RELATION OF LIGHT INTENSITY
TO FRUIT
SETTING IN THE SOUR CHERRY

THESIS FOR THE DEGREE OF PH. D.

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Relation of Light Intensity to Fruit Setting

in the Sour Cherry

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THESIS

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The validity of results secured in pollination experiments in which bees were excluded by cheesecloth or wire screens has been open to some doubt because of the possible effects of the screens in intercepting light and thereby affecting the metabolism of the trees. This paper sets forth the results of a study of the effects of the screens. Since some advantage would arise from the use of a self-fruitful variety and since results from the use of screens had already been reported on this variety (48) the Montmorency cherry was used in this study.

Review of Literature

The various factors that have a direct or indirect bearing on the setting of fruits have been discussed by a number of investigators. The importance of bees as pollenizing agents have been set forth in a number of instances, (1), (15), (2), (53), (56), (30), (40), (41), (43), (46), Gardner (23) states that the honey bee is probably more important in this connection than all the wild forms put together. In a series of very comprehensive pollination studies in South Africa, Reinecke (48) found that next in importance to bees are the syrphid flies. The investigations of Waugh (57), Lewis and Vincent (38), Howlett (29), Murneek (43), and others show that wind is of no direct importance in pollen distribution in fruit trees. Reinecke (48) states that wind may adversely affect the set of the stone fruit crop by increasing the rate of transpiration.

Lack of fertilization from self pollination, especially with self-sterile varieties, has been attributed to slow growth of the pollen tube through the stylar tissue by Osterwalder (44), Dorsey (14), Crane (9), and Chittenden (6). Slow growth of the pollen tube may be caused by low temperature (15), (31), (6), by the presence of an inhibitor (17), or by the absence of acceleration rather than the presence of an inhibitor (20), (21), (18), (19), (8). Sandsten (51) reports that in most plants pollen tube growth was not affected by sunshine, the tomato being one exception observed where cloudy weather decidedly retarded pollen germination and growth.

A number of investigators, (28), (3), (5), (55), (4), (23), and (49) report that most sour cherry varieties are highly self-fruitful and set good crops without cross pollination. Schuster (53) states that the Montmorency variety, so far as tested, was self-sterile. On the other hand, Crane (9) found that not all varieties are self-fertile. Einset (22) found that while some varieties are nearly self-unfruitful, others, including Montmorency, appeared to be self-fruitful.

Most investigators believe that, in the majority of cases, the growth and development of the young fruits ceases when embryo abortion occurs or shortly thereafter. Crane (10), however, states: "Considering the numerous cherries which reach maturity without developing perfect seeds, in many practically only the empty seed coats remain, it is safe to conclude that if embryonic growth is not arrested until a fairly late stage the fruits, if favorable conditions prevail, are able to remain and reach maturity.' Miss Bradbury (4) and Dorsey (16) found that suppression of the

embryo sac takes place even before bloom. Knowlton and Sevy (31) assume that low temperatures which retard pollen tube growth may delay embryo abortion for a short time but not indefinitely. It was observed by Miss Bradbury (3 , 4), Detjen (11), and others that fertilization had occurred in a large number of fruits that dropped. It is the opinion of many investigators that the lack of some nutritional substance or substances is responsible for embryo abortion, though no definite experimental evidence is available which proves either carbohydrates or nitrogen to be the limiting factor. Müller-Thurgau (42) demonstrated, by ringing experiments, as early as 1897 that nutrition is one of the factors affecting the setting of fruit of the grape. Harvey and Murneek (27) emphasize the importance of carbohydrates. MacDaniels and Heinicke (40) state that "In addition to water and soil nutrients the developing fruits require large amounts of carbohydrate and other food manufactured by the leaves." Petri (45), according to Chandler (5), seemed to find with the olive that an insufficient nitrogen supply resulted in an abortion of the ovaries and a dropping of the fruit.

Although it is recognized that photosynthesis plays an important part in maintaining tree vigor, the relation of different degrees of light intensity to fruit setting or development has received but little experimental attention. It has been assumed, however, that a reduction in light intensity, as with continued cloudy weather or shading, might affect the set of fruit. Howlett (27) found that bagging the flowers after self- and cross-pollinations did not appear to reduce the set when compared with the flowers left without covering. Shoemaker (55) states that "abnormal conditions such as tempera-

ture and shading under bags or tent may have exerted a detrimental effect on the setting of fruit." Dorsey (15) reports that, "other conditions being favorable, cloudiness does not prevent the setting of fruit." Gourley (25) and Gourley and Nightingale (26) shaded fruit trees for the purpose of studying the effect of shade on fruit bud differentiation. Comparative intensities were measured by the use of photographic paper. After analyzing samples from these trees Kraybill (35) states that shading is probably effective through reducing carbon assimilation or increasing nitrogen intake or by both actions. Roberts (49) and Roberts & Langord (50) found that shading cherry trees gave a tremendous reduction in set over trees not shaded but did not report how much the light was reduced by shading.

Statement of Problem

From the information that was available at the beginning of this experiment it was assumed that reduction in light intensity might affect the set of fruit by retarding, (1) bee activity, thus reducing the percentage of blossoms pollinated, (2) the rate of pollen germination and (3) pollen tube growth; and (4) by increasing the amount of embryo abortion due to a change of nutritional conditions. It was the purpose of this experiment to determine, if possible, which, if any, of these factors is influenced by a reduction in light intensity.

Experimental Methods

It was realized at the outset that in a study of this nature a large number of trees could not be used; therefore, it was necessary to have trees as nearly uniform in size and vigor as possible and not too widely scattered, yet so situated that the shade from the cage over one tree would not fall upon another tree under the treatment. With this in mind, in the spring of 1930, six mature trees in the cultivated Montmorency block of the college orchards at East Lansing were chosen and treated as follows:

Tree 1. Check

Tree 2. Completely enclosed with wire screen to exclude bees and other pollinating insects (Fig. 1)

Trees 3 and 4. Enclosed in one large cage as No. 2 with a small colony of bees placed inside. (Fig. 2) The screen was removed from Tree No. 4 immediately after petal fall.

Trees 5 and 6. Covered with muslin and burlap, respectively, over the top and half way down on three sides, leaving the north side open (Fig. 3). Thus several degrees of light intensity were secured.

All cages were 18 ft. square and 14 ft. high. These were placed over the trees just before the blossoms opened, and, with the exception of that over Tree 4, were removed at the end of the second wave of drops. The end of this wave of drops, as well as the trend of the dropping of fruits, was determined by gathering the dropped fruits daily on screens placed under the check tree (Fig. 1) in the manner described by Detjen (11).

In 1931 this experiment was repeated at the Graham Horticultural Experiment Station near Grand Rapids upon fully developed, more vigorous trees upon which production records were available. The treatment of the trees was the same as that of the previous

season, although since the limbs were closer to the ground it was necessary to lower the sides of the cages on trees 5 and 6. (Fig. 4) The trees were covered before the fruit buds opened or about four weeks before full bloom.

For a third season's records on shading, the work was repeated in the college orchard at East Lansing in 1932. Four trees were used, two as checks and two shaded as before, one each shaded with muslin and burlap. The shades were erected one week before full bloom.

To check on bee activity, hand pollinations were made on a number of blossoms in 1930 on the shaded trees. Hand pollinations on the other trees were not made due to the rapidity of opening of the blossoms after being retarded by cool weather. Blossom counts were made in all trees for fruit set records. No hand pollinating was done in 1931. Records on normal set from bee pollinations were made and considerable time was devoted to a study of bee activity under the shades and in the open. In 1932 records were taken on both normally and hand pollinated blossoms.

