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# APPLE POLLINATION

An Evaluation of Methods and Pollenizers

A. E. MURNEEK

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# APPLE POLLINATION

## AN EVALUATION OF METHODS AND POLLENIZERS

A. E. MURNEEK\*

*Abstract.*—A detailed discussion is presented of the comparative value and efficiency of various methods used in experimental apple pollination. The advantages and disadvantages of the branch-unit and screened-cage procedures are emphasized and an account is given of the use of package bees in pollination studies. Results of hand and bee pollination are presented in tabular form for the years 1929-1931, involving the following varieties: Jonathan, Delicious, Ben Davis, Grimes, Golden Delicious, King David, York, Rome, Stayman, Winesap and Wealthy. A determination of the fruit set after the final natural drop ("June drop") is considered the most reliable index of self- and cross-fruitfulness of certain varieties. This is correlated with seed counts of the fruit at harvest time. Jonathan, Delicious, and Ben Davis varieties were found the three best pollenizers for most of the popular varieties of apples grown in Missouri. A preliminary trial indicated a high value for York pollen in the bearing or "on" year, and only an average value for Golden Delicious pollen. Self-pollination by bees, by brushing the stigmas with previously collected pollen, and by bagging only the flowers, gave a somewhat higher fruit set with the second method, but the results were least variable when bees were used.

The present progress report attempts to summarize and evaluate the results obtained during the past three years with the so-called branch-unit and screened-cage methods of apple pollination. A comparison is made of these procedures with the efficiency of the popular "paper-bag" method, which was used during the preceding years, 1926 to 1928 inclusive (see Mo. Agr. Exp. Sta. Res. Bul. 138)<sup>31</sup>. Information being meager on the subject, an account is given of the utilization and management of package bees as pollenizing agents, both in experimental self- and cross-fertilization. It has been thought advisable also to discuss fully the advantages and disadvantages of the screened-cage procedure in fruit pollination investigations.

All of the presented data are analyzed with the object of their bearing on certain pollination methods and on the efficiency of particular varieties as pollenizers of others.

### POLLINATION METHODS

In this investigation the writer has been guided by the opinion, expressed already on a previous occasion<sup>30</sup>, that an acceptable orchard pollination procedure ought to contain at least the following desirable features: It should (1) leave all the blossoms of the tree intact; (2) assure the transfer of pollen from a desirable variety in the most natural

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way (as it is done by insects) and at the most appropriate time; (3) interfere as little as possible with the normal physiological functions of the tree; and (4) permit to evaluate the results in a manner more nearly comparable to a commercial set or yield of fruits. Obviously in this respect some of the commonly used experimental methods of apple pollination are more desirable than others.

Since the classical studies of Waite (1894), the Manila paper-bag method, or some modification of it, has been in common use as a protector of the flowers in practically all pollination studies with fruit trees (Fig. 1). This popularity is undoubtedly due to the many advan-



Fig. 1.—Showing Manila paper bags as commonly used in apple pollination studies.

tages that are inherent in this method, particularly for extensive field work. The equipment is inexpensive, and readily movable from place to place. The paper bags can be conveniently pulled over and made fast to a selected part of a branch by persons but little skilled in pollination technique. In the fearful rush during the often very brief flowering period, this factor alone seems to be of vital importance. It allows the employment of a large staff of assistants and thus permits to make a great variety of cross-pollinations.

Very soon after its inception, however, the paper-bag method was subjected to criticism (Ewert<sup>7, 8</sup>, Lubimenko<sup>21</sup>) but especially so during more recent years (Alderman<sup>1</sup>, Heinicke<sup>9</sup>, Knowlton<sup>14, 15, 17</sup>, Chandler<sup>4</sup>, MacDaniels<sup>23, 24</sup>). There is no question but that by covering the flowers and the adjoining foliage with an opaque paper bag, even for a few days, abnormal conditions of temperature, humidity and light supply are brought about in the immediate vicinity of the reproductive organs. Moreover, the floral structures may be directly affected by this drastic change in the "micro-environment" surrounding them, especially by the cutting down of light intensity. During the time of flowering and fruit setting, very rapid physiological activities take place in all organs constituting the fruit spur<sup>29</sup>. The enclosure of the flowers and adjoining leaves in paper bags for several days undoubtedly alters considerably the normal metabolic course in these organs. It can not help having an influence on the fruit set, although no direct measurements of the nature, direction, and extent of this effect have been made. It is probable that, due to bagging, a reduction in fertilization or gametic union may be partly neutralized by the frequent care exercised in the selection of "good" twigs, spurs or flower clusters and the liberal application of viable pollen. The reverse also may be true. An intensive pollination and fertilization may be counterbalanced by an abnormal metabolism and poor nutrition of the organs constituting the bearing apple spur. Thus several unknown and more or less "artificial" factors may come into play, now one, then another exerting a dominating influence, as a result of the use of paper bags, emasculation, and hand pollination.

A slight modification of this method by substituting for the brown, white opaque or glassine bags, has not been found of any particular



Fig. 2.—Glassine bags used to protect individual flower clusters from undesirable pollination.

advantage (Einset<sup>6</sup>) or satisfactory (Knowlton<sup>15</sup>). Though transmitting more light, white bags tend to increase the temperature and humidity considerably within the enclosure. According to Einset, an opaque paper cover may be more efficient in strong sunlight and a translucent one in cloudy weather. The writer's experience with small glassine bags, used to cover individual flower clusters, has been distinctly unfavorable (Fig. 2). The glassine bags were suggested many years ago (Heinicke<sup>9</sup>, 1917) but evidently have not been used very extensively for apple pollination studies. Considering these difficulties it is inevitable that improved pollination procedures should be developed and adopted.

A comparatively new, so-called "branch-unit" method, though introduced only recently, has gained wide recognition among horticulturists and is gaining rapidly in popularity (MacDaniels<sup>23, 24, 25</sup>, MacDaniels and Heinicke<sup>26</sup>, MacDaniels and Burrell<sup>27</sup>, Howlett<sup>11, 12, 13</sup>, Knowlton<sup>17, 18</sup>, Burrell and MacDaniels<sup>2</sup>, Burrell and Parker<sup>3</sup>). This method has been used during the past three years for apple pollination investigations at the Missouri Agricultural Experiment Station. Essentially it consists of the use of branches of a length that can be conveniently covered with a cheesecloth bag 6 by 3 feet in size. All flowers within this enclosure are under experimental treatment, whether cross-pollinated, self-pollinated by hand, or left without artificial pollination. The bags are kept over the branches for the usual period of flowering and fertilization. Comparisons may be made with the fruit set from open-pollination on branches of equal length (Fig. 3).

The branch-unit procedure has many distinct advantages over the paper-bag method.

1. Work is facilitated by covering and treating a large number of flowers within a single enclosure. Thus more pollinations may be made during a certain period.

2. Flowers on almost all portions of the branch, including some of the older wood, are involved. This is a distinct improvement over the paper-bag method. In the case of the latter, consciously or unconsciously flower clusters more favorably located (as to bagging) are frequently selected, particularly by inexperienced help. There is a marked difference in the capacity to set fruit among the spurs variously situated on a branch. But insects very likely pollinate indiscriminately all blossoms. Hence the branch-unit method more nearly approaches orchard conditions.

3. There is far less, in fact, almost a negligible amount of shading by the mosquito bar or cheesecloth bag than by any paper bag yet devised. Conditions of temperature and humidity outside and within the bags are practically the same. Consequently the normal metabolism and development of the reproductive organs

seem to be very little interfered with. These are vital advantages in favor of this method.

4. Wind and rain will destroy far less frequently a bag of mesh cloth than one of paper. This may not be an important feature in sections of calm and favorable spring weather. It seems to be of considerable value in a state with a continental climate, like Missouri.

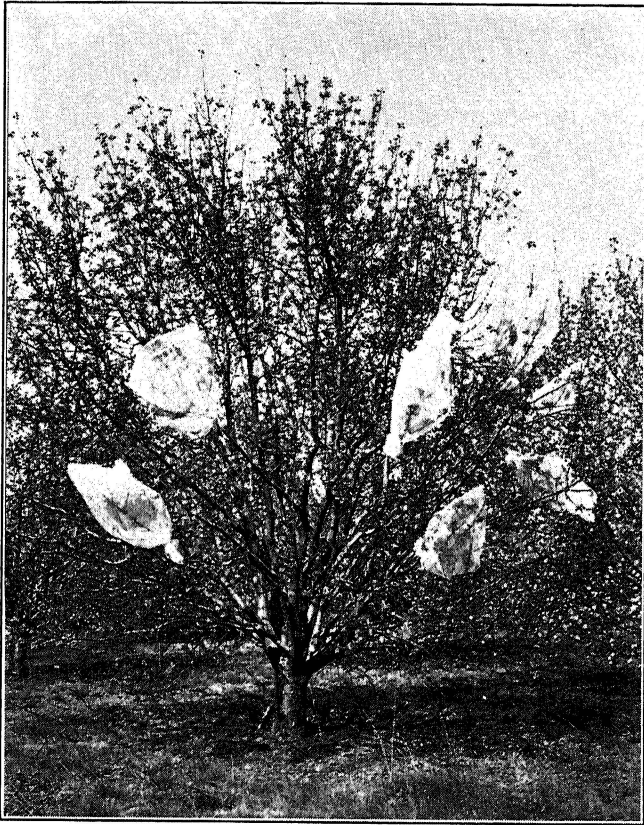


Fig. 3.—Cloth bags, 3 by 6 feet, used in connection with the "branch-unit" method of pollination.

