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Apple Pollination Investigations

A. E. MURNEEK, W. W. YOCUM, and E. N. MCCUBBIN

ABSTRACT.—Our present information on the range of self-fruitfulness of many important varieties of apples grown in Missouri and adjoining states is summarized. The various external and internal factors influencing the fruit set are discussed and their bearing on the pollination problem emphasized. Data giving the results of apple pollination investigations at the Missouri Agricultural Experiment Station for the years 1926-1928 are presented in tabular form for the following varieties: Ben Davis, Delicious, Duchess, Gano, Grimes, Jonathan, King David, Maiden Blush, Rome, Wealthy, Yellow Transparent, Winesap and York. None of these varieties was found sufficiently self-fruitful for a commercially desirable crop. The three most efficient pollenizers are Ben Davis, Jonathan and Delicious. In several cross-pollinations Grimes and Gano were satisfactory male parents. The application of effective pollen increased the percentage of flowers set several times over self-pollination. In most instances, open-pollination increased the fruit yield still further. Emasculation did not seem to affect the results from cross-pollination. Self-fruitfulness of apple varieties can be determined more accurately by application of previously collected pollen than by merely covering the flowers. The removal of a large number of small twigs ("fine pruning") in the spring increased markedly the percentage of flowers set on the remaining branches.

Apple pollination investigations have been conducted since 1926 in two orchards of the Missouri Agricultural Experiment Station. It is deemed desirable at this time to summarize the results secured during the first three years, 1926 to 1928 inclusive. This appears to be particularly advisable in view of the fact that beginning with the 1929 season, a new method requiring the use of package bees[32] has been adopted for further work on the problem.

Though being essentially a progress report, this publication contains also information and data of a somewhat general nature but strictly germane to the subject in hand. Some parts of the discussion have the object to delimit the field of this study and to show the set-up, technique, and difficulties encountered. Thus in part this bulletin will serve as an introduction to forthcoming reports on various phases of the apple pollination investigations of this station.

THE PROBLEM

Specifically this study is concerned with the determination of the extent of self- and cross-unfruitfulness* existing in and between the standard commercial varieties of apples in Missouri. It is now popularly acknowledged that practically all apple varieties are more or less self-unfruitful, but the degree of fruitfulness is not so well known. It seems to vary considerably with the various sorts, and within the same variety in different regions and in the same region from year to year. Hence pollination investigations need to be carried on for a number of years in each major apple growing region.

*Though incorrectly, the term *self-sterility* is popularly used in horticultural literature in a synonymous sense to *self-unfruitfulness* and *inter-sterility* in place of *cross-unfruitfulness*.

Cross-unfruitfulness is known to be a factor of paramount importance in the production of several other fruits, but in case of apples, it has received relatively little attention. This phase of the pollination question is of growing interest, due to the present tendency of restricting the number of apple varieties grown for commercial purposes.

Heavy financial losses frequently result in orchards that are not supplied with suitable pollenizers. In some instances this has necessitated the use of drastic measures to remedy the situation, such as up-rooting and replanting a part of the orchard or topworking many of the trees. To avoid such difficulties in the future, prospective orchardists should have more knowledge of the pollination requirements of various varieties before the orchard is started.

It is hoped that from investigations of this character ultimately enough information will be gathered to make possible more specific and more valuable suggestions for the planting of pollenizers in commercial orchards. Such recommendations should tend to make apple crops more regular and certain.

REVIEW OF LITERATURE

Numerous pollination investigations have been conducted with the object of determining the extent and degree of self- and inter-fruitfulness of apple varieties. While much has been learned through this work of the pollination requirements of particular varieties, and certain orchard practices are being followed by alert growers in order to obviate possible pollination difficulties, the general situation seems to remain largely as stated by Fletcher[12] some thirty years ago: "Self-sterility (self-unfruitfulness) is not a constant character with any variety. It is influenced by conditions under which the tree is grown. The adaptation of a variety to soil and climate has much to do with its self-fertility (fruitfulness), and if a tree is poorly nourished, it is more likely to be infertile with its own pollen. No one can separate varieties into two definite classes which are self-sterile. The problem of self-sterility is as much a study of conditions as of varieties. We can set no limits; we can only indicate tendencies." Though some conspicuous cases may be quoted as signal exceptions to this generalization, still the vast majority of apple varieties, as far as our present knowledge goes, seem to show a marked fluctuation in self- and cross-fruitfulness from year to year and locality to locality. Only further and more extensive investigations will tell what are the real facts on this subject

The following table summarizes, in chronological order, our present information on the range of self-fruitfulness of some of the most important varieties of apples grown in Missouri and adjacent states.

TABLE 1.—RANGE OF SELF-FRUITFULNESS OF SOME IMPORTANT VARIETIES OF APPLES

Variety	Investigator	Locality	No. of blossoms considered	Percentage of blossoms set
Arkansas	Lewis and Vincent (25)	Ore.	?	0.0
Arkansas	Auchter (2)	Md.	1909	0.0
Arkansas	Auchter (2)	Md.	543 (s)**	0.0
Arkansas	Auchter and Schrader (3)	Md.	500 (s)	0.0
Arkansas	Knowlton (23)	West. Va.	230 (s)	0.0
Arkansas Black	Lewis and Vincent	Ore.	?	0.0
Arkansas Black	Vincent (41)	Idaho	448	0.0
Arkansas Black	Auchter	Md.	2620	0.0
Arkansas Black	Auchter	Md.	228 (s)	0.0
Arkansas Black	Luce and Morris (27)	Wash.	118 (s)	0.0
Ben Davis	Lewis and Vincent	Ore.	?	3.0
Ben Davis	Wicks (45)	Ark.	472 (s)	2.3
Ben Davis	Gowen (14)	Me.	339	0.0
Ben Davis	Vincent	Idaho	708	1.2
Ben Davis	Morris (30)	Wash.	509	0.2
Ben Davis	Sax (39)	Me.	1695	0.4
Delicious	Vincent	Idaho	231	0.0
Delicious	Dorsey (10)	Minn.	73 (s)	0.7
Delicious	Crandall (7)	Ill.	?	0.0
Delicious	Morris	Wash.	530	0.0
Delicious	Whitehouse and Auchter (44)	Md.	687 (s)	0.0
Delicious	Howlett (18)	Ohio	200 (s)	0.5
Delicious	Overholser (35)	Cal.	426 (s)	0.0
Delicious	Luce and Morris	Wash.	263 (s)	0.0
Delicious	Marshall, *et al* (29)	Mich.	564 (s)	0.0
Duchess	Lewis and Vincent	Ore.	?	5.0
Duchess	Chittenden (4)	Eng.	348	0.3
Duchess	Logsdail (26)	Ont.	479	0.0
Duchess	Vincent	Idaho	381	19.9
Duchess	Dorsey	Minn.	271 (s)	0.0
Duchess	Morris	Wash.	253	11.5
Duchess	Crandall	Ill.	? (s)	0.0
Duchess	Macoun (28)	Canada	530	11.5
Duchess	Florin (13)	Sweden	513 (s)	0.0
Duchess	Marshall, *et al*	Mich.	2162 (s)	0.0
Early Harvest	Powell (36)	Del.	408	5.9
Early Harvest	Gowen	Me.	13	0.0
Early Harvest	Vincent	Idaho	152	1.3
Early Harvest	Crandall	Ill.	?	0.0
Gano	Lewis and Vincent	Ore.	?	0.0
Gano	Logsdail	Ont.	318	0.0
Gano	Vincent	Idaho	668	3.6
Gano	Auchter	Md.	1173	0.1
Gano	Auchter	Md.	607 (s)	0.5
Golden Delicious	Howlett	Ohio	276 (s)	0.0
Golden Delicious	Knowlton	West Va.	213 (s)	1.0
Grimes	Powell	Del.	135	0.0
Grimes	Lewis and Vincent	Ore.	?	14.0
Grimes	Sutton (40)	Eng.	36 (s)	0.0
Grimes	Wicks	Ark.	442 (s)	8.4
Grimes	Vincent	Idaho	10765	2.2
Grimes	Auchter	Md.	661	1.7

**s = covered and selfed; other figures for covered only.

TABLE 1.—RANGE OF SELF-FRUITFULNESS OF SOME IMPORTANT VARIETIES OF APPLES (CONTINUED)