The pollen used for all hand pollinations was a composite sample taken from blossoms of trees not used in the experiment. It was collected by gently rubbing the blossoms over a wire screen, thus combing off the anthers into petri dishes, then stored at room temperature until the anthers had dehissed. The pollen was then stored in vials loosely stoppered with cotton. For the most part, pollen was collected the day before it was to be used, although some was collected several days earlyer from blossoms which had been forced open in the laboratory. Where a great amount of pollination work is to be done, large amounts can be collected and stored for a considerable length of time, according to Kosemanoff (32), who found that pollen of almost all sweet and sour cherries remained germinable in a desiccator over $CaCl_2$ more than 107 days and that by this kind of storage an after ripening and an increase of germinability of the pollen occurs, with optimum between 27-40 days.

All pollen that was used was tested for germinability in 12 per cent sugar solution. Although no counts were made in 1930 and in 1932, the tests showed good germination. In 1931 germination tests were made of the samples used for pollination and also of samples taken from each of the trees under treatment.

Temperature and humidity records were secured with hygrothermographs both in the open and under the burlap shade during the seasons of 1930 and 1931 and only in the open in 1932. Records were also kept of the general weather conditions.

Light intensity measurements were secured with a Macbeth Illuminometer (37), using the horn attachment with transluscent disc directed toward the light source. It was realized that light intensity would vary from day to day and in fact within a few minutes during the day. Readings were therefore taken at four periods during the day as follows: 9 A. M., 11 A. M., 1 P. M., and 3 P. M., every day except in rainy weather. These readings were taken in 1930 in the open to get total available sunlight and in the trees subjected to the four treatments: check, wire screen, muslin, and burlap. The relative positions in the tree at which the readings were taken were approximately 8 feet above the ground at three different points around the tree and approximately half way between the trunk and the outer ends of the branches. Readings were taken near the top of the cages on several clear days to determine the reduction in light intensity by the wire screen and cloth.

In 1931, light intensity readings were taken as in the previous season and in addition readings were taken approximately 4 feet below the top of each cage, thereby securing the daily range of intensity transmitted by each screen. It was observed during the mid portion of the season that wind and rains had opened up the burlap mesh to such an extent that there was little or no difference in light transmission between it and the muslin, yet it seemed that there was considerable difference in intensity under the two shades. In order to measure this difference the testing disc in the horn of the illuminometer was held in a vertical plane, instead of at right angles to the source of light, and directed toward the four points of the compass. These "vertical plane readings" as they will be termed in the following discussion were expected to give some index of the relative intensity of the diffused light under the several treatments. This then gave three sets of readings, namely, (1) total light, or that transmitted by the screens, (2) the amount of light within the tree, and (3) vertical plane readings or diffused light.

These three sets of readings were taken also in 1932, using new burlap for that treatment.

As mentioned above, a number of investigators believe that unfavorable nutritional conditions are responsible for the dropping of immature fruits. It has also been demonstrated that leaf area has close relationship to the amount of food synthesized by the plant. For comparison with effects produced by shading in 1932, several branches were partly defoliated on one of the check trees, 60 per cent of the leaves being removed as soon as they had separated sufficiently in the cluster to reveal the number. Another tree was given less severe defoliation. This was a small tree one-half of which was left normal while 40 per cent of the foliage was removed from the other half. Counts were made on both hand pollinated and normal blossoms.

Observations were also made on bee activity and pistil receptivity.

Analytical Methods

It was realized that large samplings of leaves could not be taken without materially affecting the nutritional balance of the tree and especially the branches upon which the blossom counts were made. Therefore no leaves were removed from the branches tagged for fruit set records and histological studies. A sample of leaves was collected May 24, 1930, from each of the trees for carbohydrate analysis and moisture determinations. Since the results of this preliminary analysis were rather striking, samples were collected more frequently in 1931. Leaf samples were collected from all trees at 5 A. M., 12 M., and 6 P. M., on May 21, also at 12 M. on June 8, and July 7. The last collection was just before harvest and a month after the cages had been removed. On June 7, 1932, two lots of leaf samples were collected, one at 5 A. M., and one at 6 P. M.

All leaf samples were preserved in alcohol, about 80 per cent, by boiling in a water bath 45 minutes. Determinations were made on free reducing substances and total sugars by the titration method of Shaeffer and Hartman with several modifications. The nature of the material made it impossible to filter, after evaporating off the alcohol and taking up with water, before clarifying with lead subacetate. They were, therefore, clarified without filtering. It is possible that some of the sugars were thrown down by the clarifying agent but as all samples were treated in this way the results should be comparable. Another modification of the Schaeffer and Hartman method was in the reduction of Fehling solution. Instead of being boiled over a direct flame, the samples were reduced in a water bath at 80°C. for 30 minutes, as described by Quisumbing and Thomas (47).

In addition to the carbohydrate analyses mentioned above it was planned to make analyses of starch and hemicellulose on the dried and ground residue from the alcohol extracts. A slight sliminess made difficult the filtration of the samples taken early in the season. This was probably due to the presence of certain gums and resins which increased as the season advanced, so that the residues from samples taken later in the season, after being soaked in water about three hours, were gummy gelatinous masses which could not be filtered even after being centrifuged 15 or 20 minutes. Since the standard methods of analysis could not be used for starch determinations on these samples they are not included in this paper.

Histological Methods

To determine the possible effect of light intensity on pollen germination, pollen tube growth, fertilization, and embryo development, a number of blossoms were emasculated in the "full balloon" stage, care being taken to use only those blossoms that appeared to have perfectly normal pistils and in as near a uniform stage of advancement as possible so they would all become receptive at approximately the same time. In 1931, samples were collected at 12 hrs., 24 hrs., and 2, 3, 4, 5, 10, 15, and 21 days after pollination. In 1932, samples were collected at 9 hrs., 24 hrs. and 2, 3, 4, 5, 6, 8, 10, and 15 days after pollination. As soon as aborting fruits could be distinguished from the normal fruits they were collected separately. These samples were killed in alcohol-formalin-acetic acid killing solution and later imbedded in paraffin for sectioning. Sections were cut at 8 and 15 microns until it was found that the thicker sections were better for pollen tube studies.

Of the several stains tried, including Delafield's haematoxylin, Delafield's haematoxylin and light green, acid fuchsin, acid fuchsin and light green, and acid fuchsin and methyl green, acid fuchsin and light green gave the most satisfactory results (acid fuchsin--1 gram in 100 cc. of 70% alcohol and light green 0.2 gram in 100 cc. of 70% alcohol). The material was stained 45 minutes to one hour in acid fuchsin and 10 minutes in light green. This gave just as good, if not better, results than in acid fuchsin alone for a much longer period.

Weather Conditions

It has been shown by Dorsey (15) that weather conditions have a direct bearing upon fruit setting in the plum. Cold weather before the blossom buds open may also result in serious injury. Such a cold wave occurred about three weeks before the blooming period in the spring of 1930 when the temperature fell to 23°F. An attempt was made to prevent serious injury by the use of fire pots with partial success. Counts made while the trees were in bloom revealed that all trees had from 60 to 66 per cent live blossoms except the one covered with muslin shade which had only 49 per cent live blossoms. No such adverse conditions developed during 1931 and 1932; less than three per cent of the blossoms were injured in either season. Weather data during the blooming and fruit setting periods for the three seasons are presented in Table 1. For the most part, the blooming periods were favorable for pollination and fruit setting, although the low temperatures in 1931 retarded development of the blossoms after some had opened on May 5 and 6. Observation indicated that at temperatures below 60°F. visible development of cherry blossoms takes place very slowly. Whether or not embryo development continues at these low temperatures is still undecided.