5. By the use of the branch-unit method the fruit set more accurately reflects the normal set on the tree.

These are some of the desirable features of the large cloth bag method. It seems to have also certain disadvantages. Occasionally flowers may come in close enough contact with the loose mesh of the bag to be pollinated from outside by the larger insects, while some tiny ones

may actually enter the bag. It is unknown to what extent midges and other small insects may bring about pollination of the fairly large apple blossoms. Then, too, during the time of removal of the bag and application of pollen, a bee may suddenly alight on a flower and, presto, there is an experimental error. One should be, however, ambidextrous enough, even on a step-ladder, to swat promptly such intruders.

Another, and in many ways still better method than any of those already discussed, is the enclosing of trees in cages and the use of bees as pollenizers. Morphologically, the apple blossom is distinctly entomophilous, requiring under natural conditions the visit of insects, preferably honey bees, for effective pollination. Thus the screened-cage procedure more nearly approaches the conditions of natural orchard pollination. As early as 1912 Alderman<sup>1</sup> used muslin and cheesecloth covered frames to exclude insects from apple trees to be used for self- and cross-pollination. Bees as pollenizers within the cages did not seem to have been satisfactory in this particular experiment. Since then, however, many investigators have used successfully, though on a limited scale, such cages to test self-fruitfulness or, less frequently, cross-fruitfulness of a large

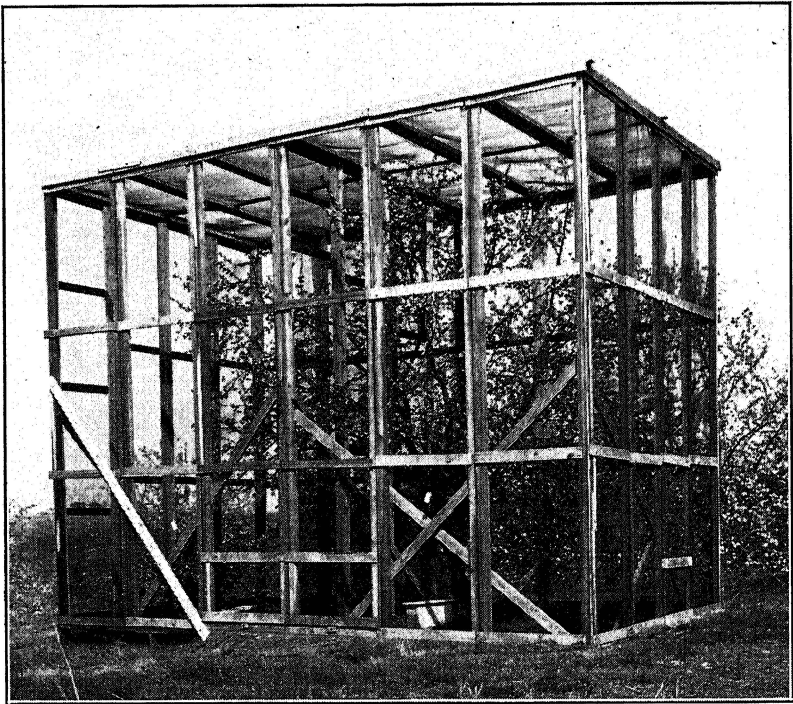


Fig. 4.—Showing tree enclosed in a two-compartment wire screen cage with small colonies of bees and a bouquet for cross-pollination (in compartment to the left).



number of apple varieties (Knowlton<sup>14, 16, 17, 18</sup>, MacDaniels<sup>23, 25</sup>, Whitehouse and Auchter<sup>36</sup>, Overholser<sup>32</sup>, Luce and Morris<sup>22</sup>, Howlett<sup>10</sup>, Marshall et al.<sup>23</sup>, MacDaniels and Heinicke<sup>26</sup>, Murneek<sup>30</sup>, Burrell and MacDaniels<sup>2</sup>, Wellington et al.<sup>35</sup>, Reinecke<sup>34</sup>).

In most instances where cages have been constructed over trees, they were usually covered with muslin or cheesecloth, rarely with wire screens (Fig. 4). They were built with the object of either to exclude all insects or to confine a colony of bees to a single tree. In either instance self-fruitfulness has been tested with and without insect pollination. In a few cases, cages have been used for cross-pollination purposes, either by screening together trees of two different varieties and enclosing a hive of bees or else keeping within the cage a bouquet of large branches to supply pollen to a single enclosed tree.

The frequent use of cages in pollination work would indicate that the procedure has been found serviceable. Indeed this method has certain real advantages over others.

1. Much less skilled labor is required than for hand pollination. The uncertain error due to the "personal equation" is, therefore, reduced to a minimum. Obviously, this is an important consideration, especially so in particular localities and in some years, when the effective apple pollination period may be less than a week and work must be done in a great hurry.

2. It permits the use of whole trees for pollination studies. Hence every flower in every position is involved for the determination of self- and cross-fruitfulness.

3. The environmental conditions of a caged tree are certainly more normal in comparison with a "bagged environment". This is especially true when wire screen is used as a covering which is removed immediately after flowering is over.

4. The blossoms are pollinated by insects (bees) as it occurs in the orchard. Skillful as our hand pollination technique may be, it probably is not nearly as "natural" as insect pollination (Fig. 5). It may be either a far better or a much worse performance even when things proceed in what may be thought an ideal fashion. There seems to be ample chance for occurrence of abnormalities and errors in gathering of pollen, its preparation, preservation, and application; in emasculation of the flowers; in the time and manner of application of pollen (Fig. 6); in the methods of blossom protection, etc. One should remember that flowers, certainly those of the apple, are very delicate, ephemeral structures that are easily affected by environmental factors. What may appear to us a "delicate and ticklish operation" may be a "rough and harmful treatment" to a n apple blossom.

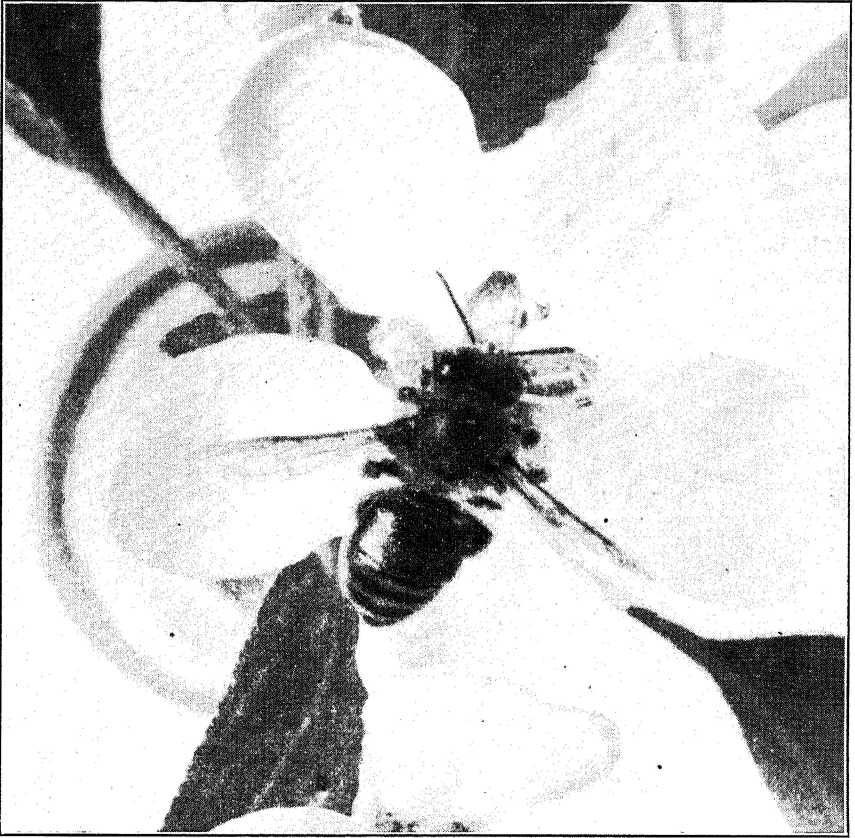


Fig. 5.—A bee visiting an apple blossom. Is hand pollination of apple flowers performed as effectively as pollination by bees?

5. Pollination by bees in cages permits to express the results on a per tree yield basis if the work is done on an extensive scale and over a period of several years. It facilitates greatly the gathering and study of the various drops. These features alone may fully compensate the effort and expense of constructing cages.

No ideal or perfect procedure in fruit pollination has yet been devised. Hence the screened-cage method has also certain undesirable features.

