later in the winter by later tillage and accomplished similar results.

The heating and smudging of orchards are also used rather extensively in some sections to ward off frosts and hold the heat radiated from the earth.

Laying trees and vines down during the winter and covering with earth or other material is also practiced to a limited extent, as well as baling trees up with straw or fodder.

The important factor here, however, is the proper location of the orchard. As indicated previously, high lands are more immune to frosts than low ones, so that there is a free movement of air and a drain of the cold air to lower levels; also coves or pockets should be avoided. The slope of the land is of some importance, particularly as the southern limits of fruit-growing are approached, and also with fruits that respond quickly to warm spells of weather occurring early in the season. The southern and southeastern slopes absorb more heat and hence trees often blossom somewhat earlier here than on the northern exposures. It is easy to overestimate the value that can be gained by such a selection, however.

The following figures indicate the proportional amount of heat received to a unit area by different slopes on June 21, at the 42d parallel north latitude:[1]

20° Southerly slope	=	106
Level	=	100
20° Northerly slope	=	81

One of the best known and in some respects most unique cases of the effect of water on climate is seen in the Michigan "fruit-belt." This is a strip of land from ten to twenty

[1] After Lyon, Fippin, and Buckman. Soils. New York. 1915. p. 318.

miles in width along the west side of the state from the Indiana line nearly to the Straits of Mackinaw. The southern boundary of this belt is about 42° N. latitude while the

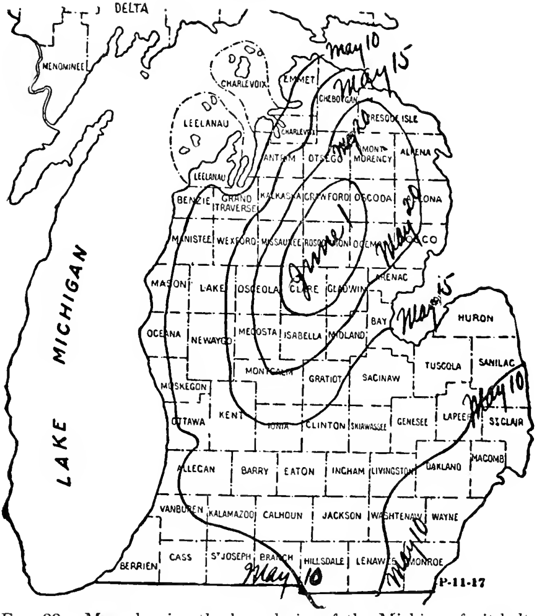


FIG. 33.—Map showing the boundaries of the Michigan fruit-belt.

northern boundary is almost 46°, and in this belt are extensively grown such tender fruits as the peach and cherry. The accompanying map[1] (Fig. 33) shows the boundaries

[1] After Seely, adapted from Taft. Commercial cherry culture. Proc. Amer. Pom. Soc. 1917. p. 107.

of the fruit-belt and indicates the isothermal lines as they locate the last killing frosts of the spring. The tempered effect along this littoral region is due to the prevailing winds passing over Lake Michigan during most of the winter and spring months. In the spring the winds are kept continually cool in passing over the lakes and hence prevent unseasonable advancement of the fruit-buds in April and May which results in disastrous effects in unprotected regions. On the other hand, the winter winds that leave the Wisconsin shore at a temperature of thirty to forty degrees below zero arrive on the Michigan side at a temperature of little if any below zero, since the waters of the lake rarely freeze over and are commonly some three to five degrees above the freezing point. While a minimum range of ten to fifteen degrees below zero may be recorded along the northern section of this "belt," it may be thirty or forty degrees below zero in the north-central counties of the state.

210. Effect of climate on the floral structure.—Climate may have a very definite effect on the floral structure and more particularly on the vitality of the parts of the flower. A long and serious controversy was waged in the early history of strawberry-growing in this country (1850–70) on the sexual characters of this fruit. In some sections certain varieties were perfect flowering and in others the same kinds were imperfect. That the climate had affected them in this way was later discovered. The same is true with the strawberry grown in eastern United States and in England, where in the latter place the mild, humid climate sometimes causes imperfect flowering sorts to become perfect.

The Bartlett pear, which is usually self-sterile, is reported by Garcia to be sufficiently self-fertile to insure fair crops of fruit in New Mexico. Likewise in California it was found that the Bartlett is self-sterile on the high elevations and partially self-fertile in the valleys.

211. The effect of climate on development of fruit.—Shaw [1] has shown that the variation in apple varieties is due to three principal causes: (1) cultural practices, (2) soil variation, (3) climate. Of the climatic influences, he places temperature as the most potent.

From his researches he draws the following significant conclusions: (1) "Variation in form in the Ben Davis, and probably in other sorts as well, is due principally to the temperature during a period of about two or three weeks following blossoming. The lower the temperature the more elongated the apple. This elongation is seen in apples grown near large bodies of water, which lower the temperature at this season of the year, and in seasons where the temperature is low owing to seasonal fluctations. This influence is also seen in the form of apples in different parts of the tree. Those in the lower north portion are more elongated than those from the warmer, upper south portion." (2) "Seasonal temperature affects the size of apples, a cool season resulting in smaller fruit. This is marked only in full season varieties, and is especially noticeable in the more northerly portions of their distribution. On the other hand, in the extreme south a variety is apt to be smaller than when grown in a somewhat cooler climate."

212. Climatic factors which delimit the geographical distribution of fruits.—As pointed out earlier in the chapter, climatic factors limit the growing of deciduous fruits as the northern and southern boundaries of the temperate zone are approached. These factors are defined by Shaw as follows: "The northern limit of apple-growing is fixed by the minimum winter temperature, and the southern limit by the heat of the hottest part of summer, occurring usually in July or August.

"The attainment of the highest quality, appearance and

[1] Mass. Agr. Exp. Sta. 22nd Ann. Rept. 1910. 23rd Ann. Rept. 1911.

keeping quality is very largely dependent on the warmth and length of the growing season. This may be measured with fair satisfaction for the apple-growing regions of North America by an average of the mean temperatures for the months of March to September, inclusive. This is called the mean summer temperature, and gives temperatures ranging from 52° to 72° F.

"The factors determining the mean summer temperature in a given orchard are (1) latitude, (2) elevation, (3) site and aspect, (4) soil, (5) culture, (6) prevailing winds, (7) sunshine.

"A departure of over 2° from the optimum mean for a given variety will result in less desirable fruit, though this may not be marked in short season varieties.

"A summer mean too low for a variety results in (1) greater acidity, (2) increased insoluble solids, (3) greater astringency, (4) less coloration, (5) decreased size, (6) scalding in storage.

"A summer mean too high for a variety results in (1) uneven ripening, (2) premature dropping, (3) rotting on the trees, (4) poor keeping quality, (5) lack of flavor, (6) 'mealiness,' (7) less intense color, (8) decreased size."

213. Specific requirements for certain varieties.—It seems to be established, as above stated, that a variety of fruit has a certain optimum temperature at which it thrives best, but this has not been determined for all varieties. Winslow [1] has contributed some interesting figures on the length of growing season required by some varieties of apples grown in the Northwest. The "length of growing season" is described by him as the number of days between killing frosts, or more accurately the period during which the mean temperature is over 43° F. He also uses the number of "heat units" during the growing season as a guide in the

[1] Winslow, R. M. Amer. Soc. Hort. Sci. 1914.

selection of a suitable location for the different varieties. The heat units for each month are determined by multiplying the number of days in the month by the mean monthly temperature. In this way, the sum total of heat during the season is expressed in heat units or given an index. The "hottest six weeks" are also made use of, since this period is considered a guide to the intensity of the summer heat.[1]

Such varieties of apples as the Yellow Newtown and Esopus (Spitzenburg) are conspicuously limited in their range of successful production. In only a few localities are they at their best, while in other places well adapted to many varieties these two are of low quality and unreliable in their behavior. Winslow shows that the Yellow Newtown requires a climate possessing a long growing season, a high mean summer temperature, a high total of heat units for the season, and it prefers a humid district where irrigation, if needed at all, is only supplementary. It is pointed out that other districts having similar conditions are adapted to the production of this variety, but if they depart much from them, the results are unsatisfactory.

The Esopus is similar in its climatic requirements to the Yellow Newtown, with the exception that irrigation sections are equally well adapted to its culture.

Likewise the Winesap, which is at its best in comparatively few sections, such as the Piedmont region of Virginia and the Wenatchee and Yakima valleys of Washington, re-

[1] See also Merriam, C. H. Laws of temperature control of the geographic distribution of terrestrial animals and plants. Nat. Geogr. Mag., VI, 1894, 220–238. The formula used for determining the hottest six weeks is: "multiply the monthly mean temperature of the hottest month by 3, add the mean temperature of the next hottest month and divide the total by 4." Example: If August monthly mean temperature is 68° and July 66°, then: $\frac{(68 \times 3) + 66}{4} = 67.5°$ temperature of the six hottest weeks.

quires a long growing season with a high summer temperature. Slight departures from these requirements are at once manifest in a smaller size and poorer color.

Figures for these more conspicuous examples are quoted:

TABLE LXXV

LENGTH OF GROWING SEASON FOR YELLOW NEWTOWN, ESOPUS, AND WINESAP APPLES (AFTER WINSLOW)

	Length of growing season	*Total heat units*	*Hottest six weeks*
Yellow Newtown	days 240–270	13,750–15,700	F. 67.5°–70.7°
Esopus	Much the same as Yellow Newtown but also irrigated sections		
Winesap	230–240	13 700	70.7°

PHENOLOGICAL STUDIES

The student will find a profitable field of study in observing the relation between climate and certain periodic phenomena of fruit-trees, such as time of blooming and ripening of fruits.

214. The physiological constant.[1]—There have been a number of attempts to calculate the total amount of heat or temperature necessary for a plant to function and go

[1] Waugh, F. A. Vt. Agr. Exp. Sta. 11th Ann. Rept. 1897–98. pp. 263–272.

I. Lamb, G. N. A calendar of the leafing, flowering, and seeding of the common trees of the Eastern U. S.

II. Smith, J. Warren. Phenological dates and meterological data recorded by Thomas Mikesell between 1873 and 1912 at Wauseon, Ohio. U. S. Dept. Agr. Weather Bur. Suppl. 2. 1915.

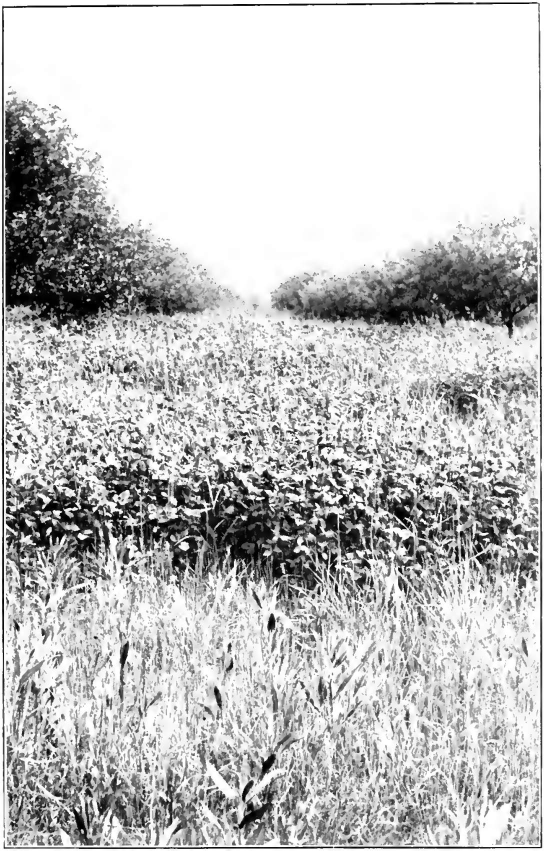


Plate VI.—In the background is shown the effect of acid phosphate on the natural growth of clover in the Ohio experiments.

through its natural phenomena, such as blossoming, putting out leaves, and the like. The formulation of such laws is not surprising, and they were at first widely accepted; however, there are several fundamental objections to them.

Hoffmann suggested that the time of bloom, as well as the other natural phenomena in the seasonal development of the tree, is dependent on the sum total of heat available to the plant up to that event. His zero point was arbitrarily fixed at the first of January after which he took the sum of the daily maximum positive temperatures (above 32° F.) of a thermometer exposed to the sun up to the beginning of the event. In this way, he accounted to a large extent for the difference in time of blooming of different seasons.

De Candolle and others have fixed the temperature at which the plant becomes active at 43° F. (6° C.) instead of 32° F., but even this ignores the well-established fact that plants have different optimum temperatures. It also may be assumed that the separate phases of the plant activities may have different optima.

Furthermore, it has been pointed out that the buds of the tree may be much further advanced when they enter the winter condition some seasons than others, due to the seasonal variations. This would probably modify the total amount of heat necessary for blossoming the ensuing season. Hence, it seems impractical to lay down any physiological constant for plants.

215. The blooming season.—As indicated above, fruit-trees of any given variety do not bloom at exactly the same time year after year, but may be a few days earlier or later than the average, depending largely on the character of the season. In an "early" season, they will bloom earlier and in a later season the blooming will be retarded. In addition to the total temperature available, other factors must also play a part in causing the difference, such as the intensity of heat at any given time in causing the blossoms to open; the age and vigor of the trees; the moisture factor; and also the character of the previous season and winter. Also winter-injured buds, if not entirely killed, are likely to open later than normal ones. Hedrick also points out that "In some seasons a species or variety may bloom a little before leaves burst forth; in others, leaf and flower come out simultaneously and in still others leafing precedes blooming. In southern climates the tendency in several fruits is to bloom before they leaf, while in the north the same fruit will leaf and bloom together with the first wave of summer weather." He also states that varieties of hardy fruits vary in the relative time at which they bloom. Some seasons one variety will bloom first and another year the order is reversed.

As pointed out previously, the location has a definite influence on blooming time, as proximity to large bodies of water which retard the blooming on the leeward side of such water; the slope of a hill which manifests a difference in temperature in the early season; and lastly but most important, the latitude and altitude.

216. Comparative blooming dates.—In order to compare the relative time at which the several fruits are most likely to begin to bloom, the following figures for New York state may be cited:[1]

[1] See also Utah Agr. Exp. Sta. Bull. 128. 1913. Vt. Agr. Exp. Sta., 11th Ann. Rept. 1897–98. pp. 248–257. Jour. Royal Hort. Soc. 36: 548–564. 1910–11. 37: 350–361. 1911–12.

TABLE LXXVI

COMPARATIVE DATES OF BLOOM OF THE MORE COMMON FRUITS

Sweet cherries	May 1
Pears	May 2
European plums, Japanese plums, Hybrid plums, Currants	May 3
Apples, Sour cherries, Hybrid cherries, Gooseberries	May 4
Peaches	May 5
Crab-apples	May 6
Native plums	May 7
Strawberries	May 16
Blackberries, Dewberries, Black raspberries	May 31
Red raspberries	June 1
Hybrid raspberries	June 7
Grapes	June 14

217. Duration of blooming period.—It is a common observation that fruit-trees are in blossom longer some seasons than others. This is due to the weather conditions at the time of bloom, cold and damp prolonging the period of florescence and bright sunny days reducing it. The following data [1] will serve to illustrate this:

[1] N. Y. Agr. Exp. Sta. Bull. 407. See also Vt. Agr. Exp. Sta., 11th Ann. Rept. 1897–98. p. 250.

TABLE LXXVII

BLOOMING RECORDS FOR PERIOD OF THREE TO FIVE YEARS AT GENEVA, N. Y. (AFTER HEDRICK)

	Ave. period of bloom	*Shortest period*	*Longest period*
Apples	12	7	18
Pears	10	5	15
Peaches	10	6	16
Sweet cherries	6	4	8
Sour cherries	8	5	11
Grapes	20	19	21
European plums	Varieties vary greatly, from middle of April to second week in May; in bloom from one to three weeks		
Salicina plums	In bloom from 4 to 8 days		
Native plums	Season the latter part of that of Domesticas		
Gooseberries	10	9	12
Currants	8	7	9
Blackberries and dewberries	24	20	27
Red, yellow, and hybrid raspberries	14	14	15
Black raspberries	7	6	9
Strawberries	17	11	26

218. Period of ripening of hardy fruits.—A distinction must be made between the time when winter fruit is picked from the tree and when it is "eating ripe." This difference does not obtain for summer varieties of fruit, for they are usually ready to use at the time of picking. The earlier fruits also are likely to show a variation in time of maturity which may necessitate several pickings. The same hypothesis considered under blossoming has also been applied to ripening of fruit, namely, Hoffman's theory of a thermal constant. Here again latitude, soil, and site are all factors that influence the ripening period.

An extensive list of the common fruits has been prepared by Hedrick [1] which gives the time of ripening of each.

219. Relation between blooming and ripening.—Whether there is a correlation between time of blooming and ripening is a question of considerable practical as well as academic importance and several conflicting views have been held in regard to it. The large amount of data collected by Hedrick permits a general statement, although many exceptions may be cited. He says, "It requires only a cursory comparison of the data in the two bulletins to show that there are no correlations between blooming time and ripening time of fruits."

From data secured from Hedrick's "Peaches of New York," Norton [2] has prepared the following table, which shows lack of a definite correlation:

[1] N. Y. Agr. Exp. Sta. Bull. 408. 1915.

[2] Norton, J. B. S. Proc. Amer. Soc. Hort. Sci. 1918.

Table LXXVIII

RELATION OF THE BLOOMING AND RIPENING PERIOD OF THE PEACH

Blooming period	*Ripening period*					
	Very early	*Early*	*Medium*	*Late*	*Very late*	*Total*
Very early..........	0	0	1	0	0	1
Early..............	3	4	13	3	2	25
Medium............	3	15	53	43	15	129
Late...............	1	1	6	7	5	20
Very late...........	0	0	1	1	2	4
Totals..............	7	20	74	54	24	179

220. Form for recording phenological data.—The following form is recommended by Hopkins[1] as adapted to the use of the orchardist for recording phenological data:

Phenological records Year......

Locality Latitude or isophane Station No. Species: *Pyrus Malus*	County Longitude or pheno-meridian Observer Common name: *Apple*							State Altitude Slope	
Species, variety, or number	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*
Ben Davis............	....	....	....	....	....	....	....	....	....
Grimes Golden.........	....	....	....	....	....	....	....	....	....
Baldwin..............	....	....	....	....	....	....	....	....	....
York Imperial.........	....	....	....	....	....	....	....	....	....

[1] *Loc. cit.*

The spaces with letters *a* to *i* for the name or designation of the seasonal events as given in the following lists for the different types of plants, and the blank spaces below the designated events are for the date of occurrence.

a. First buds opening.
b. First leaves unfolding.
c. First flowers open.
d. First flowers falling.
e. First winter-buds forming.
f. First seed or ripe fruit.
g. First leaves coloring.
h. First leaves falling.
i. Other data.

CHAPTER XI

WINTER INJURY

For convenience, the kinds of winter injury to fruit-trees may be grouped into three general classes: (1) bud injury, (2) injury of the woody parts above ground, and (3) root injury.

221. Bud injury.—While many factors are involved in winter-killing of plants or their parts, the conditions under which the buds are killed may be roughly placed in the three following categories: (1) when buds go into the winter in an immature condition and low temperatures occur early in the winter (December); (2) when mature buds are subjected to such low temperatures during the winter that their tissues are killed; and (3) when unseasonably warm weather in winter or early spring is followed by very low temperature.

Of the tissues of the fruit-buds the pistils and ovaries are the most tender and are frequently killed when the other parts remain unhurt. Such blossoms may expand, especially if the injury occurs just prior to blossoming time, but of course they can produce no fruit.[1] If the entire bud is killed, the tissues throughout turn brown and the bud dries and falls from the tree in the spring in the case of most of the stone-fruits, or it may persist for a time with the apple and pear as shown in Plate VIII *a*.

Not all varieties of fruit that are tender in the bud are also tender in wood, as may be illustrated by the Elberta peach, but generally this is true.

Winter-killing of the fruit-buds of the apple is rare, but

[1] Bailey, L. H. Principles of Fruit-Growing. 20th Ed. p. 306.

has been reported by Whipple [1] as occurring in Montana. In such cases, the axillary leaf-bud will continue the growth of the spur and, before the growing season is over, it is difficult to observe that flower-buds had been formed.

Like the apple, the fruit-buds of the pear are not likely to be injured, but the spur itself may be killed with the consequent destruction of the fruit-bud.

As a rule, the more commonly grown varieties of the sour cherry are hardy in buds as far north as central New England, except in very extreme winters or when low temperatures follow after the buds have swollen. On the other hand, Macoun [2] reports that in the fruit-growing sections of Canada the cherry, like the European and Japanese plums, is injured more or less every winter when not protected by some body of water. Similar injury to the buds of early Richmond cherries was reported in Wisconsin after the winter of 1917–18.[3] (Fig. 34).

Fig. 34.—Fruit-bud of sour cherry. Left, flower-bud alive; right, flower-bud killed.

The sweet cherry is much less reliable than the sour cherry; in fact it is not much more hardy than the peach.

Varieties of the plum vary widely in their hardiness. Many of the American species (such as *Prunus nigra*) are very hardy, while others are not. Some varieties of *P. salicina*, such as the Burbank, also are reasonably hardy

[1] Whipple, O. B. Mont. Agr. Exp. Sta. Bull. 91. 1912.

[2] Canada Exp. Farm, Rept. 1907–08. pp. 110–116.

[3] Proc. Soc. Hort. Sci. 15th Rept. 1918. p. 32.

in the northern latitudes. The European plums, while not tender, are usually not so hardy as other species and are not widely grown so far north as New England and Canada, although this again is somewhat a varietal characteristic.

Fig. 35.—Winter injury on trunk of a Baldwin apple tree.

The buds of the peach are the most tender of any of the tree-fruits commonly grown in the northern United States. Varieties vary markedly and no definite point of injury can be stated, but a temperature from 18° to 20° F. below zero is likely to destroy all the fruit-buds and hence the crop.

222. Injury to the woody parts above ground.—While a loss of the fruit-buds is a serious economic factor, the injury that may occur to the tree itself is more destructive in its nature. Winter injury to fruit-trees may take several forms, some being rather characteristic of one section and some of another or all forms may occur in a given region. The following are the more important types of such injury: killing of the terminal growth of the shoots; killing of patches of tissue on the limbs or body of the tree; crotch injury; "black heart"; collar-rot; frost-cracks; frost-cankers; and sun-scald.

223. The killing of the terminals on many kinds of fruit-trees, even the more hardy ones, is common in a severe winter. This is particularly true if the growth has continued late and has not matured well the previous season.[1] It may also be due to an inherent tenderness of the varieties. The result of this injury is much the same as from cutting or shearing back the terminal growth; that is, the uninjured buds nearest the terminal will make a longer growth than if no injury had occurred, while the more proximal ones are likely to remain dormant.

224. Killing of patches or areas of bark on the limbs and trunk is also a common type of injury. This will first appear as a sunken area which eventually dries and cracks. It is thought that considerable of the black-rot canker (*Sphæropsis malorum*, Peck) so common on the apple in some sections is due to the entrance of disease spores through openings in the bark caused by the splitting or drying out of the dead areas. This type of injury may also take the form of frost-cankers. (Fig. 35).