Wind Velocity

A few anemometer readings taken in 1930 indicated that wind velocity is materially reduced by a wire screen cage and that air currents under the cloth shades were almost negligible. In 1931 readings of 10-15 minutes duration were taken throughout the day during the blooming period in four different locations: (1) In the center of the square between the trees at an elevation of

Table I. Weather data during blooming and fruit setting periods

1930				1931				1932			
Date	Temperature Max.	Temperature Min.	General Weather Conditions	Date	Temperature Max.	Temperature Min.	General Weather Conditions	Date	Temperature Max.	Temperature Min.	General Weather Conditions
4/29	71	39	Fair	5/8	48	34	Rain				
30	73	50	Fair	9	56	45	Part Cl.				
5/1	77	60	Clear	10	55	42	Showers				
2	63	45	Clear	11	59	48	"	5/11	55	46	Rain
3	71	39	Clear	12	62	47	Part Cl.	12	63	45	Part Cl.
4	75	38	Clear	13	69	45	" "	13	70	42	Fair
* 5	83	55	Part Cl.	*14	71	41	Clear	* 14	82	57	Clear
6	85	58	" "	15	75	47	Fair	15	86	62	Clear
7	75	63	Rain	16	73	46	Part Cl.	16	72	47	Cloudy
8	80	46	Clear	17	67	40	Fair	17	59	38	Part Cl.
9	85	53	"	18	87	52	Fair	18	67	35	Clear
10	85	60	"	19	68	54	Rain	19	72	42	"
11	75	58	"	20	60	46	Part Cl.	20	81	46	"
12	78	61	Fair	21	53	42	Cloudy	21	68	43	Cloudy
13	76	54	Rain	22	52	36	"	22	64	39	Fair
14	60	54	Cloudy	23	60	36	Fair	23	73	34	Clear
15	54	49	"	24	56	33	Cloudy	24	83	46	"
16	66	50	"	25	66	48	Fair	25	79	59	Rain
17	56	42	Fair	26	75	41	Clear	26	74	59	"
18	48	42	Cloudy	27	82	54	"	27	67	47	Cloudy
19	48	41	Rain	28	88	61	"	28	61	43	Rain
20	66	44	Part Cl.	29	74	60	Cloudy	29	69	42	Clear
21	77	53	Fair	30	62	53	Rain	30	73	45	"
22	82	60	Clear	31	66	42	Clear	31	79	57	Part Cl.
23	80	48	"	6/1	73	40	"	6/1	77	59	Cloudy
24	53	37	"	2	76	47	"	2	74	62	Rain
25	61	35	Part Cl.	3	77	59	Cloudy	3	82	60	Part Cl.
26	46	35	Rain	4	75	62	"	4	85	62	Fair

* Date of full bloom.

10 ft. (the trees in the orchard averaged about 14 ft. in height); (2) At about the same height in the center of the check tree; (3) similarly in a tree under wire screen cage, and (4) under cloth shade. The results of these readings are presented graphically in Figure 5. The prevailing wind direction for the period was from the southwest, except on May 16 when it was from the northwest. This change in direction accounts for the rise in wind velocity recorded that day under the cloth shade which was open on the north side. Although the records secured in these observations are comparatively low it must be remembered that wind velocity within any block of trees is considerably less than in the open and this fact reduces the value of the wind as a pollenizing agent.

EFFECTS OF SHADING

Light Intensity

The data on light intensity are presented in Tables 2, 3, and 4. As already stated, this varies continuously during the day. The readings taken at the four different periods of each day were averaged and are presented as the average daily intensity in apparent foot candles. Although this method does not give an accurate presentation of the total amount of light available for the entire day it is well suited to comparison. Shirley (54) states that the total radiation received at the earth's surface on a cloudy day may be as low as four per cent of that received on a bright day during the same season. Although considerable reduction of light intensity during cloudy weather was observed, the lowest recorded was that on May 15, 1930, which was 12 per cent of the intensity recorded for the brightest day during that season.

Table 2. Light intensity for 1930 in terms of apparent foot candles and percentage of available sunlight for respective days.

Date	Average of daily readings in apparent foot candles.					Available light in the trees (per cent). Light in open = 100.				Light in shaded trees (per cent) Light in check tree= 100.		
	Open	Check	Screen	Muslin	Burlap	Check	Screen	Muslin	Burlap	Screen	Muslin	Burlap
May 6	4162.3	1110.3	1013.6	410.8	104.5	26.7	24.3	9.9	2.5	91.3	37.0	9.4
7	1273.7	588.0	218.2	173.5	41.8	46.1	17.1	13.6	3.2	37.0	29.5	6.9
8	4868.5	1852.5	1237.2	425.2	200.8	38.0	25.4	8.7	4.1	66.8	22.9	10.8
9	3695.1	1199.9	587.5	383.7	102.8	32.5	15.9	10.4	2.8	49.0	31.9	8.6
10-11	------	------	------	-----	-----	---	---	---	--	---	---	---
12	4124.7	856.1	345.3	218.5	67.5	20.7	8.4	5.3	1.6	40.4	25.5	7.9
13	891.3	269.8	157.3	70.2	32.5	30.3	17.6	7.9	3.6	58.3	26.0	12.0
14	1476.8	304.1	119.0	113.5	36.6	20.6	8.0	7.7	2.5	39.1	37.3	12.0
15	593.8	133.5	63.3	60.3	19.7	22.5	10.7	10.2	3.3	47.4	45.2	14.8
16	2788.0	890.9	388.8	262.1	67.4	31.9	13.9	9.4	2.4	43.6	29.4	7.6
17	3775.9	1162.8	619.3	208.8	92.5	30.8	16.4	5.5	2.4	53.2	17.9	7.9
18-19	------	------	-----	-----	---	---	---	---	---	---	---	---
20	3534.5	1346.1	628.8	186.2	106.4	38.9	17.8	5.3	3.0	46.7	13.8	7.9
21	3478.2	1042.8	698.4	208.6	95.5	30.0	20.0	6.0	2.7	66.9	20.0	9.2
22	4649.9	1416.3	1103.7	209.7	142.0	30.5	23.7	4.5	3.0	77.9	14.8	10.0
23	2299.0	813.5	490.8	138.8	33.8	35.4	21.3	6.0	1.5	60.3	17.0	4.1
24-25	------	------	------	-----	-----	---	---	---	---	---	---	---
26	874.6	136.4	117.3	69.0	56.2	15.6	13.4	7.9	6.4	85.9	50.6	41.2
27	1442.9	196.4	84.1	70.4	30.8	13.6	5.8	4.9	2.1	42.8	35.8	15.6
28	1115.2	139.0	69.6	60.0	22.5	12.5	6.2	5.4	2.0	50.1	43.1	16.2
29	4667.1	1624.0	1362.8	205.9	140.3	34.8	29.2	4.4	3.0	83.9	12.7	8.6
Ave.	2993.9	881.5	592.2	224.6	87.4	29.4	19.8	7.5	2.9	67.1	27.7	9.9
Thru Screen	5409.4		3245.6	821.7	304.0		60.0	15.2	5.6			

Table 3. Light intensity for 1931 in terms of apparent foot candles and percentage of available sunlight for respective days.