Variety	Investigator	Locality	No. of blossoms considered	Percentage of blossoms set
Grimes	Auchter	Md.	662 (s)	0.1
Grimes	Morris	Wash.	2484	1.5
Grimes	Macoun	Canada	24	0.0
Grimes	Keil (20)	Ohio	720 (s)	0.0
Grimes	Howlett	Ohio	148 (s)	.7
Grimes	Marshall, *et al*	Mich.	670 (s)	.3
Jonathan	Lewis and Vincent	Ore.	?	0.0
Jonathan	Wicks	Ark.	452 (s)	3.8
Jonathan	Vincent	Idaho	19081	2.9
Jonathan	Dorsey	Minn.	188 (s)	2.1
Jonathan	Morris	Wash.	504	0.0
Jonathan	Howlett	Ohio	174 (s)	0.0
Jonathan	Overholser	Cal.	600 (s)	0.4
Jonathan	Luce and Morris	Wash.	282 (s)	3.5
Jonathan	Marshall, *et al*	Mich.	535 (s)	0.7
Kind David	Vincent	Idaho	605	0.5
Kind David	Dorsey	Minn.	195 (s)	0.0
Ralls	Lewis and Vincent	Ore.	?	0.0
Ralls	Keil	Ohio	720 (s)	0.0
Rome	Lewis and Vincent	Ore.	?	0.0
Rome	Alderman (1)	West. Va.	16826 (s)	1.0
Rome	Logsdail	Ont.	166	0.0
Rome	Vincent	Idaho	10326	4.5
Rome	Keil	Ohio	720 (s)	0.0
Rome	Howlett	Ohio	80 (s)	2.5
Rome	Luce and Morris	Wash.	110 (s)	10.0
Stayman	Powell	Del.	106	0.0
Stayman	Auchter	Md.	845	0.0
Stayman	Auchter	Md.	560 (s)	0.0
Stayman	Crandall	Ill.	?	0.0
Stayman	Howlett	Ohio	70 (s)	0.0
Stayman	Knowlton	West Va.	1795	1.6
Stayman	Luce and Morris	Wash.	216 (s)	0.0
Wealthy	Waugh (42)	Vt.	28	0.0
Wealthy	Lewis and Vincent	Ore.	?	0.0
Wealthy	Chittenden	Eng.	30	0.0
Wealthy	Logsdail	Ont.	172	2.0
Wealthy	Vincent	Idaho	351	3.7
Wealthy	Auchter	Md.	1059	4.5
Wealthy	Auchter	Md.	799 (s)	1.9
Wealthy	Morris	Wash.	647	0.5
Wealthy	Macoun	Canada	125	6.4
Wealthy	Keil	Ohio	720 (s)	0.0
Wealthy	Howlett	Ohio	84 (s)	0.0
Wealthy	Marshall, *et al*	Mich.	658 (s)	0.8
Winesap	Powell	Del.	300	0.0
Winesap	Lewis and Vincent	Ore.	?	0.0
Winesap	Wicks	Ark.	550	0.4
Winesap	Vincent	Idaho	365	0.0
Winesap	Morris	Wash.	1096	1.6
Winesap	Crandall	Ill.	?	0.0
Winesap	Luce and Morris	Wash.	910 (s)	0.0
Yellow Transparent	Powell	Del.	363	5.5
Yellow Transparent	Lewis and Vincent	Ore.	?	8.0
Yellow Transparent	Logsdail	Ont.	605	0.9

TABLE 1.—RANGE OF SELF-FRUITFULNESS OF SOME IMPORTANT VARIETIES OF APPLES (CONTINUED)

Variety	Investigator	Locality	No. of blossoms considered	Percentage of blossoms set
Yellow Transparent	Vincent	Idaho	107	33.6
Yellow Transparent	Auchter	Md.	514	2.7
Yellow Transparent	Auchter	Md.	42 (s)	0.0
Yellow Transparent	Morris	Wash.	510	0.0
Yellow Transparent	Florin	Sweden	607	1.2
York	Powell	Del.	134	0.0
York	Lewis and Vincent	Ore.	?	0.0
York	Alderman	West Va.	21742 (s)	0.6

Not considering the usually large discrepancy in results due to a probably high experimental error and variability in methods of recording data, the present available evidence (Table 1) seems to indicate, on the whole, that some varieties are less self-fruitful than others. Thus practically no investigator has been able to secure fruit by self-pollination from Arkansas, Arkansas Black, Stayman and Winesap—all members of the Winesap group. It is now known that these varieties produce defective or almost completely non-viable pollen. As a result of this physical abnormality, they are not able to fertilize either their own flowers or those of another variety.

The degree of self-fruitfulness seems to differ greatly in the other considered varieties. In general, varieties that are known to yield well through a series of years appear to be more self-fruitful than those that are relatively poor bearers, like the Delicious and Arkansas. Moreover, these varieties on the whole appear to be also comparatively good pollenizers for most other sorts (There are conspicuous exceptions to this rule, however). Their male and female propensities evidently are generally high. This should be considered a constitutional and hence hereditary characteristic, for example, of the Jonathan, Duchess, Ben Davis, Gano, Wealthy, Yellow Transparent, and a number of other apples.

The striking discrepancies in the results of self-pollination of all sorts, excepting those that are strictly self-unfruitful, indicate quite clearly that practically all varieties are subject to marked fluctuations in this respect. To be sure a large percentage of the differences in results must be ascribed to the usual experimental error coincident with this type of study. By far a greater share of these differences, however, are most likely due to the marked effects of environmental factors and the nutritional states of the tree as a whole or parts of it.

CAUSES OF SELF-UNFRUITFULNESS

Lack of fruit setting in the apple, when self-pollinated, may result from a number of factors in the internal and external environment, or from what appears to be inherent defects in the sex organs. One or a number of causes working together may bring about unfruitfulness. Unfortunately constitutional defects of diverse character are often confused with the effects of environmental factors, which may come into operation at any time previous to or after fertilization.

Climate.—One important cause of a poor set of apples, which is largely beyond our control, is climate. An adjustment to this environment may be made to some extent by selecting a desirable location and varieties for the orchard. Climate is a very complex factor. It may prevent the setting of fruit in a number of ways. Hedrick[15], among others, is of the opinion that in New York unfavorable weather is the predominating factor causing the loss of fruit crops during flowering. This is without doubt true of apples throughout the northern and central portions of the apple growing region.

Extremely low temperature may kill outright the essential parts of the flowers during the winter or spring. A frosty temperature at flowering time, even if it does not kill, may prevent the growth of the pollen tubes or interfere with the work of bees and other insects. Hedrick[15] has observed that the average range of temperature at flowering is important. When the daily range is highest, the danger is greatest to the setting of fruit. A temperature slightly above average is usually most favorable for fruit setting, but an extremely high temperature, especially if accompanied by wind, may reduce the set by causing the stigmas to dry up and to be receptive to pollen for only a short time. The longer these unfavorable conditions last, the more serious will be the result upon the yield of fruit. Many investigators probably will agree with Knowlton[22] that "It is an established horticultural fact that a larger set of fruit occurs on selfed varieties in seasons when the temperatures are most favorable for pollen tube growth."

Humidity is also important in fruit setting. A protracted drought at any time may seriously affect the vigor and fruitfulness of trees for one or more years. Rains during the blooming period prevent insect flight, and so interfere with pollination. High humidity with low temperature increases the danger of injury to flowers. A dry wind tends to shorten the receptive period of pistils, and a strong wind will prevent bees from working. If not properly protected, emasculated flowers, according to Overholser[35], will dry out in a few days when the humidity is low. These are some of the more important ways in which climate affects fruit setting.

Nutrition.—In several pollination reports nutrition is mentioned as a vital factor in self-fruitfulness. The viability of pollen, says Kraus[24], is determined by factors among which the age and general vitality of the tree are important. This has been noted and determined also by Sandsten[37] and Wentworth[43]. Then, too, more blossoms are usually formed by the tree than can possibly be nourished and the dropping of flowers is due largely to a lack of food supply. Heinicke[16], for example, obtained results which "emphasize the importance of vigor, most especially the vigor of the individual spurs, as the factor in fruit setting. Vigorous spurs seem to favor fruit setting because they can supply the developing fruit with an abundance of water and food."

It is well known that varieties differ much in the ability of the individual flower within the cluster to set fruit[19,9]. Moreover, certain sorts, as Delicious[19], Winesap[27] and Arkansas evidently must be kept in a rather vegetative condition if they are expected to fruit well.

Abortive and Defective Pollen and Pistils.—The development of normal stamens and pistils and their ability to function as reproductive organs is absolutely essential for apple production. Very often, however, pollen and ovules may abort before they reach a functional stage or the embryo may degenerate after fertilization. Apple varieties of the Winesap group, as indicated before, and a few others produce a large percentage of non-viable pollen. This apparent hereditary defect seems to be due to various types of morphological abnormalities. But the essential organs of the flowers of any variety may become similarly affected from climatic and nutritional causes[31]. In fact, it is this uncertain environmental influence which makes unfruitfulness and sterility in apples so hard to deal with.

Incompatibility.—When pollen and pistils are in a normal and functional condition, and sterility still results after either self- or cross-pollination, the condition is spoken of as incompatibility. Explanations of the cause of this phenomenon offered by different investigators seems to vary considerably. All do agree, however, that the pollen germinates as readily upon the stigmas of one variety as upon another. The rate of growth of the pollen tubes in the styles of selfed and crossed flowers seems to differ.

In studying self-sterility in the Rome apple, Knight[21] detected no evidence that the stigmatic secretion inhibited germination and growth of the pollen tubes. They grew far enough to reach the egg, but too slowly to effect fertilization before disintegration began. A similar observation on other varieties of apples has been reported more recently by Cooper[5]. Osterwalder[34] also found that pollen tube growth was not sufficient to reach the ovules in self-pollinated flowers. Moreover, he noted club-shaped swellings on the tips of such pollen tubes. Namikawa[33],

on the other hand, could not observe any peculiar abnormal features in the manner of growth of pollen tubes in selfed flowers, nor were they appreciably delayed.

Heterostyly and Dichogamy.—Ewert[11] has pointed out the existence of heterostyly among various varieties of apples, some of which have pistils shorter and others much longer than the stamens. Whether this is strictly related to differences in maturity and receptivity of the two organs, and thus producing in the first instance protandry and the second protogyny, is unknown for lack of experimental evidence. Lewis and Vincent[25], however, obtained results from pollination studies, which they think make it quite evident in a great many apple varieties that the pistils are receptive before the blossoms open (dichogamy). This seems to indicate a mechanism whereby cross-pollination is facilitated more than self-pollination.