Large dead areas on the trunks of the older trees are also common in the more northern sections, particularly on Baldwin and King apple trees. This injury is occasioned by much the same set of conditions as produced the dead areas on the smaller branches. It is somewhat more serious, however, for there is opportunity to remove an injured branch but it is difficult to repair damage to the trunk. The bark in this case will loosen and come off. Unlike sun-scald this injury does not occur on any particular side of the tree.

225. Crotch injury is characterized by a killing of the tissues in the forks or crotches of both large and small branches. The injury may be restricted to a small area or it may be more extensive. Many varieties of apple may be affected, such as Ben Davis, Baldwin, Rhode Island Greening, and even Northern Spy. Several theories have been

[1] Emerson, R. A. The relation of early maturity to hardiness in trees. Nebr. Agr. Exp. Sta. 19th Ann. Rept. 1906. p. 101–110.

proposed to account for crotch injury, such as drying out, occurrences of ice at these points, and immaturity of the wood. The latter, according to Chandler,[1] is the principal if not the only factor involved. The last tissue formed and hence the most tender is near the base of the branches (crotches) and near the bottom of the trunk of the tree. This tissue becomes more hardy or mature as the season advances. Hence, if very low temperatures occur early in the winter, this tissue is the first that is injured. If the previous growing season is short and the tree as a whole goes into winter in an immature condition, the damage is enhanced.

226. Collar-rot or injury is an affection of fruit-trees localized at the crown or "collar." The injury may extend down on to the larger roots and also some distance up the trunk and it frequently encircles the base of the tree, resulting in its death. Such varieties of apple as the Grimes, Gravenstein, and King are particularly susceptible and for this reason they are often top-worked on to resistant sorts. The cause has been variously attributed to arsenical poisoning,[2] parasitic organisms, and to freezing.

Grossenbacher has shown that the primary injury takes place in the winter in connection with severe freezing weather and hence that fungi are not the chief cause but are the agencies of decay following the winter injury. Chandler has also pointed out that blight (*Bacillus amylovorus*) is not the cause of collar-rot since the result of "body blight" is a tightening of the bark when it dies, which is the opposite phenomenon of true collar-rot. The latter also holds that collar-rot is doubtless due to direct freezing to death from the low temperature and frequently to a rapid lowering of

[1] Chandler, W. H. Mo. Agr. Exp. Sta. Res. Bull. 8. 1913.

[2] Headden, W. P. Colo. Agr. Exp. Sta. Bull. 131. 1908. Grossenbacher, J. G. N. Y. (Geneva) Exp. Sta. Tech. Bull. 12 and 23. 1909 and 1912.

the temperature, and not to a tearing of the tissue or drying out as described by Grossenbacher.

That excessive alkali soils and arsenical poisoning are primary factors in collar-rot has also been generally abandoned through the work of Headden [1] and Ball [2] in the first case and Ball [3] and his associates in the second.

The view was held by Headden that large quantities of arsenic were found in trees suffering from collar-rot, but the fact that normal trees also often contained fairly large quantities of arsenic, that collar-rot occurred in orchards which had never been sprayed, and that herbaceous plants were growing about crown-rotted trees, caused this view to be abandoned for the one of freezing.

227. Frost-cracks or the splitting of bark or trunks of trees often accompanies other forms of winter injury. These cracks may extend up the entire length of the trunk and follow up one or more of the main branches for some distance, or they may be only a few inches in length. They may open as much as two centimeters or may be merely visible lines, but in any event they will draw together or close after the severe weather is over.

228. " Black heart " is a common result of low temperatures and consists in the killing of the sap-wood and pith, although the cambium remains alive. As a result, the tree continues growth and rapidly forms a new layer of sap-wood within and bark without. Nursery trees are frequently "black hearted," particularly pears, and they may make a

NOTE:—Following the winter of 1917–18 the author inspected several orchards of Ben Davis trees in the state of Maine in which the damage took the form of crotch injury almost entirely and while the trees were partly alive they were entirely beyond hope of repair.

[1] Headden, W. P. Colo. Agr. Exp. Sta. Bull. 157. 1910.

[2] Ball, E. D. Jour. Econ. Ent. 2: 142–48. 1909.

[3] Ball, E. D. *et al.* Jour. Econ. Ent. 3: 187–97. 1910.

stunted growth or soon recover, depending on the extent of the injury and on the growing conditions immediately following planting. Mature trees in some sections are often "black hearted" throughout their lives with no apparent incapacity.

229. Sun-scald is manifest by a dead area on the southwest (sun-exposed) side of the trunk of the tree. This damage, unlike the other forms discussed above, occurs late in the winter when days of bright sunshine follow cold nights. The cause has usually been assigned to a starting of growth or sap movement on the side of the tree exposed to the sun which activity is immediately followed by severe freezing. However, Chandler does not credit this view from his work with winter injury but suggests that the tissue is warmed by the sun until the temperature nearly reaches the freezing point when a sudden drop will cause the tissue to "freeze to death." [1]

230. Root-killing.—This form of injury is likely to be general during a severe winter when the ground is bare. It is well known that bare ground will freeze much deeper than when the surface is protected by some sort of cover, but no cover of vegetation is equivalent to a deep snowfall which lies on the ground throughout the winter.[2] Such hardy varieties as McIntosh and Wealthy will be root-killed as readily as the more tender sorts, like Baldwin and Wagener, in a snowless winter, although the trunks and branches of the latter varieties would show severe injury while none might appear on the hardy sorts.

Chandler has shown that the roots are the tenderest part of the tree, and that the portions nearest the crown are the most resistant, while the smaller remote rootlets are the most

[1] See also Mix, A. J. Sun-scald of fruit-trees a type of winter injury. Cornell Univ. Agr. Exp. Sta. Bull. 382. 1916.

[2] Neb. Agr. Exp. Sta. Bull. 79, 92. 1903, 1906.

tender. From his experiments he concludes that apple roots will be killed at about −3° C. in summer when they are tenderest and at about −12° C. in late winter with rapid freezing, this varying somewhat with conditions. He also shows that French crab stock is less hardy in the roots than the cion-roots of such varieties as Ben Davis; that "Marianna plum roots are more hardy than Myrobolan roots, and Mahaleb cherry roots seem slightly more hardly than Mazzard roots."

231. How freezing kills.—A distinction is made between the loss of fruit crops by "killing frosts" and by "freezing." The latter is here considered in studying the destruction of the tissues of fruit-trees. It is generally accepted that the freezing to death of plant tissues does not take place unless ice crystals are formed within the plant from water that has been withdrawn from the cells. While ice crystals may form within the cells themselves when the temperature falls very rapidly, the above method is much the more common. It was formerly considered that much less injury would result if thawing of the tissue was gradual so that the cells could again take up the moisture, assuming, of course, that the cells had not been ruptured in the process of freezing. Later investigators [1] have, however, shown that the rate of thawing has nothing to do with the killing of the tissue, except with ripe apples and pears, lettuce, and the leaves of *Agave americana*, but that the killing occurs when a sufficiently low temperature is reached.

"Frozen to death" is a technical phrase describing plant tissues that have been subjected to a certain temperature at which death of their cells occurs. Such tissues present a brown, water-soaked appearance shortly after they thaw and evaporation is much more rapid than from living tissue.

[1] Müller-Thurgau, Chandler, *et al.* Mo. Agr. Exp. Sta. Res. Bull. 8. p. 150.

232. Hardiness of different tissues.—As has been indicated above, the different tissues of a fruit-tree vary in hardiness, and they also change at different seasons of the year. It has been shown that when the trees are in a young growing condition, the cambium, young cortex, and sap-wood cells are the tenderest while the pith in young twigs is the first to be killed in mature trees followed by browning in the sap-wood and the outer or old cells of the cortex. The notable point here is that cambium is most tender in the growing plant but relatively hardy when it is in winter condition. This observation can sometimes be made with peach trees after a severe winter when a cross-section of the limbs or trunk will often look so brown or black that little or no hope could be entertained for saving them. The cambium may start into growth in the spring, however, and soon a new layer of sap-wood is formed, which begins functioning, and recovery of the tree takes place.

The fruit-buds of the peach are recorded to be about as hardy as the cortex, cambium, and sap-wood of the twigs in the latter part of summer, but during the winter they are the most tender of all the tissues above ground with the possible exception of the pith cells. Usually the leaf-buds are more hardy than the fruit-buds, but instances are on record in which the leaf-buds and part of the sap-wood of the peach have been killed or badly injured while a portion of the fruit-buds have survived and produced, even in the absence of leaves.[1] This is explained on the basis of lack of maturity of the wood tissue, while the fruit-buds reached maturity before the freezing occurred.

233. Rest-period.—That perhaps all plants have a more or less definite rest-period has been well established by a number of writers, notably Klebs in Germany and Whit-

[1] Chandler, W. H. *Loc. cit.* p. 224. Paddock, W. Soc. Hort. Sci. 1918. p. 30.

ten [1] and Howard [2] in this country. This phenomenon can be observed with different varieties of the same kind of fruit by the early swelling of buds and time of starting into growth. For the more southern peach-growing sections that are in the danger belt for spring frosts, the length of the rest-period becomes of serious importance, for the more forward varieties are most likely to be lost from freezes and frosts. In order to shift the resting-period to later in the winter, a series of experiments were conducted by Whitten to cause the trees to enter their rest-period at a later time and hence make them correspondingly later in awakening from this state. By means of late cultivation, it was possible to delay the rest-period and as a result the trees were a few days later in blossoming than was the case under normal conditions.

FACTORS INVOLVED IN FREEZING

234. Maturity.—Reference has already been made to the importance of having the tissues well matured if injury from low temperatures is to be avoided. It has been established experimentally [3] as well as by extensive observation that maturity is the most important single factor involved. While the nature of the season is beyond the control of man, certain horticultural practices should be followed in order to bring about as great a degree of maturity as possible. These will be considered later.

It has been observed that the hardiest varieties mature early in the season. Macoun has studied the effect of winter on a large number of plants at Ottawa, Canada, for a period of twenty-two years, having under his observation over 3000 species and varieties, many of which kill back more or

[1] Whitten, J. C. Mo. Agr. Exp. Sta. Bull. 38. 1897.

[2] Howard, W. L. Mo. Agr. Exp. Sta. Res. Bull. 1. 1910.

[3] Neb. Agr. Exp. Sta. Bull. 79 and 92. 1903, 1906. Ohio Agr. Exp. Sta. Bull. 192. 1908. N. Y. (Geneva) Agr. Exp. Sta. Bull. 269. 1905.

less every year. All those which kill back more or less regularly are native to regions having a longer growing season than that at Ottawa and hence they mature too late there and the wood is not thoroughly ripened. He, therefore, concludes that a tree or shrub which will withstand a test winter at Ottawa must ripen its wood early.[1] Not only do the more mature trees exhibit greater hardiness, but they also become more hardy as the winter advances until they again respond to growing conditions as spring approaches. While writers have commonly assigned the reason for lack of hardiness to a higher moisture-content of the tissue, Chandler has shown that, with the exception of the cambium, the tissue contains as much moisture later in the winter when it is more hardy as when it enters the dormant period. "It would seem highly probable that, except in the case of cambium, the additional hardiness acquired by the different tissues of the tree as they pass into winter, is due to a change in the protoplasm such that it can withstand the great loss of water rather than a change in the percentage of moisture or in sap concentration. It is also possible that changes in the sap solute that lower its eutectic point may occur and that these may increase the resistance to cold by holding water unfrozen to protect the protoplasm from too complete desiccation at lower temperatures."

An additional point of evidence that maturity and growth conditions the previous season affect the resistance of trees to cold, is the observation that trees having their foliage injured or destroyed by insects or spray burning suffer serious killing of the wood. Also the inner surface of branches which possess less foliage is nearly always more tender than the exposed sides.[2]

[1] Proc. Amer. Soc. Hort. Sci. 1912. p. 59.

[2] Proc. Amer. Soc. Hort. Soc. 15th Rept. 1918. p. 18. Card, F. W. Bush-Fruits. Macmillan Co., Rev. Ed., 1917. p. 56.

235. Sap concentration.—The work of Chandler on the relation of sap concentration to the freezing of plant tissue is particularly important. The experiments of Müller-Thurgau and Molisch had previously shown conclusively that practically all the formation of ice crystals takes place in the intercellular spaces and only rarely (due to very rapid freezing) in the cells themselves. Furthermore, if the protoplasm or membrane surrounding it fails to give up its water, the freezing point is thereby lowered or, in other words, a protection is afforded. They also observed that tissue could be super-cooled, just as a liquid, to a lower temperature than that at which ice would normally form in the intercellular spaces, and be raised again without ice formation and hence without injury.

Chandler has shown that if the sap concentration could be doubled it would inhibit the loss of water, for twice as much would be held in the protoplasm "at any given temperature below the freezing point, but above the eutectic point [1] of the solute," as a protection against freezing. Extensive experiments were conducted with various kinds of herbaceous and woody plants and their fruits and leaves to determine whether lowering their sap concentration would lower their freezing point. The sap concentration was lowered by placing the plants in or by watering with solutions of various salts, sugars, or glycerine. The freezing point of the sap was then determined and reported in the terms of "depression," which means "the number of degrees centigrade below zero at which, with no supercooling, ice formation begins in the sap."

The following table (after Chandler) illustrates how uni-

[1] "By the eutectic point is meant the temperature at which the substance in solution crystallizes out. At that temperature there would be at the same time ice, crystals of solute, and unfrozen solutions."

versally the lowering of the sap concentration (from any cause) has lowered the freezing point:

Table LXXIX

RELATION OF SAP CONCENTRATION TO FREEZING

YOUNG FRUITS

	Depression
Cherries fresh from tree	0.905
Cherries from twigs with ends in glycerine sixteen hours	1.180
Cherries wilted five hours	1.075
Peaches fresh from tree	0.965
Peaches from twigs with ends in glycerine sixteen hours	1.230
Peaches wilted five hours	1.085
Apples from twigs with ends in glycerine thirty hours	1.408
Apples from twigs with ends in water thirty hours	1.335
Apples from twigs with ends in cane sugar thirty hours	1.530
Apples from twigs with ends in glycerine forty-eight hours	1.417

Thus it will be seen from these data that wherever the sap concentration of young fruits has been lessened, the temperature at which it will freeze has been reduced also. The same results were secured with the leaves and tender shoots of trees and with more succulent plants such as corn and tomato. Furthermore, it was shown that the sap concentration of shaded plants is lower (*i. e.*, not so dense) than that of unshaded ones and hence they kill at a higher temperature. However, all of these researches were conducted with succulent plants, and not with woody tissue in the dormant or resting-period.

TABLE LXXX

DATA SHOWING INFLUENCE OF SHADING ON THE KILLING OF TISSUE (AFTER CHANDLER)

Material	*Treatment*	*Date*	*Temperature °C.*[1]	*Number of plants*	*Percentage all killed*	*Percentage total leaf area killed*	*Depression*
Early Harvest apple twig and leaves	Shaded	June 28	—4	39	0.0	35.9	1.975
do.	Not shaded	June 28	—4	42	0.0	6.8	2.438
do.	Shaded	June 28	—5	47	34.0	70.0	1.975
do.	Not shaded	June 28	—5	50	0.0	48.5	2.438

In order to determine whether such tissue could also be influenced in like manner by applying fertilizers, a heavy application of potassium chlorid (500 pounds to the acre) was made to peach orchards in different locations over a period of four years. No difference appeared, however, in the amount of winter-killing of the wood, hardiness of the fruit-buds, or of the bloom when spring frosts occurred. However, on determining the sap concentration of twigs from these treated trees, no difference appeared; hence, according to the previous observations with other plants, no difference in hardiness could be expected. The suggestion is made that if it were possible to increase the sap concentration by the use of fertilizers, some difference in hardiness of the blooms would be anticipated.

236. Rate of freezing a factor.—Very conclusive data are available to establish that a rapid fall in temperature is much more injurious than a gradual one, either with tissue after the sap is flowing or when it is entirely dormant; particularly is this true with the buds. It has also been shown

[1] To convert centigrade and Fahrenheit temperatures:

$$\text{Degrees } \frac{\text{F.} - 32}{1.8} = \text{Degrees C.}$$

$$\text{Degrees C.} \times 1.8 + 32 = \text{Degrees F.}$$

that a rapid fall of temperature near the freezing point is more harmful than near the point at which the tissue is killed and this fact is applied as a possible explanation of "sun-scald" of apple trees.

The following excerpts from Chandler's data illustrate this:

TABLE LXXXI

THE EFFECT OF SLOW AND RAPID LOWERING OF TEMPERATURE ON THE KILLING OF PLANT TISSUE

Kind of buds	*Date*	*Number buds*	*Percent. killed*	*Number buds*	*Percent. killed*
		Slowly to —18° C.		Rapidly to —13.5° C.	
Rice's seedling peach	Mar. 22	138	44.2	154	51.9
Elberta peach.......	Mar. 22	100	88.0	85	92.9
Jonathan apple......	Mar. 22	34	64.7	33	75.7
Montmorency cherry	Mar. 22	176	58.5	184	62.5
Chabot plum	Mar. 22	236	78.3	183	86.8

When twigs of the apple, peach, cherry, and plum were exposed to a temperature which gradually fell to −18° C., the killing was about the same as when it fell rapidly to −13.5° C. These with other data show conclusively that both buds and wood are more surely injured if the temperature drops rapidly than slowly, even though it does not go so low in the rapidly frozen tissues.

237. Protection of bud scales.—It has usually been assumed that the bud scales afford protection from cold as well as prevent loss of moisture from or entrance of water into the buds. However, this has not held true experimentally [1] for buds which had their scales removed were not frozen any quicker or at a higher temperature than were

[1] Wiegand, K. M. Bot. Gaz., Vol. 41, pp. 373–424.

such buds with their scales. This work was done with peaches only, and they were treated on different dates from February 26 to March 12. The temperature was reduced to various points from −10° C. to −22.5° C. with the following average results:

Total number of buds, scales off, 4430, 51.0 per cent killed; total number of buds, scales on, 5078, 68.5 per cent killed.

238. Relation of crop the preceding season.—It has been observed in various sections of the country that trees which fruit heaviest are most likely to be injured by very low temperatures the winter immediately following. This observation was repeatedly reported after the severe winter of 1917–18.

Macoun describes a row of Wealthy apple trees (21 years old) at Ottawa that behaved in this way. Of fourteen trees, the eight which bore a medium to heavy crop in 1917 were killed or badly injured, while the six bearing either a light crop or none at all came through the winter in good condition.[1]

In New York state and in New England it was noted that hardy varieties of the apple were killed more readily than such tender sorts as the Baldwin, if the former had set a heavy crop the preceding season while the latter had not.

This result was earlier indicated when it was shown that well thinned peach trees seemed to be more resistant than unthinned ones which bore a heavy crop:[2] average percentage of peach buds killed, tree thinned, 35.4; average percentage of peach buds killed, trees not thinned, 51.4.

239. Correlation of wood structure and hardiness.—Various attempts have been made to discover any correla-

[1] Proc. Amer. Soc. Hort. Sci. 1918. p. 17.

[2] Mo. Agr. Exp. Sta. Bull. 74. 1907.

tion that might exist between the wood structure or other morphological characters and the hardiness of plants. Halsted [1] made a special investigation and reported that "No constant difference in all structures probably exists among apple twigs by means of which one sort may be unmistakably distinguished from all others. Much less is there any point in minute structure invariably present with those sorts which are classed as hardy and absent from tender varieties. Maturity of twigs is a condition of successful wintering, and therefore the so-called hardy sorts are quite sure to finish their seasons' growth before autumn frosts arrive."

More recently Beach and Allen [2] conducted some extensive investigations on this problem, and observed a large number of plant characters of hardy and tender varieties of fruits. In general, no outstanding and consistent correlations could be found, but they report that "The hardier varieties on the average had a slightly lower moisture content than the more tender varieties," also "Large, thick petals are correlated with hardiness, although the converse of this is not always true."

240. Influence of type of soil.—Inasmuch as the type of soil materially influences the maturity of the trees, this factor becomes one of importance in studying winter injury. In general, a soil that is heavy and inclined to be wet will delay maturity and hence, other things being equal, there would usually be more winter injury on such a soil than on one of a lighter nature. This is particularly true of the subsoil, as indicated in Chapter VII. Bouyoucos [3] has shown that a heavy soil contains more moisture and will not freeze so deeply as a lighter one, although a sand or gravel will

[1] Halsted, B. D. Iowa Agr. Exp. Sta. Bull. 4. 1889. Mem. Torrey Bot. Club, 2: 1, 26.

[2] Iowa Agr. Exp. Sta. Res. Bull. 21. 1915.

[3] Bouyoucos, G. J. Mich. Agr. Exp. Sta. Tech. Bull. 26, 1916.

fluctuate more with the air temperature than the heavy soil because of the difference in specific heat.[1]

Hedrick [2] reports on the experience of Michigan and New York growers with the peach. In the first case the growers, almost without exception, considered a sandy, gravelly, or stony soil much more favorable to peach-growing and that peach trees are more hardy in such a soil than in a heavy one.

Bouyoucos investigated the depth and rate of freezing of the following types of soil: gravel, sand, loam, clay, and peat. It was found that "they all froze about the same time in the upper 6 inches, but in the spring they thawed and warmed up at different rates. This was attributed to their different specific heats and to the downward and upward trend of air temperature in the fall and spring respectively. The gravel and sand thawed first, followed by clay 1 day later, loam 2 days later, and peat 10 days later. After they were entirely thawed out all the types of soil had almost the same temperature from then on throughout the summer, autumn, and winter."

He further shows, however, that if very cold weather is experienced early in the winter without any fluctuations in temperature, the light soil freezes deeper than the heavy ones, thus giving an advantage to higher moisture-content in such a case. In New York state, however, the growers would not distinguish between a heavy and a light soil so far as winter injury is concerned, provided the heavy soil is "warm and dry." In both states the growers preferred a gravelly subsoil in order to secure a hardy tree.

[1] There would seem to be a discrepancy between this statement and the one following by Hedrick, but this is probably explained by the fact that trees growing on clay soil usually mature later and hence are more subject to injury in the tops. If the injury occurred in the roots rather than in the tops, it would be much worse in the sandy soil.

[2] Hedrick, U. P. Trans. Mass. Hort. Soc. 1919.

As to the moisture of the soil, Hedrick reports that "Either extreme of moisture—excessive wetness or excessive dryness—gives favorable conditions for winter-killing. A wet soil is conducive to sappiness in the tree and also freezes deeply." It was also reported that a very dry soil failed to furnish the trees with sufficient moisture during winter and the buds and twigs died out and serious winter-killing followed.[1]

241. Proximity to bodies of water.—The proximity of an orchard to a large body of water has a greater effect on the frost injury in the spring than on winter injury. However, an effect on the latter is not infrequently noted. A conspicuous example of this is seen in the fruit sections bordering on the various lakes. "The distance to which the influence of a body of water will extend inland depends upon the volume of water, its temperature relative to that of the land, the area of its free surface, the slope of its shores, and the prevailing winds. The influence of Lake Michigan, mainly because of the gentle slope of its eastern shore, extends nearly halfway across the state of Michigan, while the influence of Lake Erie, because of the abrupt rise of its eastern shore, extends inland only a few miles." [2]

Many examples could be noted of peach orchards favorably located near lakes that are injured only in the most severe winters, while sections within a few miles frequently suffer a loss of the crop in whole or in part. However, the vagaries of winter injury seem endless, and many instances might also be cited where such an influence has not been noted.[3]

[1] See also Paddock, W. Colo. Agr. Exp. Sta. Bull. 142. 1909. p. 11.