Daily average of light intensity in apparent foot candles

	Check			Screen			Muslin			Burlap		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Date	Open	In tree	Vert. plane	Thru screen	In tree	Vert. plane	Thru screen	In tree	Vert. plane	Thru screen	In tree	Vert. plane
May 13	5388	3449		1827	1549		790	450		425	345	
14	3766	2428		2200	1755		460	352		377	267	
15	3530	2105		8143	1242		440	338		389	249	
16	3947	2712		1666	947		462	359		323	238	
17	4189	2786		2379	1582		600	386		487	348	
18	3750	3338		2539	1908		474	323		461	239	
19	---	---		---	---		--	--		--	--	
20	3710	2547		1787	1539		450	343		375	269	
21	1224	1021		791	601		275	252		181	165	
22	1075	779		684	484		233	196		153	147	
23	4987	4068		3005	2485		531	360		536	302	
24	538	387		270	200		147	125		76	70	
25	2839	2080		1890	1286		468	307		502	276	
26	4506	4003		2488	2109		459	331		508	390	
27	4542	3736	674	2726	2127	374	474	320	204	428	354	104
28	4209	3432	644	2587	1866	365	478	348	224	517	372	108
29	1317	904	370	909	482	199	236	201	199	184	124	97
30-31	---	---	--	---	---	--	--	--	--	--	--	--
June 1	4349	3633	695	2249	1676	345	407	289	195	506	367	84
2	3606	3295	642	2180	1957	339	402	278	197	476	306	97
3	1096	738	286	690	463	175	248	152	136	169	111	79
4	2622	2238	508	1638	1063	311	383	204	179	449	289	93
5	3186	2706	672	1471	1102	327	401	250	198	374	276	96
6-7	---	---	--	---	---	--	--	--	--	--	--	--
8	5044	4387	741	2884	2425	413	509	340	177	730	488	93
9	1481	1272	446	899	1009	262	265	221	136	326	142	60
Ave.	3257	2525	560	1824	1385	314	417	291	184	389	267	96

Light intensity under various treatments

	Available light transmitted by screens (per cent) (Light in open = 100)			Light in shaded trees (per cent) Light in check tree = 100)			Light on vertical plane (per cent) (Vert. pl. readings in open = 100)		
	(4 ÷ 1)	(7 ÷ 1)	(10 ÷ 1)	(5 ÷ 2)	(8 ÷ 2)	(11 ÷ 2)	(6 ÷ 3)	(9 ÷ 3)	(12 ÷ 3)
Date	Wire screen	Muslin	Burlap	Wire screen	Muslin	Burlap	Wire screen	Muslin	Burlap
May 13	33.9	14.6	7.9	44.5	12.9	9.9			
14	58.4	12.2	10.0	72.3	13.7	11.0			
15	52.2	12.5	11.0	59.0	16.1	11.8			
16	42.2	11.7	8.2	34.9	13.2	8.7			
17	65.4	14.3	11.6	56.8	13.9	12.5			
18	67.7	12.6	12.3	57.2	9.7	7.2			
19	---	---	---	---	---	---			
20	48.2	12.1	10.1	60.4	12.7	10.6			
21	64.6	22.5	14.8	49.1	24.7	16.2			
22	63.7	21.7	14.4	62.1	25.2	18.9			
23	60.2	10.7	10.7	61.1	8.8	7.4			
24	50.1	27.4	14.2	51.8	32.2	18.0			
25	66.5	16.5	17.7	61.8	14.7	13.2			
26	55.2	10.2	11.3	52.7	8.3	9.7			
27	60.0	10.4	9.4	56.9	8.6	9.5	57.8	31.5	16.0
28	61.5	11.4	12.3	54.4	10.1	10.8	56.7	34.9	16.8
29	69.1	17.9	14.0	53.3	22.3	13.8	53.9	53.9	26.2
30-31	---	---	---	---	---	---	---	---	---
June 1	51.7	9.4	11.6	46.1	7.9	10.1	49.6	28.1	12.0
2	60.4	11.2	13.2	53.4	8.4	9.3	52.8	30.7	15.1
3	63.0	22.7	15.5	62.7	21.6	15.0	60.9	47.6	27.2
4	62.4	14.6	17.1	47.5	9.1	12.9	61.1	35.2	18.3
5	46.2	12.6	11.7	40.7	9.2	10.2	52.9	32.0	15.6
6-7	---	---	---	---	---	---	---	---	---
8	57.2	10.1	14.5	55.3	7.7	11.1	55.7	23.9	12.5
9	60.7	17.9	22.0	79.3	17.4	11.2	58.7	30.6	13.4
Ave.	56.0	12.8	11.9	54.9	11.5	10.6	55.9	32.9	17.1

Table 4. Light intensity for 1932 in terms of apparent foot candles and percentage of available sunlight for respective days.

Date	Daily average of light intensity in apparent foot candles									Light intensity under various treatments						
	Check			Muslin			Burlap			Available light transmitted by screens (per cent)		Amount of available light on vertical plane (per cent)			Light on vertical plane (per cent) (Vert. pl. readings in open = 100)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(4 ÷ 1)	(7 ÷ 1)	(3 ÷ 1)	(6 ÷ 1)	(9 ÷ 1)	(6 ÷ 3)	(9 ÷ 3)
	Open	In tree	Vert. plane	Thru screen	In tree	Vert. plane	Thru screen	In tree	Vert. plane	muslin	burlap	open	muslin	burlap	muslin	burlap
13	2536	1784	602	428	333	231	225	151	110	16.9	8.9	23.8	9.1	4.3	38.3	18.2
14	4090	3100	658	549	294	265	299	188	107	13.4	7.3	16.1	6.5	2.6	40.3	16.3
15	4141	3182	662	652	248	249	278	150	94	15.7	6.7	16.0	6.0	2.3	37.6	14.2
16	---	---	--	--	--	--	--	--	--	---	--	---	--	--	---	---
17	3554	2522	766	537	225	264	301	141	112	15.1	8.7	21.6	7.4	3.1	34.5	14.6
18	4696	4150	896	636	260	250	346	179	106	13.5	7.4	19.1	5.3	2.3	27.9	11.9
19	4909	3805	618	647	249	251	374	218	91	13.2	7.6	12.6	5.1	1.9	40.6	14.7
20	4413	3715	711	603	240	244	364	188	112	13.7	8.3	16.1	5.6	2.5	34.3	15.8
21	---	---	--	--	--	--	--	--	--	---	--	---	--	--	---	---
22	4924	4120	747	632	159	266	271	149	101	12.8	5.5	15.2	5.4	2.7	35.4	13.6
23	4907	4766	731	660	181	247	346	180	86	13.4	7.0	14.9	5.0	1.8	33.8	11.8
24	4943	4285	699	650	145	303	344	170	101	13.1	7.1	14.1	6.1	2.0	43.3	14.4
25-28	---	---	--	--	--	--	--	--	--	---	--	---	--	--	---	---
29	4548	3955	688	582	135	261	370	111	98	12.8	8.1	15.1	5.7	2.2	37.9	14.3
30	4889	4085	762	637	145	260	382	132	109	13.0	7.8	13.0	5.3	2.2	34.1	14.3
31	3694	2525	653	558	117	221	319	94	113	15.1	8.6	15.1	6.0	3.1	33.9	17.4
June 1	1995	1494	607	379	98	211	223	101	89	19.0	11.2	30.4	10.6	4.5	34.7	14.7
2	728	---	--	--	--	--	--	--	--	---	--	---	---	--	---	---
3	3879	2851	619	461	116	201	257	86	86	11.9	6.6	16.0	5.2	2.2	32.5	12.4
4	3639	2230	636	457	68	176	230	52	81	12.5	6.3	17.5	4.8	2.2	27.7	12.7
5-6	---	---	--	--	--	--	--	--	--	---	--	---	--	--	---	---
7	4045	3486	548	556	119	200	331	78	95	13.7	8.2	13.5	5.0	2.3	36.4	17.4
8	4434	3701	588	589	120	195	347	101	88	13.3	7.8	13.3	4.4	2.0	33.1	14.9
Ave.	3902	3320	677	567	181	239	312	137	99	13.7	7.6	17.3	6.1	2.5	35.2	14.6

It must be remembered, however, that no readings were taken on rainy days. In a similar experiment in 1931 Roberts and Langord (50) covered some trees with a burlap enclosure which they state "had the effect of cutting out the direct rays of the sun, thus creating much the same result as would be true if the weather were continuously cloudy." It can be seen readily by comparing columns 1, 7, and 10 in Table 3, and columns 1, 4 and 7 in Table 4 that shading with either muslin or burlap reduces the light more on a clear day than the difference between a clear and a cloudy day (Compare May 23 and 24, 1931 or May 24 and June 2, 1932. Tables 3 and 4). Furthermore, as the light intensity is reduced by clouds the reduction in intensity under muslin and burlap is increased although not proportionately.