Pollen Supply.—Apple varieties differ considerably in the amount of viable pollen produced. Varieties which form a small amount of pollen or whose pollen is of low viability are, as a rule, poor pollenizers. If they are used alone for that purpose, the set of fruit may be very small. The viability of pollen of the same variety seems to vary from year to year. The requirements which a variety must meet if it is to be an efficient pollenizer may be summarized as follows: It must (a) produce an abundance of viable pollen; (b) be compatible with varieties which it is to pollenize; (c) bloom at the same time as the other varieties; and (d) be a standard variety itself.

Effect of Cultural Practices.—It is well known that fruit setting in apples is affected by the diverse cultural practices, since these determine in a large measure the condition of the tree. Cultivation, fertilization, irrigation, pruning, and spraying are intended to keep the trees vigorous, healthy, and supplied with an abundance of water and nutrients. The best cultural practices should be so directed as to produce the kind of vegetative growth which will set and mature fruit.

Nitrogen fertilizers are at present commonly used to improve fruit setting in apples. Evidently self- and inter-fruitfulness and even self-sterility may be altered by a change in nutrition, especially by a drastic modification in nitrogen metabolism in the peripheral region of the tree. Many varieties of apples will produce fruit without seeds by having the trees well nourished and self-pollinated. It seems that if the ovules have been stimulated and the stimulus transmitted to the vascular system, the fruit will continue to develop whether seeds are produced or not (provided there is an abundant food supply)[8].

Good cultural and nutritional conditions alone, however, will not overcome nor affect all types of self-unfruitfulness. An ample food supply is not sufficient to cause flowers to set.

In this connection it may be of interest to note that Sandsten[37] has observed that within the same variety pollen from neglected orchards seems to be inferior to that secured from orchards under good cultural treatment. The former was irregular in form and size, germinated slowly, and set a low percentage of fruit. Undoubtedly the nutritional state of the trees has an equally marked effect on the structure and performance of the pistils.

Relation to Seed Production.—Although Ewert[11] and others[24,6] believe that the development of parthenocarpic fruit is possible, this is of rare occurrence in the apple. Of course, most varieties, when self-pollinated, will produce fruit the seeds of which will be abortive in large numbers[25 et al.] In horticultural literature such apples have been frequently referred to as "seedless"—a very inappropriate term indeed.

Premature dropping of apples has for a long time been thought to be due to lack of pollination. Heinicke[16] has observed that "the heavy loss of partially developed fruits during the June drop is frequently associated with poor pollination and lack of fertilization." Morris[30] has expressed himself in a similar vein by saying that "lack of fertilization of the flowers is a causal factor in June drop of apples", while Sax[38] found that "apples which fall in the 'June drop' contain fewer seeds than apples which set and develop." But more recently Detjen[8] emphasizes the fact that "lack of pollination and lack of fertilization, which are commonly supposed to be chief causes of the shedding of young fruits, are found to be factors of but minor importance. And that the factors (of whatever nature) that "bring about embryo abortion appear to be the chief cause for the shedding of the majority of young fruits."

As might be expected, fruits with abortive embryos and seeds are at a disadvantage in competition with those in which seeds develop normally, and if the food supply is inadequate, such fruits will drop before maturity.

Most horticulturists agree that the size of the apple is affected by the number of normally developed seeds. Crandall[6], for instance, concludes from his study that "the capacity to produce seeds is a varietal characteristic", but that variations in size of fruit within a variety are largely due to differences in the number of seeds present. Moreover, it has been found[16] that the vigor of the fruit bearing spur and the size of the embryos in the seeds play a part in determining the size of the fruit. In this connection Sax[38] suggests that the variations found among different apples seem to indicate that "seed (number) and apple weight relationships found in a single tree or one variety cannot be applied to all trees of all varieties."

The rather notable influence of seeds on the uniformity of development of apples has been pointed out and pictured frequently[30, 38, 29].

EXPERIMENTAL

The major problem of this investigation is to determine the extent of self- and inter-fruitfulness existing in and between the most important commercial varieties of apples in Missouri. The studies reported here were carried out during three successive seasons, 1926-1928.

The effect of pruning on the set of open-pollinated flowers was recorded in the spring of 1927, and certain pollination methods were studied and contrasted in 1928. The extent of frost injury to pistils was also determined in this year.

Material.—The varieties studied were Ben Davis, Delicious, Duchess, Gano, Grimes, Jonathan, King David, Maiden Blush, Rome, Yellow Transparent, York, Wealthy, and Winesap. The trees used were as uniform in size and vigor as could be obtained. They were bearing good crops and were considered in average condition for trees of a commercial orchard. About half of the trees are growing on loess soil at the Turner Station Experimental orchard seven miles southwest of Columbia. They were sixteen years old at the beginning of the experiment. The other trees were approximately thirty years old and are in the University Experiment orchard at Columbia. Both orchards are in sod and receive each spring 4-5 pounds of sulphate of ammonia or equivalent amounts of nitrate of soda per tree. They are pruned regularly and sprayed well.

Methods of Procedure.—The commonly used method of study of self-fruitfulness by covering the unopened blossoms with paper bags was employed. Excepting where indicated otherwise (1928), self-pollination was left to take care of itself.

In 1928 a comparison was made in methods of self-pollination between bagging only (designated in the tables "self-pollinated") and bagging with application of previously collected pollen to emasculated flowers of the same variety. A test was made at the same time of the effects of a good pollen, such as Delicious or Ben Davis, on both emasculated and non-emasculated blossoms. All flowers under experimental treatment, excepting of course, those open-pollinated, were protected by paper bags.

Cross pollination was begun as soon as a majority of the buds on the tree were about ready to open. The usual method of emasculating and pollinating apple blossoms were adhered to. Branches about twelve to eighteen inches long bearing several buds were selected for this purpose.

The few open flowers that were present were removed from the chosen branches. The petals were pulled off the still closed flowers and

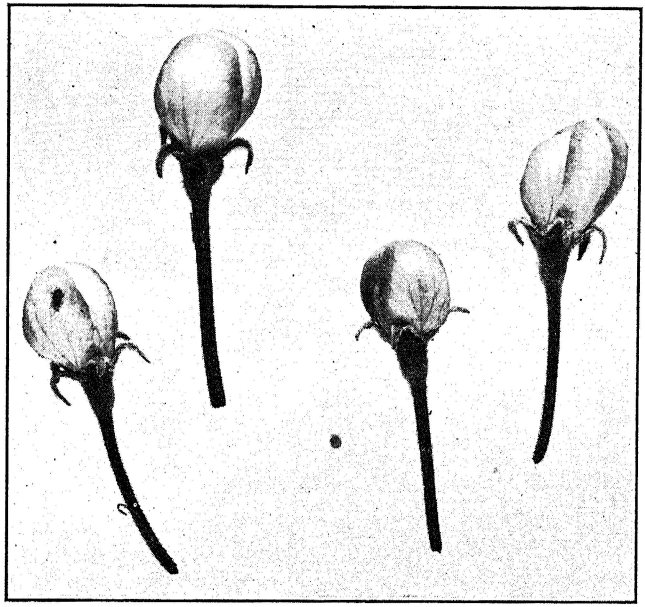

Fig. 1.—Apple blossoms ready for collection of pollen.

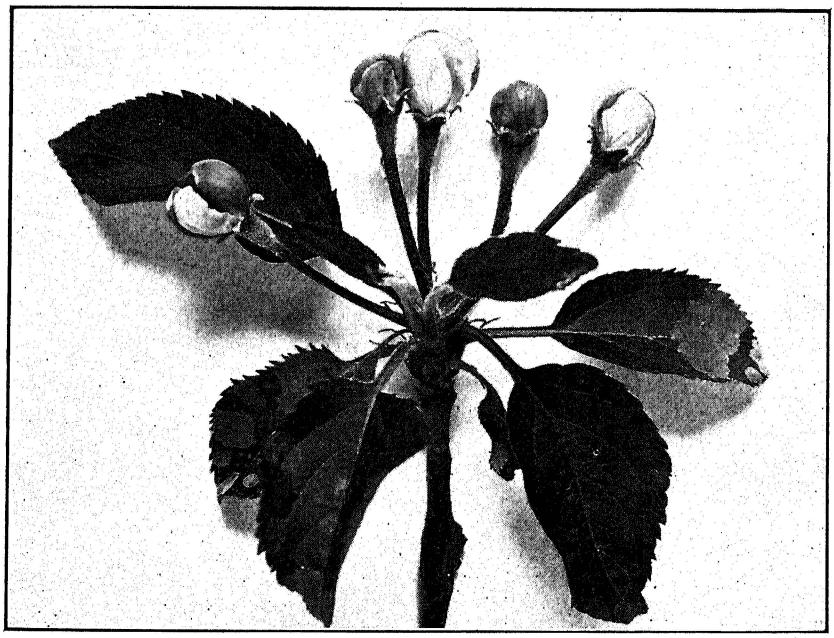

Fig. 2.—Showing stage of development of flowers when emasculation and artificial pollination was performed.

anthers removed with tweezers by working carefully around the pistils. When all the buds had thus been emasculated, the pollen of the desired variety was dusted lightly over the stigmas by means of a fine brush. The flowers were protected from foreign pollen by enclosing them in large paper bags. (Figs. 1 and 2.)

All pollen used in this study was secured in the following manner: About a week before it was needed branches were gathered from all the desired varieties, brought into the greenhouse, and forced into bloom. Pollen was collected from unopened buds in the most advanced "pink stage." The anthers were removed either by the aid of tweezers or by rubbing the buds lightly over a fine mesh sieve. After thorough drying, the pollen was preserved in plugged vials. Before using, germination tests were made in order to find that the pollen was viable. (Figs. 3 and 4.)