[2] Standard Cyclo. Hort., Bailey. Vol. 3, p. 1284. (W. M. Wilson.)

[3] For several years the author noticed the difference in date of blooming of apple trees near the Atlantic coast line of New Hampshire and inland, showing a decided retarding effect of the cold winds of spring

242. Topography of land.—While it would seem patent to all careful observers that low lands suffer much oftener from frosts and freezes than the higher elevations, yet many orchards are located unfavorably in this regard. While the average temperature of the air decreases at the rate of 1° F. for each 300 feet of elevation above sea level, yet it does not follow that more injury from low temperatures occurs at the higher elevations. The disturbing factor of wind and the fact that cold air will settle and flow down hill accounts for the apparent contradiction. Here again, orchards located on high elevations are sometimes injured more than those at lower levels during severe winters; however, the reverse of this is true on the average. Frost pockets, coves, and flat low lying lands are to be avoided for orcharding.

In some of the western fruit sections, the reverse of this principle holds true, owing to special conditions. In some of the narrow river canyons, the fruit-trees suffer less from injury in the winter and from spring frosts and ripen their fruit from one to two weeks earlier than those planted on the land along the "rim rock" or at a distance from the canyon. This phenomenon is explained by the fact that the rocks of the canyon walls hold the heat, are dark colored and hence absorb a maximum of the sun's rays, and that there is a "draw" of air down the canyon that wards off frosty conditions.

243. Winds.—While winds play an important rôle in frost prevention, they also are a factor in augmenting win-

on the coast. Yet in the severe winter of 1917–18, the effect of the water was insufficient to prevent the winter-killing of a well-cared-for young orchard within sight of the open water. The slope was a gentle one to the coast line, yet such hardy varieties as Wealthy and McIntosh were killed as readily as the tender ones, such as Baldwin and Wagener. The ground was bare at the time of the low temperature in December, and hence the root-killing was extensive.

ter injury in some sections. Frequently high wind velocity will accompany low temperatures and if the soil is not well protected by a covering of snow or of vegetation, it will dry out to the point at which root injury is extensive. The twigs and buds may also be injured to a greater extent under such conditions, and it is commonly supposed that their tissues are directly dried out by the action of the wind. It is more probable, however, that these tissues experience a drying to death due to the water supply being shut off by the freezing of the roots.

ORCHARD PRACTICES

244. Cultivation.—As indicated above, the chief factor in hardiness of fruit-trees is their maturity before going into winter condition. Therefore, in sections in which winter injury is likely to occur, the orchard practices should be such as to obtain a good growth and yet allow the wood and buds to mature before winter. In a cultivated orchard the tillage should stop by the first or middle of July in most districts (except when it is an advantage to delay the rest-period). A cover-crop should also be sown at the time of the last cultivation as it has a twofold function in relation to winter injury, (1) by serving to withdraw any excess moisture in the soil and hence aid in maturity of the trees; and (2) by acting as a mulch to prevent such deep freezing, and alternate freezing and thawing as would occur if the land were bare. Emerson [1] and others note the effects of various cover-crops on depth of freezing in orchards. They show that in a season of snowfall corn or cane is a good crop for the orchard as it holds the snow to good advantage, while in a season of no snow such crops as mat down well will afford the greatest protection.

[1] Neb. Agr. Exp. Sta. Bull. 92. 1906.

TABLE LXXXII

DEPTH OF FREEZING (AFTER EMERSON)

	No snow	Heavy snow	
		Depth of snow	Depth of freezing
Cornstalks	17 in.	18 in.	6 in.
Clean cultivation	19 "	2 "	24 "
Oats	12 "	12 "	12 "
Millet	12 "	12 "	15 "

245. Pruning.—Not much can be said in regard to the relation of pruning to winter injury except what has already been stated, namely, that practices which maintain a strong vigorous tree and yet permit normal maturity are likely to reduce danger from winter injury. At the Missouri Experiment Station it was found that the vigor and relatively late growth caused by stimulation of peach trees would have some effect in reducing bud injury in the spring. This was due to the shifting of the rest-period to later in the season, as indicated before. "In Missouri nearly every winter warm weather starts the buds into growth more or less. Fruit-buds on trees that have made a vigorous growth, caused by reasonably severe heading back or by cultivation, are the less liable to winter injury." [1]

If, however, the injury has taken place, it becomes important to prune judiciously if the best response is to be obtained. If peach trees have been severely frozen in the wood, it is best to give them a moderate pruning. If such trees are severely pruned (leaving only bases of the main limbs), they are very likely to be killed, but if the same trees

[1] Mo. Agr. Exp. Sta. Bull. 74.

are moderately pruned, experience shows that the maximum number can be saved.[1] (See Plate VIII *b*.)

246. Protecting trees and buds.—Various efforts have been made to protect tender trees and their buds during the winter, with some degree of success. Such precautions are of special value in sections in which growth is likely to be excited by premature warm spells, followed by low temperatures.

When the wood or buds are likely to be frozen during the winter season while they are entirely dormant, the only practice that seems efficient is to layer the vines or trees entirely, and this is not often feasible. Some peach orchardists do, however, cut the roots on one side of the tree, pull it down into a trench and cover it with soil, which has prevented injury. Entire grape vineyards are also laid down and covered with soil, with success.[2]

Baling the trees with hay, straw, or other material has also been practiced with success, but is not generally recommended.

Chief among the experimental efforts to coat the trees and buds with a protective material is the work of Whitten.[3] He observed that the chief damage to the peach in Missouri resulted from killing after the trees had been started into premature growth from unseasonable weather in the winter or early spring. As a means to prevent the swelling of the buds, the following treatment was given: "During the winter a row of peach trees, running diagonally across the orchard, so as to embrace several varieties, was whitened by spraying with a lime white wash. These trees had been set only two years and had but few fruit-buds. Four older

[1] Mo. Agr. Exp. Sta. Bull. 55. 1902.

[2] Hedrick, U. P. Proc. Amer. Pom. Soc., 35 Bienn. Rept. 1917. p. 48.

[3] Whitten, J. C. Mo. Agr. Exp. Sta. Bull. 38. 1897.

trees, in various parts of the grounds, were also whitened." The following table gives the results on time of blooming:

TABLE LXXXIII

EFFECT OF WHITEWASHING PEACH TREES TO DELAY BLOOM (AFTER WHITTEN)

Variety	*Treatment*	*First flower*	*Full bloom*	*Last bloom*
Health Cling.....	Whitened	April 13	April 21	April 29
	Not "	" 11	" 18	" 27
Wonderful.......	Whitened	" 14	" 22	" 29
	Not "	" 11	" 18	" 25
Rivers Early.....	Whitened	" 13		" 29
	Not "	" 9	" 21	" 27
Silver Medal.....	Whitened	" 13	" 18	" 28
	Not "	" 7	" 13	" 21

As a more striking effect of the winter on the treated and untreated trees, it is recorded that 80 per cent of whitened buds passed the winter safely when only 20 per cent of the unwhitened ones were unharmed.

A very interesting set of experiments was conducted to illustrate the difference in absorption of heat between white and colored material. Thermometers were covered with various colored cloth and whitewash and exposed in the orchard and on the side of a building. When the sun was not shining the thermometers registered much the same, but when the sunlight was intense marked differences occurred. "At one time, during bright sunshine a difference of 21 degrees was recorded between the white covered and the purple covered thermometers. A difference of 10 to 15 degrees was frequently noted between these two. This is sufficient to indicate that we might expect considerable difference in the growth and time of flowering of whitened and unwhitened peach trees."

247. Securing hardier fruits.—A discussion of breeding hardier fruits is included in the general subject of breeding (Chapter XIII), but a statement in regard to the acclimatization of plants is apropos at this point. There is a lack of unity of opinion on this point, although it has been discussed for many years and many observations have been recorded. It seems unlikely that individuals of a tender species will manifest any permanent character for hardiness when such plants are removed to a colder climate. While an occasional individual may be more resistant to cold than its companions of the same origin, the environment may be different or some other cause operating which would not be permanent. To attempt to select biotypes showing this hardy character would be a slow process with the weight of evidence against its success. The better procedure to follow would be to breed such tender species with hardy "relatives" and select individuals exhibiting the desirable qualities of both parents. Hence it is practically useless to attempt to find a particularly hardy Baldwin apple or Crawford peach tree from which to propagate a strain that will withstand the northern winters where these varieties are unreliable.

248. Treatment of frozen trees.—Great care must be exercised in treating trees which have been frozen or the injury may be extended rather than reduced. As indicated previously, the pruning given winter-injured trees calls for moderation and the operation should not be hastened but rather delayed until the probable injury can be determined. Some seasons the peach is so injured that the buds are delayed in starting; this calls for careful observation lest live wood be cut away and the tree unnecessarily reduced.

In addition to proper pruning, it is also advantageous to apply a quickly available form of nitrogen, such as nitrate of soda or sulfate of ammonia, as a means of stimulating growth. Thorough cultivation should, of course, be followed when conditions permit.

Special repair work may also be necessary, such as bridge-grafting and cleaning and disinfection of the wounds.[1]

249. Variation in hardiness of fruits.—While the varieties within any given kind of fruit vary widely in hardiness, yet there is a rather marked difference between species and genera of the common fruits. The apples as a class are the most hardy of the commonly grown tree-fruits, followed by the American plums, Japanese plum, sour cherry, European plum, pear, sweet cherry, apricot, and peach. It is true that the currant and gooseberry and certain species of American plums are more hardy than the apples. There is so much variation in different localities and in different seasons, however, that such a classification cannot be consistent.

250. Hardy and tender varieties.—As with the different species and genera, so the varieties of fruits are variable in hardiness, depending on a multitude of conditions.[2] The following lists are an attempt to rate some of the more commonly grown varieties, the hardiest being in the first column and those in the other columns decreasingly hardy.

[1] Purdue Univ. Agr. Exp. Sta. Circ. 87. 1918.

[2] U. S. Dept. Agr. Bur. Plant Ind. Bull. 151. 1909. Fruits recommended by the American Pomological Society for cultivation in the various sections of U. S. and Canada.

RELATIVE HARDINESS OF SOME COMMON VARIETIES OF FRUIT

APPLE (HARDINESS IN WOOD)

1	2	3	4	5
Hibernal	Wealthy	Northern Spy	Ben Davis	Baldwin
Ontario	Fameuse	Red Canada	Gano	R. I. Greening
McIntosh	Delicious	Rome	Jonathan	King
Oldenburg	N. W. Greening		Wagener	Hubbardston
Tolman	Wolf River		Twenty Ounce	Gravenstein
Yellow Transparent	Pewaukee		Grimes	Fall Pippin
Red Astrachan			Winesap	Stayman
Haas			York Imperial	Black Gilliflower
Malinda				
Patten Greening				

PEACH (HARDINESS IN BUD)

1	2	3	4
Crosby	Champion	Elberta (hardy in wood)	Crawford (early and late)
Rochester	Georgia (Belle of)	St. Johns	Chairs Choice
Hill's Chili	Carman	Mt. Rose	Niagara
Gold Drop	Waddell	Foster	J. H. Hale
Wager	Alton		Surprise
Stevens Rareripe	Ray		Salway
Greensboro	Hiley		Reeves
Lemon Free	Kalamazoo		Fox Seedling
Fitzgerald	Bernard		
	Triumph		
	Smock		

CHERRY (HARDINESS IN WOOD)

1	2	3
Windsor	Montmorency	Reine Hortense
Eugenia		Schmidt
May Duke		Governor Wood
Late Duke		
Early Richmond		
Tartarian		
English Morello		
Ostheim		
Vladimir		

PEAR (HARDINESS IN WOOD)

1	2
Flemish Beauty	Angouleme
Anjou	Bartlett
Sheldon	Bosc
Seckel	Clairgeau
Tyson	Kieffer
Longworth	Clapp Favorite
Winter Nelis	
Orel	

251. The grape.—With the grape as with other fruits the chief factor affecting its hardiness is maturity. Gladwin [1] shows that the length of the growing season has a decided effect on the subsequent wintering of the vines. Not only does a longer growing season permit greater maturity of the canes and an increased thickness of the cell-walls of the wood tissue, but it also permits the ripening of the fruit which bears a correlation to the maturity of the canes. He says, "Our observations during the years 1915–16 indicate quite clearly that until an actual freeze occurs the vine extends its energies to maturation of its fruit at the expense of wood maturity; and if the unripe fruit be allowed to hang throughout the fall, wood maturity is not nearly so complete as when the fruit is picked some time previous to a freeze."

It is also pointed out that the incipient floral parts within the complex bud of the grape may be destroyed by low temperatures and hence result in an "off year." This is often erroneously accredited to a heavy crop the previous season having robbed the buds of sufficient nutrient material to permit fruit-buds to form.

The application of such fertilizing materials as nitrogen, phosphorus, and potassium had no appreciable effect on the killing of grape vines.

[1] N. Y. Agr. Exp. Sta. Bull. 433. 1917.

CHAPTER XII

POLLINATION AND THE STERILITY PROBLEM

THE sexual relation of plants and the union of male and female elements to the proper development of fruits have been known since ancient times, but it is only within the past quarter of a century that marked progress has been made in understanding the causes of these phenomena and many of them are not yet fully apprehended. In studying the effect of pollination on the setting of orchard fruits, one should keep in mind that two points are involved: first, the importance of pollinization in effecting the development of fruits even though no actual fertilization takes place; and second, that as a result of such pollination there may be fertilization and development of the embryo, resulting in viable seed capable of producing new progeny. From the standpoint of the breeder, the latter is paramount (*i. e.*, the production of fertile seeds), but the orchardist is concerned primarily with the former of the two results. The vegetable-grower, on the other hand, may be interested in the production of viable seed, depending on the crop involved, and with the nut-grower, it likewise becomes a matter of practical importance.

252. Investigations in pollination.—Centuries prior to the Christian era, the peoples of Egypt and Mesopotamia were cultivating diœcious plants for food and practicing artificial pollination of the fig and date palm.[1] However, the first scientific investigation of this problem was not forthcoming until A. D. 1694 when Camerarius proved that fer-

[1] Johnson, D. S. Sexuality in plants. Jour. Heredity, 6: 3–16. 1915.

tile seeds are not produced if the pollen or male element is lacking or unavailable when the flowers are in bloom. This has later been observed for angiosperms in general. Other subsequent investigators made contributions on this problem, but the work of Sprengel of Germany (1793) marked an epoch when he published "The Secret of Nature in the Form and Fertilization of Flowers Discovered." His contemporary in England, Thomas Andrew Knight, published a number of articles bearing on the pollination question and, as a matter of fact, almost discovered "Mendelism," and he announced as a law that "in no plant does self-fertilization occur for an unlimited number of generations." This idea found its great culmination in Darwin's work when he said "nature abhors self-fertilization." And yet notwithstanding the wide application which this principle may have, it is by no means universal. Wheat, for example, is self-fertile, likewise peach varieties in general, the cleistogamous flowers of violet never open, the tomato is regularly self-fertilized, and so with many other plants.

In this country a great impetus was given to a careful study of the inter-relations of varieties of any kind of fruit in an orchard plantation by the works of Beach,[1] Waite,[2] and Waugh.[3]

The problems of pollination incident to the setting of fruit will be considered in this connection, but the study of cross-pollination for the purpose of producing new varieties will be discussed in the next chapter.

253. Causes of unfruitfulness.—Many diverse reasons or causes must be given for the failure of trees to produce fruit. Some cases of barrenness still lack explanation. The

[1] Beach, S. A. Rept. N. Y. State Agr. Exp. Sta. 1892, '94, '95, '98, '99, 1900, '02.

[2] Waite, M. S. U. S. Dept. Agr., Div. Veg. Path. Bull. 5. 1894.

[3] Waugh, F. A. Rept. Vt. Agr. Exp. Sta. 1896, '97, '98, 1900.

following may be listed as the more common causes: failure of fruit-buds to develop; lack of vigor or excessive vigor resulting in the dropping of the expanded flowers; winter injury to the floral parts; frost at blossoming time resulting in injury to flowers or inactivity of pollen-carrying insects and the consequent lack of pollination; lack of "affinity" between varieties (self- or inter-sterility); defective pollen or embryo sacs; or hybridity, the causes of which are not understood.

Some of these factors are treated elsewhere and only the various problems having to do with pollination and sterility will be considered at this time.

254. Development of pollen.[1]—The pollen produced within the anther-sacs of the stamens contains the male element of the reproductive system of flowering plants. A brief statement of the development of the pollen will more clearly introduce the problems encountered in a study of pollination. A sufficient similarity exists between the several tree-fruits that all need not be considered.

The stamens, as indicated in Chapter III, originate as an outgrowth from the torus, differentiating in their development into filaments and anthers. The anthers consist essentially of four lobes of pollen-forming tissue which, on further development, become differentiated as four sacs or locules, each of which contains the pollen-grains, one sac corresponding to each lobe. In the early development of the anther, the sporogenous tissue is first seen within each lobe, and surrounding the future "pollen-making" tissue is a layer of cells known as the tapetum. The cells within the tapetum become the mother cells which, on further di-

[1] See Sandsten, E. P. Wis. Agr. Exp. Sta. Res. Bull. 4. 1909. Kraus, E. J. Ore. Agr. Exp. Sta. Res. Bull. 1, Part 1. 1913. Dorsey, M. J. Minn. Agr. Exp. Sta. Bull. 144. 1914. Black, C. A. N. H. Agr. Exp. Sta. Tech. Bull. 10. 1916.

vision (reduction division), become the microspores or pollen-grains. Usually the anthers are partially developed prior to winter of the season before the blossom opens. If the development has gone sufficiently far in the autumn so that the first division of the cells in spring is the reduction division, then they are in the pollen mother cell stage at that time. However, they may or may not have reached that point in the autumn. When growth is resumed in the spring, cell division becomes active and pollen-grains are eventually formed. The pollen-grains are unicellular and are known botanically as microspores, each one finally developing two male gametes. The pollen-grain has a covering of two layers, the outer of which in some plants is frequently oily, gelatinous, or possessing minute projections useful in aiding in its distribution. This latter adaptation, however, is not encountered with common fruits. When "ripe" or mature, the anthers dehisce or expose the pollen-grains and on transfer to a receptive stigma, the latter germinate, as later described. If conditions are favorable and the two tissues are "congenial," fertilization takes place.

A similar development occurs with grape pollen as for pollen in general. It has been shown that a fundamental defect may occur in its development which accounts for sterility in the grape as is described later.

255. Germination of the pollen.—The condition of the stigma when it becomes receptive or at the time of pollination should next receive attention. The stigmatic surface just prior to the receptive period has a velvety papillose appearance which is readily distinguished from the moist often viscid condition when it is receptive. When the pollen-grains reach the receptive stigma, they are surrounded by the stigmatic fluid which has been secreted and in which the pollen germinates.

It has been shown that sunshine had little or no effect on the germination of apple and plum pollen, or on the rate of growth of the pollen-tube. These tests refer to the artificial germination of pollen-grains in various media. It is well known that blossoms will be fertilized and the petals fall much more quickly in bright than in cloudy weather. The following data support the above conclusions in regard to germination:

Table LXXXIV

PERCENTAGE OF GERMINATION AND RATE OF GROWTH OF POLLEN IN SUNSHINE AND CLOUDINESS (AFTER SANDSTEN)

	Prunus americana			*Apple (Pyrus Malus)*			*Prunus domestica*		
Temperature, degrees C	34	31	33	33	32	33	32 [1]	30 [1]	33 [1]
In sunshine.	70	68	69	71	68	69	62	60	64
In cloudiness.	72	67	70	70	70	68	60	59	65

The rate of growth of the pollen-tube appears to be readily affected by low temperature and, therefore, actual fertilization may be delayed some seasons more than others by several days. Sandsten reported that "Under favorable conditions it requires nine to thirty-two hours for the pollen tube of apples, plums, and cherries to reach the ovary when placed on the stigma or in the germinating medium. Cherry pollen requires a little over 12 hours. Two or three bright days at the time of full bloom is sufficient for the setting of the fruit." Dorsey questions these observations in regard to the plum and thinks the time would be greater, as much as eight to ten days under some conditions.

Goff has shown that "Plum pollen does not germinate at temperatures below 40° F., and even at temperatures as high as 51° F. that there is slow pollen tube growth."

[1] Medium, a 3 per cent cane-sugar solution.

256. Longevity and viability of pollen.—At present there is considerable difference of opinion in regard to the length of time pollen remains viable. One investigator [1] records interesting observations on the longevity of pollen secured from widely different sources, namely, Washington (state), Tennessee, Missouri, and Minnesota. Part of the samples were on the road four to five days but arrived in "perfect condition." Germination tests on its arrival showed all samples to be practically normal. It was then placed in the laboratory in a temperature ranging from 10° to 18° C., and tests were made each month for six months with the exception of the last, which was eight months after its arrival. The following data show the results of this test:

TABLE LXXXV

LONGEVITY OF APPLE AND PLUM POLLEN. (AFTER SANDSTEN)

Lots		*First germination*	*Second*	*Third*	*Fourth*	*Fifth*	*Sixth*	*Seventh*
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	Apple	47	43	44	38	39	38	12
	Plum	53	52	42	35	30	18	0
2	Apple	58	57	50	43	38	33	10
	Plum	54	48	38	26	21	11	0
3	Apple	42	46	40	38	39	19	5
	Plum	60	48	42	25	18	2	0
4	Apple	56	51	52	40	23	28	8
	Plum	50	47	38	20	12	0	0

[1] Sandsten, E. P. Wis. Agr. Exp. Sta. Tech. Bull. 4. 1909.

The work of Crandall,[1] however, indicates that apple pollen may not remain viable so long as indicated by Sandsten. After observations for three seasons, he shows that when pollen was used that varied in age from one to eleven days, "The percentages indicate no definite relation between age of pollen and success obtained. . . . Apple pollen one month old has been tested several times in drop cultures, but no germination took place." He quotes Pfundt as finding that the pollen of *Pyrus Malus* (presumably the wild apple of Europe) retained its vitality in dry air for thirty-eight days and when preserved over sulfuric acid, for seventy days. "Records at the Illinois station contain no evidence of duration of vitality beyond the fairly successful use of pollen of *Malus malus* when eleven days old." Another investigator reports that a few pollen-grains of apple germinated after nearly three months and of pear after two months, but no tests were made after longer periods than these.[2] Sweet cherry pollen also has a reasonably long period in which it is viable, as germination tests showed it to be in as good condition three weeks after it was gathered and dried as when it was first collected.[3]

Further data show that pollen is not injured by a temperature ranging from 25° to 55° C., if it be dry, but "at a temperature of 40 to 50 degrees C., in a saturated atmosphere, the pollen grains burst open due to the rapid inhibition of water and the number of bursted pollen grains increased as the temperature increased. Freezing temperatures ranging from -1.5 to -1 degree C. were not seriously injurious to the pollen of apple, pear, and plum while less than 50 per cent of

[1] Crandall, C. S. The vitality of pollen. Soc. Hort. Sci. 1912. pp. 121–130.