To permit more satisfactory comparison these intensity records were reduced to a percentage basis. These percentages also are presented in Tables 2, 3, and 4. Several interesting facts are brought out:

1. The results show that a considerable reduction in light intensity was caused by wire screen as well as by muslin and burlap. Readings taken on several clear days in 1930 show that wire screen transmitted 60 per cent of available light, muslin 15 per cent and burlap 5.6 per cent. The average for the entire season in 1931 was: wire screen 56.0 per cent, muslin 12.8 per cent and burlap 11.9 per cent. As mentioned above, however, the small difference between muslin and burlap was due to the gradual opening of the burlap mesh due to wind and rains. In 1932, the muslin had been laundered and new burlap installed; the average transmission was: muslin 13.7 per cent, and burlap, 7.6 per cent.

These results with muslin correspond closely to the results of Coblentz et. al. (7) who found that muslin (4.6 oz.) transmitted 13.1 per cent of ultraviolet light and 21.5 per cent of the visible light rays.

2. The percentage of available light under the shades is greater on cloudy than on clear days.

3. The relation between the available light and that transmitted by the screens, and the relation between the light within the tree in the open and that within the trees under the shades show similar trends.

4. Vertical plane readings show a greater difference in intensity under the two shades than readings of direct transmission (Figure 6).

5. Daily variation may be greater in one season than in another (Figure 6). It would seem from these results that in studies of light intensity as related to plant growth, differences in amount of diffused light are not to be overlooked.

Fruit Set

The records on the per cent of blossoms setting fruit are presented in Table 5. As several degrees of light intensity were secured, as shown above, one might expect the same relation to hold with respect to fruit set. The records show, however, that with a reduction of light intensity to almost 50 per cent, as under wire screen, there is no reduction in fruit-set where bees are enclosed for pollination purposes. In fact there was a better set in these trees than in the check tree. The question raised by MacDaniels (39) that stigmas may be injured by excessive work of

Table 5. Fruit set under different light intensities for 1930, 1931, and 1932.

Year	Treatment	Total blossoms counted	Set at end of 2nd.wave of drops (per cent)	Set just before harvest (per cent)
1930	Check	1236	31.0	25.5
"	Wire screen--no bees	1212	10.2	8.0
"	" " --bees enclosed	1644	30.8	25.0
"	" " --bees enclosed*	2172	41.3	33.8
"	Muslin shade--bee pollinated	1006	44.1	38.6
"	" " -hand pollinated	3078	39.8	34.2
"	Burlap shade--bee pollinated	1339	23.2	20.4
"	" " -hand pollinated	5044	23.8	19.7
1931	Check	1917	27.1	20.1
"	Wire screen--no bees	1502	6.1	5.6
"	" " --bees enclosed	2056	35.1	23.6
"	" " --bees enclosed*	1728	39.1	28.5
"	Muslin shade	4091	34.2	21.4
"	Burlap shade	2392	18.0	10.0
1932	Check (1) hand pollinated	1068	48.0	42.5
"	" bee "	3725	46.5	35.2
"	Check (2) hand "	438	24.6	19.4
"	" bee "	2932	35.5	32.9
"	Muslin shade--hand pollinated	1187	26.7	20.3
"	" " --bee pollinated	2137	22.4	15.2
"	Burlap " -hand pollinated	1256	25.9	18.7
"	" " --bee pollinated	3322	19.8	14.2

*Screen removed from this tree at end of petal fall, all other screens removed at end of second wave of drops.

insects is answered in the negative by these results. One of these screened trees gave practically the same set as the check tree in 1930 but this tree had a higher percentage of live blossoms than the check tree.

In 1930 the tree shaded by muslin gave a higher per cent set than the other trees. This may have been due to the fact that this tree had 51 per cent of its blossoms killed by frost before opening while the other trees had only 34 to 40 per cent killed. This killing of blossoms had the effect of blossom thinning, giving a higher per cent set of the blossoms pollinated. This is in line with the results of Sax (52) who reported a much better set of flowers pollinated on thinned trees than on trees not thinned. The tree shaded by burlap, having the same ratio of live blossoms as the check tree, gave a much lower per cent set.

In 1931 there was little or no blossom injury and the trees were uniformly vigorous. The tree shaded with muslin gave a slightly lower set than those enclosed with bees and slightly higher set than the check tree but the differences are not significant. However, the reduction in light intensity, as mentioned above, was in excess of the reduction normally obtained during cloudy weather. The tree shaded with burlap, which gave the greatest reduction in light intensity, set only 10 per cent as compared with 20 per cent set on the check tree.

The results for 1932 do not show such wide differences between the two types of shade but the relation is the same. The orchard had not been cultivated for two seasons and the trees were in a

non-vegetative condition; therefore, these records may not be as representative as those of the previous season. It is possible, that trees in a non-vegetative condition are more easily affected and therefore the shading caused by muslin was sufficient to reduce materially the per cent of blossoms setting, while the difference in intensity between muslin and burlap was not sufficient to reduce the set of fruit much beyond that caused by the muslin.

A comparison between hand- and bee-pollinated blossoms in 1932 shows a difference in favor of hand pollinations in every case except one. This advantage in favor of hand pollination may have been due to the fact that the blossoms were not emasculated and may have been visited by bees also, or it may have been that pollinating the tagged branches several days in succession affected a higher percentage of blossoms.

It seems obvious that there was something wrong with the two branches that were hand pollinated on check tree No. 2. Another single branch included in the data on bee pollination on the same tree gave only 23 per cent set out of 300 blossoms while the total of 2932 blossoms gave 33 per cent set. It should be emphasized, therefore, that in studies of this nature small populations will not always give a true index of the entire tree's performance.

The results on fruit set secured in these experiments are not in accord with those secured by Roberts (49) and Roberts and Langord (50) in similar shading experiments with sour cherries.

The set of fruit where insect pollination was prevented by enclosing the tree in a screened cage was very low. This is in accordance with the findings of other investigators. It is of interest to note that practically all of the blossoms had dropped by the end of the second wave and that there was no material reduction in the per cent set by the so-called June drop wave. The number of fruits falling, in the June drop wave, from the other trees was of some consequence, varying from 3 to 13 per cent.

Bee Activity.

Observations made in 1930 seemed to indicate that bees were just as numerous on the trees under the shade as in the open and the records on fruit set support this view. In 1931 more extensive observations were made and again the bees seemed to be just as numerous under the shades as in the open, in fact during periods of higher wind velocity they seemed more numerous under the shades. To check on the visitation of blossoms by the bees, numerous blossoms were examined with a hand lens each day during the blooming period and in every case where the stigma had become receptive and the condition of the flower indicated that it had been open during at least 24 hours of weather favorable for bee activity, there was an abundance of pollen on the stigma. It was also observed that during days of occasional showers and high humidity the bees would become quite active after each shower before the blossoms had dried sufficiently to cause normal shedding of pollen.

Development of Blossoms

The interval between the erection of the cages and full bloom was not sufficient in 1930 and 1932 to have any influence on the

rate of blossom development. In 1931, however, the cages were erected about four weeks before full bloom. One would not expect any great effect on the rate of development by a reduction of light intensity as rate of development is thought to be influenced mainly by temperature and moisture relations. There was no apparent difference in the rate of development between the tree under muslin shade and the surrounding trees, while the tree under burlap was slower in reaching this stage by almost two days. This retarded development however, may have been due to individual tree differences rather than to shading.

Receptivity of the Pistils

In 1931 and 1932 a number of flowers were emasculated on May 14 and records kept on their receptivity as evidenced by the presence of stigmatic secretion. In 1931 browning and an apparent reduction in amount of stigmatic secretion occurred in five to six days in the open and six to seven days in the shade. In 1932 this occurred in four to five days in the open and five to six days in the shade. This shorter period in 1932 may have been due to the higher temperatures during the first three days of their receptive period. The apparent prolongation of receptivity under the shades was probably due to the protection from strong air currents rather than the difference in light intensity.