The paper bags were removed promptly from all branches as soon as the petals had fallen and the pistils were past the receptive stage.

The set of fruit from self-, cross-, and open-pollination was determined after the last or "June drop."

Weather and Other Factors.—The spring of 1926 was very favorable for the work of artificial as well as for insect pollination. There was a heavy bloom and an unusually good set of fruit on most varieties. The result of that season's work, therefore, are considered very reliable wherever they are based on large enough numbers of crosses.

Very extreme weather conditions marked the apple blooming season of 1927. This interfered seriously with all pollination procedure. There were only three really favorable days for desirable orchard work. Following pollination a high wind tore off some of the bags. These were replaced promptly, but a few of the flowers appeared to be severely battered and there was a brief opportunity for introduction of foreign pollen into the controlled crosses. A light frost and some hail injury in one of the orchards may also have affected the set. Consequently the results of this season may not be considered as reliable as those of 1926.

Continuously cool weather prevailed in the spring of 1928. A very severe frost occurred on April 15, when some of the earlier varieties were about to come into full bloom and the buds of others were well advanced. It is difficult to measure accurately the influence of such a frost on the normal performance of either the pistils or the exposed pollen. That the injury was severe to many varieties is indicated by the following count of the number of stigmas and styles actually dead at the time immediately preceding full bloom. (Table 2.)

The crop was uneven on most of the trees used in 1928, but, in spite of the frost, fairly good crops were produced on a large number of varieties.

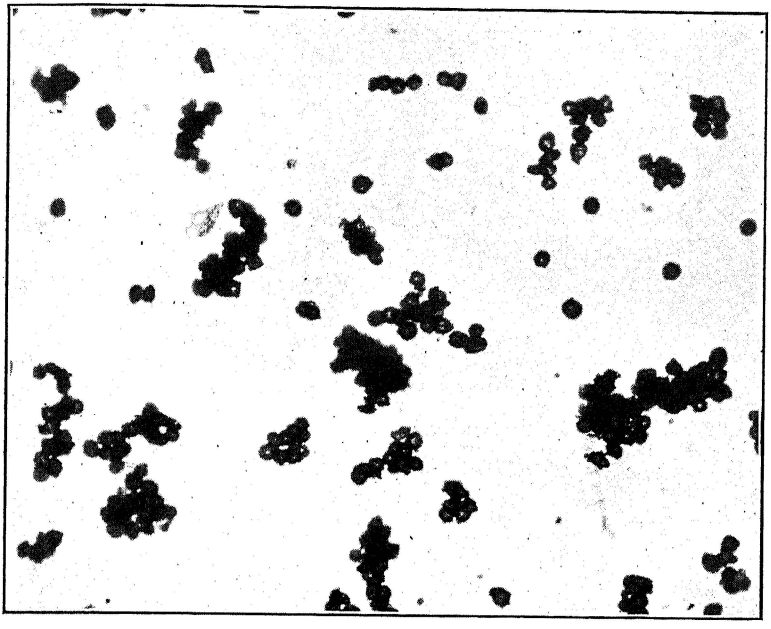

Fig. 3.—Example of pollen that does not germinate or germinates poorly. Variety, Stayman. Sugar-agar drop culture in Van Thiegham cell. 48 hours.

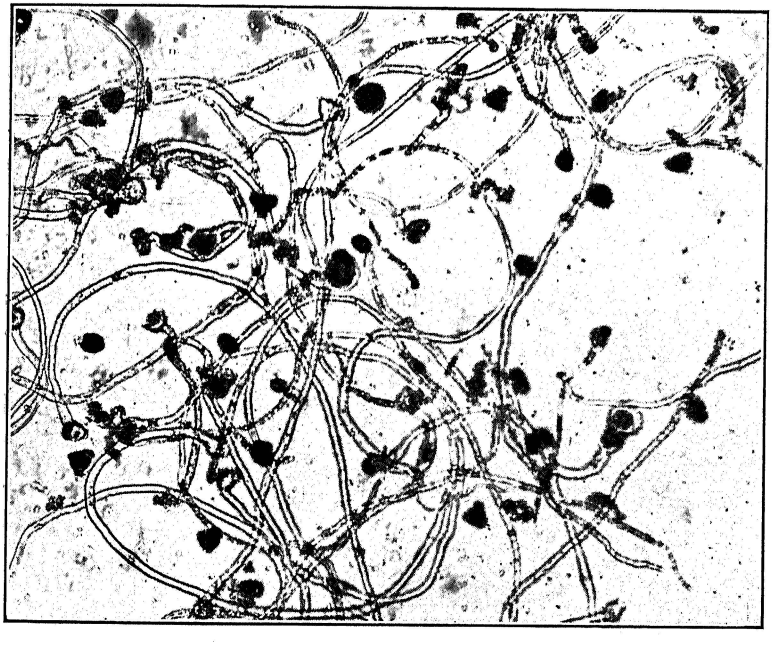

Fig. 4.—Example of pollen that germinates satisfactorily. Variety, Jonathan. Sugar-agar drop culture in Van Thiegham cell. 48 hours.

TABLE 2.—EFFECTS OF FROST ON APPLE FLOWERS, SPRING, 1928

	No. of flowers examined	No. of pistils killed	Percentage of pistils killed
Turner Station Orchard			
Delicious	469	190	40.4
Jonathan	510	66	13.0
York	494	44	8.9
Grimes	550	11	2.0
Winesap	344	4	1.2
Stayman	467	1	0.2
Columbia Orchard			
Delicious	246	138	56.0
Duchess	230	119	51.8
Ben Davis	505	92	18.2
Maiden Blush	341	53	15.5
Jonathan	368	34	9.2
Gano	438	28	6.4
Wealthy	514	31	6.0
Yellow Transparent	504	28	5.5
Grimes	382	14	3.7
King David	541	14	2.6

The Blooming Period.—The flowering dates for the most important varieties of apples in Missouri have been recorded for a number of years, including 1926-1928. For cross-pollination it is, of course, necessary that the pollenizers bloom at the same time that the varieties they are to pollinate bloom. Figure 5 shows that the flowering periods of practically all of our leading varieties overlap, excepting in seasons when, because of protracted cold weather and intervening warm spells, it may be unduly long. In such years varieties that may have come into full bloom comparatively early may be past the pollination stage before the others are ready to shed pollen freely. It is evident that cross-pollination troubles may be encountered with the comparatively early flowering Duchess and the late blooming Rome, Ralls and Ingram, but not very likely with most other varieties.

The graphs indicate also the time during which artificial cross-pollination can be done effectively and the peak of the blooming period of all evarieties considred.

PRESENTATION AND DISCUSSION OF RESULTS

Self-, Cross- and Open-Pollination.—Since the various environmental factors and the nutritional state of the tree, which varies so markedly from season to season, usually affect the results in pollination work, it is felt desirable to present the data separately by varieties and by years. They are given for the three seasons in Tables 3 to 15. The results refer specifically to the percentage set from self-pollination, to cross-pollina-

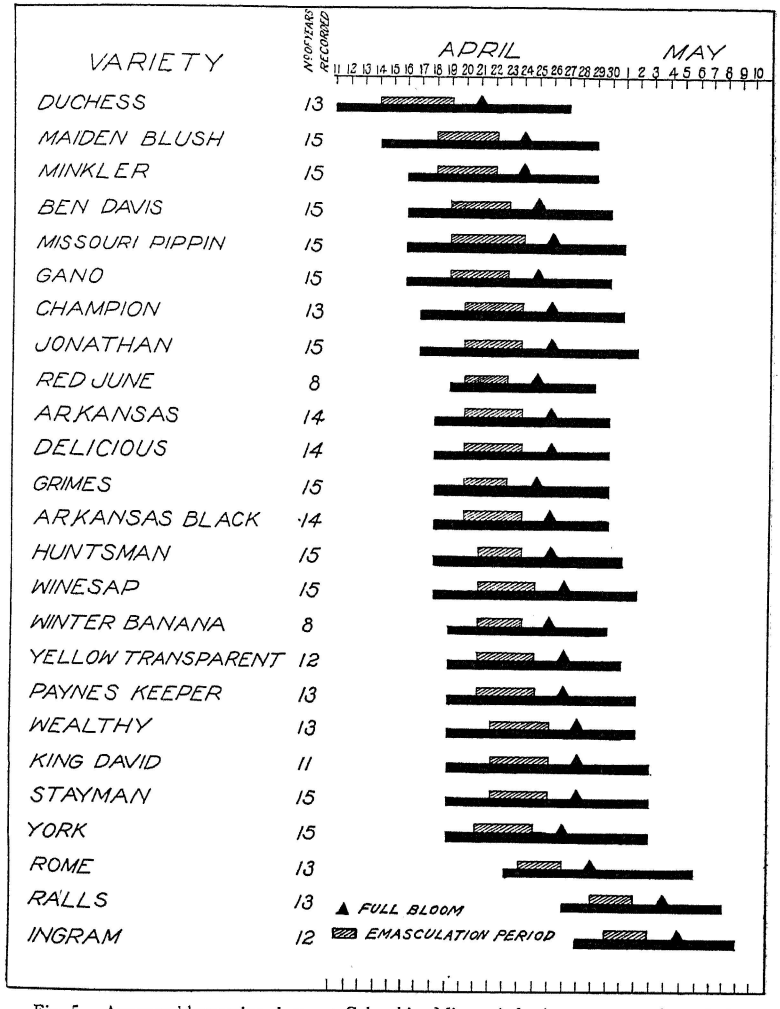

Fig. 5.—Average blossoming dates at Columbia, Missouri, for important apple varieties.

tion with pollen from a known variety, and to open-pollination. It should be emphasized that the percentage of flowers set was determined when *all* the drops had occurred, or after what is commonly referred to as "June drop." With ten varieties the comparative effect of self-pollination by merely bagging the flowers and of self-pollination by application of pollen to emasculated flowers is also presented as well as the influence of emasculation in cross-pollination.