The building of strong cages, particularly over large trees, is costly. Therefore, but a limited number of trees have been screened in most investigations, the work has been of a sporadic nature, and the results fragmentary. Data based on one or two trees, of course, are subject to considerable error, when the study is not continued for a number of

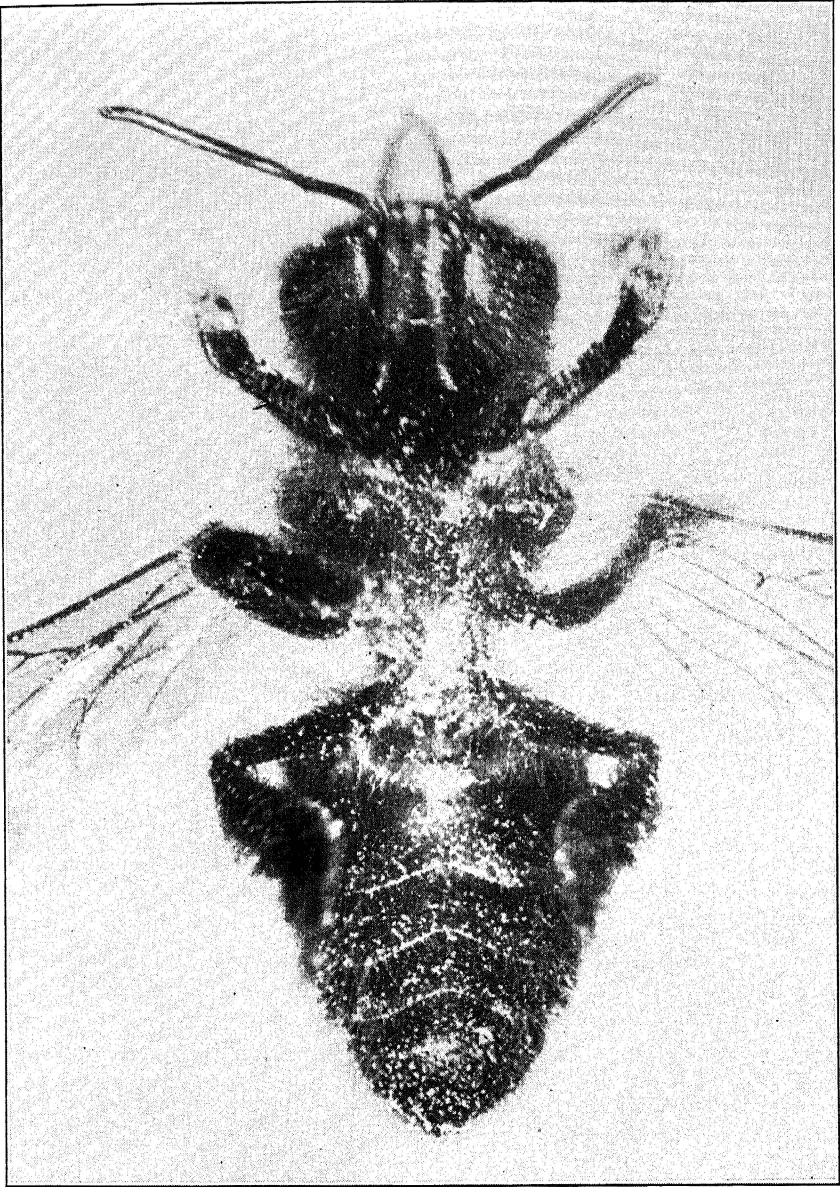


Fig. 6.—Apple pollen adheres to the hairy body of honey bees. Is the application of pollen to the stigma by a brush, or other means, as efficient a process as the transfer of pollen by bees?

years. Considerable difficulty likewise may be experienced in the proper handling of bees unless there is a close cooperation with an apiculturist or entomologist. Furthermore, when bouquets of flowering branches are used for cross-pollination purposes, care must be exercised that the blossoms are in the proper stages of development when they are to perform their function of supplying pollen. It has been suggested<sup>24</sup> that, if a strong colony of bees is placed in the cage, overpollination may take place, resulting in an abnormally large set of fruit, and that an excessive visit of bees may injure the stigmas. It is doubtful that these conjectured things may actually happen when relatively small colonies of bees (package bees) are used.

In general, then, it may be safely stated that aside from the cost and labor, the favorable features of the screened-cage method in apple pollination easily outweigh all the disadvantages.

### THE OBJECT AND PROCEDURE

After a considerable experience in apple pollination and a growing dissatisfaction with the paper-bag method, the writer began in the spring of 1929 to use extensively the screened-cage and cloth-bag procedures. It was decided to apply these methods on a scale large enough to make the results comparable to the Manila bag procedure and thus test the efficiency of the three methods. It was thought that at the same time the accumulated data should be useful in determining still further the value of certain pollenizers for varieties commonly grown in Missouri. The minimum period for this study was set at three years.

Standard commercial varieties of apple trees, 19 to 21 years old, in the respective years 1929 to 1931, were used as material. This particular block of apples in the experimental orchard consists of alternate rows of a large number of varieties. The trees are in a healthy state, vigorous and bearing good crops. The orchard is in sod and each tree received four pounds of sulphate of ammonia about two weeks before flowering.

When an examination of buds early in the spring indicated which trees were going to flower abundantly, cages were constructed so as to enclose one-half of each chosen tree. These cages were made of strong lumber and were covered with ordinary screen wire. They were mostly 20 feet by 12 feet by 16 or 18 feet high, and had a partition in the center. Two quarters of each tree were thus screened separately and the remaining half left uncovered (Fig. 7). Care was exercised to make the cages insect tight.

Wire screens seem to produce far less shade within the cage than a covering of cloth. But to reduce even this little shading to a minimum, all cages were built in sections (Fig. 8), permitting a ready removal of the

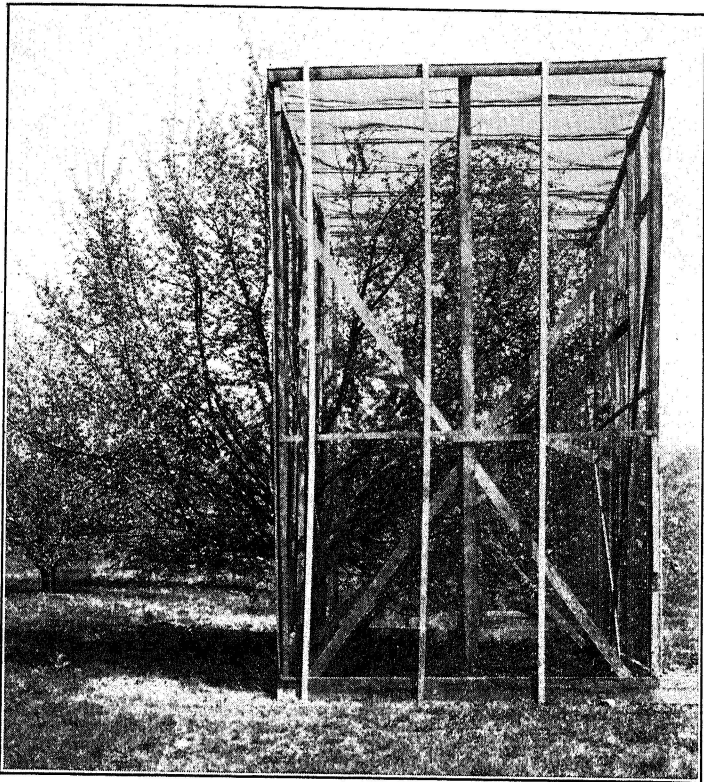


Fig. 7.—Showing a two-compartment cage covering one half of an apple tree. The other half was left for "open pollination".

tops and sides. These were removed in all cases as soon as flowering was over. Whenever it was found undesirable to dismantle a cage, the screens were removed promptly, rolled up, dipped in oil and stored for future use. The building of cages in sections facilitated greatly the taking apart and moving of a cage to a desirable tree. In many instances this was necessary due to the biennial bearing habit of some of the varieties. When two adjoining trees had to be enclosed, a large four-compartment cage was found to be stronger and more economical to construct than two individual ones (Fig. 9).

When the flowers were about to come into full bloom, bouquets of large branches of a chosen variety were placed in selected compartments (Fig. 10). These bouquets were kept in an ample amount of water. In the meanwhile the ordering of package bees was carefully timed. As a rule they were received promptly by express from the South (Fig. 11). A 1- or 2-pound package is just the right amount of bees for pollination

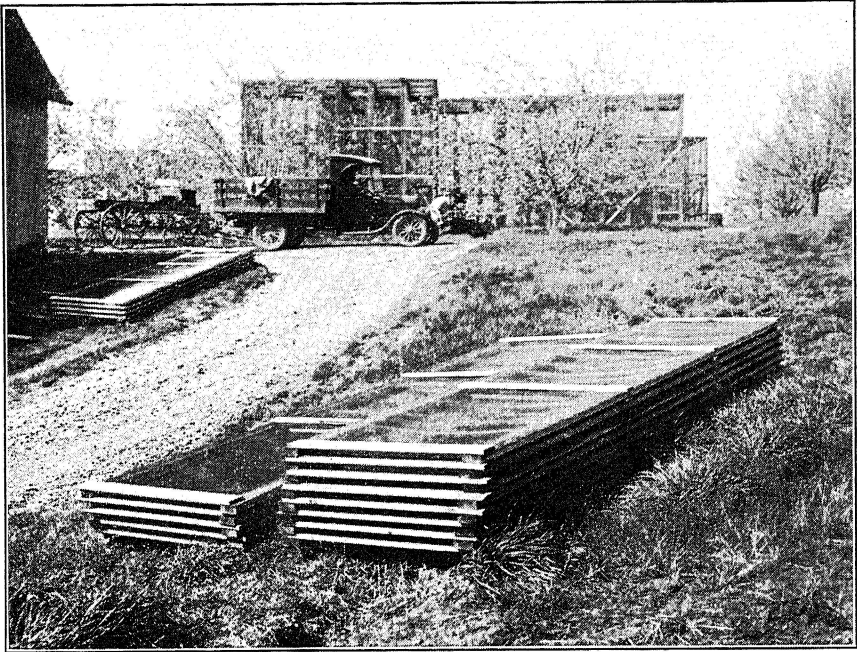


Fig. 8.—In order to facilitate the setting up and dismantling, all cages were built of sections as shown in foreground.