[2] Adams, J. Germination of the pollen grains of apple and other fruit trees. Bot. Gaz. 61:131–147. 1916.

[3] Ore. Agr. Exp. Sta. Bull. 116. 1913.

peach and apricot pollen grains were killed by this temperature." The lack of cultivation and fertility in orchards greatly injures the production and fertility of pollen.

From these investigations it can be seen that the pollen of the apple, plum, peach, and cherry, (and it can be added for other fruits as well) will remain viable throughout the period of blooming and probably for a much longer time if kept under ordinary conditions of temperature and humidity.

257. Length of receptive condition of the stigma.—In contrast to the surprisingly long time that pollen is viable and capable of germination and to the untoward conditions that it can withstand, the pistils are most delicate and of short duration. They are readily susceptible to mechanical injury as well as to damage from inclement weather. There is some question as to whether a stigma has more than one period of active secretion; in some cases there is only one, while other observers have held that more than one occurs. The pistils are sensitive to cold and are often injured when other floral parts are unhurt. Frosts or drying winds may cause a loss of the whole or a part of the fruit crop if they occur when the blossoms are open.

Waugh[1] found that the stigmas of plums are receptive "From four to six days if pollen is withheld and conditions are favorable. If pollen is abundant they are almost immediately pollinated and cease to be receptive." Dorsey found that "under normal conditions, the plum stigma remains receptive for a maximum period of about one week, but usually from four to six days."

258. Fertilization.—The process of fertilization may be briefly stated in this connection since the whole problem of fertility and sterility of orchard fruits is intimately associated with it. When the pollen-grain or microspore is formed, it possesses two nuclei, one known as the tube (vegetative)

[1] Vt. Agr. Exp. Sta. 11th Ann. Rept. 1897–1898. p. 258.

nucleus and the other the generative nucleus. When the pollen-grain germinates the latter nucleus divides, forming two sperm or male nuclei.

As the pollen-tube grows down the style of the pistil, the male nuclei as well as the tube nucleus continue to approach the embryo sac in which are the ovules. Here the tip of the tube enters the micropyl and discharges the two nuclei into the embryo sac so that fusion may take place, one with the egg or female nucleus and the other with the primary endosperm nucleus. Hence it is seen that two fertilizations take place, one having to do with the origin of a new seed (ovule) and the other with the development of the endosperm or food-storage tissue surrounding the germ within the seed. As is well known from a study of an immediate cross between field and sweet corn, there is an effect on the endosperm of the first or immediate generation. This effect may be seen in the condition of the kernel, *i. e.*, when it is wrinkled or smooth or in the color of the endosperm or in both.

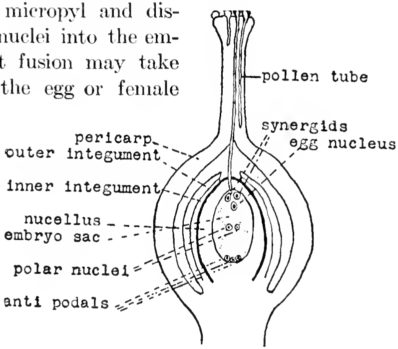


Fig. 36.—Diagram of a simple pistil as seen in lengthwise section, showing a single ovule just prior to fertilization.

In a study of sterility of the common fruits (as well as many other plants), it will be seen that not infrequently the endosperm will develop but the embryo will perish, a phenomenon termed embryo abortion. (Fig. 36.)

259. Cross-pollination.—The experiments of Waite and many subsequent workers have shown that, with many kinds and varieties of fruits, it is necessary to have a transfer of pollen from one variety to another in order to insure fertilization and the setting of fruit. This transfer between varieties, instead of from the stamens to the pistils of the same flower, has come to be known as cross-pollination in contradistinction to self-pollination. That cross-pollination should be the rule with many fruits will be shown later.

In selecting a pollinizer, the chief concern is to choose a variety that possesses the following characteristics:

1. It must blossom at the same time and preferably at the same age as the variety which is to be pollinated.
2. It must be inter-fertile with it.
3. Should be a standard variety, *i. e.*, be of high value for the purpose grown.
4. Should be a good pollen-producer.

260. Means of effecting cross-pollination.—Two agencies have usually been considered instrumental in the transfer of pollen: wind and insects. Experimental work and extensive observation, however, have shown that wind is of little or no importance with the tree-fruits, the nuts being excepted. Insects play a most vital part in pollinating the blossoms. Chief among the insects are the bees, particularly the honey bees.

Nature has provided for the visitation of insects in a most conspicuous way. Students of nature, particularly Darwin and his followers, are in full agreement that the insects are attracted by the bright or showy flowers and by the nectar secreted at the basal parts, thus bringing about the transfer of the pollen-grains which adhere to them, from flower to flower. When the flowers are so constructed as to permit pollination by the wind, they are said to be anomophilous and when insect pollination is the rule, they are called entomophilous.

261. Nature's methods of avoiding self-pollination.—Several means have been developed in nature to prevent self-pollination. Not all of these obtain with fruit-trees but several are very effective. The chief devices among flowering plants are:

1. Special devices or contrivances of the flower which ensure cross-pollination when insects enter the flower. Orchids exhibit these adaptations to a greater degree than any other group.

2. Difference in time of maturity of the stamens and pistils. This phenomenon is called dichogamy. When they mature simultaneously, it is homogamy. When the stamens precede the pistils in maturity, it is termed proterandrous, and if the reverse they are said to be proterogynous.

3. Even though flowers may exhibit homogamy, the relative position of the pistils and stamens or their relative lengths may be such as to prevent self-pollination. Such a condition is termed kerkogamy (dimorphous of Darwin).

4. Separation of sexes. With most fruits the flowers are perfect, *i. e.*, possess both stamens and pistils, but with some forms this condition does not exist. The strawberry is particularly notorious in this regard, as some varieties possess perfect flowers and others have pistillate flowers only, while others which are perfect have more or less abortive and hence worthless stamens. The grape also exhibits the same set of conditions. That cross-pollination is necessary under such circumstances appears evident.

262. Effect of cross-pollination on the fruit.—Entirely aside from the results of cross-fertilization on the offspring, the horticulturist is interested in any effect cross-pollination would have on the somatic tissue of the fruit which immediately develops. The experiments seem to establish rather thoroughly that the color or markings of a fruit are not affected by the pollen used in fertilization, and neither is the flavor, quality, acidity, or "sweetness." That some of these characteristics are materially changed is sometimes reported but they do not seem to be well authenticated; at least such changes have not been observed under controlled conditions. Careful observations have been made to determine whether color of fruit could be modified by the pollen parent. The conclusion is reached that color in the immediate cross is not directly influenced by the kind of pollen used, since any such effect must be found within the seed (endosperm) and there is no opportunity for an influence on the fleshy portion.

It is not uncommon to see fruits in which the color shows distinct "banding." This has been explained as a somatic segregation of the characters for color, permitting a more or less independent manifestation of them. The several colors may appear as bands more or less parallel or a band of but one color surrounded by the normal color.[1]

The results reported in regard to size and shape, however, are not in harmony. It is possible that under varying conditions the outcome may be different. Fletcher [2] states that his investigations (mostly with apples and pears) show that there is "no immediate effect of pollen, and no differences obviously due to mutual affinity. The cross-fertilized fruits have averaged about the same in size, shape, color, and quality regardless of the pollen used." Wicks [3] comes to a similar conclusion from his studies with the apple. He

[1] For further details see Kraus, E. J. "Bud variation in relation to fruit markings." Biennial Crop Pest and Horticultural Report. 1911–12. Ore. Agr. Exp. Sta.

[2] Va. Agr. Exp. Sta. Ann. Rept. 1909–10. pp. 213, 224.

[3] Ark. Agr. Exp. Sta. Bull. 143 (Technical). 1918.

says, "No influence of the male pollen of any variety can be detected on size, color, shape and quality of the female parent."

Alderman,[1] on the other hand, shows a decided benefit from cross-pollination of the apple over blossoms which were "selfed" or crossed with pollen from a tree of the same variety. A summary of his results in weight of fruit as affected by pollination is here given:

Rome Beauty	cross	Gain over selfed	27.8 per cent
York Imperial	cross	Gain over selfed	42.7 per cent

Likewise, Lewis and Vincent found an improvement in size of the apple from cross-fertilization.

These latter observations are in line with the original investigations of Waite. He observed, among other things, that the self-fertilized Bartlett pears which he secured weighed on an average 100.4 grams, while the cross-fertilized pears averaged 145.2 grams each.

263. Effect of seed-bearing on the fruit.—It is a fact of considerable interest that there is commonly a correlation between the weight of seed and that of fruit. This of course loses force in the case of parthenocarpic fruits, since practically no seeds are developed. Not only is there a correlation in regard to size but also it is not uncommon to find a lack of full development in a portion of an apple or pear where no seeds have matured within the adhering carpel or carpels, thus giving somewhat one-sided fruits. This phenomenon is of wide application and may often be seen, for example, on examining a bean pod in which one or more ovules did not develop, resulting in a hardened constricture or other evidence of lack of development of the parts immediately surrounding the abortive ovules. In such cases, there is a lack of stimulation of the surrounding parts and,

[1] Proc. Amer. Soc. Hort. Sci., 14th Rept. 1917. pp. 94–101.

as no development of the seeds takes place, the fleshy or surrounding parts usually fail to develop also.

Not only is there an influence on the size of the fruit, but the number of seeds that has developed may also affect the quality, the more seeds the higher the quality. A striking case is that of the Japanese persimmon (*Diospyros Kaki*) [1] which develops many parthenocarpic fruits, but whether pollination is useful as a stimulation is not known. The fruits which develop seeds manifest a richer and better flavor than the seedless ones, and also other marked characteristics obtain. The seedless fruits are larger in size, of a smoother texture and usually ripen later than those developing seeds. Outstanding is the effect of the seeds on the color of the flesh. When seeds develop, the flesh is dark in color and light when seedless.

Heinicke records the relation between size of apples and the number of seeds that has developed. The following fruits of Fallawater apples were produced on spurs of equal vigor.[2]

Number of seeds	*Weight grams of fruit*
3	16.84
5	18.72
8	23.15
9	24.02
11	29.40

264. Artificial pollination.—The artificial pollination of common deciduous fruit blossoms is not practiced except for experimental purposes or the production of new varieties. Perhaps the nearest approach to any intervention by man is the occasional practice of placing flowering branches of plums or cherries in jars of water and hanging them in a

[1] Hume, H. H. Proc. Soc. Hort. Sci. 1913. pp. 88–93.

[2] Factors influencing the abscission of flowers and partially developed fruits of the apple. Proc. Amer. Soc. Hort. Sci. 1916.

tree of a self-sterile variety, thus affording insects an opportunity to effect cross-pollination.

When pollination is to be practiced artificially, for experimental purposes or for securing new varieties, it is usual to protect the essential parts of the flowers in order to assure accuracy. The blossoms which are to be used as the female parent are inclosed prior to the opening of the petals. The blossoms from which the pollen is to be secured are also protected in order to prevent a mixture with foreign pollen, by insects, or other agency. This covering is usually a paper bag, either manila paper or a translucent, paraffined bag being employed. A question has been raised occasionally as to whether an abnormal condition would not be produced in this way and thus reduce the possibilities of success. However, when coverings of cheese-cloth or other material allowing a passage of air have been used, no increase in efficiency has been noted. Others have covered the entire areas with a frame of muslin and either hand-pollinated the flowers or, in case the study is one of self-sterility, bees have been included. Such an equipment has some advantages, but the percentage of set is not greater than by the bag method.

In manipulating the flowers, it is customary to cover the blossoms just before they are ready to expand and expose the essential parts. If the purpose is cross-fertilization, the stamens (and often petals) are removed at time of bagging, before pollen has been exposed, so that danger of self-pollination is eliminated. It has been demonstrated that the removal of the sepals as well as the petals and stamens has no injurious effect in securing a perfect functioning of the pistils, if carefully done. When the work is performed by a novice or very hurriedly, it is doubtful whether this procedure is best, since fruits may be deformed by careless manipulation and many stigmas are often badly injured. The pollen from another tree is frequently collected in a glass vial and applied with a camel's-hair brush or the finger. Others pick the flowers and brush the anthers over the pistils of the female parent.

THE STERILITY PROBLEM

When it is recognized that many varieties of fruit exhibit self-sterility, inter-sterility, and self-barrenness, and hence require cross-pollination with some other variety, the subject becomes one of great economic importance. There is considerable variation of opinion in regard to the ultimate causes of sterility, and consideration here can well be confined to some of the established facts which closely pertain to pomology.

265. Definition of terms.—Self-sterility refers to the inability of a plant to develop fertile seeds when the pistil is pollinated with pollen from its own flower or from one of the same variety of fruit. Other meanings are given to it, such as lack of development of any fruit at all when the flower is self-pollinated. It must be understood that such a condition does not mean that either the pistils or stamens are defective but merely that fertilization does not take place, even though the pollen may germinate on the stigma, as often occurs; or if fertilization does take place, the young embryo does not complete its development. The ultimate reason for this phenomenon is not clear, but the phrase "lack of affinity" has been given to it. In other cases, the pollen may be defective and hence cause self-sterility, or the embryo sacs may be defective.

Self-fertility, on the other hand, refers to the ability of a plant to produce germinable seeds when its pistils are pollinated from the same flower, tree, or variety, *i. e.*, in the fertilization of the ovule, the male gametes were not derived from another variety or species.

Varieties are said to be inter-sterile when certain ones fail to fertilize one another, but are readily fertilized by the pollen of a still different variety.

These various phenomena must not be confused with the condition that exists in the case of imperfect flowers, such as with some of the strawberries. Here there is an actual lack of one of the essential organs (stamens). The term morphological self-sterility may be applied to this case, which is not infrequent with other fruits such as the grape and mulberry.

It has been shown that self-sterility is a heritable character but that it may be modified by changing the environment. Further, a tobacco plant which is ordinarily self-sterile may become partially fertile and produce a few seeds at the end of a flowering period and under conditions adverse to vegetative growth.[1]

While not particularly related to the sterility problem, the term parthenocarpy may here be defined. This indicates fruits which develop wholly independently of any pollination of the stigmas or fertilization of the ovules. The term refers to the development of fruit structures other than the seeds. This phenomenon is not uncommon with the apple and pear.[2]

Another case of interest and quite unlike the above is when the flesh of the fruit develops only if pollination of the stigmas has taken place. Fertilization may or may not follow pollination, but if so there is an abortion of the embryos at a more or less advanced stage and hence no viable seeds develop.

Thus, finally, all fruit-trees are classed as either barren or fruitful, and if the former they are always sterile, whereas

[1] East, E. M., and J. B. Park. Studies on self-sterility. Genetics, 2: 505–609. 1917.

[2] See Kraus, E. J., and H. R. Kraybill. Ore. Agr. Exp. Sta. Bull. 149. pp. 6–11. Also Sturtevant, E. Lewis. Seedless fruits. Mem. Torrey Bot. Club, Vol. I, No. 4, 1890.

a

b

c

PLATE VII.—*a*. Trees grown permanently in sod. *b*. Trees grown under the grass mulch system. *c*. The tillage-cover-crop system used in this orchard.

the latter may be sterile or fertile depending on the seed relationship.

266. Sterility not a constant factor.—Since the time of Darwin it has been known that self-fertility and -sterility of varieties of fruit may not be a constant characteristic, but that it may vary with the age of the trees, health and vigor, climate, general ecological conditions, and the like. This led to many disputes and apparent misstatements until the dual behavior of a variety was disclosed. The same tree may be self-sterile at one time and self-fertile at another. Vincent [1] reviews this question and calls attention to the case of the Yellow Newtown apple which is listed as self-sterile in one place and self-fertile in another, while the same variation is recorded for the Rhode Island Greening and Grimes Golden. Garcia reports the Bartlett pear as self-fertile in New Mexico while most other observers record it as quite self-sterile. Gardner [2] reports a similar variation with sweet cherries in different parts of Oregon.

267. Causes of sterility.—Kraus [3] divides the causes of sterility into two general groups: (1) morphological and (2) physiological. Several of the causes belonging to the first group are rather well known, while those of the second are more complicated and intangible. Among the more important of the former may be listed the following: (1) a lack of germinability of pollen which in some cases may amount to as much as 1 to 100 per cent; (2) imperfect pollen or pollen in which some of the structures have degenerated; (3) more complete abortive pollen as occurs with some of the parthenocarpic fruits; (4) imperfection of the ovules which is frequent in many kinds of fruit; (5) a physical impossibility of self-fertilization as with diœcious plants; (6) various

[1] Better Fruit, Feb., 1920.

[2] Ore. Agr. Exp. Sta. Bull. 116.

[3] The self-sterility problem. Jour. Heredity, Dec. 1915.

modifications of perfect flowers which prevent self-pollination; and (7) the possible case of the inability of the pollen-tube to grow sufficiently long to reach the ovary.

Among the physiological causes the following may be included: (1) possible lack of nourishment of the pollen-tube in the case of some pistils; (2) negative chemotactic action, although this is not known to occur with fruits; (3) possible toxic effect of the stigmatic fluid on the pollen or vice-versa (investigations tend to disprove this with the fruits); lack of fertilization; lack of development of the embryo after fertilization may have taken place. It might also be added that hybridity frequently results in entire sterility (heterosis). In studying the causes of self-sterility, it has been observed that there is a slow growth of the pollen-tube which results in a lack of fertilization, as with the Rome Beauty apple [1] and also with the tobacco.[2] In the latter case, it was noted that the pollen germinates as freely on the stigmas of flowers of the same plant as those of other kinds with which they are compatible. After germination, however, the pollen-tubes on selfed flowers grow so slowly that decay of the flower occurs before fertilization can be effected.

268. The cherry.—One of the most interesting cases of sterility that has developed in American pomology is that of the cherry. It had been known for some time that varieties of the sweet cherry in particular were inclined to be self-sterile and were not parthenocarpic, but it later developed not only that the sweet cherry was practically always self-sterile as grown in Oregon, but also that several of the standard varieties were inter-sterile.

This appears to be a clear case of "lack of affinity" between certain varieties and is not due to any lack of germin-

[1] Knight, L. I. Proc. Amer. Soc. Hort. Sci. 1917. pp. 101–105.

[2] East, E. M., and J. B. Park. Genetics, 3: 353–366. 1918.

ability of the pollen or to defective pistils, as was demonstrated by careful tests.[1] The three varieties notoriously inter-sterile are Bing, Lambert, and Napoleon, and mixed plantings of them will give little or no fruit unless they are within the range of influence of some other variety that is inter-fertile with them. Of those studied, the Black Republican, Black Tartarian, and Waterhouse seemed to be the most efficient pollinizers for this group.

While not entirely germane to the sterility problem, it is of interest to note that some members of the Duke group of cherries and also some varieties of the sour cherries (*P. Cerasus*) are capable of fertilizing some of the Bigarreaus. The sour cherries are usually credited with being self-fertile but there would seem to be many exceptions to this statement.

269. The almond.—Tufts [2] has shown that all the common varieties of almonds grown in California are self-sterile to a large extent and certain of them are inter-sterile. The honey bee is considered the best pollinating agent for the almond.

270. The grape.—The first important work in this country on the sterility problem of the grape was that of Beach, although Goff had previously shown that the variety Concord would set fruit as well when the clusters were covered with a bag as when left open. Beach found that "Cultivated American grapes show remarkable differences in the degree of self-sterility of different varieties. Many of them fruit perfectly of themselves. Others form no fruit when cross-pollination with other varieties is prevented. Most varieties are found between these two extremes, being neither fully self-fertile nor completely self-sterile." After

[1] Gardner, V. R. Ore. Agr. Exp. Sta. Bull. 116. 1913.

[2] Tufts, W. P. Almond pollination. Calif. Agr. Exp. Sta. Bull. 306. 1919.

testing 169 cultivated varieties (and many seedlings), he classified them as follows:

Class I.—Self-fertile varieties having perfect clusters or clusters varying from perfect to somewhat loose, 38 varieties (21.8%).

Class II.—Self-fertile varieties having clusters loose but marketable, 66 varieties (39.0%).

Class III.—Varieties which are so imperfectly self-fertile that the self-fertilized clusters are generally too loose to be marketable, 28 varieties (16.5%).

Class IV.—Self-sterile varieties, 37 varieties (21.8%). He also noted that varieties with short or recurved stamens are always self-sterile or nearly so. The explanation offered at that time for sterility was "a lack of affinity between the pollen and pistils of the same variety." [1]

Dorsey [2] illustrates the method of testing sterility from the work of Beach as follows:

"When 143 clusters of Brighton were covered with bags and self-pollinated, the average rating of the clusters formed, counting 100 as a perfect cluster, was approximately one, and when thirty-two clusters distributed among eight other varieties were pollinated with Brighton pollen, the average rating was three, showing Brighton, for those varieties used, as well as for itself, to be a poor pollenizer. On the other hand, when 116 clusters of the Catawba were selfed, the average rating on the same basis as above was eighty-six, as compared with one in Brighton. When the thirty-three clusters of eight other varieties were pollinated with pollen from Catawba, the average rating was sixty-seven, showing a marked difference between the Brighton pollen and the Catawba pollen when used either in selfing or crossing."

[1] N. Y. Agr. Exp. Sta. Bull. 157. 1898.

[2] Dorsey, M. J. Jour. Heredity, 6: 1915. p. 243. Minn. Agr. Exp. Sta. Bull. 144. 1914.

It has been shown [1] that a marked difference in appearance exists between the dry pollen of self-fertile and self-sterile grape varieties. The former or normal pollen is oblong in outline with slightly flattened ends, while the latter is quite irregular and folded, and fails to germinate when placed in a nutrient solution.

Dorsey has shown that the development of the pollen in self-sterile varieties of the grape is normal "up to the formation of the microspores, but here a degeneration takes place which renders the pollen grains (microspores) sterile." A careful study of the pollen produced by those varieties which bagging tests have shown to be more or less self-sterile, show that the generative nucleus and, in some cases, also the vegetative nucleus, degenerate. Such degeneration precludes the possibility of normal functioning in every pollen-grain where it occurs. Sterile pollen in the grape, then, is due to degeneration in the generative nucleus.

He has also shown that "the germ spores are not formed in pollen borne by the reflexed type of stamen."

To summarize the causes and correlations in the sterility of the grape, the following statements seem warranted from present knowledge:

1. Self-sterility in the grape is due to defective pollen and not to the pistils.

2. "All varieties tested set fruit when potent pollen was used, which shows that the pistils are normal."

3. Potent pollen can be distinguished from impotent by its shape when dry.

4. Impotent pollen is correlated with the reflexed type of stamens.

5. The defective pollen is due to an abortion of the generative nucleus.

These studies lead to one very practical recommenda-

[1] Booth, N. O. N. Y. State Agr. Exp. Sta. Bull. 224, 291–302. 1902.

tion, viz., mixed plantings of the grape will be more fruitful than those of one variety only.