Ben Davis

Ben Davis is known to be an excellent bearer. Still the presented results agree with those secured by several other investigators that it is quite self-unfruitful. The best set was secured with Jonathan and Delicious pollen. But only in one year this set was equal to or exceeded that from open-pollination. Ben Davis is an excellent pollenizer for other varieties.

TABLE 3.—POLLINATION RESULTS WITH BEN DAVIS (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of fruit set	Percentage of flowers set
1926			
Self-pollinated	860	0	0.0
1927			
Self-pollinated	274	0	0.0
Delicious	506	108	21.3
Jonathan	394	109	27.7
King David	310	2	0.6
Rome	249	12	4.8
Winesap	109	1	0.9
Open-pollinated	1411	303	21.5
1928 (Columbia Orchard)			
Self-pollinated	274	1	.4
Ben Davis	469	13	2.8
Delicious	217	20	9.2
Delicious (not emasculated)	224	8	3.6
Gano	176	2	1.1
Jonathan	347	21	6.1
Stayman	141	0	0.0
Open-pollinated	476	81	17.0

Delicious

Delicious seems to be fully self-unfruitful. The small set secured in 1926 from self-pollinated flowers of this variety most likely was due to accidental presence of foreign pollen. Jonathan, Ben Davis, and Grimes pollen gave the best set. The 1927 yield from open-pollination was several times greater than that secured from the use of a known pollen.

The very poor set of fruit obtained in the Columbia orchard in 1928 from all types of pollination most likely was caused by the severe frost at the beginning of the flowering period. More than half (56%) of the pistils were killed outright and probably a large percentage of the remaining ones were seriously injured.

Delicious produces an abundance of pollen, which usually germinates well, hence this variety is a very good pollenizer.

TABLE 4.—POLLINATION RESULTS WITH DELICIOUS (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1926			
Self-pollinated	144	2	1.4
Jonathan	329	36	10.9
Open-pollinated	130	16	12.3
1927			
Self-pollinated	1246	0	0.0
Ben Davis	334	6	1.8
Grimes	243	3	1.2
King David	229	0	0.0
Rome	255	3	1.2
Winesap	222	0	0.0
Open-pollinated	1105	105	9.5
1928 (Columbia Orchard)			
Self-pollinated	453	0	0.0
Delicious	521	2	.4
Ben Davis	105	0	0.0
Ben Davis (not emasculated)	267	9	3.4
Gano	164	4	2.4
Grimes	193	0	0.0
Jonathan	189	1	.5
Stayman	203	0	0.0
Open-pollinated	778	8	1.0

Duchess

The pollination requirement of this variety has been tested only in one year when a damaging frost occurred. Duchess is but moderately self-fruitful. All cross pollinations gave excellent sets of fruit, exceeding in every instance those from open-pollination. Delicious, Wealthy and

TABLE 5.—POLLINATION RESULTS WITH DUCHESS (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of fruit set	Percentage of flowers set
1928 (Columbia Orchard)			
Self-pollinated	116	1	.9
Duchess	350	4	1.1
Delicious	189	11	5.8
Wealthy	135	8	5.9
Yellow Transparent	128	9	7.0
Open-pollinated	412	17	4.1

Yellow Transparent seem to be good pollenizers for the Duchess, though many other varieties not tried by us may give equally good results.

Were it not for the comparatively early blooming of this variety (Fig. 5), which in some years may not overlap many other standard

sorts of apples, the Duchess would be a good pollenizer. It seems to have a tendency to flower biennially.

Gano

This variety like its near relative, Ben Davis, seems largely self-unfruitful and, as may be expected, cannot be pollinated successfully by Ben Davis. This, however, is probablynot a case of cross-incompatibility, but rather a matter of possible clonal self-sterility. Pollen varieties that are giving a good performance on Ben Davis should be equally potent on the Gano. Despite weather disturbance, it was successfully pollinated in 1928 by Grimes, Delicious, and Jonathan.

TABLE 6.—POLLINATION RESULTS WITH GANO (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1928 (Columbia Orchard)			
Self-pollinated	225	1	.4
Gano	533	0	0.0
Ben Davis	149	0	0.0
Delicious	168	3	2.0
Delicious (not emasculated)	249	6	2.4
Grimes	67	3	4.5
Jonathan	143	2	1.4
Stayman	181	0	0.0
Open-pollination	701	51	7.3

Grimes

Only in one year out of three a fair crop was secured from self-pollination of Grimes. Ben Davis (Gano), Delicious, Jonathan, and Rome evidently are desirable pollenizers for this variety. Poor results were obtained with King David and York pollen and practically no set at all with Stayman and Winesap, which is to be expected, since it is well known that these two varieties produce defective pollen.

Though apparently not as effective as some other varieties, Grimes is a fairly good pollenizer for most apples. In our orchards it has been quite consistently an annual bearer.

Jonathan

For many reasons Jonathan must be considered the leading apple variety in Missouri. It is a rather regular bearer and an excellent pollenizer for other apples. Our results indicate that it is only partly self-fruitful. Ben Davis and Delicious were most effective pollenizers,

TABLE 7.—POLLINATION RESULTS WITH GRIMES (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of fruits set	Percentage of flowers set
1927			
Self-pollinated	374	0	0.0
Ben Davis	275	39	14.2
Delicious	446	82	18.4
Jonathan	129	32	24.8
King David	170	1	0.6
Rome	116	22	18.9
Winesap	148	1	0.7
Open-pollinated	368	63	17.1
1928 (Turner Orchard)			
Self-pollinated	189	3	1.6
Grimes	262	3	1.1
Delicious	65	6	9.2
Gano	126	6	4.8
Gano (not emasculated)	191	16	8.4
Jonathan	88	3	3.4
Stayman	150	0	0.0
York	112	0	0.0
Open-pollinated	654	51	7.8
1928 (Columbia Orchard)			
Self-pollinated	215	0	0.0
Grimes	489	2	.4
Ben Davis	159	14	8.8
Delicious	223	18	8.1
Delicious (not emasculated)	261	27	10.3
Gano	184	4	2.2
Jonathan	160	4	2.5
Stayman	207	1	.5
Open-pollinated	687	37	5.4

TABLE 8.—POLLINATION RESULTS WITH JONATHAN (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1926			
Self-pollinated	1013	1	0.1
Ben Davis	155	34	21.9
Delicious	460	72	15.6
Grimes	320	61	19.0
King David	290	45	15.5
Rome	115	9	7.8
Open-pollinated	487	84	17.3
1927			
Self-pollinated	211	0	0.0
Ben Davis	102	27	26.4
Grimes	383	9	2.3
Winesap	166	1	0.6
Open-pollinated	618	43	6.9
1928 (Turner Orchard)			
Self-pollinated	156	0	0.0
Jonathan	151	2	1.3
Delicious	133	9	6.8
Delicious (not emasculated)	195	21	10.8
Gano	146	8	5.5
Grimes	68	1	1.5
Stayman	109	0	0.0
York	68	2	2.9

TABLE 8.—POLLINATION RESULTS WITH JONATHAN (♀) (CONTINUED)

Open-pollinated	520	32	6.2
1928 (Columbia Orchard)			
Self-pollinated	228	0	0.0
Jonathan	353	1	.3
Ben Davis	172	10	5.8
Delicious	170	13	7.6
Delicious (not emasculated)	215	18	8.4
Gano	237	6	2.5
Grimes	153	0	0.0
Jonathan	353	1	.3
Stayman	127	1	.8
Open-pollinated	698	33	4.7

though Grimes, Gano, York and King David were also satisfactory in some years at least. In general, Jonathan seems to be compatible with many other varieties.

King David

Though only moderately self-fruitful this variety was successfully pollinated by any of the leading pollenizers, such as Jonathan, Delicious, Grimes, and Ben Davis. No set was secured with Rome pollen.

King David has a marked tendency to flower biennially when the trees get older. It does not seem to be a conspicuously good pollenizer for other sorts of apples.

TABLE 9.—POLLINATION RESULTS WITH KING DAVID (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1926			
Self-pollinated	945	1	0.1
Delicious	491	45	9.2
1927			
Self-pollinated	633	5	0.8
Ben Davis	180	6	3.3
Grimes	345	30	8.7
Jonathan	497	59	11.9
Rome	239	0	0.0
Open-pollinated	1152	201	17.4

Maiden Blush

Only two rather old trees were used for pollination studies with this variety. Excellent sets were secured from all popular pollenizers, exceeding in almost every case the yield from open-pollination.

TABLE 10.—POLLINATION RESULTS WITH MAIDEN BLUSH (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1928 (Columbia Orchard)			
Self-pollinated	164	1	.6
Maiden Blush	717	4	.6
Ben Davis	203	16	7.9
Delicious	208	11	5.3
Delicious(not emasculated)	257	14	5.4
Grimes	189	2	1.1
Jonathan	199	11	5.5
Stayman	168	1	.6
Open-pollinated	792	25	3.2

Rome

It seems to be self-fruitful to some extent. Very good yields of fruit were obtained with Jonathan, Delicious and Ben Davis as pollenizers. Grimes was moderately effective and King David not at all. The set from open pollination was much heavier than from artificial cross-pollination.