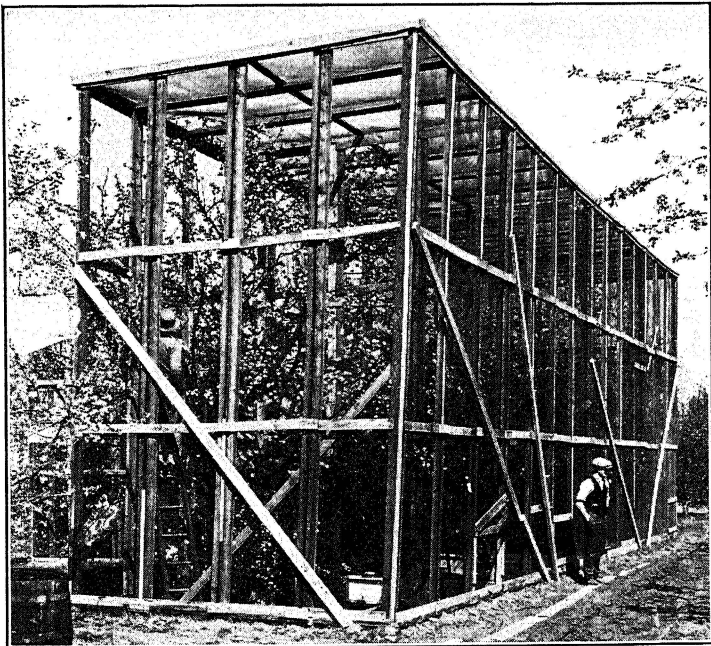


Fig. 9.—A four-compartment cage built to accommodate two adjoining trees (Stayman and Winesap). Note the size of the cage, its strong construction, and very little shading by the wire screens.



Fig. 10.—Large bouquets of flowering branches used with bees in cages for cross-pollination studies.

purposes in a cage of the size used by us. In a favorable year a 1-pound colony will be sufficiently large, but if the weather is mostly cold and rainy, one of 2 pounds will be of greater service. As soon as most of the flowers are open, the bees are transferred to specially constructed small hives, which are placed in each cage (Fig. 12).

With proper feeding and care and weather conditions that are not altogether ruinous, bees usually adapt themselves promptly to the new environment and visit the enclosed flowers in large numbers. If for one reason or another a colony becomes weak and fails to perform properly, it is replaced at once by a stronger one kept in reserve for this purpose. After three years' experience it may be said with little qualification that the procedure of using package bees for apple pollination studies works satisfactorily. And, without a protecting gear, the author has been stung only five or six times during this period.

As soon as the petals have dropped, hives and bouquets are removed and cloth is spread on the ground in each cage to facilitate the gathering of the various drops. At the same time, the screens are removed from the tops and side sections to allow the entrance of a maximum amount of light.

To check on the efficiency of bees as pollenizing agents, when used in the manner described, a representative number of branches were

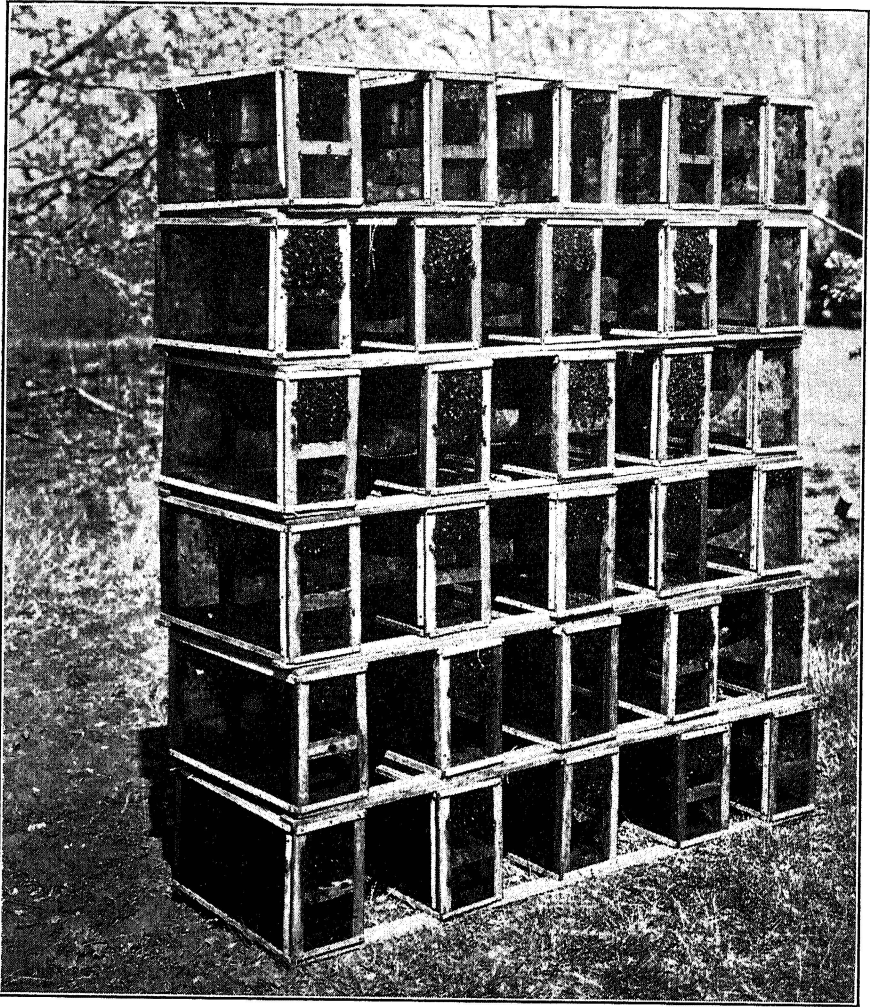


Fig. 11.—A group of 30 one-pound packages of bees at the time of arrival from the South, ready to be transferred to hives in the pollination cages.

tagged both within the cages and on the half of each tree that was not screened. Some of these branches were covered with a mosquito bar bag, 3 by 6 feet, and left without pollination ("covered only"). Flowers on others were hand pollinated, without emasculation, with previously collected pollen. On still others, they were cross-pollinated, without emasculation, with pollen of a desirable variety and covered with the cloth bags during the blooming period. Emasculation was not practiced since our previous experience had shown that it is not necessary for this type of work<sup>31</sup>.



A group of branches on each tree was tagged and left for open-pollination.

The branch-unit method of procedure was tested extensively in 1929 on eight standard varieties of apples. A comparison of the efficiency of this with the screened-cage method was also determined in this year. For the two successive years, the screening in and use of package bees was the basic procedure in all of our pollination work.

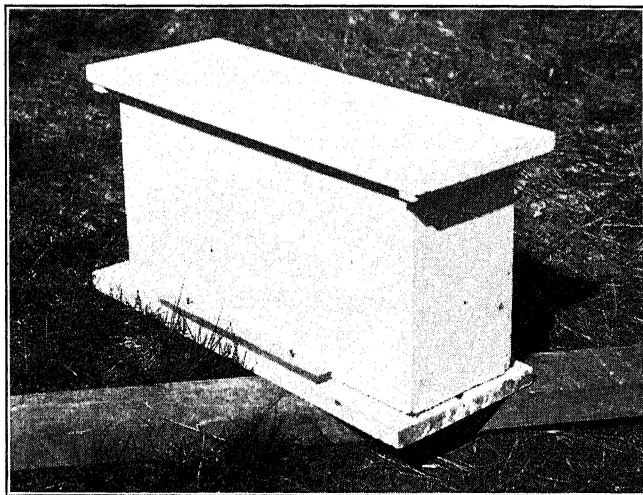


Fig. 12.—Special hives of this type were used to house in each cage small colonies of bees for pollination purposes.

Records of the fruit set were secured after the first drop, which is by far the most important one in numbers. They were again taken after the last drop had occurred and, in 1930 and 1931, also at harvest time. The data are expressed both as percentages of flower clusters and of individual flowers that had set. In the past two years the average weights of the fruit<sup>a</sup> at maturity and their seed contents were likewise recorded.

### PRESENTATION AND DISCUSSION OF RESULTS

Under average orchard conditions, environmental factors, the nutritional state of the trees, and their previous performance have a decided bearing on the results of pollination work. The trees selected for our investigation were as uniform in growth and yielding capacity as could be obtained in the orchard. In respect to fruit setting, their performance was quite gregarious. For this and other reasons it is felt desirable to present the results separately by years and by varieties.

## The 1929 Data

Practically all of the trees used in pollination work flowered abundantly this year. There were, however, serious disturbances during the time of pollination due to abnormally bad weather. It was unusually cold and rainy, with only a day or two of clear, though cool weather, when there was a chance for bees to visit flowers. Two destructive hail storms visited the orchard after the fruit had set and the screens had been removed from the cages. Therefore, the 1929 results with the screened cage and bee pollination methods are subject to bad pollination weather as the most influential factor. It was indeed a discouraging start in the use of this method.

Table 1 gives the data of pollination by bees and table 2 furnishes parallel records secured by means of the branch-unit (cloth-bag) method. The percentages of clusters and flowers that had set fruit were obtained from counts on 4-6 representative branches within and outside of the cages. In either case the branches were of such size as would conveniently fit into the cloth bags. The results were recorded at the end of the first major drop (May 21) and after the final or so-called "June drop" (July 9).