271. The plum.—Some of the most extensive investigations on the self-sterility problem have been with the plum, notably by Bailey,[1] Waugh,[2] Hendrickson,[3] and Dorsey.[4] There is a general tendency throughout the plum species to self-sterility but there are many exceptions, as would be anticipated from a knowledge of the problem. The *salicina* (Japanese) varieties are as a rule self-sterile and self-barren. The Climax is the only one of several kinds observed by Hendrickson to be self-fertile in California. He also reported that, in general, the early blooming Japanese varieties such as Combination, Kelsey, and Satsuma, are scanty pollen-producers and not effective pollinizers, while the later blossoming sorts such as Burbank, Wickson, Climax, Sultan, and Abundance produce pollen abundantly and are effective pollinizers.

Varieties of the native American species of plums vary in regard to the sterility character but are much inclined to be self-sterile, as is notable in the case of the Wild Goose which is perhaps more generally grown than any other single kind. They are for the most part fully inter-fertile, however, so that one given variety will pollinate any other, providing the two bloom at the same time.[5] Waugh has shown that in the *P. americana* group the pistils are frequently defective, averaging 21.2 per cent in the trees studies. The anthers are also defective in some cases but not so frequently as the pistils. In some cases, the anthers mature before the

[1] Bailey, L. H. Cornell Agr. Exp. Sta. Bull. 52, 106, 139, 175.

[2] Waugh, F. A. Vt. Agr. Exp. Sta. Ann. Rept. 1897–98, 1898–99.

[3] Hendrickson, A. H. Plum pollination. Calif. Agr. Exp. Sta. Bull. 310. 1919.

[4] Dorsey, E. J. Jour. Agr. Res. 17: No. 3, 1919.

[5] Waugh, F. A. Standard Cycl. Hort. V: 2719. (1916.)

pistils are receptive (proterandrous), while in other cases the pistils mature before the pollen is ripe for pollination (proterogynous).

It is true, however, as has been stated, that the Japanese and American plums are generally inter-fertile both within their respective species and also in hybridizing between the species. *P. americana* is less inclined to hybridize than some other species of American plums.

The Domestica plums (European species) are variable, some varieties being self-fertile and others self-sterile,[1] but as a class they may be considered inter-fruitful.[2] They are, however, largely inter-sterile with Japanese and American plums but may be inter-fertile to some degree, as indicated by Hendrickson.[3]

He has shown also that the French prune is abundantly self-fertile in California if bees are present to work over the blossoms, but that the Imperial prune is very much less so. His work with these varieties well illustrates the value of the common honey bee as an agent in prune pollination.[4] The following data which he obtained are self-explanatory:

[1] Bailey, L. H. Principles of Fruit-Growing, 20th Ed. p. 158. 1915.

[2] Marshall, Roy E. Proc. Amer. Soc. Hort. Sci. 1919. p. 42.

[3] Hendrickson, A. H. Proc. Amer. Soc. Hort. Sci. 1919. p. 50.

[4] As an interesting side light on the application of these pollination studies, the following excerpt is quoted from W. L. Howard, letter, dated March 11, 1920. "Our investigations in the Santa Clara Valley, carried on for five years, showed that bees are an important factor in prune pollination. Before our investigations were started, bee men paid the fruit growers from 50c to $1.00 an acre for the privilege of pasturing their bees in the orchards during the blooming season. Since our experimental findings were published, three years ago, there has been a complete change in the situation. This season bee men have been able to rent every hive they have to fruit growers for from $2.00 to $3.00 per hive, depending upon whether they are bunched in one place or scattered over the orchard."

TABLE LXXXVI

BEHAVIOR OF FRENCH PRUNE TREES WITH AND WITHOUT CROSS-POLLINATION (AFTER HENDRICKSON)

		1916	1917
		Per cent	Per cent
FRENCH PRUNE	Average orchard set	3.5	13.2
	Set on trees from which bees were excluded	1.04	0.43
	Set on trees inclosed with bees and with an Imperial prune tree	18.05	15.5
	Set on tree inclosed with bees alone	.....	19.4
IMPERIAL PRUNE	Average orchard set	7.2	7.2
	Set on trees from which bees were excluded	0.0	0.34
	Set on trees inclosed with bees and with French prune	1.7	7.9
	Set on trees inclosed with bees alone	.....	3.02

In many cases of experimentation, plums have been more highly inter-fruitful than inter-fertile, some producing fruits which contained abortive seeds.

272. The peach.—Unlike practically all other fruits, the peach, as a rule, is quite self-fertile and capable of setting and maturing a crop when self- or close-pollinated.

Fletcher reports, "The results of hand-pollinating 2939 Gold Drop peach blossoms in 1906 showed no benefit to this variety from cross-pollination with St. Johns, Late Cranford, or Lewis; the self-fertilized fruits were perhaps a trifle superior." All experiments confirm this work in general and the recommendation that peaches of one variety may be planted in a solid block is standard, although growers frequently feel that they prefer to mix them somewhat.

273. The quince is reported by Waite to be nearly as fruitful when self-pollinated as when cross-pollinated.

274. The apple.—As a class, the apple is inclined to be self-sterile although a number of varieties are known to be at least partially self-fertile. In contrast with the grape, the sterility is, according to Kraus, "due almost wholly to embryo abortion," and Knight [1] says also to lack of pollen-tube growth. From a practical standpoint, it is always better to have mixed plantings than a solid block of one variety, although the latter may be successful under some conditions.

Waugh worked with eighteen varieties of apple commonly grown in New England and reported them all to be practically self-sterile. Out of 2586 blossoms covered, only three apples set, or 1/10 of 1 per cent.

Lewis and Vincent reported that of eighty-seven varieties tested, fifty-nine were self-sterile, fifteen self-fertile, and thirteen partially self-fertile.[2]

Waite states that "The varieties of apples are more inclined to be sterile to their own pollen than the pears. With the former, in the great majority of cases, no fruit resulted from self-pollination."

Alderman [3] investigated the Rome Beauty, York Imperial, and Wagener for a period of three years, with the following results:

[1] Proc. Soc. Hort. Sci. 1917.

[2] Ore. Agr. Exp. Sta. Bull. 104. 1909.

[3] *Loc. cit.*

TABLE LXXXVII

EFFECT OF CROSS-POLLINATION ON THE SET OF FRUIT
(AFTER ALDERMAN)

	Number blooms	*Fruits set*	*Per cent set*
Rome Beauty, not crossed	16,826	168	.99
Rome Beauty, crossed	20,587	702	3.41
York Imperial, not crossed	21,742	129	.59
York Imperial, crossed	25,775	2,137	8.29
Wagener, not crossed	3,407	43	1.26
Wagener, crossed	6,993	611	8.73

Here it will be seen that the set of fruit was materially increased by crossing. The percentage of set was increased with the Rome three and a half times, with the York fourteen, and with the Wagener seven times. In addition, the weight of the Rome was increased nearly 28 per cent and the York 42.7 per cent over the size of the self-pollinated fruits.

275. The pear.—Since many varieties of pears are self-sterile and probably because of the influence of the work of Waite,[1] considerable attention has been given to a study of this fruit. Bailey [2] says "Many of the varieties of pears are infertile with themselves: they need the pollen of other varieties to cause them to set fruit freely. Probably any variety will fertilize any other variety in case the two bloom simultaneously." Waite showed that out of thirty-six varieties tested, twenty-two were self-sterile, but called particular attention to the sterility of the Kieffer.

Fletcher [3] has shown that "unsatisfactory results may be expected from planting either Bartlett or Kieffer in large blocks, so that cross-pollination by insects is not general.

[1] *Loc. cit.*

[2] Standard Cycl. Hort. V: 2506.

[3] Va. Agr. Exp. Sta. Ann. Rept. 1909–10. pp. 213–224.

Anjou, Lawrence, Duchess, and Kieffer are satisfactory varieties for planting with Bartlett so far as pollination is concerned. Some years Kieffer does not blossom simultaneously with Bartlett, but usually the blossoms overlap sufficiently. Le Conte, Garber, Lawrence, Bartlett, Duchess, Anjou, and Clairgeau are satisfactory varieties for planting with Kieffer, so far as pollination is concerned. Some seasons the latter five varieties do not blossom simultaneously with Kieffer, but usually the blossoming seasons overlap sufficiently."

He obtained the following results under Virginia conditions:

Table LXXXVIII

RESULTS OF SELF- AND CROSS-POLLINATION OF BARTLETT PEAR (ATER FLETCHER)

Pollinations	*Average amount of blossoms set*	*Average weight of mature fruit, ounces*
Bartlett x Bartlett	1 in 513	2.00
" x Kieffer	1 in 10	3.00
" x Anjou	1 in 7	3.75
" x Lawrence	1 in 9	3.50
" x Angouleme (Duchess)	1 in 10	3.50

In California the Bartlett is grown very extensively and, in spite of the advice given to the growers to inter-plant with other varieties, there are large blocks planted alone. As a result of this situation, some experiments were conducted during 1916–18 by Tufts [1] to determine the status of the sterility (barrenness) of this variety in California and to determine the best pollinizers, if such are necessary.

It was found that the Bartlett is to a limited degree self-sterile under valley conditions, but entirely so in the foot-

[4] Tufts, H. P. Calif. Agr. Exp. Sta. Bull. 307. 1919.

hills. Hence it is advisable to inter-plant with one or more varieties for cross-pollination purposes. These experiments showed that the Angouleme, Anjou, Clairgeau, Comice, Dana Hovey, Easter, Howell, and Winter Nelis will all pollinate the Bartlett successfully.

It was also learned that no cases of inter-sterility existed between the varieties studied and, therefore, any which blooms with the Bartlett will be a suitable pollinizer. Also, there does not appear to be the same tendency to fall at the June drop if cross-pollination has taken place.

CHAPTER XIII

THE ORIGIN AND IMPROVEMENT OF FRUIT

In a study of the vast number of fruit varieties now grown in America, the fortuitous nature of their origin is impressive. The larger part of the varieties of apples planted in this country originated here, but the history of many is obscure and only a very few came into existence as the result of direct breeding. This statement is true in large part for the other fruits also, in contrast to such other horticultural crops as flowers, ornamentals, and vegetables. Some workers have devoted their lives to the production of new fruits, but not until comparatively recent times have practical results of much consequence been secured through breeding.

The history of the activities of man in the origin and establishment of American pomology is highly interesting, much of it being available in the writings of Bailey.

The outstanding difficulties in the production of new fruits by breeding or in the study of the laws of inheritance as they pertain to fruit-trees are: (a) the length of time required to secure the fruit of a new generation; (b) the small number of individuals that can be handled in such work with the larger tree-fruits; and (c) self-sterility, which is often encountered in lines of attack.

The first great stimulus to the breeding of fruits came from the conspicuous work of Van Mons in Belgium and Knight in England. The theories and work of these men should be perpetuated in our literature.

276. Theory of Van Mons.—Jean Baptiste Van Mons was a celebrated chemist of Belgium (1765–1842) who became interested in the improvement of fruits, particularly the pear. He placed himself in the unfortunate position of conceiving a theory and setting about to prove it. However, in so doing, he greatly stimulated the science of plant-breeding; and although his theory was without foundation, the net result of his work is a landmark in the progress of the origination of new varieties of fruits.

His theory, in brief, may be summarized as follows:[1] All fine fruits are artificial products; the aim of nature, in a wild state, being only a healthy vigorous tree, and perfect seeds for continuing the species. It is the object of cultivation, therefore, to subdue or enfeeble this excess of vegetation; to lessen the coarseness of the tree; to diminish the size of the seeds; and to refine the quality and increase the size of the flesh or pulp.

There is a tendency for fruit-trees to return, by means of their seed, to a wild state, and such a tendency is more marked in old trees than in young ones. Hence, the older a tree is the nearer will the seedlings raised from it approach a wild state, although they will never return entirely to it. Therefore, in order to secure superior varieties, the seed from young trees only should be selected, as these are in a state of amelioration. Again, there is a certain limit to perfection in fruits. When this point is reached, as in the finest varieties, the next generation will be more likely to produce poor fruit, than that from seeds of an indifferent sort in the course of amelioration.

In following out this theory, Van Mons began with seeds from inferior sorts and sowed a new generation as soon as fruit could be procured from the last sown, continuing this process year after year. "To sow, to re-sow, to sow again,

[1] Van Mons, J. B. Arbres Fruitiers. 1835–36. Downing, A. J. Fruits and Fruit Trees of America. 1900. pp. 5–7. Bailey, L. H. The Survival of the Unlike. pp. 141–151. 1897.

to sow perpetually; in short to do nothing but sow is the practice to be pursued and which cannot be departed from."

He concluded that pears require the longest time to attain perfection, and he carried the process with this fruit through five generations. Apples, he found, needed but four races, and peaches, cherries, plums, and other stone-fruits were brought to perfection in three successive reproductions from the seed.

"Van Mons' work, which was largely confined to pears, was begun in 1785. Thirty years later, in 1823, when he had commenced distributing scions freely throughout the world, he had 80,000 seedling trees in his nursery. At this time his first catalog was issued and in it 1050 pears were mentioned by name or number. Of this list 405 were his own creation and 200 of them had been considered worthy of naming, among them being some of the varieties still raised the world over, including Diel, Bosc, Colmar, Manning's Elizabeth, and many others of equal merit.

"Probably no worker with plants has ever given to the world so clear a demonstration of the value of selection as Van Mons; and this demonstration is worth all the efforts put forth, even though this was made in the attempt to prove another and, as is now believed, erroneous doctrine." [1]

277. Work of Knight.—Thomas Andrew Knight (1759–1838) was the first practical and scientific breeder of fruits. Bailey describes him as a man "who in the variety, accuracy, significance and candor of his experiments stands to the present day without a rival amongst horticulturists." He conducted experiments which are still standard in plant physiology and horticulture.

Knight avoided the error of Van Mons, that of having a theory to prove, but devoted himself to a study of nature

[1] Munson, M. W. Plant breeding in its relation to American pomology. Maine Agr. Exp. Sta. Bull. 132. 1906.

and to the results of his manipulation of plants. Van Mons worked entirely along the line of selection of the best from each generation, but Knight was the first actually to cross-breed fruits in order to secure better varieties. That his conception of the problem was different from that of Van Mons and far in advance of it is shown from the following statement (1806): "New varieties of species of fruit will generally be better obtained by introducing the farina of one variety of fruit into the blossoms of another, than by propagating any from a single kind." His investigations included apples, pears, plums, peaches, nectarines, cherries, and strawberries, and he produced several varieties of each which were standard in their day. Hence to this early worker is owed the beginning of real progress in the improvement of fruits and the methods to be employed in securing them. Knight spent considerable time in studying the duration of varieties of fruit. This work, while not entirely germane to the present subject, is worth recording, although it is not now accepted. His theory may be briefly summarized as follows:

The life of a variety of fruit is about as long as the life of the original tree which produced it; cions or buds taken from the tree will not come into bearing until the original tree bears fruit; and all trees propagated from the parent will die soon after the death of the original tree. Or, in other words, the life of a variety is about as long as the natural life of the tree which produced it.

This, then, is a brief statement of two of the most interesting personalities in horticulture. It will be instructive to contrast their views with some of the more modern theories in the breeding of horticultural plants.

278. Selection as a means of securing new fruits.— The voluntary act of selection must enter into every method of securing new or improved varieties of fruits. It refers to the individual choosing of forms that meet the ideal of the person conducting the work and has been unconsciously practiced by man in all stages of civilization since the time he began to cultivate plants and to domesticate animals. With plants commonly grown from seed, such as grains and vegetables, this method of improvement has found wide usage and has been claimed by some to be the only means necessary. This belief is founded on the principle of variation, and on the fact that all possible genetic combinations may occur in natural crosses. With fruit-trees, however, selection as a method of plant improvement has been given less attention, as fruits are reproduced asexually. Every Baldwin apple or Elberta peach tree is a part of the original tree which was a chance seedling.

Such being the case, there remain but two methods of selection with fruits: namely, of bud sports or mutations, and of new forms that have come from seed. The latter may properly be subdivided into three phases: (1) a choice of trees that are chance seedlings, in the origin of which man has played no part; (2) a selection of the superior trees from a miscellaneous lot of seeds sown; and (3) a selection of trees which result from flowers crossed or hybridized by the grower.

First, it must be recognized that man has nothing whatever to do with the occurrence of the superior individual or variety under the first two methods of selection, but rather he "finds" it. On the other hand, through crossing or hybridizing, new forms may be secured by the combination of desirable characters within one plant, or by "breaking the type" or causing the original plant to vary.

The chief methods of selection commonly used in improving plants are: (1) mass; (2) line; and (3) clonal selection. The method will of necessity depend on the object in view and the nature of the material used in breeding.

The terms "mass selection" and "line selection" cannot properly be applied to the methods employed in obtaining new fruits. They refer to securing an improved variety in plants that are propagated sexually (*i. e.*, by seed), where an effort is made in each generation to obtain individuals that will be superior to the original form.

279. Mass-selection refers to the choice of several superior individuals from which seed would be sown *en masse*, no effort being made to keep the progeny from any single plant separate; and from the new individuals which arise, the superior ones would again be selected, until a strain or race is secured which is superior to the original stock. Such a process has never been undertaken with fruit-trees, since it is not necessary for a variety to be homozygous in order to propagate it asexually or for it to have superior fruit characteristics.

The term mass-selection may be applied in a broad way to the method used by Van Mons and to that of Burbank. Seeds selected from one or more trees (themselves heterozygous) are planted in order to secure a large number of new individuals. From these new forms the superior ones are selected, usually after they come into fruiting, and are propagated as new varieties with no further selection.

280. Line-selection has no special application to fruits because, as yet, no one has tried to secure a race or variety which will come true from seed, as is necessary with the common farm and garden crops. With the latter plants, the term refers to a line of progeny derived originally from one individual.

281. Clonal-selection.—The term "clonal-selection" applies only to plants which are propagated asexually, hence to fruit-trees. Clones have been defined as "groups of cultivated plants the different individuals of which are simply transplanted parts of the same individual, the reproduction being by the use of vegetative parts such as bulbs, tubers, buds, grafts, cuttings, runners, and the like. The various sorts of apples, . . . commonly denominated varieties in a more restricted sense would be clons. Clons of apples, pears, strawberries, and the like, do not propagate true to seed, while this is one of the most important characters of races and strains of wheat, corn and others." (Webber.)

Hence, any selection for propagation of superior trees of any of the fruits would properly be termed "clonal-selection." Thus, a tree which appears different from others in a plantation or is superior to them, as being a regular or heavy bearer, having better color, quality, or size of fruit, or being particularly hardy, might be selected for the purpose of propagating a desirable variation within the clone. The term "strain" is commonly used in referring to such differences.[1]

282. Bud-selection, as commonly used in horticultural literature, refers to the selection of a bud or branch which shows a superiority over or difference from the remainder of the tree. Instead of the whole tree being the unit of variation, the individual bud is the unit and is so selected. Before discussing the improvement of fruits by clonal- or bud-selection, it should be determined whether such variations occur within the tree-fruits. The data refer to deciduous fruit-trees for the most part, although the bud variations which have been reported for citrus fruits are so conspicuous that they are mentioned in this connection.

283. Individuality of fruit-trees.—It is well known that many plants have given rise to bud-sports or mutations, particularly under high cultivation, such as greenhouse roses and carnations. Here such variations as the occurrence of a pink rose on a plant producing white ones or a change in form of the flower have been so distinct as to be unmistak-

[1] Babcock and Clausen. Genetics in Relation to Agriculture. McGraw-Hill Co., New York. 1916.

able. With fruit-trees it has been more difficult to determine between variations due to environment and not of a permanent character and those which are true bud-sports.

The following data are presented to show that decided variations do occur between fruit-trees of the same variety (clones) and between branches of the same tree, but whether they are due to internal or external causes is not determined. It is assumed that the trees are always comparable and that there is no apparent external cause for the variation.

TABLE LXXXIX

THE VARIATIONS IN YIELD OF BEARING APPLE TREES AS REPORTED BY SEVERAL EXPERIMENTAL STATIONS IN AMERICA

New York [1]		
Trees, exp. sta. numbers	*Total yield for 10 years, bushels*	*Ratio*
2 and 6	246.5	179.6
1 and 4	137.2	100.0
Canada [1]		
	Total yield for 14 years, gallons	
4 trees	477.94	288.0
4 trees	165.50	100.0
Maine [1]		
	Total yield for 5 years, barrels	
10 trees	157.9	415.5
10 trees	38.0	100.0

[1] Stewart, J. P. Penn. Agr. Exp. Sta. Ann. Rept. 1911.

TABLE LXXXIX—*Continued*

New Hampshire [1]

Tree		*Total yield for 6 years, pounds*	
	No. 3............	4432	860
Group A	No. 4............	1527	269
	No. 15...........	515	100
	No. 278..........	4204	711
Group D	No. 280..........	6817	1153
	No. 281..........	591	100

It will be seen from this table that there are conspicuous differences in yield of seperate trees or sets of trees in the same orchard. The time covered by these records is sufficient to eliminate short-time differences. Such variations in yield have an important economic bearing and some of the outstanding instances of attempts to improve fruits by bud-selection may be noted.

284. Results of selecting bud variations.—If the data are granted to prove that decided variations occur between trees and their branches and that they are consistent year after year, then the question arises as to whether such variations are permanent in nature (mutants) or whether they are due to some undetermined local condition (fluctuating variations) and hence are not transmissible by asexual propagation. Unfortunately, sufficient work has not yet been done to establish this point definitely, but most of the evidence for deciduous fruit-trees warrants the conclusion that such variations cannot usually be propagated (asexually) and hence the burden of proof lies with those who make such

[1] Gourley, J. H. N. H. Agr. Exp. Sta. Tech. Bull. 9. 1915. See also Gardner, V. R. Bud selection with special reference to the apple and strawberry. Mo. Agr. Exp. Sta. Res. Bull. 39. 1920.

claims. There are a few cases, however, which indicate the origin of new varieties in this way, although for the most part they represent an increase or change in color, as variation of other characteristics is not common.

Among apples, the Banks is recorded as a bud-sport of the Gravenstein, differing from the latter in being more highly colored, less ribbed, more regular in shape, and a little smaller in size. Other sports of the Gravenstein have been reported in Europe and in this country. Two bud-sports are credited to the Twenty Ounce apple—Collamer and Hitchings. The former bears fruits less mottled and striped, more highly colored and more regular in shape. The twigs of Collamer trees are more deeply tinged with red than are those of Twenty Ounce. Hitchings also produces more highly colored fruit than its parent. The same sort of mutation has been recorded in several places for Rome Beauty, the fruit of the new forms being a solid dark red, smaller, and quite regular in size.

Red Russet is another bud-sport which originated in New Hampshire as a variation of Baldwin. This is the only authentic variation of the Baldwin which has been propagated, although it varies widely in different localities.

Dorsey [1] describes an "improved Duchess" apple which seems to be a bud mutation, although conclusive evidence cannot be produced. The new form is identical with the old in all characters except color, which is much brighter and redder. Trees propagated from the red type retain the character, and this seems to add another to the list of fruits originating as bud mutations.

Another interesting case of a bud-sport or mutation described by Shamel [2] is an improved French prune. This

[1] Dorsey, M. J. Jour. Heredity, Dec., 1917. p. 565.

[2] Shamel, A. D. Origin of a new and improved French prune variety. Jour. Heredity, Nov., 1919. pp. 339–343.

variety is grown more largely in California than any other, but the small size has been a matter of concern, and many efforts have been made to improve it. Leonard Coates, a nurseryman and fruit-grower of Morganhill, California, observed a branch of a French prune tree that produced fruit of large size. Grafts of it were inserted into peach stock and the new form was found to be identical with that of the original branch. Extensive tests were made to determine its value, and so successful do they appear that it is believed it may prove to be "the most valuable addition to the commercial prune varieties ever introduced in America."