The Rome is an extremely late bloomer and hence the pollen used was as a rule several days old. A number of late blooming sorts of apples are growing nearby these Romes.

TABLE 11.—POLLINATION RESULTS WITH ROME (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1926			
Self-pollinated	503	6	1.2
Delicious	245	34	13.9
1927			
Self-pollinated	452	1	.2
Ben Davis	457	23	5.0
Delicious	424	31	7.3
Grimes	417	7	1.7
Jonathan	342	55	16.0
King David	492	0	0.0
Winesap	122	1	0.8
Open-pollinated	472	135	28.6

Wealthy

But moderately self-fruitful, this variety gave good sets with Jonathan and Ben Davis pollen. For some reason Duchess and Yellow Transparent were not efficient pollenizers of the Wealthy in our tests.

TABLE 12.—POLLINATION RESULTS WITH WEALTHY (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1928 (Columbia Orchard)			
Self-pollinated	130	1	.8
Wealthy	345	1	.3
Ben Davis	205	4	1.9
Duchess	196	1	.5
Jonathan	200	5	2.5
Yellow Transparent	203	1	.5
Open-pollinated	598	57	9.5

Undoubtedly many of the Wealthy flowers were injured in 1928 by the severe frost. It is a biennial bearer.

Winesap

It is well known that this variety produces very defective pollen, and, as a consequence of this abnormality, is comparatively self-sterile. Still in both years of our study a small percentage of set was secured when the flowers were bagged. It is difficult to account for this purely on the basis of a possible experimental error. Jonathan gave the most marked set, but Ben Davis and Grimes were also effective pollenizers.

As noted elsewhere already, the extremely bad weather in 1927 interfered greatly with pollination operations. This accounts for the very poor results of this season.

TABLE 13.—POLLINATION RESULTS WITH WINESAP (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1926			
Self-pollinated	757	7	.9
Ben Davis	201	26	12.9
Delicious	133	3	2.2
Grimes	327	57	17.4
Jonathan	175	66	37.7
Rome	116	2	1.7
Open-pollinated	618	211	32.5
1927			
Self-pollinated	1092	2	.2
Ben Davis	100	4	4.0
Delicious	607	1	.2
Grimes	503	0	0.0
Jonathan	177	0	0.0
Rome	737	0	0.0
Open-pollinated	661	88	13.3

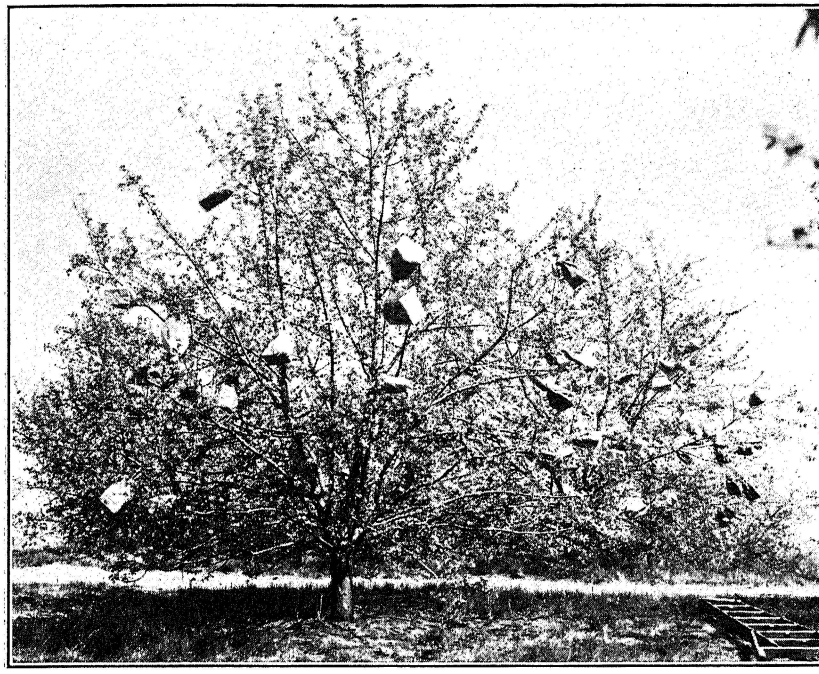

Fig. 6.—A typical tree (Winesap) used for apple pollination studies at the University of Missouri Agricultural Experiment Station.

Yellow Transparent

No fruit was secured from bagged flowers and only one small specimen from a large number of artificially self-pollinated flowers. Our results, therefore, are negative. Several other horticulturists, however, have found this variety fairly self-fruitful. Pollen from Delicious and Jonathan produced an ample set, but open-pollination was decidedly more effective.

TABLE 14.—POLLINATION RESULTS WITH YELLOW TRANSPARENT (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1928 (Columbia Orchard)			
Self-pollinated	122	0	0.0
Yellow Transparent	438	1	.2
Delicious	165	16	9.7
Delicious (not emasculated)	254	16	6.4
Duchess	189	4	2.1
Jonathan	174	7	4.0
Wealthy	196	2	1.0
Open-pollinated	762	145	19.0

York

Excepting when injured by abnormally cold weather, York bears well every second year in Missouri. It was quite self-fruitful in 1928, which was an "on year" for these trees. Delicious was a very effective pollenizer; Gano, Jonathan and Grimes only moderately so. The set from open-pollination was good. A considerable percentage of the flowers were injured by frost.

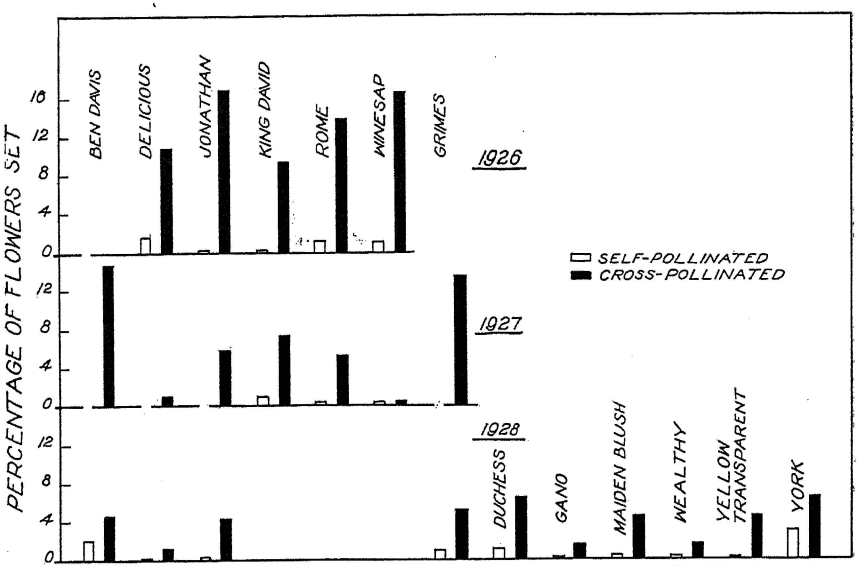

Fig. 7.—Chart showing comparative percentages of flowers set from self-pollination and cross-pollination in certain varieties of apples, 1926-1928 inclusive.

TABLE 15.—POLLINATION RESULTS WITH YORK (♀)

Pollen Variety (♂)	No. of flowers pollinated	No. of flowers set	Percentage of flowers set
1928 (Turner Orchard)			
Self-pollinated	189	2	1.1
York	320	14	4.4
Delicious	110	3	2.7
Delicious (not emasculated)	182	31	17.0
Gano	112	3	2.7
Grimes	121	2	1.6
Jonathan	124	2	1.6
Open-pollinated	611	71	11.6

A general summary of results from all self-, cross-, and open-pollinations is given in Table 16 and Figure 7. It is quite apparent that in practically all instances cross-pollination has increased the set several times over self-pollination. If for a commercial set 3-7% of the flowers

must mature into fruit, then a vast majority of the cross-pollinated flowers were within this requirement of efficiency, while none of the self-pollinated ones even approach it. One is compelled, therefore, to agree withmany other investigators that no variety of apples can be considered sufficiently self-fruitful to be planted alone.