TABLE 1.—RECORDS OF FRUIT SET ON MAY 21 AND JULY 9, 1929  
Screened-Cage Method with Bees as Pollenizers

Variety (♀) × Pollen (♂)	No. of flower clusters	% clusters set on May 21	% clusters set on July 9	No. of flowers	% flowers set on May 21	% flowers set on July 9
Winesap (2 trees) × Grimes-----	202	4.5	.5	826	1.10	.12
Winesap (2 trees) × Golden Delicious----	370	11.6	2.2	1514	2.84	.54
Winesap (2 trees) × Jonathan-----	235	8.9	0.0	961	2.18	.00
Winesap (2 trees) — Self-pollinated-----	364	.5	0.0	1489	.12	.00
Stayman (2 trees) × Golden Delicious----	247	8.5	2.4	984	2.15	.61
Stayman (2 trees) × Jonathan-----	361	8.0	5.8	1438	2.03	1.47
Stayman (2 trees) × Delicious-----	271	17.5	11.1	1080	4.43	2.81
Stayman (2 trees) × Self-pollinated-----	228	3.1	2.6	908	.78	.66
Grimes (2 trees) × Delicious-----	87	37.9	----	313	10.53	----
Grimes (2 trees) × Golden Delicious----	167	33.5	----	602	9.31	----
Grimes (2 trees) × Jonathan-----	216	36.6	33.5	778	10.16	9.30
Grimes (2 trees) × Self-pollinated-----	238	15.1	13.0	858	4.19	3.61
Jonathan (2 trees) × Golden Delicious----	188	25.0	14.4	84	5.32	3.06
Jonathan (2 trees) × Delicious-----	168	32.7	18.8	790	6.95	4.00
Jonathan (2 trees) × Grimes-----	306	10.1	1.5	1439	2.15	.32
Jonathan (2 trees) × Ben Davis-----	273	62.2	28.9	1283	13.24	6.15
Jonathan (2 trees) — Self-pol nated-----	142	10.6	5.8	68	2.25	1.24
Delicious (2 trees) × Jonathan-----	373	7.2	1.6	1530	1.76	.39
Delicious (2 trees) × Grimes-----	290	22.7	9.6	1189	5.54	2.34
Delicious (2 trees) × Ben Davis-----	219	21.9	8.2	898	5.34	2.00
Delicious (2 trees) — Self-pollinated-----	308	.6	.6	1263	.15	.15
Ben Davis (2 trees) × Delicious-----	289	18.7	3.8	1561	3.46	.70
Ben Davis (2 trees) × Golden Delicious----	236	28.8	8.5	1274	5.34	1.57
Ben Davis (2 trees) — Self-pollinated-----	210	10.5	6.2	1134	1.94	1.15
Ben Davis (2 trees) — Self-pollinated-----	212	27.6	5.6	1137	5.11	1.04
Rome (2 trees) × Golden Delicious----	255	17.2	7.1	1287	3.41	1.41
Rome (2 trees) × Delicious-----	71	50.7	43.6	359	10.05	8.64
Rome (2 trees) — Self-pollinated-----	87	12.6	2.3	439	2.49	.46
Rome (2 trees) — Self-pollinated-----	121	3.3	2.5	611	.63	.50

The percentages of flowers set with bees as pollenizers (Table 1) though variable, are quite comparable with similar data obtained on the same trees by the branch-unit method (Table 2). Thus if self-pollination by bees vs. self-pollination by brushing and bagging (branch-unit method) is averaged for the seven standard varieties, the results will show considerable agreement (Table 3).

TABLE 2.—RECORDS OF FRUIT SET ON MAY 21 AND JULY 9, 1929  
Branch-Unit Method of Pollination

Variety (♀) × Pollen (♂)	No. of flower clusters	% clusters set on May 21	% clusters set on July 9	No. of flowers	% flowers set on May 21	% flowers set on July 9
Winesap (2 trees) × Jonathan	65	16.9	4.6	266	4.13	1.12
Winesap (2 trees) × Golden Delicious	78	5.1	5.1	319	1.25	1.25
Winesap (2 trees) × Delicious	91	15.4	6.6	372	3.76	1.61
Winesap (2 trees) × Grimes	62	12.	3.2	253	3.16	.78
Winesap (2 trees) — Open pollinated	305	21.6	8.8	1249	5.28	2.15
Winesap (2 trees) — Self-pollinated	158	10.1	1.3	646	2.47	.32
Winesap (2 trees) — Covered only	161	0.0	0.0	659	.00	.00
Stayman (3 trees) × Jonathan	71	18.3	15.5	280	4.63	3.92
Stayman (3 trees) × Golden Delicious	104	11.5	7.7	411	2.91	1.95
Stayman (3 trees) × Delicious	118	5.9	3.4	466	1.49	.86
Stayman (3 trees) — Open pollinated	387	29.5	29.4	153	7.47	7.44
Stayman (3 trees) — Self-pollinated	144	4.2	1.	569	1.06	.35
Stayman (3 trees) — Covered only	217	2.3	.0	853	.58	.00
Grimes (2 trees) × Jonathan	23	73.9	60.8	83	20.54	16.89
Grimes (2 trees) × Golden Delicious	21	53.3	28.6	76	14.80	7.94
Grimes (2 trees) × Delicious	21	42.8	23.8	76	11.89	6.61
Grimes (2 trees) — Open pollinated	102	75.4	51.0	367	20.94	14.17
Grimes (2 trees) — Self-pollinated	51	19.6	15.7	184	5.44	4.36
Grimes (2 trees) — Covered only	38	23.7	21.0	137	6.58	5.84
Jonathan (3 trees) × Grimes	124	25.8	15.3	583	5.49	3.25
Jonathan (3 trees) × Golden Delicious	127	37.0	10.2	597	7.88	2.17
Jonathan (3 trees) × Delicious	106	18.9	5.7	498	4.02	1.21
Jonathan (3 trees) × Ben Davis	131	42.0	42.0	616	8.93	8.93
Jonathan (3 trees) — Open pollinated	456	39.0	15.8	2143	8.30	3.36
Jonathan (3 trees) — Self-pollinated	222	8.6	5.0	1043	1.83	1.06
Jonathan (3 trees) — Covered only	220	11.8	7.5	1034	2.51	1.60
Delicious (2 trees) × Grimes	55	0.0	0.0	225	.00	.00
Delicious (2 trees) × Golden Delicious	50	16.0	8.0	205	3.90	1.95
Delicious (2 trees) × Ben Davis	47	17.0	4.3	193	4.14	1.05
Delicious (2 trees) — Open pollinated	325	45.6	24.9	1332	11.12	6.08
Delicious (2 trees) — Self-pollinated	64	0.0	0.0	262	.00	.00
Delicious (2 trees) — Covered only	167	4.8	3.0	685	1.17	.73
Ben Davis (2 trees) × Delicious	95	37.9	16.8	513	7.02	3.11
Ben Davis (2 trees) × Golden Delicious	85	40.0	21.2	459	7.40	3.92
Ben Davis (2 trees) — Open pollinated	254	50.4	27.5	1372	9.34	5.09
Ben Davis (2 trees) — Self-pollinated	119	37.8	16.0	643	7.00	2.96
Ben Davis (2 trees) — Covered only	51	19.6	7.9	275	3.63	1.46
Rome (2 trees) × Delicious	68	58.8	27.5	343	11.64	5.44
Rome (2 trees) × Golden Delicious	63	47.6	30.1	318	9.43	5.96
Rome (2 trees) — Open pollinated	142	114.0*	52.8	717	22.59	10.45
Rome (2 trees) — Self-pollinated	46	10.9	6.5	232	2.16	1.29
Rome (2 trees) — Covered only	116	13.8	6.3	586	2.73	1.25
King David (2 trees) × Jonathan	92	10.9	7.6	326	3.8	2.15
King David (2 trees) × Delicious	96	22.9	11.5	340	6.47	3.25
King David (2 trees) × Golden Delicious	100	23.0	11.0	354	6.50	3.11
King David (2 trees) — Open pollinated	391	76.5	37.6	1385	21.61	10.62
King David (2 trees) — Self-pollinated	64	20.6	7.8	226	5.82	2.20
King David (2 trees) — Covered only	102	10.8	6.9	361	3.05	1.95
Wealthy (2 trees) × Jonathan	80	55.0	22.5	397	11.10	4.54
Wealthy (2 trees) × Delicious	63	47.6	15.9	312	9.60	3.21
Wealthy (2 trees) × Golden Delicious	70	44.4	14.8	347	8.95	2.98
Wealthy (2 trees) — Open pollinated	255	92.8	38.4	1265	18.70	7.74
Wealthy (2 trees) — Self-pollinated	90	22.2	18.9	446	4.43	3.81
Wealthy (2 trees) — Covered only	63	47.6	14.3	312	9.60	2.88

\*On the average more than one fruit per spur.

The percentage deviation from the mean results of self-pollination by bees is as low as that of any of the other two methods and less variable for the two considered dates of recording. Thus, with our set-up, pollination by bees was satisfactory in the first year, despite the fact that the weather in 1929 was extremely unfavorable for insect activity. It indicated clearly the possibilities inherent in this method.

TABLE 3.—SELF POLLINATION BY BEES VS. SELF-POLLINATION BY BRUSHING AND BY BAGGING  
(Weighted Average of 7 Standard Varieties, 1929)

Method of pollination	No. of flowers	Percentage flowers set May 21	Percentage deviation from mean	Percentage flowers set July 9	Percentage deviation from mean
By bees.....	8504	1.85	-.29	.91	-.14
Brushed.....	3579	2.82	+.68	1.26	+.21
Bagged.....	4234	1.75	-.39	.97	-.08

Referring to the percentages of selfed flowers that had set on May 21 and July 9 (Table 1) on two Ben Davis and two Rome trees, it will be noted that the results are almost identical for the last (July 9) count, but rather variable for the early (May 21) count. This suggests that it may be more valuable to determine the results from self-pollination after all the drops have occurred than at any preceding stage of the development of the apple.

When a comparison is made of the efficiency in cross-pollination of the screened-cage and branch-unit methods, it is very evident that in this year of extremely bad weather cross-pollination by hand had given distinctly better results than cross-pollination by bees (Table 4).