There are no known cases of bud variations of the cherry, and only four mutations of the peach out of 2181 varieties described by Hedrick in "The Peaches of New York."

Knight records the case of a Yellow Magnum Bonum plum, one branch of which bore red Magnum Bonum fruits.[1] A Coes Golden Drop is reported by Powell as producing a branch which bears red fruit. An Isabella grape vineyard, in California, is said to have produced several mutating vines which bore fruit superior in quality to the mother plants, and that have been propagated under the name "Pieree." The Golden Queen raspberry originated as a sport from Cuthbert, formerly called Queen of the Market, and was introduced to public notice by J. T. Lovett, Little Silver, New Jersey.

The occurrence of nectarines as bud-sports on peach trees is, of course, common and has been observed by horticulturists for a long time.

Whitten took cions from a high- and low-yielding Ben Davis tree in 1895 and has observed trees propagated from them until 1917. He says: "Summing up the results for the entire period of years since the trees came into bearing

[1] Munson, W. M. *Loc. cit.*

there is no significant difference between the total yield of the trees of high yielding parents and low yielding parents." [1]

Stewart [2] reports an experiment in which trees showing marked variation in yield and color were propagated and planted for observation. At the time of his report, however, no progress had been made which would indicate that such superiority had been transmitted, thus again pointing to the conclusion that the differences were due to environment.

Macoun [3] also propagated some trees which showed marked variation in yield, amounting to 100 and 200 per cent difference, and records were kept on the yields from the trees. However, no decided evidence is at hand after they have produced three crops to substantiate any claim that they will be superior in bearing.

Extensive observations have been made in recent years of bud variation of orange, lemon, and grapefruit trees by Shamel [4] and others. These fruits, particularly certain varieties, are found to be in a very variable condition, and bud-sports are frequently observed with a number of the characters of both tree and fruit. In recording the performance of the trees, such characters are observed as: habits of growth of the trees; characteristics of the bloom; season and amount of production of fruit; size, shape, and color of fruit; texture, thickness, and appearance of the rind; amount and quality of the juice; and other tree and fruit characteristics.

Shamel states in regard to lemon trees that "The productive strains in every case known, produce a higher percentage of first-grade commercial lemons than the unproductive

[1] Whitten, J. C. Mo. Agr. Exp. Sta. Bull. 163. p. 55. 1919.

[2] Stewart, J. P. Penn. Agr. Exp. Sta. Bull. 134.

[3] Macoun, W. Dominion Exp. Farmers Bull. 86. 1916.

[4] Shamel, A. D. Bud variation in lemons. Jour. Heredity, Feb., 1917. Lemon orchard from buds of single selected tree. Jour. Heredity, Nov., 1918.

strains. For example, about 80 per cent of the crop of tree of the productive strain of the Eureka variety in the performance record plots has been of the best grade, while the unproductive strains have produced only about 20 per cent of the best grade of fruit." This statement does not refer to orchards which have been propagated from superior trees, but rather to superior trees under observation in orchards. However, several citrus orchards are now in bearing in California which have been propagated from superior trees or branches, and according to their records give distinct promise of perpetuating the desirable characters of the parent trees.

285. Plant introduction.—In colonial times it was not surprising to find that many European fruits were introduced into America regardless of their adaptability. As a result there were many failures,[1] and not until seedlings of these as well as of native sorts began to appear were valuable American fruits secured. The entire history of American pomology is intimately associated with that of the introduction of foreign fruits. England, continental Europe, Siberia, Japan, and China have all made contributions to the present catalogue of fruits.

Perhaps the most interesting chapter in the history of fruit introductions is that dealing with the effort to secure hardy fruits from Russia. These fruits, which were introduced during the 70's and 80's of the last century, were heralded as the solution of apple-growing in the cold parts of the United States and Canada. Enthusiasm ran high for several years, but at the present time few of the varieties so introduced are considered valuable and the chief interest lies in using their seedlings for hardy stock on which to work other sorts and also for producing new varieties either from seedlings or from crosses.

[1] Bailey, L. H. Survival of the Unlike. Macmillan Co., New York. 2nd Ed. 1896. Evolution of Our Native Fruits. Macmillan Co., New York. 1898.

286. Chance seedlings.—It is well known that the larger number of varieties of the tree-fruits originated as chance seedlings and were discovered and introduced into cultivation by some observer and admirer of them. Hedrick and Wellington [1] review this matter in regard to the apple and say that "of the 3000 or more varieties which have been described, nearly all, as their histories show, have come from chance seedlings." Beach describes 698 varieties in "The Apples of New York" and of these "no case is recorded of a variety known to have come from a self-fertilized seed." Even the seed parent is given for only thirty-nine varieties in all, while the seed and pollen parent is known certainly for only one (Ontario). Both parents are named for the Pewaukee and Gideon, but in each case one of the parents is guessed. Seventy-one are listed as coming from chance seedlings, *i. e.*, from seed sown without knowledge of either parent or from natural seedlings. The origin of 517 of the 698 varieties is unknown. However, progress is being made and several new varieties, produced by breeding, are about to be introduced from some of the experiment stations.

TABLE XC

ORIGIN OF THE COMMON FRUITS

	Both parents known	*One parent known*	*Neither parent known*	*Originated as bud sport*	*Total*
Apple......	2 (?)	39	588 (?)	4	633
Cherry.....	20	61	1064	0	1145
Grape......	74	57	72	0	203
Plum.......	49	108	542	1	700
Peach......	37	214	1765	1 (?)	2181
	182	479	4031	6	4862

[1] Hedrick, U. P., and Wellington, R. An experiment in breeding apples. N. Y. (Geneva) State Exp. Sta. Bull. 350. 1912.

For cherries, Hedrick has searched the literature and finds that little is known in regard to their origin. The histories of the varieties described in "The Cherries of New York" show that nearly all of them have come from chance seedlings. No case is recorded of a variety known to have come from self-fertilized seed. The seed parent is given for sixty-one of 1145 varieties. The seed and pollen parents of twenty of the cherries described are given. Of these, sixteen are hybrids originating with N. E. Hansen, of South Dakota, leaving but four sorts the parents of which were known before the recent work of Hansen. Cherries arising from seed sown without knowledge of either parent or from natural seedlings are put down as chance seedlings. Of these there are 147. The origin of 1064 of the varieties described by Hedrick is unknown.

In "The Peaches of New York," Hedrick describes 2181 varieties of peaches, no one of which is known to have come from a self-fertilized seed. The seed parent is given for 214 varieties; the seed and pollen parents for 37 varieties. Of chance seedlings, sorts from seed with neither parent known, there are 161. The origin of 1765 out of a total of 2181 varieties described is unknown.

287. Work in Canada.[1]—The low winter temperatures and the relatively short growing season in many parts of Canada have made it necessary to secure varieties of fruits which would be adapted to such climatic conditions. It, therefore, devolved on the earlier workers in that country either to introduce or to originate new varieties, as standard commercial sorts were not sufficiently hardy.

[1] Macoun, W. T. The apple in Canada. Dom. Canada Dept. Agr. Bull. 86. 1916. Apple breeding in Canada. Proc. Amer. Pom. Soc. 1917. pp. 11–27. Saunders, Wm. Hardy apples for Canadian Northwest. Central Exp. Farms. Bull. 68. 1911. Macoun, W. T. Apple breeding in Canada. Amer. Breed. Assoc., Vol. 8, 1911. pp. 479–487.

Great credit is due the amateur and professional horticulturists of Canada for the results of their efforts along this line. Not only have they produced varieties of apples which are hardy in sections where previously no fruit could be grown, but they have also arrived at some conclusions which will be of value to future plant-breeders.

The Central Experimental Farms, where most of the work is conducted, are located at Ottawa, but there are also several substations at various points in the Dominion. At Ottawa, 734 named varieties of apples have been tested as well as many unnamed seedlings; also 160 Russian sorts, though many which were at first thought to be different have proved to be identical.

The first recorded apple breeding in Canada seems to be that of Charles Arnold, of Paris, Ontario. He made several crosses between Northern Spy and Wagener and exhibited eighteen of the cross-bred apples in Boston in 1873. One of these apples, which was named Ontario, has attained some commercial importance.

In 1869 Francis Peabody Sharp, of Upper Woodstock, New Brunswick, began some crossing with apples, having as his object the production of an apple of extreme hardiness and productivity. He used as parents the New Brunswicker —either Oldenburg or very similar to it—and Fameuse (as the male). Several of his crosses have been propagated, but Crimson Beauty is doubtless the best known and is most widely distributed commercially.

The first extensive work in growing seedling trees was begun in 1890 by William Saunders when an orchard of about three thousand seedling trees was planted. The seed from which these trees were grown came from north of Riga, Russia. About fifty of them began to bear in 1897. "The number of trees was gradually reduced by winter-killing, by fire-blight, or were removed on account of weak growth and inferior quality. All but a few of those which fruited were as good as the named varieties of Russian apples."

Again in 1898 a large number of seedling trees was planted by Macoun. The seeds were taken from varieties of standard quality, such as McIntosh, St. Lawrence, Fameuse, Wealthy, Gano, and Northern Spy. Excellent results were obtained, and in 1916 he reported that "During the past twelve years, 1211 of these seedling varieties have fruited, and of these, 83.30 per cent were of marketable size (medium to large) and only 3.95 per cent were small or crab-like. Of the 1211 varieties, there have been 378 considered so promising that they are being propagated for further test and 99 of the best have been named." Some of the hardiest of his apples have fruited as far north as latitude 58°, at Fort Vermilion on Peace River.

In addition to this work, a somewhat different procedure was followed by Macoun in 1910. Seed was saved of the hardiest Russian apples, including Transparent, Charlamoff, Oldenburg, Tetofsky, and Hibernal. The seedling trees were sent to the prairie provinces, where the winters are particularly severe, and planted in nursery rows. After three years, any that survived the winter were transplanted to an orchard for further trial, and in this way the hardiest trees were selected and those producing worthy fruit were retained for propagation.

Special work is also being conducted with crossing and hybridizing apples. Preliminary studies are being made on the transmission of fruit characters as a basis for future investigation. This work in crossing was begun by William Saunders about 1894. He introduced the berried crab (*Pyrus baccata*) from Russia several years before; and after determining its hardiness he made crosses between that species and many of the best and hardiest sorts of apples (*P. Malus*) grown in Ontario. In 1896 he used another hardy wild crab, known as *P. prunifolia*, in his crosses. The best hybrids obtained from these crosses with *P. baccata* and *P. prunifolia* were again crossed with the large fruited *P. Malus* and thus he introduced a second quota of "blood" of the larger varieties. Several of these second crosses are now fruiting and are promising sorts.

From the work in Canada the following conclusions are reached in regard to originating new varieties of apples:

1. To produce a hardy apple where no apples have yet been hardy: (a) cross the apple with the wild Siberian crab (*Pyrus baccata*); (b) sow seeds of apples which have ripened in a climate as nearly similar as possible.

2. To produce a hardy long-keeping apple of good quality: sow seeds of long-keeping varieties of good quality of which both parents are long-keeping.

3. To produce an apple having certain characteristics, as regards hardiness, vigor, and productiveness of tree, and quality, size, and appearance of fruit: sow seeds of varieties having most of the characteristics desired.

4. In cross-breeding apples where quality is an important factor, as it should be in most places, cross two varieties which are both good or very good in quality. It has been the experience at Ottawa that in crossing a variety of good quality with one inferior, the crosses will nearly always bear fruit of a quality inferior to that of the better parent.

288. Work of Peter Gideon and other pioneers in the United States.—The name of Peter Gideon will always be associated with the early struggles to produce an apple which would be of good quality and hardy enough to withstand the severe climate of the Upper Mississippi Valley. His work continued for more than thirty years, in which time he grew thousands of seedlings of apple, peach, plum, and cherry, and shortly before his death (1899) he wrote that of all these thousands of seedlings and named varieties of fruits tested, "only two trees remain." "One of these, the Wealthy, grown from a cherry-crab seed, obtained from Albert Emerson, of Bangor, Maine, of whom I obtained scions at the same time, from which I grew the Duchess, Blue Pearmain, and the cherry-crab, all of which, combined, were the foundation of Minnesota horticulture, that to-day is the pride and hope of the Northwest."[1] "Thus far it has taken from three to five hundred seedlings to give us one first-class apple, and from seed taken from the best apples we had."

Patten, Watrous, and others of Iowa and the Central West also contributed much of the foundation work in securing hardy fruits for the prairie states.

289. Hansen hybrids.—N. E. Hansen of South Dakota has effected many inter-specific combinations between *Prunus Besseyi*, the western sand cherry, as one parent and varieties of *P. salicina* or *P. Munsoniana* as the other; and other combinations have also been made. In these "Hansen hybrids" a new type of plum has come into use in the Northwest. While these sand cherry crosses have been experimented with for some time, the success of the variety "Compass" cherry has added impetus to the movement. While the sand cherry is one of the parents of these crosses, they in reality are not cherries but plums. One of the outstanding characteristics of these hybrids is the profuse early fruiting habit. They often bear at three years of age and as they grow best in bush form and fruit on the terminal shoots, winter-killing affects them less. Under the prairie conditions of the Upper Mississippi Valley in the United States and Canada, varieties like Sapa, Opata, Etopa, Wakapa, and Okiya have been a boon to the homesteader. These fruits rot easily and cannot be shipped for long distances, but for

[1] Some doubt exists in regard to the source of the seed which produced the Wealthy apple, as is reported in Minn. Hort. 1917. p. 85.

home use they have filled a need in regions where other plums could not be grown. This tribe is of special interest also because of its hybrid origin and suggests the promise to new regions which such combinations may have. From this work of Hansen, the Northwest has profited by varieties of many fruits and his work shows clearly what can be accomplished in horticulture by breeding.

290. Burbank's work.—The life and work of Luther Burbank of Santa Rosa, California, has been a great stimulus to plant-breeding. This is doubtless due to the great novelty of his creations and to the extent of his work. He has ever held in mind the production of fruits and other plants which would be of the greatest use and economic value and has held as secondary the accumulation of scientific data.

Perhaps pomology has profited more from his introduction of Japanese plums, and the seedlings and hybrids which he has obtained from them, than from any other achievement. He has succeeded in hybridizing diverse forms of fruits, some valuable for commercial purposes and others as novelties.

291. Inheritance of characters in the apple.—One of the few definite experiments in breeding apples, which has thrown some light on the inheritance of characters, is the one conducted by Hedrick and Wellington.[1] The results not only throw light on some of the laws of inheritance of apples but also furnish some practical results in the way of promising new varieties.

There were 148 crosses made between standard varieties in 1898 and 1899. The seedling trees began fruiting in 1908 but the grafts from them four years earlier. Crosses were made between Ben Davis, as the female parent, and Esopus, Green Newtown, Jonathan, McIntosh, and Mother; between Esopus as the female and Ben Davis and Jonathan; McIntosh and Lawver; Ralls and Northern Spy; Rome and North-

[1] *Loc. cit.*

ern Spy; and Sutton and Northern Spy. Some of the important observations by the authors as a result of the work are as follows: (1) These crosses strikingly contradict the idea that seedling apples (of cultivated sorts) revert to the wild prototype. (2) The stimulus of hybridity is very marked in the vigor of the crosses under consideration. (3) The behavior of some of the crosses strongly suggests that apples may be "preponent" in one or more of their characters.

Other conclusions which bear on the laws of inheritance are:

In color of skin, the fruits in which yellow predominates over red seem from the data to be in a heterozygous condition for yellow and red. The fruits in which red predominates are either homozygous or heterozygous. The pure yellows are homozygous.

The data favor the supposition that so far as size and shape are concerned, these characters are inherited practically as intermediates.

While all the varieties were sub-acid, the progeny indicate strongly that crosses of these sub-acid varieties break up in the proportion of three sour apples to one sweet one.

292. The heterozygous nature of fruits.—If an individual plant is pure or homozygous for any one or all of its characters, then all of the sexual gametes produced by it would, if the plant is self-fertilized, produce progeny which are alike. Thus, if a Grimes Golden apple were homozygous for all of its characters when self-fertilized, all the seedling trees produced would be practically identical with the parent. Such a condition does not exist, however, for the seeds of a self-fertilized apple tree will produce a motley array of progeny, varying in color, form, quality, and tree characters. Therefore, all of the common varieties are heterozygous and may be regarded as the F_1 generation of previous crosses.

It so happens, however, that it makes no practical difference whether fruit varieties are homozygous or heterozygous since a valuable new kind is propagated asexually and hence has little opportunity to break up, or lose its type. Therefore, it is unnecessary in breeding fruits to take this into consideration and in crosses between heterozygous parents the recombination of characters takes place in the F_1. This being the case, new combinations can be obtained from which to select desirable fruiting types without selfing individuals and encountering sterility or the great reduction in vigor which so often happens.

293. Pedigreed nursery stock.—Following the usage of the animal-breeders, certain nurserymen have adopted the term "pedigreed" to designate fruit-trees which have been propagated from a tree of known behavior or superior worth. This, of course, carries with it the idea that such trees will be better producers, have better color and quality, or have some other merit which individuals of the same variety selected at random would not possess.

It must be remembered that animal-breeders always refer to a new individual produced by the union of sex cells while the nurseryman refers to the same identical tree which has been increased by asexual propagation. Therefore, unless a true mutation occurs, the varying forms of a fruit variety will not be transmitted by vegetative propagation. Owing to the failure of practically all the experiments in the eastern United States to secure a superior strain of trees by propagating from a high producer or otherwise superior plant, there is a distinct prejudice among horticulturists to the use of the term "pedigreed" trees. On the other hand, the cases cited from California show that many true bud-sports do occur in that state, and Coit has adopted the use of a better term to designate trees propagated from these mutants in the phrase "recorded trees."

Nurserymen and fruit-growers will continue to search for superior strains of the old varieties and it cannot now be stated with absolute assurance that some success will not crown their efforts.

294. Graft-hybrids[1] represent one of the most interesting phenomena that occurs in nature. They remained unexplained for centuries although many of them had been observed. A graft-hybrid may be defined as the combination of the stock and cion tissues into a form which is intermediate between the two. The explanation for these queer "freaks" or chimeras was not clear until they had been produced artificially. It appears that either there is a mingling of the tissues at the point of contact of the graft or else that an adventitious bud arises where the callous has formed, which partakes of both tissues. The result is either a periclinal chimera in which one tissue envelops the other (the hand-in-glove type) or a sectorial chimera in which the two tissues occur side by side on the same stem, leaf, or flower, yet each retains its independent form. In at least one case, the number of chromosomes in the graft-hybrid is the same as if the hybrid were sexual in nature, thus being a true hybrid.

An apple called Sweet and Sour, which is described in "The Apples of New York" and is occasionally seen, is probably a graft-hybrid. The apple is somewhat ribbed and this ribbed portion is green while the part between is yellowish. The flesh beneath the green skin is distinctly acid, while that under the yellowish skin is mildly sub-acid or sweetish.

295. Breeding the grape.—The early varieties of American grapes were seedlings of merit derived principally from *Vitis Labrusca*. The early efforts to grow the European

[1] Popenoe, Paul. Plant chimeras. Jour. Heredity, Vol. 5, p. 521. Dec., 1914. Castle, W. E. An apple chimera. Jour. Heredity, Vol. 5, pp. 200–202. 1914.

grape (*V. vinifera*) in eastern United States failed utterly, but on the Pacific Coast they have been successful since the early Mission days. Recently Hedrick has succeeded in establishing *V. vinifera* in New York state where several are proving capable of withstanding the climate except that some winter protection must be given.

In general, the breeding work that has been done with grapes, covering the period since the introduction of the Isabella (1816) and Catawba (1823) up to the present time, is one of the most valuable chapters in the history of breeding fruits in this country.

296. Inheritance of self-sterility in grapes.—It will be recalled that grape varieties differ in regard to the structure of their flowers. They are classified as (1) true hermaphrodites, (2) hermaphrodites functioning as females, owing to completely or partially abortive pollen, and (3) pure males with the pistils absent or rudimentary. There are also two distinct types of stamens among these classes: (1) those which are upright, and such varieties are practically always self-fertile; and (2) those which are reflexed or bent backward and downward which are self-sterile. Of the 132 important commercial varieties of the grape described in "The Grapes of New York," Dorsey (1909) shows that 95 have upright stamens and 37 reflexed. The question arises as to whether this character of the stamens will behave as a unit character or, in other words, whether self-sterility can be eliminated by breeding.

297. The inheritance of sex in the grape.—In the grape the flower type has such an important economic bearing that considerable attention has been given to the inheritance of flower type or sex. Since the wild vines are diœcious for the most part, the question has often been raised as to the origin of the perfect or hermaphrodite flower type such as is found in Concord. Some recent investigations have thrown light on this question. When the data of Hedrick and Anthony [1] are presented according to the formula suggested by Valleau, the following ratios are obtained:

TABLE XCI

FLOWER TYPES AND RATIOS OBTAINED IN GRAPE CROSSES

Flower type of the parents	*Formula of the genetic constitution*	*Flower types of the progeny*			*Ratio of flower types*
		Hermaphrodite	*Female*	*Male*	
Upright x Upright	FH x FH	180	47	0	3.8 : 1
Upright selfed (same as above)...........	FH x FH	673	152	0	4.4 : 1
Reflexed x Reflexed....	FF x FF	16	16	0	1 : 1
Reflexed x Upright.....	FF x FH	207	206	0	1 : 1
Upright x Reflexed (cross not made)					
Reflexed selfed.........	FF x FF	91	73	0	1.2 : 1
Upright x Wild male ...	GF x FM	7	6	9	1 : 1 : 2

The appearance of the large number of hermaphrodite seedlings in these crosses is of great importance to grape-growers, because it is possible to select seedlings which will be self-fertile.

In crosses made between varieties of another species, *Vitis rotundifolia*, Detjen [2] presents data which throw some light on the first appearance of the hermaphrodite flower in a di ecious species. This is epochal in southern grape-growing because it had heretofore been necessary to grow unproductive male vines in vineyards in order to secure proper pollination. His evidence is so clear cut on this point that some of it will be included here in a condensed form for the convenience of the student:

[1] Hedrick, U. P., and Anthony, R. D. Inheritance of certain characters of grapes. Jour. Agr. Res. 4: 315–330. 1915; also N. Y. State Agr. Exp. Sta. Bull. Tech. 45. Valleau, W. D. Inheritance of sex in the grape. Amer. Nat. 50: 554–564. 1916.

[2] Detjen, L. R. Inheritance of sex in Vitis rotundifolia. N. C. Agr. Exp. Sta. Tech. Bull. 12. 1917.

Table XCII

FLOWER TYPES AND RATIOS OBTAINED IN CROSSES IN *Vitis rotundifolia*

Cross	Flower type		
	Hermaphrodites	*Females*	*Males*
Female x male	0	1420	1509
Scuppernong x Hope	348	461	0
Thomas x Hope	197	228	0
James x Hope	79	74	0

The great contrast in the number of hermaphrodite vines bearing flowers with upright stamens when Hope is taken as a pollen parent and when male vines are so used is outstanding. Hope was found in the wild in 1910 and differs from the typical male vine in that it has a partially developed pistil. Its genetic constitution is shown by its behavior in crosses in which it is seen to be decidedly different from others of its kind.