Pollen Germination

In 1931 samples of pollen were collected from each of the trees and germinated in 12 per cent sugar solution at room temperature. The pollen from the check tree and those under wire screen gave practically the same per cent germination (78.6, 78.1, 79.5 and 79.6), while that from the trees under muslin and burlap gave 72.1 and 71.5 per cent, respectively. Although the latter two did give a lower percentage of pollen germination it was still sufficient to effect good pollination. A composite sample from a number of surrounding trees gave 81.3 per cent germination. This sample was used in pollinating blossoms that had been emasculated for histological studies. Composite samples taken in 1930 and 1932 showed good germination, although no counts were made.

Abscission of Petals and Fruits

The periods for petal fall and abscission of fruits were apparently delayed to some extent by shading. However, upon examination it was observed that abscission had taken place but due to the absence of strong air currents both petals and fruits remained in place for a longer period after abscission was completed.

Condition of the Foliage

Gourley and Nightingale (26) reported that shading of apple, peach, and plum trees caused an increase in leaf area, reduction in leaf thickness, intensified the green color, the surface became distinctly glabrous and the leaves lost their convex character, becoming distinctly flat. These same conditions were observed in the shaded cherry trees.

Temperature and Humidity

The constant temperature and humidity records for 1930 and 1931 showed that the difference in temperature under the shade and in the open did not vary more than two degrees F. in either direction and the difference in relative humidity was likewise insignificant.

Effect of Defoliation on Fruit Set

The results of defoliation tests are presented in Table 6. These results show that with 60 per cent defoliation there was a reduction in fruit set while with 40 per cent defoliation no such reduction was secured. This would indicate that a cherry tree could function normally during the fruit setting period with but 60 per cent of its leaves. However, such an assumption would be hazardous from only one season's results. Harvey and Murneek (27) found, however, that defoliation with apples had a direct effect on the setting of fruit. The fact that the tree which had 40 per cent of its leaves removed had not reached full size and that the normal set on this tree was less than the normal set on either check tree is sufficient to minimize the importance of these results. However, they are important for the purpose of pointing out the fact that too frequently conclusions have been drawn from results secured with young trees that have not become stable in their ability to set fruit. It is also undesirable to draw any conclusions from the results where 60 per cent of the foliage had been removed. Nevertheless, it is interesting to note that the set at the end of the second wave was practically the same on the defoliated branches as on the normal branches. It is possible to account for this when one considers the fact that by the time the leaf cluster has developed sufficiently to reveal the number of leaves therein fertilization has been effected and the embryo well started; a reduction in nutrients at this time might be slow in making itself manifest because all of the developing fruits would be affected equally at first.

Table 6. Effect of defoliation on fruit set. 1932.

Treatment	Leaves re-moved (per cent)	Blossoms counted	Set at end of 2nd.wave (per cent)	Set just before harvest (per cent)
Check (1) normal	0	3725	46.5	35.2
Check two branches defoliated	60	6646	43.5	28.3
Small tree--West half--normal--hand pollinated	0	714	28.7	21.8
Small tree--West half--normal--bee pollinated	0	4050	21.6	16.7
Small tree--East half--defoliated-hand pollinated	40	1124	25.2	20.5
Small tree--East half--defoliated--bee pollinated	40	7951	22.1	20.0

ANALYSIS OF LEAF SAMPLES

It has been frequently mentioned that an abundant supply of available nutrients is necessary to a good set of fruit. Though nitrogen, because it is within the fruit grower's control, has received most attention in this respect, carbohydrates have been suggested as important (42), (27), (40). The results of the analyses presented in Tables 7, 8, and 9 do not show any great differences, but they bear the same general relation as differences in fruit set (Table 5).

Free reducing substances--The analyses of free reducing substances are not very consistent, although the general trend seems to be that with a reduction in light intensity there is a slight reduction in reducing substances. It is believed that these sub-

Table 7. Analyses of leaf samples taken 6:00 A. M., May 24, 1930. (Carbohydrates in per cent of dextrose, dry weight basis)

Treatment	Free reducing substances (per cent)	Total sugars (per cent)	Dry matter (per cent)
Check	3.4	4.7	25.0
Wire screen--no bees	3.0	3.5	25.7
" " --bees	2.7	3.3	24.0
*" " "	3.4	4.9	26.7
Muslin shade	3.3	3.9	23.0
Burlap shade	1.9	2.6	20.4

*Screen was removed from this tree at end of petal fall.

stances are rather unstable and therefore no great differences could be expected.

Total Sugars--The analyses of total sugars are more consistent. It is shown that with a great reduction in light intensity there is a reduction in total sugars. This is true with but very few exceptions in samples grown under burlap (Table 8). The results of the analyses of leaves grown under muslin are less consistent. However, this inconsistency may account for the fact that the set of fruit on the tree under muslin shade was not materially reduced.

Water soluble and insoluble starches--No figures are presented on starch analyses due to the extreme variation in results and because those results which were considered reliable showed very slight differences in starch content.

Dry matter--The results show that the amount of dry matter produced under shade is lower than that produced in full sunlight

Table 8. Analyses of leaf samples taken in 1931. (Carbohydrates in per cent of dextrose, dry weight basis)

Date of sampling	Treatment	Tree No.	Carbohydrates								Dry matter per cent			
			5:00 A. M.		12:00 Noon		6:00 P. M.		12:00 Mt.		5:00 A. M.	12:00 M.	6:00 P. M.	12:00 Mt.
			Free reducing substances	Total sugars	Free reducing substances	Total sugars	Free reducing substances	Total sugars	Free reducing substances	Total sugars				
May 21	Check	1	5.5	9.8	5.9	9.7	5.9	10.6			25.7	25.4	27.0	
" "	Wire screen-no bees	2	5.7	8.7	5.0	9.0	5.4	10.2			24.7	25.0	26.0	
" "	" " bees	3	4.7	9.4	5.5	9.2	5.6	10.1			22.8	25.9	23.8	
" "	" " "	4*	5.5	8.7	6.0	9.5	6.1	9.4			22.2	25.7	25.6	
" "	Muslin shade	5	5.3	10.0	3.8	8.4	5.8	10.2			23.1	26.9	24.2	
" "	Burlap shade	6	3.6	6.1	3.4	6.1	6.3	8.1			20.6	22.2	22.3	
June 9	Check	1	4.2	6.8	4.3	7.0	4.4	7.8	4.2	7.0	27.1	29.1	29.9	28.1
" "	Wire screen-no bees	2	4.2	6.8	4.7	6.9	3.9	7.2	4.3	7.1	26.4	29.5	27.5	26.2
" "	" " bees	3	5.2	7.8	4.9	7.5	4.9	7.4	5.0	7.6	24.8	27.9	27.5	25.3
" "	" " "	4*	4.0	6.8	4.1	6.2	4.2	6.7	3.9	6.9	26.6	29.0	29.3	27.9
" "	Muslin shade	5	4.4	7.8	4.2	6.7	4.5	7.5	4.5	6.9	24.1	25.4	25.5	22.9
" "	Burlap shade	6	4.7	6.8	4.1	6.5	4.7	7.2	4.7	6.7	22.0	22.4	21.8	20.9
July 7*	Check	1	2.3	3.8	2.3	4.6	2.6	5.1	2.3	4.7	32.1	34.5	33.0	32.5
" "	Wire screen-no bees	2	1.8	3.8	2.2	4.4	1.9	4.3	2.0	4.4	33.4	37.2	37.9	35.0
" "	" " bees	3	1.7	3.1	2.0	4.2	1.9	5.6	2.1	4.1	31.8	34.4	35.2	32.5
" "	" " "	4	2.1	3.6	2.3	4.4	2.3	4.6	2.3	5.3	32.1	34.8	35.2	32.7
" "	Muslin shade	5	1.6	3.4	1.9	4.0	1.7	4.0	1.8	4.1	32.1	35.7	35.1	30.6
" "	Burlap shade	6	1.4	2.7	1.7	3.7	1.7	3.8	1.9	3.6	32.7	36.1	35.2	33.6

*Cage was removed from Tree No. 4 at end of petal fall and from all other trees June 11.