TABLE 4.—CROSS-POLLINATION BY BEES (SCREENED-CAGE METHOD) VS. CROSS-POLLINATION BY HAND (BRANCH-UNIT METHOD), 1929

Pollen variety (♂)	No. of crosses	Pollination by Bees			Pollination by Hand		
		No. of flowers (♀)	Per cent flowers set on May 21	Per cent flowers set on July 9	No. of flowers (♀)	Per cent flowers set on May 21	Per cent flowers set on July 9
Ben Davis.....	2	2181	9.99	4.44	809	7.79	7.05
Jonathan.....	3	3177	4.07	2.94	629	6.52	4.45
Golden Delicious..	6	6545	4.26	1.21	2180	6.34	3.12
Delicious.....	5	4103	5.50	2.53	1896	5.90	2.62
Grimes.....	3	3454	3.06	.97	1061	3.77	1.97
Open-pollinated..	9 varieties	9983	13.09	6.34			

### The 1930 Data

A protracted period of warm and sunny weather early in April speeded up the development of flower buds. Practically all apple varieties used in our investigation came into bloom at the same time. Conditions for pollination were very desirable, but the total time during which apple

TABLE 5.—RECORDS OF FRUIT SET ON JULY 3 AND IN SEPT.-OCT., 1930. COMPARATIVE FIGURES WITH BRANCH-UNIT AND SCREENED-CAGE METHODS OF POLLINATION

Variety (♀) × Pollen (♂ <sup>1</sup> )	Type of pollination	No. of flower clusters	No. of flowers	July 3		Sept.-Oct.		Ave. weight of fruit Grams	Ave. No. of seeds
				Clusters set—%	Flowers set—%	Clusters set—%	Flowers set—%		
<b>Delicious</b>									
× King David.....	By hand	64	346	0	0	0	0	0	0
	By bees	78	421	0	0	0	0	0	0
× Grimes.....	By hand	41	221	0	0	0	0	0	0
	By bees	62	335	1.6	0.3	0	0	0	0
× Jonathan.....	By hand	60	312	13.3	2.6	13.3	2.6	114.0	6.62
	By bees	75	390	1.3	0.3	1.3	0.3	176.0	10.00
× Ben Davis.....	By hand	36	174	2.8	0.6	2.8	0.6	117.0	10.00
	By bees	81	393	1.2	0.3	1.2	0.3	156.0	9.00
— Open Pollinated.....		430	2217	11.4	2.2	10.0	1.9	134.7	7.39
— Self-Pollinated.....	By hand	94	474	4.3	0.8	4.3	0.8	147.5	5.00
	By bees	139	695	2.9	0.6	2.2	0.4	107.7	3.66
— Covered Only.....		289	1463	2.8	0.5	2.8	0.5	85.1	3.25
<b>Jonathan</b>									
× Delicious.....	By hand	52	287	36.5	6.6	15.4	2.8	105.0	7.75
	By bees	80	501	31.2	5.0	23.7	3.8	120.1	6.16
× Ben Davis.....	By hand	6	29	0	0	0	0	0	0
	By bees	15	74	40.0	8.1	40.0	8.1	122.2	6.50
— Open Pollinated.....		269	1496	20.1	3.6	12.3	2.2	98.5	5.82
— Self-Pollinated.....	By hand	115	624	22.6	4.2	22.6	4.2	112.5	5.06
	By bees	151	827	19.2	3.5	19.2	3.5	100.5	5.15
— Covered Only.....		217	1187	15.6	2.8	15.6	2.8	120.7	5.50
<b>Grimes</b>									
× King David.....	By hand	14	55	42.8	10.9	42.8	10.9	146.8	8.84
	By bees	27	106	48.1	12.2	44.4	11.3	119.0	7.34
× Ben Davis.....	By hand	27	93	40.7	11.8	18.5	5.4	121.4	8.00
	By bees	33	113	36.4	10.6	27.3	7.9	139.7	6.45
× Jonathan.....	By hand	39	134	30.8	9.0	25.6	7.5	57.6	7.50
	By bees	25	86	32.0	9.3	28.0	8.1	81.3	5.86
— Open Pollinated.....		321	1188	25.0	6.7	21.5	5.8	107.4	6.52
— Self-Pollinated.....	By hand	10	39	10.0	2.6	10.0	2.6	120.0	3.00
	By bees	29	114	17.2	4.4	17.2	4.4	102.4	3.20
— Covered only.....		129	474	11.6	3.2	11.6	3.2	85.1	2.33
<b>Winesap</b>									
× Delicious.....	By hand	41	175	26.8	6.3	26.8	6.3	144.6	9.36
	By bees	41	175	26.8	6.3	26.8	6.3	140.0	7.81
× King David.....	By hand	65	278	7.7	1.8	7.7	1.8	124.6	9.60
	By bees	53	227	24.5	5.7	20.8	4.8	143.4	7.81
— Open Pollinated.....		346	1480	18.5	4.3	17.6	4.1	105.0	7.59
— Covered Only.....		213	912	0.47	0.1	0	0	0	0
<b>Stayman</b>									
× Rome.....	By hand	97	452	4.1	0.8	2.1	0.4	246.5	4.50
	By bees	43	200	2.3	0.5	2.3	0.5	83.0	7.00
× Jonathan.....	By hand	70	326	5.7	1.2	4.3	0.9	203.0	3.33
	By bees	70	326	4.3	0.9	0	0	0	0
× King David.....	By hand	27	126	7.4	1.6	0	0	0	0
	By bees	33	187	12.1	2.1	0	0	0	0
— Open Pollinated.....		382	1780	7.1	1.5	2.6	0.56	167.2	3.30
— Self-Pollinated.....	By hand	45	210	0	0	0	0	0	0
	By bees	69	322	1.5	0.3	0	0	0	0
— Covered Only.....		266	1240	1.1	0.2	0.4	0.08	193.0	3.00

flowers were receptive was extremely short, a matter of 5-7 days. Bees in the pollination cages behaved splendidly, student assistants worked cheerfully overtime.

Having borne good crops for a number of years and being somewhat crowded now, almost all varieties of apples in this block of our experimental orchard are beginning to acquire a biennial bearing habit. The year 1930 was more or less an "off year" for many of the trees. The bloom was considerably lighter than in 1929. Of course, only trees with a fair amount of flowers were chosen for our study. Whenever necessary, the cages were moved to such trees. The number of pollinations perforce was limited. Another thing worth noting is the fact that, though the usual quantity of a nitrogen fertilizer, four to five pounds of ammonium sulphate per tree, was applied early in the season, the rainfall was very light up to and including the period of flowering. It is very doubtful, therefore, that any appreciable amount of this fertilizer had become available and was absorbed by the trees previous to pollination and fruit setting.

Table 5 gives results of this year's pollination. The data are arranged in parallel lines in order to permit a ready comparison of the efficiency of the branch-unit and screened-cage methods. In the column headed "Type of pollination", "by hand" refers to applications by brushing of previously collected pollen to stigmas of non-emasculated flowers and the use of the branch-unit cloth-bag methods of procedure. "By bees" is understood in this table the pollination by bees within a wire-screened cage and the use of large bouquets to supply pollen in all cross-pollinations. In 1930 the fruit set was recorded on July 3 after all the drops had occurred and again when the fruit was harvested (September-October). In the fall when the fruit was gathered all specimens or representative samples, in the case of a heavy crop, were weighed and the number of seeds in each apple determined. This count includes all seeds of normal size, whether plump or shriveled. Most of the large but "flat" seeds undoubtedly contain embryos in various stages of development<sup>5</sup>. Moreover, it has been shown by Einset<sup>6</sup> that in the Gravenstein variety, at least, there is a better correlation between fruit weight and the combined number of empty and filled seeds than the filled seeds alone.

In Table 6 the results of cross-pollination by the two methods are summarized by giving the percentage set after all drops had occurred (July 3) and at picking time. It is quite evident from the figures that the two methods were comparable in efficiency during this season. Excepting the discrepancies with King David and Jonathan as pollenizers, the results are very consistent and rather uniform.

TABLE 6.—CROSS-POLLINATION BY BEES (SCREENED-CAGE METHOD) vs. CROSS-POLLINATION BY HAND (BRANCH-UNIT METHOD), 1930

Pollen variety (♂)	No. of crosses	Pollination by Bees			Pollination by Hand		
		No. of flowers (♀)	Per cent flowers set on July 3	Per cent flowers set in Sept.-Oct.	No. of flowers (♀)	Per cent flowers set on July 3	Per cent flowers set in Sept.-Oct.
Delicious-----	2	676	5.34	4.48	462	4.32	4.12
Ben Davis-----	3	580	3.30	2.77	296	3.92	1.91
Jonathan-----	3	802	1.51	1.01	772	3.12	2.73
King David-----	4	941	3.16	2.43	805	1.62	1.37
Rome-----	1	200	.5	.5	452	.8	.4
Grimes-----	1	335	.3	.00	221	.00	.00
Open-pollination	5 varieties	8161	3.34	2.63			

### The 1931 Data

This was an excellent year for pollination studies in the experiment station orchard. Practically all of the varieties were blooming heavily. The weather was desirable in many respects, excepting that the summer was hot and abnormally dry. This resulted in reduction of fruit size and may have affected the extent of the various drops. Very few of the cages had to be moved, since almost all of the trees enclosed during the previous season were flowering abundantly. Bees visited the blossoms in large numbers and hand pollination went on as per schedule.

A much larger number of cross-pollinations were undertaken this season than in any preceding one. The following varieties were used in 1931, both for bee and hand pollination: Delicious, Jonathan, Grimes, Rome, Stayman and Winesap. As pollen varieties, Jonathan, Delicious, Golden Delicious, Grimes, York and Ben Davis were used.

The results of the 1931 experiments will be found in Table 7. The records are arranged in the same way as those of the preceding year, hence they can be easily compared. An examination of the figures in the table will show that the screened-cage method with bee pollination compares very favorably with the cloth-bag method. In most instances pollination by bees gave a higher set of fruit than pollination by hand. While in other years the fruit set from open-pollination was markedly higher than that from most of the artificial cross-pollinations, this was not true in 1931 (Table 8). It may indicate that in this year pollination was relatively "sufficient" in the case of all methods employed but that the crop was limited and determined primarily by physiological causes, possibly the moisture and food supply. This probably is true in all years of abundant flowering of the apple or in all so-called "on" or bearing years. If that be the case, then in the two preceding seasons neither method of experimental pollination was as efficient as open-pollination. This points to the possibility that certain favorable but unknown factors may be operative when insects bring about pollination under normal conditions in a mixed planting of several varieties.