In the instances cited here, there is an excellent illustration of the solution of the commercial problem of sterility in the grape by breeding. Contributions like these to the knowledge of horticultural plants will have a far reaching influence on practice.

298. Rogers' hybrids.—The work of Rogers in hybridizing the native American grape with the European is epochal in the history as well as in the commercial status of the grape. Rogers conducted his breeding work at Salem, Massachusetts, during the early 1850's. As a result of hybridizing large-fruited Labrusca grapes with the Black Hamburg and White Chasselas, both vinifera varieties, he secured about 150 seedling plants but only raised 45 to maturity. They were tested by himself and others, being known by numbers, from 1 to 45, but several were later named for persons of note in science or for other attainments, as well as for counties and towns of Massachusetts. The named varieties which are now grown commercially are Goethe, Massasoit, Wilder, Lindley, Gaertner, Agawam, Merrimac, Requa, Aminia, Essex, Barry, and Herbert. These grapes are of exceptionally high quality, combining the richness of the European with the general type of the American grape; but unfortunately these hybrids are usually somewhat deficient in vigor, hardiness of root or vine, self-fertility or productiveness.

299. Breeding disease-resistant fruits.—Most of the definitely planned experiments in breeding of deciduous fruit-trees in the United States and Canada have had as their purpose the securing of hardier varieties. Of equal importance to the orchardists of the large fruit regions of this country is the problem of securing fruits resistant to such diseases as blight (*Bacillus amylovorus*), peach yellows, and the like, and breeding seems to be the ray of hope to these breeders. The selection of disease-resistant individuals would be the first means of attacking this problem, since many other kinds of plants have produced disease-resistant strains, as for example, flax, cotton, and melons. In these genera, however, there is a new sexual generation each year, which affords an opportunity for variation that does not obtain within a clone. It, therefore, remains for the breeder to combine a variety or species which is immune to the trouble in question with a variety of commercial importance subject to it. Thus, if a Bartlett subject to blight is crossed or hybridized with a blight-free pear, there is a possibility of obtaining a fruit as valuable as the Bartlett but with the "factor" for blighting absent. This possibility rests on the assumption that disease-resistance or susceptibility is a unit character and thus permits of recombination.

300. Stocks for pears.—According to the findings of Reimer, the following species of pear are quite blight-resistant: *Pyrus sinensis*, *P. ovoidea*, and *P. Pashia* (*vario-*

losa). While he records that *P. betulæfolia* is somewhat susceptible to blight in Oregon, it has been remarkably free in South Dakota where it has been grown for twenty years, and in the trial plots at Washington, D. C.

Pyrus Calleryana is a recently described species of pear native to China which is very promising as a stock. Hence, if a variety of high quality can be produced by hybridizing *P. communis* (from which all the commonly grown pears originated) with one of the hardy, blight-resistant species, the solution to one of the most serious problems in pomology would be at hand.

Hansen has crossed *P. sinensis* and *P. betulæfolia* with several of the best cultivated pears (*P. communis*) and distributed thirty-nine promising sorts throughout several states for trial. It is hoped that they may prove to be the basis of pear breeding to secure valuable varieties immune to blight.[1]

301. Stock for grapes.—What appears to be a clear case of the Mendelian behavior of disease-resistance is seen in the work of Rasmuson [2] who attempted to secure varieties of *V. vinifera* which would be immune to the great scourge of phylloxera. He made crosses between certain American species and *V. vinifera*, and also crosses between different varieties of *V. vinifera*. In studying the F_2 generation of these crosses, he found that the vinifera crosses yielded offspring susceptible to the disease while crosses between the American species and vinifera yielded varieties part of which were resistant and part susceptible, but the latter were in the minority. The fact that disease-resistance proved to be dominant and susceptibility recessive in the progeny of this latter set of crosses, bodes well for the future.

[1] Reimer, F. C. Proc. Amer. Pom. Soc. 1915. Hansen, N. E. S. D. Agr. Exp. Sta. Bull. 159. 1915. Galloway, B. T. Jour. Heredity, Vol. 9. Jan., 1920.

[2] E. S. R. 36: 537.

CHAPTER XIV

PROPAGATION AND FRUIT-STOCKS

SINCE most of the tree-fruits do not come "true" from seed, it is necessary to provide a root or stock on which to bud or graft them. The term "fruit-stocks," therefore, refers to the seedlings on which are "worked" varieties of the tree-fruits, nuts, and sometimes grapes. This is in distinction to "cion" which refers to the piece of wood of the desired variety introduced on the seedling stock.

The entire fruit-stock situation is not well worked out, as miscellaneous seedlings of unknown genetic constitution are used.[1] The seedlings, however, have given very good results, and the improvements that could be made by a more intelligent selection of material must remain a conjecture. Certainly as regards hardiness, disease, and insect resistance, improvements of note could be accomplished. Already something has been undertaken and the proper organization for a further extension of this work is now in existence. However, as referred to later, the relation of stock and cion is only meagerly understood.

302. Handling the seed and stock.—After the fruit-seeds have been collected in the fall, they are assembled at the nurseries, either at foreign points or in this country, where they are properly handled for the raising of seedling stock. Apple seed is secured by washing pomace obtained at cider mills and it is then dried in the open air. The seed is then stratified in sand until early spring. The apple seed will

[1] See Chapter XIII.

usually begin to sprout rather early in the spring, when it should be sown in a well prepared, deep, rich soil. This is important in order to produce straight long roots, as these are superior for propagation purposes. The seed is sown in rows four feet apart and the seedlings should be cultivated thoroughly throughout the summer. After the leaves have dropped in the fall, the little trees are dug, a part of the tops removed (leaving about six inches of the stem), the plants tied in bundles, and the bundles packed in boxes of green sawdust, sand, or other material in which they may be kept reasonably moist and cool. Such seedling roots are known as apple "stock."

303. The more common fruit-stocks.—The stock used for propagating a fruit must be "congenial," that is, the cion must be capable of making a good union and growth on such stock. A number of unusual combinations can be made, but the more common are here listed:

Apple—French crab; Vermont crab; Minnesota crab; Virginia crab; and for dwarfing, Paradise and Doucin.

Pear—French pear seed; Japan pear; Kieffer seed collected in eastern United States. For dwarfing, Angers or other quince.

Quince—from cuttings, stools, or mound-layering; and seed (to a limited extent).

Peach—seeds of wild or standard varieties, usually secured in this country.

Plum—seedlings of *Prunus domestica;* St. Julien; myrobolan (*P. cerasifera*); and sometimes *P. americana.* The peach may be used for plum stock when the latter is to be grown on light soils. For dwarfing myrobolan, also mirabella (a form of *P. cerasifera*), and several forms of the native plums.

Cherry—Mazzard cherry (*P. avium*); *P. Mahaleb* and *P. pennsylvanica* to some extent.

304. Apple stocks.—A change or adaptation of the nursery-stock situation is taking place, owing to the partial exclusion of stock formerly imported from foreign countries. However, the following are in use at present, as indicated above.

French crab (*Pyrus Malus*, Linn.) is most commonly used for the apple, whether the seedlings are grown in France and then imported to the United States, or whether the seed is imported and the stock grown in this country. It is estimated that about 40 per cent of the apple stock used in this country is imported from France at the present time. (See Fig. 37.) Howard [1] answers the question as to what French stock is by quoting a French nurseryman, as follows:

FIG. 37.—French crab, imported apple seedling.

"The crab apple seed comes from *Pyrus Malus*, Linn. (*Malus communis*, DC.) which is simply a natural apple. This is a cider apple. Although there are numerous grafted varieties none but the cider apple is used from which to procure seed. Occasionally small quantities of seeds from grafted varieties may become mixed with the crab seed but this makes the latter less valuable as such seeds do not give satisfactory results for the production of seedlings.

"The apples from which we get our seed are used for cider-making purposes. Seed collectors go to the mills and to the farms and wash the pomace that is left after the juice has been pressed out and the seed thus secured are dried in the open air.

"Small quantities of apple seed come from Germany and

[1] Howard, W. L. Plant propagation. Pub. by Univ. of Mo. 1914.

even Russia and Austria, but France is known to be the one great exporter of this seed. Apple seedlings are sold by dealers in Holland and the industry seems to have grown there during the last few years although the Dutch seedlings are much inferior to the French.

"The grower generally receives his apple seed in January, places it in a very sheltered spot—often in a stable—thoroughly mixed with damp river sand. The sand is kept moist and occasionally the mixture of sand and seeds is stirred. When the seeds begin to swell—which will be in about four weeks—they are either placed in cold beds for transplanting or sown directly in the field. In three or four weeks they begin to come up. By soaking in lukewarm water before planting the seeds may be caused to germinate quicker, but I consider it to be better to follow the more natural plan and not force the seeds.

"We never use ice. A few growers soak the seed for a period of two days at the most, but this practice is far from being common and is resorted to only when the season is advanced and it seems necessary to hurry the germination."

Vermont crab stock is raised from seed collected at the cider mills of New England. In the past it was obtained largely from the pomace of seedling apples which abounded in the rough pastures, around stone walls, and even in the woods. There was also mixed with the "wild" apples, fruit of grafted varieties, often of poor grade. However, the fact that the seedling apples and uncared-for orchards of New England are rapidly passing out makes this stock of no great consequence in the trade.

Virginia and Minnesota crabs are grown from seed collected at the cider mills in these states and in the past were used to a considerable extent, but at present the French crab stock has largely replaced them.

For dwarfing, the Paradise and Doucin stocks have long been employed. The usual understanding has been that the former produced a "full dwarf" tree and the latter a "half dwarf"; however, there seems to be much confusion in regard to these terms. "The original significant distinction betwixt the true Paradise or dwarfing apple stock and the true crab or free growing stock, had imperceptibly changed to a distinction in method of propagation, all those apple stocks which were raised vegetatively (from layers) being known as 'Paradise,' and those raised sexually (from seed) being known as 'Crab.' "[1] The work of Hatton shows that in a lot of seedlings from crab and "Paradise" stock, there will be in each both surface and deep-rooted plants. It also indicates that in lots of Paradise stock collected at various places in England and on the Continent, there were "17 distinct types, easily distinguishable botanically, and varying in health and vigour of growth from the very dwarf French Paradise, which on our soil dies out with apple canker in a few years, through intermediate types such as the Doucin, moderate and sturdy in growth and precocious in cropping, to the very vigorous forms of Paradise, which have a vigour and robustness of growth previously supposed to belong only to 'crabs.' "

Such is the situation in regard to apple stocks and much experimenting remains to be done before a uniform type is secured.

305. Pear stocks.—For the propagation of the pear the seedlings are usually obtained from France (Mayenne Province) where pear cider is made in quantity and hence the pomace is available. Probably 80 per cent of the pear seedlings used in this country are imported. The seedlings are grown in France as disease frequently ruins the crop when the seed is imported and an attempt made to grow them here.

[1] Hatton, R. G. Results of researches on fruit tree stocks at East Malling. Jour. Pomology, Vol. 2, No. 1. 1920.

The pears collected for this purpose are the native *Pyrus communis* of Europe, fully 90 per cent being worked on this stock. Japanese sand pears, *Pyrus serotina*, are also employed to some extent and are believed by some nurserymen to be superior to the French pear stock. In France this contention finds no support, as nurserymen there think the Japanese stock is quite inferior. This stock is secured directly from Japan or the seedlings are first grown in France. Kieffer pear seed is also used to a limited extent in this country, the seed being obtained from canning factories in the eastern United States. It will be remembered that the Kieffer has as one of its parents the Japanese sand pear, the other being the Bartlett.

306. Quince stocks.—The fruit-bearing quinces (*Cydonia oblonga*) are commonly grown on their own roots, *i. e.*, from cuttings or by mound-layering. When worked on to another stock, the French Angers quince is most frequently used. This Angers stock is grown from cuttings, or by mound-layering or, more rarely, from the seed. In rare cases, the desired varieties of quince are root-grafted on the apple or pear and the original stock is cut away when the tree is moved to its permanent place in the orchard.

307. Peach stocks.—In the eastern United States, peaches are budded on stocks grown in this country. The pits are obtained from either seedling trees or standard varieties, but the former are usually preferred as more trees can be grown to a given measure of pits and the trees are supposed to be hardier.

Pits produced the current season give a higher percentage of germination and are, therefore, selected. The plum (St. Julien and myrobalan) is sometimes used for the peach, especially in the South and on wet or heavy land. Pits obtained in China are being investigated in regard to their desirability as stock but have not yet come into use.

308. Plum stocks.—In Europe and to some extent in this country, the plum is propagated by suckers which arise freely from the roots of several of the species. To make use of such suckers, the tree must of course be on its own roots. Mound-layering and root-cuttings are also employed to some extent with the plum and in all of the above cases obtaining a stock is not a problem. When plums are worked on other stocks, the species must be considered. *P. domestica* is usually worked on seedlings of the same species, the stocks being largely imported. The myrobalan (*P. cerasifera*) is chiefly used for plums because of its cheapness and because it makes a good union with all varieties; 80 per cent of this stock is imported. For colder regions, *P. americana* stocks are preferred. For light soils the peach is often taken as a plum stock. Marianna (probably a hybrid form of myrobalan and some native plum of the Wild Goose type), St. Julien, apricot, and almond are also used as stock for the plum. For dwarfing, the myrobalan stock is employed as is also the mirabelle (also a form of *P. cerasifera*), the *P. americana*, *P. Munsoniana*, and *P. angustifolia*.

309. Cherry stocks.—Like the plum, the cherry will grow readily from root-cuttings, but it is usually budded on the seedling stock. The stock most commonly used is the Mazzard, a hardy and vigorous variety of the common sweet cherry (*Prunus avium*). This tree occurs along roadsides in the Central West and the seed is obtained in this country to some extent, but probably 90 per cent of the cherry stock is imported. The sour cherries are frequently worked on the Mahaleb (*Prunus Mahaleb*) in this country as it makes a congenial stock and the seedlings are relatively cheap. The Morella cherries are worked on the Mahaleb stock, although Morella seedlings are sometimes used to a limited extent. *P. pumila* and *P. Besseyi* are listed as promising for dwarfing the cherry.

310. Quarantine measures.—For a period of years it had become evident that some measure should be taken to stop the introduction of foreign disease and insect pests which were annually finding their way to this country on nursery stock and other plants and plant products. As a result, a Plant Quarantine Act was passed by Congress on August 20, 1912, under authority of which the United States Department of Agriculture has, from time to time, issued various quarantine rulings which restricted or prohibited the importation of certain plants and plant products found to be infested with noxious diseases and insects. The ruling which particularly affected the nursery and florist business, and which was strongly protested by special interests, was known as Quarantine 37, and was issued November 18, 1918. This measure, together with later interpretations and rulings thereon, provides that:

"Stocks, cuttings, cions, and buds of fruits for propagation" and "seeds of fruit, . . . may be imported from countries which maintain inspection, under permit upon compliance with these regulations, but, where a particular purpose is specified, for that purpose and no other. . . . Importations of nursery stock and other plants and seeds specified in this regulation, from countries not maintaining inspection, may be made under permit upon compliance with these regulations in limited quantities for experimental purposes only, but this limitation shall not apply to tree seeds." [1]

From this ruling it will be seen that fruit-stocks for propagating purposes are still admitted into the United States, but possibly the time may come when all such stocks must be grown here.

311. Importations of stock.—While no restriction was placed on the entry of fruit-stocks, the impression went out

[1] U. S. Dept. Agr. Off. of Sec'y. Notice of Quarantine 37. Aug. 1, 1921. Item 2, Regulation 3.

that there was a falling off of the importations. This was largely due to scarcity of stock in Europe, as a result of war conditions, together with a prohibitive price placed on this stock. The following figures are enlightening on the large amount of stock imported, following the establishment of quarantine measures by the United States Government:

TABLE XCIII

IMPORTATION OF FRUIT-STOCKS, JULY 1, 1919, TO JUNE 30, 1920

NUMBER OF PLANTS

Country of origin	*Apple*	*Plum*	*Cherry*	*Quince*	*Pear*	*Persimmon*	*Unclassified*
England....							
France.....	1,825,000	707,800	2,868,720	758,800	1,107,900		459,900
Holland....	103,000			500	500		
Italy.......							300
Japan......						24,200	
Total.......	1,928,000	707,800	2,868,720	759,300	1,108,400	24,200	460,200

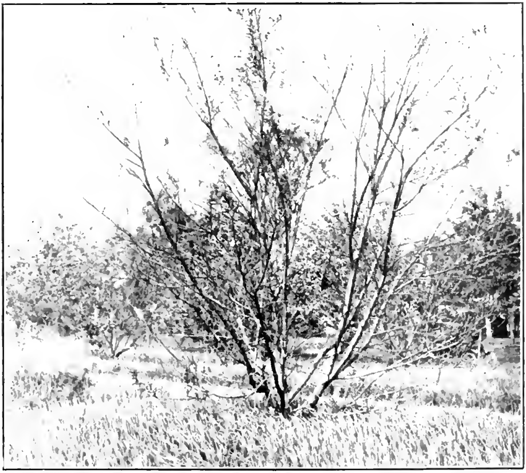
312. Fruit-trees on their own roots.—Since the fruit-tree above ground is of the variety desired, and a part or all of the root system is of seedling origin, it can be seen that considerable variation may be expected among the trees of any given variety. No two of the seedlings used as stock are alike (genetically) and they may vary markedly in vigor of growth, susceptibility to disease and insect pest, as well as in hardiness. It is well known to what extent a dwarfing stock may influence the cion part, but the smaller differences are not readily observed in the standard trees. In Australia, New Zealand, South Africa, and to some extent in California, it is recognized that Northern Spy roots are more resistant to injury by woolly aphis (*Schizoneura lanigera*) than are the ordinary crab roots and hence are finding wide usage. Some varieties are more resistant to crown-gall (*Bacterium tumefaciens*) than are others, and this is doubtless true also of other diseases, pointing to an important field of endeavor for the future. In the prairie section of the northern United States and Canada, one of the serious problems in fruit-growing is the damage done to the roots of the trees by low temperature, and hence it is important to secure stock which is most resistant to cold.

The first problem is the securing of own-rooted trees. Apples do not root readily from stem-cuttings and this process cannot be used commercially with the present knowledge of the subject. Root-cuttings, however, can be planted with success, and the method is employed commercially to some extent.

The most common process of securing own-rooted trees is by the "long cion—short root" method, also known as the "nurse-root" method. Advantage is taken of the fact that deeply planted root-grafted trees will often send out roots from the cion, and later (after two seasons) the trees are dug and the stock portion removed. There seems to be great variation in the ability of varieties to form roots. Shaw [1] made trials of over 150 different varieties and species to measure their rooting ability. There was a variation of rooting from 0 to practically 100 per cent. A few of those exhibiting a high percentage of rooting are: Arkansas (77), Bailey Sweet (95), Sweet Bough (98), Fameuse (80), Opalescent (89), Primate (92), and Westfield (83). Some exhibiting a low percentage of rooting may also be cited: Bethel (0), Black Gilliflower (6), Ensee (6), Ingram (2), Jeffris (3), Lady (3), Ortley (2), Paradise Winter Sweet (2), Red Canada (2), Tolman (3), and Yellow Belleflower (3). It cannot be stated at present with much definiteness just what factors influence certain varieties to root freely from cions and others to root very poorly. The following are suggested as entering into the problem: a correlation between hardness of wood and rooting ability, the softer the wood the higher

[1] Shaw, J. K. Mass. Agr. Exp. Sta. Bull. 190. 1919.

a



b

Plate VIII.—*a*, The twig terminals of these Baldwin apple trees were killed in winter of 1917–18. *b*, A winter-injured peach tree that was not cut back.

the proportion rooting from the cion; fertile, well-drained, sandy loam soils offer the best conditions for securing a high percentage of rooting trees; there seems to be a relation between the varietal ability to produce roots from the cion and the thickness of the cambium layer during the dormant season.

313. Relation of cion and stock.—Little has been added to the literature on this subject during recent years other than that already mentioned. It has commonly been considered that each part, *i. e.*, stock and cion, maintained its own individuality with such exceptions as when dwarf trees were produced by working on slow-growing stock. It was argued that the trees and fruit in an orchard of Baldwin apples, for example, were always practically the same, allowing a reasonable amount of natural or continuous variation, and such other differences as could easily be traced to environment factors. Additional exceptions were noted occasionally, such as the effect of a given variety on the root system as could be seen clearly when the trees were dug from the nursery; and a tendency of an individual tree to be more prolific, earlier or later in bearing than was usual for the variety.

The question may now be raised as to whether the relation of stock and cion is not more important than previously supposed, and whether the whole problem of congenial stocks for fruit varieties may not need investigation.

PROPAGATION OF FRUIT-TREES

In the foregoing paragraphs it is apparent that most of the tree-fruits are grown on a foreign root system, *i. e.*, the root parts are of seedling origin, largely for the reason that fruit-trees do not "come true" from seed. It is not the province of this text to deal in detail with the practice or manipulation of the processes used in general plant propagation, but a brief review of budding and grafting of fruit-trees is germane to the general treatment.

Layerage.—Layerage consists in taking advantage of the habit of certain plants to throw out roots from decumbent shoots and runners. Portions of the stems or branches are artificially placed in contact with the ground, either by fastening them on the surface or by covering with soil. Fruit-trees are not propagated in this way with the exception of a few by what is known as "mound-layering." On the other hand, strawberries, grapes, raspberries, gooseberries, and many ornamentals are propagated by different forms of layerage.

314. Mound-layerage is so termed because the soil is mounded about the base of shrubs or other plants which will throw out roots from the stems when in contact with the soil. The several rooted portions are then severed from the mother plant and thus begin an independent existence. The quince, gooseberry, and several forms of the Paradise apple are propagated in this way.

315. Cuttings.—None of the commonly grown tree-fruits is propagated by means of stem-cuttings, with the exception of quinces which are handled to some extent in this way. A number of attempts have been made to propagate the apple by cuttings but none has as yet succeeded, although they may be rooted from the cion by the nurse-root method as previously described. The apple cuttings will frequently form a callus, but such activity does not favor root development. Plums (Mariánna) are occasionally grown from cuttings as are also the quince and persimmon. The grape and currant are most commonly propagated by means of cuttings. Climate exerts considerable influence on the tendency of plants to develop from cuttings, the moist warm southern sections being much the more favorable. Root-cuttings are commonly used in propagating such fruits as have a natural tendency to sucker or send up shoots from the roots. The blackberry, Japanese quince, and to some extent the peach, cherry, apple, and pear may be propagated by root-cuttings.

316. Grafting and budding.—The arts of grafting and budding are indispensable to the fruit industry, since practically all the tree-fruits are propagated in this way. Both processes involve the introduction of a portion of one plant into or onto the living or actively vegetative portion of another. In the former, a piece of the woody shoot bearing one or more buds is used, while in the latter one bud only is removed from the mother plant and introduced beneath the bark and in contact with the cambium of the "stock." Grafting is usually done in early spring just prior to or during the active period of growth, or in the case of root-grafting (bench-grafting) in the winter period. It is usually desirable for the cion material to be in a dormant condition when the union is made, although it is not necessarily fatal to have the buds of the cion beginning to open.