The Efficiency of Certain Pollenizers.—It is of considerable interest to know the comparative efficiency of some of the most important pollenizers. Table 17 shows that in our tests on nine varieties during three seasons, Ben Davis gave, in aggregate, the highest set—12%. Jonathan and Delicious varieties, in still larger number of tests, were found to be almost equally effective pollenizers. In fact, during the three years each of the three-varieties in turn produced the largest set of fruit. There is hardly any doubt that Ben Davis, Jonathan and Delicious are by far the most desirable cross-pollenizers of all the varieties studied by us. Grimes is another fairly good pollenizer, and in most years with most varieties will produce a satisfactory set. If further tests were tried it is very likely that in the majority of cross-pollinations Gano would show a much higher set than indicated in Table 17. It may even ap-

TABLE 16.—COMPARISON OF RESULTS FROM SELF-, CROSS- AND OPEN-POLLINATIONS. TOTAL AVERAGES FOR 1926, 1927, AND 1928

♀ Variety	No. of flowers self-pollinated	Percentage set	No. of flowers cross-pollinated	Percentage set	No. of flowers open-pollinated	Percentage set
1926						
Ben Davis	860	0.0				
Delicious	144	1.4	329	10.9	130	12.3
Jonathan	1013	0.1	1340	16.5	487	17.3
King David	954	0.1	491	9.2		
Rome	503	1.2	245	13.9		
Winesap	757	0.9	952	16.2	211	32.5
1927						
Ben Davis	274	0.0	1568	14.8	1411	21.5
Delicious	1246	0.0	1283	0.9	1105	9.5
Grimes	374	0.0	1658	13.8	368	17.1
Jonathan	211	0.0	651	5.7	618	6.9
King David	633	0.8	1261	7.5	1152	17.4
Rome	452	0.2	2254	5.2	472	28.6
Winesap	1092	0.2	2124	0.3	661	13.3
1928						
Ben Davis	743	1.9	1105	4.6	476	17.0
Delicious	974	0.2	1121	1.2	778	1.0
Duchess	466	1.1	452	6.2	412	4.1
Gano	758	0.1	957	1.5	701	7.3
Grimes	1155	0.7	1926	5.1	1341	6.6
Jonathan	888	0.3	2146	4.2	1218	5.3
Maiden Blush	881	0.6	1224	4.5	792	3.2
Wealthy	475	0.4	804	1.4	598	9.5
Yellow Transparent	560	0.2	978	4.6	762	19.0
York	509	3.1	649	6.3	611	11.6

TABLE 17.—COMPARATIVE EFFICIENCY OF CERTAIN VARIETIES AS POLLENIZERS. TOTAL AVERAGES FOR 1926, 1927 AND 1928

♂ Variety	No. of varieties involved	Total No. of flowers pollinated	Percentage of flowers set
Ben Davis	9	3064	12.0
Jonathan	11	3667	11.3
Delicious	11	6573	9.4
Grimes	8	3329	5.3
Gano	5	1336	3.7
King David	5	1491	3.2
Rome	6	1827	2.6

proach the value of Ben Davis as a pollenizer. King David and Rome fall far short as producers of good pollen. As a matter of fact, of the 3.2% set secured from five pollination groups, with King David pollen, 94% of the fruit came from cross-pollination with one variety. Hence the results are doubtful. In most years the Rome comes into full bloom so late and passes through anthesis so rapidly that it cannot be considered a desirable pollenizer for other varieties, excepting those flowering equally late.

It is understood, of course, that there are many other especially early varieties of apples that seemingly produce effective pollen. Our investigations to date, however, have not been extensive enough to permit the drawing of definite conclusions.

In a large number of instances open-pollination increased the set still further (Table 16). This undoubtedly indicates that the efficiency of the artificial cross-pollination, involving a somewhat unnatural treatment of the flowers, was not conducive to the highest set of fruit. A less disturbing method of testing cross-fertility would be more desirable than the one so widely used by experiment station workers at present. From the standpoint of orchard economy, an abnormally high percentage of set of flowers, of course, is undesirable.

TABLE 18.—SELF-FRUITFULNESS AS DETERMINED BY BAGGING AND BY HAND POLLINATION. 1928

Treatment	No. of varieties used	No. of flowers involved	Percentage of flowers set
Flowers bagged only ("self-pollinated")	10	2461	0.4
Bagged and hand pollinated	10	4948	0.9

TABLE 19.—EFFECTS OF EMASCULATION AND NON-EMASCULATION IN CROSS-POLLINATION WITH DELICIOUS (♂). 1928

Treatment	No. of varieties studied	No. of flowers involved	Percentage of flowers set
Emasculated	7	1394	6.7
Not emasculated	7	1837	7.7

Bagging vs. Hand Pollination.—A comparison of the efficiency of bagging only and of bagging plus hand pollination shows (Table 18) that the latter is to be preferred as a method in self-pollination studies. This has been emphasized lately (Table 1) by several investigators, while many others seem to think that there is no preference. When compared with a commercially desirable set, the difference in results from the two methods, after all, is not so great.

Fig. 8.—Artificial pollination of flowers should approximate as closely as possible the work done by bees (Courtesy of A. I. Root Co.).

Effect of Emasculation.—As shown in Table 19, there seems to be very little difference in the percentage of fruit set whether the flowers are emasculated or not preparatory to cross-pollination. Therefore, when the results of pollination investigations are to be applied in orchard practice, which certainly is the ultimate object of our efforts, then the very tedious and time consuming operation of the removal of the anthers (emasculation) is quite unnecessary. For a more detailed study of self-sterility, however, this may be a required technique.

Influence of Pruning.—It is generally acknowledged that such orchard practices which lead to an increased vigor of bearing trees will influence favorably the fruit set, hence the wide appreciation of the benefit that is usually obtained from spring application of nitrogen

Fig. 9.—The numerous flowers on this branch were self-pollinated. No fruit set. Variety Rome.

Fig. 10.—As a result of cross-pollination 10 apples (marked ∠) set on this branch of a Rome tree.

fertilizers. A similar though somewhat localized increase in vigor can be brought about more directly by pruning, but the effects of pruning on fruit setting, though often referred to, have not been observed and demonstrated as well as those of soil fertilization. Comparatively recently, however, Heinicke[17] has called our attention to two instances where in one orchard pruning evidently increased considerably the set of apples in the second year, while in another orchard heavy heading back seemed to decrease it.

As a phase of the pollination investigation, it was thought of interest to study the influence of so-called "detailed" pruning on the fruit set of the same year. Early in the spring of 1927 four trees of each of Duchess Grimes, Rome, Stayman and Jonathan and two trees of Ben Davis were selected for this purpose. The trees were paired off, each pair being as nearly alike as could be ascertained by close observation. All of these trees had received similar treatment throughout their life. They are growing in typical loess soil which is kept in sod. At the time of the experiment the trees were 17 years old. They had received lately a moderate dormant pruning and were fertilized with four pounds of sulphate of ammonia two weeks before flowering.

One tree of each pair was "fine pruned" early in the spring, the other serving as a control (Fig. 11). Pruning in this case consisted of thinning out systematically and thoroughly small twigs throughout the top of the tree (Fig. 12).

The weather was extremely unfavorable during the flowering period in 1927, hence, though practically all of the trees produced a heavy bloom the set was comparatively light. The percentage sets of open-pollinated blossoms of these trees is given in Table 20.

It will be seen that in nine instances out of eleven, pruning of this type did result in an increased set. The two negative cases, where the set on the non-pruned trees was higher than on the pruned, most likely was due, in part at least, to a relatively larger number of flowers on these particular control trees. Naturally this would lead to a very much smaller percentage set of flowers, which could not be overbalanced by pruning. But considering all varieties, pruning of this character more than doubled the number of flowers set. With several varieties it was tripled and in one case (Rome) even quadrupled. The difference is wide enough to justify the placing of emphasis on pruning as a factor in the setting of apples.

If these trees had not been pruned to some extent already during the winter preceding this experiment, the results probably would have been still more favorable. It is, of course, very likely that a thorough pruning of this character performed earlier in the season—any time during the winter, for that matter—may be equally effective by increasing fruitfulness.

Fig. 11.—Grimes tree, not pruned. Used as one of the "controls" in a study of the effects of spring pruning on fruit set.

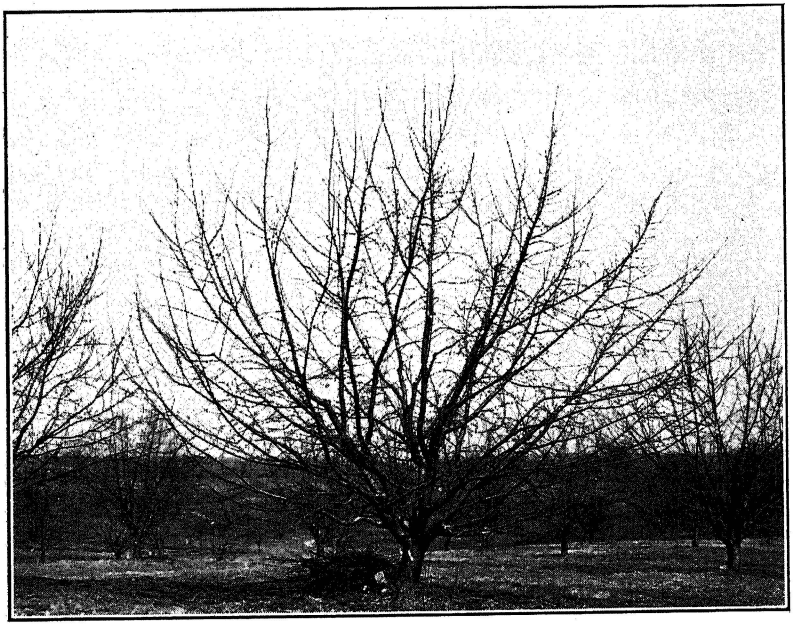

Fig. 12.—Grimes tree, "fine pruned." The percentage of fruit set was more than doubled by this type of pruning. Note the amount of small twigs removed (brush pile under tree).

TABLE 20.—EFFECTS OF SPRING PRUNING ON FRUITFULNESS IN THE APPLE

Variety	Treatment	No. of flowers recorded	Percentage of flowers set
Ben Davis	Not pruned	485	1.79
Ben Davis	Pruned	529	.75
Delicious	Not pruned	417	0.0
Delicious	Pruned	654	.15
Delicious	Not pruned	537	0.0
Delicious	Pruned	356	3.65
Grimes	Not pruned	516	.38
Grimes	Pruned	553	.72
Grimes	Not pruned	507	.99
Grimes	Pruned	538	2.21
Jonathan	Not pruned	423	2.37
Jonathan	Pruned	445	.88
Jonathan	Not Pruned	516	1.16
Jonathan	Pruned	394	3.27
Rome	Not pruned	530	.74
Rome	Pruned	417	1.67
Rome	Not pruned	376	2.39
Rome	Pruned	702	9.97
Stayman	Not pruned	425	6.11
Stayman	Pruned	450	6.22
Stayman	Not pruned	442	.23
Stayman	Pruned	433	.93
Average	Not pruned	5174	1.35
Average	Pruned	5471	2.91

SUMMARY

1. A review of all available data on self-fruitfulness of some of the most important varieties of apples in Missouri and adjoining states indicates a conspicuous variation in results.