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TABLE 7.—RECORDS OF FRUIT SET ON JUNE 4, JULY 8, AND IN SEPT.-OCT., 1931. COMPARATIVE FIGURES WITH BRANCH-UNIT AND SCREENED-CAGE METHODS OF POLLINATION

Variety (♀) × Pollen (♂)	Type of pollination	No. of flower clusters	No. of flowers	June 4		July 8		Sept.-Oct.		Ave. weight of fruit Grams	Ave. No. of seeds
				Clusters set - %	Flowers set - %	Clusters set - %	Flowers set - %	Clusters set - %	Flowers set - %		
Jonathan × Delicious.....	By hand	65	348	7.69	1.43	7.69	1.43	6.16	1.15	93.00	5.50
	By bees	137	734	32.84	6.13	24.82	4.63	24.82	4.63	89.08	4.79
× Golden Delicious	By hand	54	289	33.33	6.23	20.37	3.80	14.82	2.77	58.25	6.62
	By bees	124	664	70.16	13.10	55.62	10.39	50.00	9.33	38.80	5.64
× Grimes.....	By hand	45	241	57.77	10.78	35.56	6.64	31.10	5.81	48.92	6.71
	By bees	61	326	72.13	13.50	60.65	11.33	55.74	10.42	44.03	6.47
— Open Pollinated		122	653	40.16	7.50	36.07	6.74	23.77	4.44	59.79	6.55
— Self-Pollinated	By hand	54	289	20.37	3.81	14.82	2.77	14.82	2.77	55.87	2.12
	By bees	73	391	50.68	9.46	36.99	6.90	32.89	6.14	79.79	3.65
— Covered Only		185	990	28.10	5.25	11.89	2.22	11.35	2.12	67.43	3.62
Grimes × Golden Delicious	By hand	58	267	34.49	7.49	34.49	7.49	32.78	7.12	69.94	8.21
	By bees	94	434	67.02	14.52	67.02	14.52	64.90	14.05	55.08	6.05
× Jonathan.....	By hand	53	244	26.41	5.74	26.41	5.74	24.53	5.32	57.31	8.38
	By bees	110	507	37.27	8.08	37.27	8.08	35.47	7.69	55.87	7.05
× Delicious.....	By hand	31	143	106.50	23.07	103.30	22.38	96.80	20.98	85.90	9.43
	By bees	36	166	50.00	10.74	41.65	9.03	27.78	6.02	90.30	8.60
— Open Pollinated		361	1665	22.71	4.92	19.10	4.14	18.90	4.08	69.44	7.56
— Self-Pollinated	By hand	56	258	1.78	0.39	1.78	0.39	1.78	0.39	34.00	6.00
	By bees	66	304	10.60	2.30	9.09	1.97	9.09	1.97	60.00	2.33
— Covered Only		205	945	7.80	1.69	7.80	1.69	6.83	1.48	59.35	3.93
Delicious × Golden Delicious	By hand	67	337	4.48	0.89	1.49	0.30	1.49	0.30	157.00	6.00
	By bees	101	508	4.95	0.98	4.95	0.98	4.95	0.98	172.40	8.80
× Grimes.....	By hand	62	312	3.23	0.64	3.23	0.64	1.61	0.32	152.00	8.00
	By bees	106	533	6.60	1.31	6.60	1.31	6.60	1.31	134.00	7.43
× York.....	By hand	83	418	13.25	2.29	10.85	1.87	7.23	1.25	98.83	7.83
	By bees	65	327	12.31	2.45	12.31	2.45	7.69	1.53	104.80	8.06
× Ben Davis.....	By hand	86	422	9.30	1.89	8.14	1.66	5.82	1.18	126.40	7.60
	By bees	79	397	10.13	2.01	10.13	2.01	8.86	1.76	161.57	8.71
× Jonathan.....	By hand	56	282	46.42	9.22	39.30	7.80	33.91	6.74	116.94	7.68
	By bees	51	257	23.51	4.67	23.51	4.67	13.73	2.72	111.85	7.14
— Open Pollinated		526	2646	23.00	4.57	20.74	4.12	16.55	3.29	121.71	7.64
— Self-Pollinated	By bees	78	392	20.51	4.08	17.95	3.57	16.66	3.31	90.46	5.84
		286	1438	1.39	0.28	0.70	0.14	0.70	0.14	105.50	6.50
Stayman × York.....	By hand	45	216	68.88	14.35	55.60	11.57	48.90	10.19	60.00	4.59
	By bees	41	197	107.30	22.33	95.20	19.79	78.04	16.24	49.28	5.62
× Grimes.....	By hand	58	279	65.50	13.62	53.42	10.44	41.38	8.08	85.45	4.16
	By bees	39	188	107.70	22.33	97.50	20.41	71.80	14.89	109.46	4.25
× Golden Delicious	By hand	59	284	18.64	3.87	16.95	3.52	13.56	2.82	87.25	5.12
	By bees	57	274	54.40	11.32	49.12	10.22	49.12	10.22	99.78	5.57
× Jonathan.....	By hand	44	212	38.64	8.02	27.27	5.66	27.27	5.66	93.00	5.41
	By bees	71	341	9.86	2.05	9.86	2.05	9.86	2.05	112.43	3.86
× Delicious.....	By hand	68	327	35.30	7.34	16.18	3.36	16.18	3.36	82.00	5.27
	By bees	69	332	34.79	7.23	28.99	6.02	23.19	4.82	97.50	5.12
— Open Pollinated		478	2300	29.30	6.08	24.69	5.13	18.62	3.87	96.12	4.77
— Self-Pollinated	By bees	68	327	1.47	0.31	1.47	0.31	1.47	0.31	107.00	3.00
		245	1178	2.86	0.59	2.86	0.59	2.50	0.51	103.33	4.33



TABLE 7.—RECORDS OF FRUIT SET ON JUNE 4, JULY 8, AND IN SEPT.-OCT., 1931. COMPARATIVE FIGURES WITH BRANCH-UNIT AND SCREENED-CAGE METHODS OF POLLINATION

Variety (♀) × Pollen (♂)	Type of pollination	No. of flower clusters	No. of flowers	June 4		July 8		Sept.-Oct.		Ave. weight of fruit Grams	Ave. No. of seeds
				Clusters set - %	Flowers set - %	Clusters set - %	Flowers set - %	Clusters set - %	Flowers set - %		
Winesap × Jonathan-----	By hand	81	374	79.01	17.11	71.60	15.51	70.40	15.25	51.36	9.40
	By bees	111	513	73.90	15.98	65.80	14.25	65.80	14.25	45.95	9.14
× York-----	By hand	62	286	93.54	20.28	87.20	18.87	87.20	18.87	32.13	9.02
	By bees	77	356	71.43	15.46	67.53	14.61	66.23	14.33	48.58	8.82
× Delicious-----	By hand	68	314	23.53	5.09	22.05	4.78	14.71	3.18	83.60	9.20
	By bees	159	735	21.38	4.61	16.98	3.67	16.98	3.67	52.00	8.22
× Golden Delicious	By hand	78	360	21.80	4.72	15.38	3.33	14.10	3.05	31.18	9.45
	By bees	113	522	8.85	1.92	8.85	1.92	7.97	1.72	62.22	8.77
- Open Pollinated		396	1830	45.48	9.83	35.88	7.76	33.85	7.32	58.55	9.06
- Covered Only--		280	1294	1.07	0.23	0.71	0.15	0.36	0.07	77.00	3.00
Rome × Jonathan-----	By hand	38	245	47.36	7.35	47.36	7.35	42.05	6.53	116.25	7.93
	By bees	92	593	109.70	17.02	89.20	13.83	84.80	13.15	38.71	5.34
× Grimes-----	By hand	25	161	108.00	16.76	104.00	16.15	96.00	14.91	99.53	8.00
	By bees	113	729	79.64	12.35	37.16	5.76	37.16	5.76	70.81	5.88
× Golden Delicious	By hand	26	168	88.50	13.69	46.15	7.14	46.15	7.14	95.08	7.33
	By bees	115	742	56.52	8.76	34.76	5.39	31.60	4.85	83.86	5.87
× Delicious-----	By hand	38	245	52.63	8.16	47.36	7.34	44.73	6.94	100.82	8.76
	By bees	81	522	40.75	6.32	39.52	6.13	39.52	6.13	98.97	5.34
- Open Pollinated		323	2082	43.34	6.72	32.40	4.97	28.17	4.37	96.48	7.36
- Covered Only		119	768	34.45	5.34	22.69	3.53	18.49	2.87	63.77	3.86

TABLE 8.—CROSS-POLLINATION BY BEES (SCREENED-CAGE METHOD) VS. CROSS POLLINATION BY HAND (BRANCH-UNIT METHOD), 1931

Pollen variety (♂)	No. of crosses	Pollination by Bees				Pollination by Hand			
		No. of flowers (♀)	Per cent flowers set on June 4	Per cent flowers set on July 8	Per cent flowers set in Sept.-Oct.	No. of flowers (♀)	Per cent flowers set on June 4	Per cent flowers set on July 8	Per cent flowers set in Sept.-Oct.
York-----	3	880	12.16	11.25	10.00	920	10.71	9.43	8.83
Jonathan-----	5	1911	10.04	9.08	8.61	1357	10.24	9.14	8.62
Grimes-----	4	1776	10.30	7.00	6.25	993	9.36	7.36	6.20
Delicious-----	5	2489	6.17	5.13	4.78	1377	7.11	5.88	5.23
Golden Delicious--	6	3144	8.30	6.84	6.39	1705	5.39	3.87	3.46
Open-pollinated-----	6 varieties	11176	6.36	5.24	4.45				

### SELF-POLLINATION IN RELATION TO FRUIT SIZE AND SEED NUMBER

The relative size of the apple fruit seems to be affected primarily by two major factors, the leaf area in the immediate vicinity of the fruit and the number of seeds present. Fruit size, therefore, is but partly correlated with seed number. But there seems to be a more or less direct correlation between seed number and pollination. It is of interest to

know how the three types of self-pollination compare in regard to fruit size, but particularly seed number.