Table 9. Analyses of leaf samples taken June 7, 1932. (Carbohydrates in per cent of dextrose--dry weight basis.)

Treatment	Free reducing substances (per cent) 5:00 A.M.	6:00 P.M.	Total sugars (per cent) 5:00 A.M.	6:00 P.M.	Dry matter (per cent) 5:00 A.M.	6:00 P.M.
Check	4.1	4.1	7.5	8.1	28.8	31.5
Check	5.0	4.8	8.4	9.8	25.6	33.8
Muslin shade	4.8	4.6	6.7	7.9	25.6	28.1
Burlap shade	2.4	2.8	4.9	5.5	22.2	24.9

with one exception, i. e., the lot of samples taken under muslin May 21, 1931. (Table 8.) It should be mentioned, however, that at this time the leaves were only 1/2 to 2/3 full size and in a state of rapid growth. It is also shown in Table 8 that after the shades had been removed for almost one month these differences in dry matter no longer existed.

HISTOLOGICAL STUDIES

So far as could be determined from stained sections a reduction in light intensity had no effect on pollen germination, rate of pollen tube growth, time of fertilization, or rate of embryo development. Within nine hours after pollination, germination had taken place in 1932 and the pollen tubes had grown well into the stigmatic tissue. The temperature at the time of pollination was above 60°F. and did not drop below that point within the next 48 hours. In 1931, the temperature at the time of pollination was just 60°F. and remained above that point for a period of only 10 hours, yet sections showed that pollen tubes had advanced farther in 12 hours

after pollination than they did in a 9-hour period the following season. (Plate I, A and B). There was a higher mean temperature by about 10°F. during the 12-hour period immediately following pollination in 1932 than in 1931 (See Table I.) Experiments conducted by Goff (24), under laboratory conditions, indicate that pollen germination is not likely to be much retarded until the temperature falls below 51°F., while these observations seem to indicate that with temperatures ranging between 60° and 80°F. there is little difference in rate of pollen germination and pollen tube growth under field conditions.

With the exception of the first sample of each season all samples were collected at uniform time intervals after pollination. Comparison of the samples that showed the most advanced stage of development, revealed a striking uniformity between seasons and between treatments. Pollen tube growth is apparently rather rapid in the sour cherry under normal conditions. Within 24 hours after pollination the pollen tubes had passed beyond the base of the style and in some instances were found in the ovarian cavity (Plate I). Material collected 48 hours after pollination showed that the pollen tubes had entered the embryo sac but there was no evidence that fertilization had taken place. However, the considerable elongation of the embryo sac and the extensive development of free nuclear endosperm at 72 hours would indicate: (1) that fertilization had taken place soon after the pollen tube had entered the embryo sac and (2) that endosperm development is more rapid than embryo development as there was no evidence that cell division had taken place within the egg. The embryo had reached the eight-celled stage in most instances in four days and showed fairly rapid development after that. Although endosperm development was rapid, the free nuclear condition seemed to persist for some time. There were only slight indications, in a few specimens, of cellular endosperm in the samples collected 10 days after pollination. As mentioned above, there was a striking uniformity between treatments and between seasons and therefore this discussion on the rate of development, which is illustrated in Plates I, II and III, is representative of the conditions under any treatment for either 1931 or 1932.

A number of pollen tubes had developed pronounced swellings on the ends. This swelling occurred in some instances very soon after germination and in others after the tube had grown a considerable distance down the style. This type of growth has been observed also by Osterwalder (44) and Cooper (8). Osterwalder states that it is more common in self sterile varieties that have been self pollinated but it has been observed also in varieties that have been crossed. He believes that in the latter case when some pollen tubes reach the micropyle stimulatory action on the tubes still in the style ceases.

Variation between specimens collected from the same tree, and also slight variation between seasons, became more evident as the season advanced. This variation was noticeable in the size of the fruits but was more pronounced in the size of the developing embryos (See Figs. A and B Plate III, 15 days after pollination). It has been observed that fruits which have been fertilized develop fairly uniformly and that those fruits which drop undergo a rapid retardation in rate of development until growth finally ceases (13). It has also been observed that fruits which have been pollinated, even though fertilization has not taken place, undergo various degrees of development. Not all of these fruits have functional ovules at the time of pollination and therefore this development may be due to a stimulus caused by pollen tube growth. Pollen tubes were found in the ovarian cavities, 24 and 48 hours after pollination, where the ovules had obviously aborted after they had undergone complete development and before pollination was effected. Abortion of the embryo after fertilization may take place at any stage of development. It is first evident by a slight separation of the cells due either to a slight plasmolysis from a withdrawal of nutrients or a slight enlargement of the cell walls after normal development ceases. At first all of the cell contents are distinguishable but later there is a complete breakdown (Fig. C Plate IV).

Rate of Shedding of Aborted Fruits.

It has been observed with apples, peaches and plums (12), that the same variety sheds its aborted fruits in a similar manner in different seasons. The same relationship holds true with sour cherry (Figure 7) even though the first drop may not begin within the same number of days after either first or full bloom each season. In 1930, 1931 and 1932 the first drop began 12, 22, and 17 days, respectively, after the first bloom and 8, 13, and 11 days, respectively, after full bloom. It is interesting to note how closely the two waves coincide and that there was an interval of five days between the first and second waves. The apparent double peak of the second wave for 1930 was probably caused by a heavy rainfall May 19 causing dropping of fruits which would otherwise have shed on the next day, together with low temperature which retarded the rate of abscission, giving a much lower number of drops on May 20. Although no counts were made of the June drop wave, its significance can be noted by comparing the set of fruit at the end of the second wave with the set just before harvest (Table 5.) The rate of shedding on the shaded trees closely coincided with that of the check tree.

DISCUSSION

The observations recorded above indicate that adverse weather conditions during the blooming period may reduce the set of fruit: (1) by preventing pollination by bees during rainy weather even though the temperatures are sufficiently high to permit normal development of the pistils and (2) by preventing the normal shedding of pollen during periods of high humidity when the bees may be fairly active. It is obvious that with temperatures sufficiently low to prevent bee activity there is also a retardation in rate of development of the blossoms. Abortion within the embryo sac before the time of full bloom, as recorded by Miss Bradbury (4) and Dorsey (14), was observed in these studies. It has not been determined whether this early abortion is due to (1) adverse weather conditions, (2) insufficient nutrient supply, or (3) the genetic constitution of the plant.

It appears from the results reported here that cloudy weather alone does not reduce the normal set of fruit by affecting nutrition. The results show that, though shading with muslin reduced the light intensity to a point lower than that normally received during cloudy weather, there was little or no reduction in fruit set even though this shading did affect the total sugars, dry matter and character of the foliage. The contention of Roberts and Langord (50) that faulty nutrition induced by cloudiness is responsible for poor set of cherries during cloudy weather is not supported by these results. The evidence clearly indicates that any such shading as is incident to the usual pollination studies in screen, muslin, or other cages, paper bags, etc., does not disturb normal fruit setting processes in the Montmorency cherry and results obtained under such experimental condtions are strictly applicable to field conditions. Furthermore, whatever the other functions of pruning may be in the sour cherry tree, it is not required from the standpoint of admitting more light to blossoms and their associated leaves to promote better fruit setting. Since light or cloudiness at blossoming does not appear to be a limiting factor in the setting of the sour cherry, one of the most important limiting factors with normal trees is the actual transfer of pollen from stamen to stigma--and this factor is largely under the grower's control through the use of bees.