2. The various external and internal factors influencing the fruit set are discussed in their bearing on the pollination problem emphasized.

3. Apple pollination investigations at the Missouri Agricultural Experiment Station during 1926-1928, inclusive, have involved the following female parents: Ben Davis, Delicious, Duchess, Gano, Grimes, Jonathan, King David, Maiden Blush, Rome, Wealthy, Yellow Transparent, Winesap and York. None of these varieties was found sufficiently self-fruitful to assure a commercial crop when planted in isolated blocks of one variety.

4. The following varieties were tested in respect to their comparative efficiency as pollenizers: Ben Davis, Delicious, Duchess, Gano, Grimes, Jonathan, King David, Rome, Stayman, Wealthy, Winesap, Yellow Transparent, and York. The three outstanding pollenizers for most varieties were: Ben Davis, Jonathan and Delicious, but Grimes and Gano were also satisfactory in many cross-pollinations.

5. The average blooming dates of most apple varieties grown in Missouri overlap. No difficulty in the supply of proper pollen, therefore, should be anticipated in orchards containing several varieties of which some are effective pollenizers. The comparatively early flowering Duchess and late blooming Rome, Ralls and Ingram make an exception to this rule. In most years their flowering periods do not coincide.

6. Cross-pollination increased the percentage of flowers set several times over self-pollination, and, when effective pollen was used, resulted in a commercially desired yield of fruit. Open-pollination, in most instances, increased the set still further. This may indicate that a considerable experimental error is involved in present methods and technique of artificial cross-pollination, or that an unknown factor or factors may have been operative.

7. Emasculation does not seem to affect greatly fruit setting in cross-pollination with a known and efficient pollenizer. The results from non-emasculated, but otherwise similarly treated flowers, were nearly the same.

8. As a method of determining self-fruitfulness of apple varieties, covering the flowers with paper bags and hand pollinating with previously collected pollen is to be preferred to merely bagging the flowers.

9. "Fine pruning" in the spring increased markedly the percentage of open-pollinated flowers that set. In several cases this increase was two or three times over the set on non-pruned trees.

REFERENCES CITED

1. Alderman, W. H. *Experimental Work on Self-sterility of the Apple.* Proc. Ame. Soc. Hort. Sci. 1917:94-101.
2. Auchter, E. C. *Apple Pollen and Pollination Studies in Maryland.* Proc. Ame. Soc. Hort. Sci. 1921:51-80.
3. Auchter, E. C. and Schrader, A. L. *Cross Pollination of the Arkansas (Mammoth Black Twig) Apple.* Proc. Ame. Soc. Hort. Sci. 1925:96-105.
4. Chittenden, F. J. *Pollination of Orchards III. Self-fruitfulness and Self-sterility in Apples.* Journ. Roy. Hort. Soc. 39:615-634, 1914.
5. Cooper, J. R. *The Behavior of Pollen Tubes in Self- and Cross- Pollination.* Proc. Ame. Soc. Hort. Sci. 1928:138-140.
6. Crandall, C. S. *Seed Production in Apples.* Ill. Agr. Exp. Sta. Bul. 203, 1917.
7. Crandall, C. S. *Results from Self-pollination of Apple Flowers.* Proc. Ame. Soc. Hort. Sci. 1922:95-100.
8. Detjen, L. R. *Physiological Dropping of Fruits.* Del. Agr. Exp. Sta. Bul. 143, 1926.
9. Detjen, L. R. *The Effects of Nitrogen on the Set of Apple Flowers Situated Variously on the Cluster Base.* Proc. Ame. Soc. Hort. Sci. 1928:153-157.
10. Dorsey, M. J. *The Set of Fruit in Apple Crosses.* Proc. Ame. Soc. Hort. Sci. 1921:82-94.
11. Ewert, Dr. *Blütenbiologie und Fruchtbarkeit unserer Obstbäume.* Landw. Jahrb. 35:259-287, 1906.
12. Fletcher, S. W. *Pollination in Orchards.* Cornell Agr. Exp. Sta. Bul. 181:335-365, 1900.
13. Florin, R. *Pollen Production and Incompatibilities in Apples and Pears.* Mem. Hort. Soc. N. Y. 3:87-118, 1927.
14. Gowen, J. W. *Self-sterility and Cross-sterility in the Apple.* Me. Agr. Exp. Sta. Bul. 287, 1920.
15. Hedrick, U. P. *The Relation of Weather to the Setting of Fruit, with Blooming Data for 866 Varieties of Fruit.* N. Y. (Geneva) Agr. Exp. Sta. Bul. 299, 1908.
16. Heinicke, A. J. *Factors Influencing the Abscission of Flowers and Partially Developed Fruits of the Apple.* Cornell Agr. Exp. Sta. Bul. 393, 1917.
17. Heinicke, A. J. *The Set of Fruit as Influenced by Pruning at Different Periods Preceding the Bloom.* Proc. Ame. Soc. Hort. Sci. 1926:46-48.
18. Howlett, F. S. *Apple Pollination Studies in Ohio.* Ohio Agr. Exp. Sta. Bul. 404, 1927.
19. Howlett, F. S. *Fruit Setting in the Delicious Apple.* Proc. Ame. Soc. Hort. Sci. 1928:143-148.
20. Keil, J. B. *Apple Pollination.* Ohio Agr. Exp. Sta. Monthly Bul. 51-58, 1923.
21. Knight, L. I. *Physiological Aspects of Self-sterility of the Apple.* Proc. Ame. Soc. Hort. Sci. 1917:101-105.
22. Knowlton, H. E. *Studies in Pollen with Special Reference to Longevity.* Cornell Agr. Exp. Sta. Mem. 52, 1922.
23. Knowlton, H. E. *Studies in Apple Sterility.* Proc. Ame. Soc. Hort. Sci. 1927: 111-114.
24. Kraus, E. J. *The Self-sterility Problem.* Journ. Heredity. 7:12:549-557, 1915
25. Lewis, C. I. and Vincent, C. C. *Pollination of the Apple.* Ore. Exp. Sta. Bul. 104, 1909.
26. Logsdail, A. J. Canada Experimental Farms. Rept. 1917:680-685.
27. Luce, W. A. and Morris, O. M. *Pollination of Deciduous Fruits.* Wash. Agr. Exp. Sta. Bul. 223, 1928.
28. Macoun, W. T. Report of the Dominion Horticulturist for 1922:13-15.
29. Marshall, R. E. et al. *The Pollination of Orchard Fruits in Michigan.* Mich. Agr. Exp. Sta. Spec. Bul. 188, 1929.
30. Morris, O. M. *Studies in Apple Pollination.* Wash. Agr. Exp. Sta. Bul. 163, 1921.
31. Murneek, A. E. *Physiology of Reproduction in Horticulural Plants. II. The Physiological Basis of Intermittent Sterility with Special Reference to the Spider Flower.* Mo. Agr. Exp. Sta. Res. Bul. 106, 1927.
32. Murneek, A. E. *The Use of Bees in Apple Sterility Studies.* Proc. Ame. Soc. Hort. Sci. 1929:39-42.
33. Namikawa, I. *Growth of Pollen Tubes in Self-pollinated Apple Flowers.* Bot. Gaz. 76:302-310, 1923.

34. Osterwalder, A. *Blutenbiologie, Embryologie und Entwicklung der Frucht unserer Kernobstbäume.* Landw. Jahrb. 39:917-998, 1910.
35. Overholser, E. L. *Apple Pollination Studies in California.* Cal. Agr. Exp. Sta. Bul. 426, 1927.
36. Powell, G. H. *The Pollination of Apples.* Del. Agr. Exp. Sta. Rept. 13:112-116, 1902.
37. Sandsten, E. P. *Some Conditions Which Influence the Germination and Fertility of Pollen.* Wis. Agr. Exp. Sta. Res. Bul. 4, 1909.
38. Sax, K. *Studies in Orchard Management. II. Factors Influencing Fruit Development of the Apple.* Me. Agr. Exp. Sta. Bul. 298, 1921.
39. Sax, K. *Sterility Relationship in Maine Apple Varieties.* Me. Agr. Exp. Sta. Bul. 307, 1922.
40. Sutton, I. *Reports on Tests of Self-sterility in Plums, Cherries and Apples at the John Innes Hort. Inst.* Journ. Genetics 7:281-300, 1918.
41. Vincent, C. C. *Results of Pollination Studies at Idaho University.* Better Fruit 14:8:11-15, 1920.
42. Waugh, F. A. Proc. Ame. Pom. Soc. 25:86-94, 1898.
43. Wentworth, S. W. *Relative Effectiveness of Apple Pollen from Vigorous and Weak Trees as Determined by the Spur-unit Method.* Proc. Ame. Soc. Hort. Sci. 1928:149-153.
44. Whitehouse, W. E. and Auchter, E. C. *Cross-pollination Studies with the Delicious Apple.* Proc. Ame. Soc. Hort. Sci. 1926:157-161.
45. Wicks, W. H. *The Effect of Cross-pollination on the Size, Color, Shape and Quality of the Apple.* Ark. Agr. Exp. Sta. Bul. 143, 1918.