Table 9 shows that in the two years self-pollination by bees, as judged by the average number of seeds per apple, appeared to be more effective than self-pollination which took place when the flowers were only covered by a cloth bag. Seed counts from hand pollinations were obtained only in one year (1930), when it was higher than from the other two types of pollination. All apples were much larger in size in 1930 than in 1931, with no corresponding increase in the average number of seeds per fruit. This is to be expected, since the fruit set was much heavier in 1931.

TABLE 9.—RELATION OF METHOD OF SELF-POLLINATION TO FRUIT SIZE AND NUMBER OF SEEDS

Type of pollination	1930			1931		
	No. of fruit	Ave. weight of fruit—grams	Ave. No. of seeds	No. of fruit	Ave. weight of fruit—grams	Ave. No. of seeds
By hand-----	31	117.25	4.96	*		
By Bees-----	37	101.29	4.75	44	78.13	4.11
Covered only --	57	107.59	4.33	66	69.06	3.91

\*Only a small amount of self-pollination by hand was done in 1931. The few fruit that set can not be considered representative.

### EFFICIENCY OF CERTAIN VARIETIES AS POLLENIZERS

It was demonstrated in previous years (1926-1928) by the paper-bag method that certain varieties of apples are more efficient pollenizers than others. (Murneek et al.<sup>31</sup>). These conclusions were drawn from extensive cross-pollination work involving a large number of varieties and several thousand flowers. Ben Davis, Jonathan, and Delicious appeared to be exceptionally desirable pollenizers for other commercial sorts of apples. It is of interest to learn of the relative efficiency of these three and other varieties when used as pollenizers in connection with the branch-unit and screened-cage methods of procedure.

In Table 10 are summarized the average percentages of flowers that set when certain pollen was involved. The data are grouped under three methods of pollination, each having been employed over a period of three years. It should be emphasized that such a comparison is at best only an approximation, for the number of varieties and flowers involved in cross-pollination and the amount of fruit produced varied greatly from year to year. The percentage set is that obtained after all the natural fruit drops had taken place.

Even a cursory examination of the data in Table 10 will show that with all methods of procedure, the varieties Jonathan, Delicious and Ben Davis appear to be excellent pollenizers. Only in the case of the branch-unit method of pollination, Grimes has excelled Delicious in this respect,

but by a very small margin. The York variety is at the head of the list twice due, undoubtedly, to the fact that it was used but one season in cross-pollinations involving a relatively small number of varieties. Our Yorks flower and produce fruit biennially and 1931 was a year of their heavy performance. This may have influenced the relative effectiveness of this variety as pollenizer. Much additional data are required to allow a more definite conclusion regarding the York variety as a pollenizer.

TABLE 10.—COMPARATIVE EFFICIENCY OF CERTAIN VARIETIES AS POLLENIZERS

♂ Variety	No. of varieties (♀) involved	Total No. of flowers pollinated	Percentage of flowers set
<b>Paper-bag method, 1926-1928</b>			
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
<b>Branch-unit method, 1929-1931</b>			
York (1931 only)	3	920	9.43
Jonathan	11	2758	6.38
Ben Davis (1929 and 1931)	5	1105	6.21
Grimes	8	2275	4.13
Delicious	12	3735	4.03
Golden Delicious (1929 and 1931)	12	3885	3.45
King David	4	805	1.62
Rome (1930 only)	1	452	0.80
<b>Screen-cage method, 1929-1931</b>			
York (1931 only)	3	880	11.25
Jonathan	11	5990	4.65
Ben Davis (1929 and 1930)	5	2761	4.19
Delicious	12	7268	3.68
King David (1930 only)	4	941	3.16
Golden Delicious (1929 and 1931)	12	9689	3.03
Grimes	8	5565	2.85
Rome (1930 only)	1	200	0.50

Although Golden Delicious, a comparatively new variety, seems to produce viable pollen abundantly, its efficiency has been but mediocre. Our cross-pollinations, extending over two seasons and involving twelve varieties and some 14000 blossoms, may be fairly representative. But further tests appear to be desirable in order to decide definitely about the real value of this variety as a pollenizer. Investigations in other localities with Golden Delicious pollen seem also inconclusive<sup>10, 33, 26</sup>. As in 1926-1928, so in 1930, a relatively low percentage set of flowers was obtained when King David and Rome were used as the pollen variety.

The direct results of pollination is the production of seed, a more secondary (biologically speaking) effect of which is the formation of the fleshy part of the fruit. The seed counts, therefore, should give a further, more definite clue as to the relative value of certain pollen. Table 11 presents data which show definitely that during the two years and with both types of pollination, Delicious, Ben Davis and Jonathan were efficient males, as judged from the average number of seeds per fruit.

TABLE 11.—SEED CONTENT OF CROSS-POLLINATED APPLES, 1930 AND 1931

Pollen (♂) variety	1930						1931					
	Pollination by Hand			Pollination by Bees			Pollination by Hand			Pollination by Bees		
	No. of crosses	No. of fruit	Ave. No. of seeds	No. of crosses	No. of fruit	Ave. No. of seeds	No. of crosses	No. of fruit	Ave. No. of seeds	No. of crosses	No. of fruit	Ave. No. of seeds
King David.....	2	11	9.18	2	23	7.56	5	72	8.38	5	119	6.08
Delicious.....	2	19	8.68	2	30	6.76	1	5	7.60	1	7	8.71
Ben Davis.....	2	6	8.33	3	16	6.62	5	117	8.40	5	204	7.30
Jonathan.....	3	21	6.57	2	8	6.37	1	5	7.74	4	111	5.74
Grimes.....							4	63	6.25	4	111	5.74
York.....							3	82	7.74	3	88	7.65
Golden Delicious..							6	59	7.59	6	201	6.02

The top position of the King David variety is due to the fact that it participated in cross-pollinations with two varieties both of which happened to be in that particular year high performing females. For reasons already referred to, York was an efficient pollenizer in 1931, as is indicated also by the seed count of the fruit which set when this pollen participated in fertilization. A low average number of seeds per apple was secured with Grimes and Golden Delicious pollen.

### CONCLUSIONS

After three years' experience with the branch-unit and screened-cage methods of apple pollination, it is very evident that both of these procedures offer certain definite advantages in comparison to the popular paper-bag method. During the period under consideration, the weather was extremely variable. Bad pollination weather will, of course, put to a disadvantage a procedure in which bees are used as pollenizers, while weather that is ideal for insect flight will tend to enhance it. The branch-unit method, being more "artificial", seems to be appreciably less subject to the effects of climatic factors. As it is far less expensive and considerably more flexible, this procedure most probably will be preferred to the screened-cage method for the usual orchard pollination studies.

In a normal year, the results from either of the above methods of apple pollination will more closely approach those that might be expected under natural conditions of insect pollination in an orchard planted to several varieties. When paper bags are used and hand pollination is practiced, the fruit set appears to be more variable. It will produce results that will be considerably, even conspicuously, above or below a normal yield of fruit. This factor alone may account in part for the great variability of the apple pollination data now extant.

In many ways the screened-cage-package-bee pollination procedure would be a very desirable and practical method, were it not for the comparatively high initial cost of constructing the cages. With an endowment fund of a few thousand dollars and the cooperation of a good bee man,

this method should make a horticulturist happy in his pollination activities, and would make him considerably more certain that he is making real progress with his field work. It should permit one to advance farther and more rapidly in the determination of the various factors involved in the complex relationship between insect pollination and fruit setting. Moreover, it may be emphasized once more that the screened-cage method permits a more accurate study of the nature and extent of the various apple drops—a problem quite germane to the general subject of pollination.

When the fruit set is determined in either self- or cross-pollination, it seems to be much more desirable to make the counts several times during the growing season. While in self-pollination most, if not all, of the flowers and young fruit usually are shed soon after pollination, in cross-pollination there are normally several waves of shedding, terminating with what is commonly called the "June drop". A count taken after this last drop should give a fairly accurate estimate of the value and efficiency of a particular pollen and certain pollenizers. The amount of fruit harvested will, of course, constitute the final crop—a record of significance in commercial practice, but probably of less value in the determination of self- and cross-fruitfulness of particular varieties of apples. External factors of diverse type, including diseases and insect enemies, may reduce markedly the amount of fruit that will remain on the tree between the "June drop" and time of harvesting. And it is not a pleasant task to hunt for every rotten apple under the trees. The seed count seems to be an important index in all pollination experiments. It permits a still closer check on the effectiveness of a particular pollen.

For reasons not yet fully known, certain varieties of apples appear to be much better pollenizers than others. Thus, in the six years of our investigations, Jonathan, Delicious and Ben Davis have been most excellent pollen producers and very efficient cross-pollenizers of almost all the varieties studied by us. This capacity of being an effective male seems to be inherent in these varieties. Though tried only in one year, York pollen gave an unusually large set of fruits from all crosses, and with a high seed content. These particular York trees bear abnormally heavy crops every alternate year. It is possible that this striking performance in the "on" year may have been due to the biennial bearing habit. Information on this variety as a pollenizer is still very incomplete.

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