317. Tongue-graft or whip-graft.—For the propagation of nursery trees the tongue- or whip-graft is most commonly used, and the work is performed in the winter. The one- or two-year-old seedling trees are dug in the fall and stored where they can be kept cool, reasonably moist, and dormant. In January or February the grafting is done in-doors, which gives it the name bench-grafting. To produce what the nurseryman calls "whole-root" trees, the entire seedling root is used, trimming off branching or superfluous parts, and the cion is inserted into the crown of the root. For "piece-root" grafts the seedling roots are divided into several pieces, about 3 or 4 inches long, thus securing several trees from one root. Both the cion and root are severed with a long oblique cut and an incision is made into the center of these surfaces so that the "tongue" of the cion will enter into the incision of the root, thus allowing the cambium areas to come into contact. It is not necessary but desirable that the cion and stock be of the same diameter. After the two portions are inserted, they are bound tightly together with waxed string or raffia and the wounded areas covered with waxed tape to prevent the entrance of disease until the wounds are calloused. These grafts are then stored in sand or sawdust until early spring when they are planted in loose fertile soil. Such plants are allowed to remain in the nursery row for one or two years, when they are dug and are ready to put on the market.

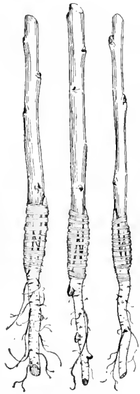


Fig. 38. — The tongue- or whip-graft of apple. (The piece-root-graft.)

The apple and pear are often root-grafted, although "budded" trees of all kinds are becoming more popular. (Fig. 38.)

318. Budding is practiced entirely with the "stone or drupe" fruits in the East, and a large part of the pome-fruits are also propagated in this way at present. The fact that the budded tree has the advantage of the entire root system of the seedling, and that the likelihood of crown-gall is reduced by this method, has made it popular with the trade.

The essential difference between grafting and budding, in producing nursery trees, is merely that one bud instead of several is introduced into the stock. The work is usually done in the latter part of summer while the bark is still loose and will "work readily." A "bud-stick" is cut from the variety desired and a shield-shaped portion of the bark is cut away from the shoot, including a bud in the center. The leaves are removed as soon as the "stick" is cut, leaving a small portion of the petiole to be used as a "handle" in placing the bud into the bark of the stock. A T-shaped incision is made into the bark of the seedling tree an inch or two above the ground, on the north side of the tree so that the bud will be shielded from the sun. The amateur usually inserts two or three, one superimposed above the other, so that he may have several chances of securing a "catch." One only is retained when growth starts in the spring.

Fig. 39.—Shield-budding. The bud tied; new growth of bud tied to stock (the following spring); stub completely removed.

After inserting the bud, it is tied into place with raffia or cotton string, although the former is preferable. (Fig. 39.) After the bud has grown tight, which will be within two weeks if at all, the stricture is cut if it has not already loosened. The bud remains dormant until spring when it begins growth just as any other bud on the tree. The top of the seedling is then removed, usually a few inches above the bud so that the rapidly growing shoot may be loosely tied to the stub to prevent breakage. Later the stub is removed to within a half inch above the shoot. If the tree makes a growth of three to six feet the first year, it is usually dug in the fall and stored for spring delivery to the trade, but with the apple and pear they are frequently allowed to grow two years in the nursery row before being sold. The peach should always be dug at the end of the first year.

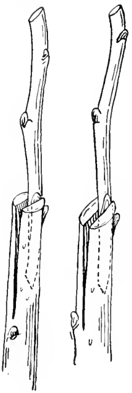


FIG. 40.–Method of double-working the apple.

319. "June-budding" differs from the usual method in that "bud-sticks" are kept over winter, usually on ice, until seedling trees have made sufficient size by June or early July to allow of budding. The bud of the previous year is inserted into this rapidly growing stock, which soon starts into growth and the top is then removed. This gives a "one-year-old" tree the first season, thus saving a year's time. This practice is followed in the South, more especially with the peach.

320. Double-working of apple trees.—To avoid certain of the troubles affecting the crowns and trunks of apple trees, such as collar-rot and winter-injury, a method of reworking nursery trees with varieties known to be subject to these troubles has come into rather common use.

Trees of hardy or resistant varieties are secured, among which may be mentioned Northern Spy, Tolman Sweet, or even Ben Davis for some purposes. Two- or three-year-old trees are preferred, if they are in good condition and have well-developed root systems. These are set in the orchard in the usual way and allowed to grow a season in order to become well established.

Before the next growing season begins, they are cut off about 20 to 24 inches from the ground line and grafted to the desired variety. If the cions are carefully gathered and labeled, there is the additional certainty of having the varieties true to name; in fact the double-working is sometimes done for this purpose.

A single cion 6 to 8 inches in length is used, and in order to promote healing over of the stub with the least resultant weakness or deformity, the stock may be cut obliquely rather than square, with the cion inserted in a cleft at the top of the cut, as indicated by Fig. 40.

Ordinary grafting-wax may be used to cover the wound but the work is facilitated by the use of waxed tape, which also gives better support to the cion until union takes place, and is more easily applied if the work must be done in cool weather.

The nursery trees may be worked immediately after setting, but the chances of success seem to be greater if they are first allowed to become established in their permanent location.

CHAPTER XV

STORAGE OF FRUIT

A great industry has been developed since the advent of the cold storage plant and it has become a large factor in handling the country's fruit crop. The details of its commercial importance and economic value will not be canvassed in this text, but rather the effect of storage on the fruit itself.

321. Definition.—Storage developments during the past quarter of a century represent a most valuable contribution of science in making perishable products available over a relatively long period of time. As used in this connection, storage usually refers to cool or cold storage of products and may be defined as the means by which perishable products are maintained at a temperature sufficiently low to arrest disease and the natural physiological and chemical processes of ultimate maturity and decay, yet not sufficiently low to injure the tissue or quality of the materials stored.

322. History of storage.[1]—The idea of prolonging the season of fruits and other food products by the means of low temperatures is by no means modern. Meyer reports cold-storage methods applied to fruits in remote parts of China, wholly out of touch with civilization. He states that the Chinese have practiced cold storage for centuries.[2] The earliest efforts along this line were to use the natural caves or artificial cellars where a fairly uniform temperature from 50° to 60° F. can be maintained at all seasons. Successful

[1] We are indebted to "Practical Cold Storage" by Madison Cooper, Nickerson and Collins Co., 1914, for important parts of this account.

[2] Stubenrauch, A. V. Storage and refrigeration of fruits and vegetables. Standard Cyclo. Hort., Vol. VI, p. 3245.

experimental refrigeration by mechanical means was accomplished as early as the middle of the eighteenth century, but no successful commercial application of cold storage was evolved until after the invention of Lowe's carbonic acid machine in 1867. The present growth of the industry, however, is due to the invention of the ammonia compression machine by Carl Linde in 1875. The process was first extensively applied to the preservation of meats, fish, and the like, but as early as 1881 the Mechanical Refrigerating Company of Boston opened a cold-storage warehouse, which marks the beginning of mechanical refrigeration as applied to horticultural products.

The use of natural ice for refrigerating purposes does not seem to have come into general use until comparatively modern times. The first large ice-house for the storage of natural ice was built in 1805. At first the ice was packed about the articles to be preserved, much as is done at present in shipping fish and oysters. Later a chest or box was used in which the ice was stored in one end and the products in the other, but such an arrangement lacked any means for securing a circulation of air. Later improvements in the design of storage-rooms called for the storage of the ice overhead with shafts allowing for a circulation of air, which added greatly to the success of this type of refrigeration.

323. Types of storage.—As can be inferred from the foregoing, there are two general types or systems of storage: (1) common, and (2) cold storage. The common, or non-refrigeration storage, refers to some system by which reasonably low temperatures can be maintained, either by locating the rooms in a cellar, thus utilizing the low natural temperature of the earth, or by the use of air currents to keep a room at the temperature of the out-door air.

The cold storage has been evolved from the early efforts at refrigeration and involves the cooling of the storage-rooms by artificial agencies, either ice or mechanical means being used.

324. The function of storage.—It must be recognized that a fruit is a living organism and life processes continue until disintegration takes place. In common with many other organic products, the higher the temperature the more rapid is the disintegration and, therefore, the function of storage is to delay the ripening process in a temperature that will not injure the fruit. It is also designed to retard the development of diseases with which the fruit may be affected, but it cannot entirely prevent their growth.

Much depends on the condition of the fruit when it enters storage as to how long and how well it will keep. If the fruit is over-ripe, has been bruised, or is covered with rot spores, the low temperature may retard but cannot prevent its premature decay.[1]

325. Factors influencing the keeping quality of fruit.—The following factors have been outlined by Powell as affecting the keeping quality of fruit after it has been placed in cold storage: (1) the maturity of the fruit when picked; (2) the promptness with which it is placed in storage; (3) the temperature at which it is stored, as well as the uniformity of this temperature; (4) influence of a first wrapper; (5) the cultural conditions under which the fruit was produced; and (6) the type of package in which it is stored. These factors will be treated separately.

326. Maturity of fruit.—In considering the keeping quality of fruit, it must of course be recognized that this is first of all a varietal characteristic (a unit character), just as much as color and size. Also the condition of the fruit when it enters storage will determine whether or not it can be kept for the maximum time for the variety. Numerous

[1] Powell, G. Harold, and S. H. Fulton. The apple in cold storage. U. S. Dept. Agr. Bur. Plant Ind. Bull. 48. 1903.

tests have been made to determine at what stage of maturity a fruit will keep best in storage. It is well known that an under-ripe apple will wilt and shrivel and an over-ripe one will decay rather rapidly even when put in storage. It then remains to determine what is the best time for storing in order to secure the maximum keeping quality. This stage has been determined as "hard ripe," *i. e.*, when the apple has developed full size and good color for the variety. If the fruit is left on the trees until the highest color is developed, it will often be to the detriment of the keeping quality. The proper time for picking is usually associated with a browning of the seeds, but this is not always a reliable guide.

An exception to this rule is noted when apples are grown on young rapidly growing trees. Such fruit is likely to be overgrown, and under such conditions the apples will usually keep better if picked before fully grown. In general, as will be seen later, light colored apples scald worse in storage than do well-colored ones. The following striking results were secured by the Department of Agriculture [1] which demonstrate the value of storing mature fruit only. The variety used in this test was the Rome Beauty, which by nature is a long keeper, but subject to scald if conditions are favorable for it. The immature pickings of fruit were made during the last two weeks of September and the mature pickings from October 2 to 20.

[1] Ramsey, H. J., A. W. McKay, E. L. Markell, and H. S. Bird. U. S. Dept. Agr. Bull. 587. 1917.

Table XCIV

KEEPING QUALITY OF MATURE VERSUS IMMATURE FRUIT: ROME BEAUTY [1]
FOUR-YEAR AVERAGE. (AFTER RAMSEY, MARKELL, MCKAY AND BIRD)

	Bad scald		*Decay*	
	At withdrawal	*10 days later*	*At withdrawal*	*10 days later*
First withdrawal, January 8–12				
Mature	0.0	1.7	0.0	0.1
Immature	0.0	49.9	0.1	0.6
Second withdrawal, February 16–19				
Mature	0.0	5.4	0.0	0.2
Immature	20.5	70.5	0.0	0.0
Third withdrawal, March 31–April 2				
Mature	1.0	10.4	0.0	1.6
Immature	48.9	81.5	0.2	9.8
Fourth withdrawal, May 4–11				
Mature	3.5	17.8	0.1	2.7
Immature	58.9	81.6	0.4	18.0

327. Effect of over-maturity.—As mentioned before, it is very detrimental to the keeping quality of fruit to allow it to remain on the tree after it is ready to harvest, *i. e.*, hard ripe, or to delay placing it in storage immediately after it is picked. Some conclusive experiments have been conducted

[1] Percentage bad scald and decay at withdrawal from storage, and after a holding period of ten days under market conditions. Time in storage at first withdrawal, 3½ months; second, middle of February; third, late March; and fourth, May.

by the United States Department of Agriculture which point to the necessity for storage before the fruit is over-mature if the best results are to be secured. The chief storage troubles from over-maturity are physiological and fungous decays. The following data are taken from work with the Esopus:

TABLE XCV

EFFECT OF OVER-MATURITY. ESOPUS.[1] (AFTER RAMSEY, ET AL.)

	Decay	
	At withdrawal	10 days later
First withdrawal, January 12, 1914		
First pick	0.0	1.3
Second pick	2.3	2.3
Second withdrawal, February 19, 1914		
First pick	0.0	1.3
Second pick	9.1	25.0
Third withdrawal, April 1, 1914		
First pick	1.3	2.7
Second pick	4.0	26.0
Fourth withdrawal, May 4, 1914		
First pick	2.7	6.7
Second pick	14.0	36.0

At the second withdrawal, February 19, which is somewhat later than the usual commercial storage limit for this

[1] Percentage physiological and fungous decay at withdrawal from storage, and after a ten-day holding period under market conditions. The first pick was made September 25, stored September 26, 1913. The second pick was October 10 and stored October 11, 1913.

variety, the first picking was free from decay or other storage troubles, while the latter picking had developed 9.1 per cent decay. After being held outside for ten days, approximating the usual length of time from storage to consumption, the decay in the late picking increased to 25 per cent. The first picking developed only 1.3 per cent in the same period. The later inspections are well past the commercial limit for the variety, and the decay is correspondingly heavier, though still consistently less in the first picking.

328. Effect of delayed storage.—As has been seen, it is important to have fruit at the proper stage of maturity when picked, but it is also important that it be stored immediately or its keeping is impaired correspondingly. In the experiments here referred to, the fruit was picked at the height of the season for the variety and a portion stored in a warehouse in a temperature but little below that of the outside air. Other lots of the same fruit were immediately placed in cold storage. In studying the tabulated results, it should be added that the fruit immediately stored "was always brighter, less yellow, and usually firmer than the delayed." It will depend much on the season as to the extent of damage which results from delay in storage.

Table XCVI

IMMEDIATE VERSUS DELAYED STORAGE

FOUR-YEAR AVERAGE. JONATHAN. (AFTER RAMSEY, ET AL.)

Condition	*First withdrawal, Jan. 9–12*		*Second withdrawal, Feb. 16–29*		*Third withdrawal, Mar. 27–April 2*		*Fourth withdrawal, May 5–14*	
	Imm.	*Del.*	*Imm.*	*Del.*	*Imm.*	*Del.*	*Imm.*	*Del.*
Bad scald								
At withdrawal	0	4.0	0.1	6.7	8.5	21.5	17.9	33.8
10 days later	1.0	7.3	8.4	20.0	14.7	35.8	27.0	46.4
Decay								
At withdrawal	0	.3	4.6	10.3	6.8	13.1	7.8	13.0
10 days later	1.2	1.2	10.1	12.7	12.2	17.5	12.0	17.0

329. The storage temperature.—The difficulty under many conditions is to secure a uniform temperature for the storing of fruits. This is an important phase of the problem, since fluctuating temperatures are harmful. The exact temperature which is best will depend somewhat on the fruit, the variety, the length of time the fruit is to be stored, and perhaps some other factors. In general, however, the minimum temperature given for a variety of fruit is to be preferred to a few degrees above, if the maximum keeping is to be secured. Powell's experiments indicate that a temperature of 31° or 32° F. is best for the apple since the rots, molds, and other diseases were retarded to a much greater extent than at 35° to 36° F. Cooper, however, states that a temperature of 30° F. is better than any degree above that, and 29° F. is practicable and advisable for long-period storing of the better keeping varieties. To store safely at 29° to 30° F. it is necessary that a forced circulation of air be employed. In cooling the fruit down to the final carrying temperature, the refrigeration must not be applied too suddenly.

TABLE XCVII

STORAGE TEMPERATURE FOR FRUITS. (AFTER COOPER)

Apples	30°–31° F.
Oranges	32°–35° F.
Lemons	38°–50°
Plums	32°
Pears	32°–33°
Peaches	32°
Grapes	36°
Berries, fresh (few days only)	40°
Currants " " "	32°

330. Influence of a fruit wrapper.—If each individual fruit is wrapped in paper before placing in the package, its life will be extended beyond that of unwrapped fruits. This has been particularly tested with apples, since they have a long period of storage. The wrapper affects the keeping qualities in several different ways: it retards the ripening processes; it prevents the transfer of rot from one apple to another; it protects against bruising and the discoloration that may result from improper packing or rough handling; it checks transpiration; and in general adds to its commercial value. (Powell.)

A striking difference in the keeping quality of wrapped and unwrapped fruit is shown in the following table:

Table XCVIII

AMOUNT OF DECAYED FRUIT, APRIL 29, IN BUSHEL PACKAGES (AFTER POWELL AND FULTON)

Variety	*Newspaper wrapped*	*Unwrapped*
	Per cent	*Per cent*
Baker	3.7	27.2
Dickenson	6.4	43.0
McIntosh	7.7	15.0
McIntosh (second lot)	19.7	32.0
Northern Spy	5.6	52.0
Wagener	38.0	63.0
Wealthy	42.0	60.0

Several different types of wrappers were used in these experiments—tissue, parchment, waxed or paraffin, and unprinted news—but no important difference was observed except with the parchment, on which mold developed freely at 36° F. but only slightly at 32° F.

A double wrapper proved more efficient in retarding ripening and transpiration than a single one.

Greene[1] found a considerable variation in the value of wrappers but states that they will extend the cold storage season from two weeks to several months, according to variety of fruit. He concludes, however, that they "are out of the question excepting where apples are packed in boxes or where packed for special purposes in barrels." Much the same results are recorded in a later report on this experiment.[2]

331. Influence of cultural conditions.—It is well known to those who grow, store, and sell fruit that any given variety will vary somewhat in its keeping quality, depending on where it is grown and on the particular season. Apple buyers become very discriminating after they are acquainted with fruit districts. Fruit raised on young trees, on low land, and on very light soils is likely to have a poorer keeping quality than fruit grown under the opposite conditions. However, it is difficult to determine the keeping quality of the product from any given orchard except by trial, for no definite rules can be laid down which will have wide application.

332. Type of package for storage.—The usual types of package for storage are the standard apple barrel and the standard bushel box. Other packages are coming into use, such as the paper carton package of varying capacity, the basket and the Boston bushel box. The barrel is used for the great bulk of the apples grown in the eastern United States but it is not entirely satisfactory, for it requires a longer time for the fruit throughout this package to cool than is true with a smaller one. It is not convenient to handle and considerable bruising occurs incident to proper packing. There is

[1] Greene, L. Cold storage for Iowa grown apples. Iowa Agr. Exp. Sta. Bull. 144. 1913.

[2] Whitehouse, W. E. Cold storage for Iowa apples. Iowa Agr. Exp. Sta. Bull. 192. 1919.

some difference of opinion in regard to an open and a closed package. The recent investigation on scald of apples shows that aëration of the fruit is important in preventing the trouble, which would argue for a somewhat open package. On the other hand, a slatted or otherwise open package often results in a shriveling of the fruit which is very serious with some varieties.

333. The shrinkage of fruit in storage.—As indicated before, the fruit in storage continues a life process which results in certain changes and losses through respiration. By far the greatest loss in weight, however, takes place through loss of moisture which amounts to about 10 per cent of the weight of fruit for a season. The dry-skinned and russet apples lose moisture much more rapidly than the oily-skinned ones. The Roxbury Russet, Spitzenburg, and Jonathan shrivel readily in storage unless the humidity is kept to nearly 85 per cent.

334. Apple-scald.—The development of scald is one of the serious problems to be dealt with in the storage of apples. Scald has been defined as a "superficial browning" of the skin which does not extend deep into the flesh but detracts from the appearance of the fruit and reduces its commercial value.

A number of experiments have been conducted to determine its cause and how it might be prevented, and as a result the following general conclusions have been drawn:

1. The cause of scald is apparently an abnormal respiratory condition. The disease can be readily produced artificially by storing under conditions of restricted aëration, and no scald can be produced on apples that are well aërated. The small amount of scald that usually develops in cellar and air-cooled storage-houses appears to be explained by the important rôle that aëration plays in the development of the disease.

2. Humidity apparently has no effect on the development of the disease, according to Brooks, Cooley, and Fisher,[1] while Whitehouse found that the drier the storage-rooms the less the scald.

3. All experiments showed that scald will develop more rapidly as the temperature increases. Powell and Fulton found that scald appeared to a much greater extent if apples were stored at 36° F. than at 32° F., although both lots were stored immediately after picking. Brooks and Cooley found a consistent difference in favor of the lower temperature in the prevention of scald. Scald developed rapidly at 50° F. during the third month of storage, whereas it was four months before it appeared at 41° F., and five months at 32°.

4. Apple-scald has been more serious on green than on ripe fruit, but it develops more rapidly on the latter. All investigators have laid emphasis on this point as the most important so far as the fruit itself is concerned. "Immature fruit scalds readily in storage. Whatever the variety of apples under consideration, it is in the best condition for cold storage when it has reached prime maturity for picking, is well colored, hard-ripe, and neither immature nor over-mature."

5. Wrapping apples in paper delays the appearance of scald during storage.

335. Pre-cooling.[2]—It has been determined that fruit will carry better and keep longer if it is cooled immediately after it is picked from the tree and before going into cold storage or refrigerated cars. This is particularly true of citrus fruits and such soft kinds as peaches.

Experiments by the United States Department of Agriculture have shown that it requires warm fruit from three to

[1] Jour. Agr. Res. 18: 4. 1919.

[2] Practical Cold Storage. Madison Cooper. Second Ed.

four days to reach a temperature of 45° F. when it is placed in a refrigerator car, and that the fruit was not uniformily cooled, the top of the car being from 10° to 25° higher in temperature than the floor and near the ice bunkers. Such fruit arrives at its destination in poor condition and hence entails heavy losses to the shippers. The greater part of these losses can be saved by pre-cooling, providing the fruit is in good condition and well handled.

336. Methods of pre-cooling.—Two general methods are used to effect the pre-cooling of the fruit: (1) the car pre-cooling, and (2) the warehouse pre-cooling. The first consists in loading the fruit in a car ready for shipment and then attaching a cold air duct or chute to the trap doors into which ice is loaded into the bunkers or even to the doors of the car. A fan forces the circulation of the air through the car and the warmer air back into a room where it is again cooled and continued through the system of circulation. This method seems to be favored by transportation companies but it is objected to by the warehouse men because the fruit is lowered in temperature so quickly that injury to its quality results. The temperature has been lowered from 80° or 90° F.—the outside temperature—to 35° or 40° F. in one to three hours. Another objection is that space must be left between packages and, therefore, by the warehouse method from 25 to 50 per cent more fruit can be loaded in a car. Neither is the car of fruit cooled so uniformily as by the other method.

In the warehouse method, the boxes of fruit are placed in warehouse rooms similar to those of a cold storage plant and the temperature is lowered to the point desired for shipping the fruit. The boxes are frequently handled on endless belts. This system seems to be gaining in favor, although the whole practice of pre-cooling is relatively new and is not fully established.

It has been suggested that if refrigerator cars were so built as to be as well insulated as a modern cold storage room, it would not be necessary to ice cars in a ten-day haul in summer weather, if they were pre-cooled.

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