Although there was little or no reduction in fruit set under muslin shade there was considerable reduction in fruit set under burlap shade. It appears from the studies on the rate of embryo development that a high percentage of abortion takes place within two weeks after pollination. Chemical analyses show that one week after full bloom there was considerable reduction in total sugars in the trees shaded by burlap. Since lack of proper nutrition is undoubtedly the direct cause of embryo abortion it appears that the reduction in set of fruit under burlap shade was not caused by a retarded rate of development but rather by an increase in the percentage of embryo abortion.

Severe defoliation did reduce the set of fruit but this was not made manifest in either the first or second wave of drops, although there was an appreciable retardation in the rate of development of the fruits until the heavy June drop from the defoliated branches.

Both defoliation and reduction in light intensity reduce the supply of carbohydrates. However, this does not prove carbohydrates to be a controlling factor in fruit setting, since both manipulations obviously affect the supply of elaborated nitrogen as well as of carbohydrates.

SUMMARY

1. Shading by either muslin or burlap reduced the light intensity in excess of the reduction normally effected by cloudy weather.
2. Cherry trees withstand a considerable reduction in light intensity without materially reducing the set of fruit; therefore, cloudy weather alone is not responsible for a poor set when adequate pollination has been effected.
3. Under normal conditions the reduction in light intensity in the center of the tree is not sufficient to be the direct cause of a reduction in fruit set.
4. Shading caused by covering a tree with wire screen or muslin during the blooming period was not sufficient to affect the set of fruit.
5. The reductions in light intensity effected in this work suffic-

ient to decrease the production of total sugars and dry matter and affect the character of the foliage did not affect the set of fruit.

6. The effect of light intensity reduction on time of blossoming, pistil receptivity, bee activity, temperature and humidity, petal fall, and abscission of fruits was insignificant.

7. Reduction of light intensity did not affect pollen germination, rate of pollen tube growth, or rate of embryo development.

8. Very heavy reduction of light intensity indirectly affected the set of fruit by reducing photosynthesis, thus causing a higher per cent of embryo abortion. Therefore, adverse conditions during the first two weeks after pollination resulting in a deficiency of nutrients in general appear to be responsible for the majority of aborting embryos.

9. Severe defoliation caused a material reduction in fruit set.

10. Endosperm development was more rapid at first than embryo development.

11. Increase in diameter of the fruit was correspondingly more rapid than embryo development until the seed reached normal size.

12. Cold weather retarded the development of stigmatic secretion after the blossoms opened but there is no available experimental evidence to show that development of the ovule can be retarded to the same degree and still remain functional.

13. Wind is of little importance in affecting pollination in the center of large blocks of trees. On the other hand, strong winds may prevent complete pollination by interfering with bee activity.

14. Pistils are not injured by repeated visits of bees.

ACKNOWLEDGEMENT

Grateful acknowledgement is made of the assistance rendered by others in the initiation and pursuit of this study, particularly to V. R. Gardner for making available the facilities of the Michigan Agricultural Experiment Station and for a helpful interest throughout; to R. E. Marshall for helpful suggestions all along the way; to J. W. Crist for pertinent suggestions on laboratory techniques; to F. C. Bradford for timely suggestions in histological studies; to W. C. Dutton for help with photographic work and to C. E. Hoxsie and L. R. Farish for assistance in collecting samples.

LITERATURE CITED

1. Alderman, W. H. Experimental work on self-sterility of the apple. Proc. Amer. Soc. Hort. Sci. 14:94-101. 1917.
2. Auchter, E. C. Importance of pollination. Proc. Peninsular Hort. Soc. 1924.
3. Bradbury, D. Notes on the dropping of immature sour cherry fruits. Proc. Amer. Soc. Hort. Sci. 22:105-110. 1925.
4. Bradbury, D. A comparative study of the developing and aborting fruits of Prunus cerasus. Amer. Journ. Bot. 16: 525-542. 1929.
5. Chandler, W. H. Fruit growing. Boston, 1925.
6. Chittenden, F. C. Sterility in fruits: a summary of twenty years of study at the Royal Horticultural Society's Gardens. Mem. Hort. Soc. N. Y. 3:79-85. 1927.
7. Coblentz, W. W., Stair, R., and Schoffstall, C. W. Some

measurements of the transmission of ultra-violet radiation through various kinds of fabrics. Bureau of Standards, J. Res. (U. S. Dept. Comm.) 1: 105-124. 1928.

8. Cooper, J. R. The behavior of pollen tubes in self and cross pollination. Proc. Am. Soc. Hort. Sci. 25:138-140. 1928.

9. Crane, M. B. Report on tests of self-sterility and cross-incompatibility in plums, cherries and apples at the John Innes Hort. Inst. II. Jour. Pom. and Hort. Sci. 3: 67-84. 1923.

10. Crane, M. B. Studies in relation to sterility in plums, cherries, apples and raspberries. Mem. Hort. Soc. N. Y. 3:119-134. 1927.

11. Detjen, L. R. Physiological dropping of fruits. Del. Agr. Exp. Sta. Tech. Bul. 6. 1926.

12. Detjen, L. R. and Gray, G. F. Physiological dropping of fruits. Del. Agr. Exp. Sta. Tech. Bul. 9. 1928.

13. Detjen, L. R. and Gray, G. F. Annual report. Del. Agr. Exp. Sta. Bul. 162. p. 47. 1929.

14. Dorsey, M. J. A study of sterility in the plum. Genetics 4: 417-486. 1919.

15. Dorsey, M. J. Relation of weather to fruitfulness in the plum. Jour. Agr. Res. 17: 103-126. 1919.

16. Dorsey, M. J. The relation between embryo sac development and the set of fruit in the apple. Proc. Am. Soc. Hort. Sci. 26: 56-61. 1929.

17. Duruz, W. P. Sterility of sweet cherries. Ann. Rept. Cal. Agr. Exp. Sta. pp. 208-9. 1923.

18. East, E. M. and Mangelsdorf, A. J. A new interpretation of the hereditary behavior of self-sterile plants. Proc. Nat. Acad. Sci. 11:166-171. 1925.

19. East, E. M., and Mangelsdorf, A. J. Studies on self sterility. VII--Heredity and selective pollen tube growth. Genetics 11:466-481. 1926.

20. East, E. M. and Park, J. B. Studies on self-sterility. I--The behavior of self sterile plants. Genetics 2:505-609. 1917.

21. East, E. M. and Park, J. B. Studies on self sterility. II--Pollen tube growth. Genetics 3: 353-366. 1918.

22. Einset, Olav. Experiments in cherry pollination. N. Y. (Geneva) Agr. Exp. Sta. Bul. 617. 1932.

23. Gardner, V. R. The cherry and its culture. New York. 1930.

24. Goff, E. S. A study of certain conditions affecting the setting of fruits. Wis. Agr. Exp. Sta. 18th Ann. Rpt. 1900: 289-303. Fig. 61-80. 1901.

25. Gourley, J. H. The effect of shading some horticultural plants. Proc. Am. Soc. Hort. Sci. 17:256-260. 1920.

26. Gourley, J. H. ~~and~~ Nightingale, G. T. The effects of shading some horticultural plants. N. H. Tech. Bul. 18. 1921.

27. Harvey, E. M. and Murneek, A. E. The relation of carbohydrates and nitrogen to the behavior of apple spurs. Ore. Agr. Exp. Sta. Bul. 176. 1921.

28. Hedrick, U. P. et al. The cherries of New York. 1915.

29. Howlett, F. S. Nitrogen and carbohydrate composition of the developing flowers and young fruits of the apple. Proc. Amer. Soc. Hort. Sci. 20:31-37. 1923.

30. Howlett, F. S. Apple pollination studies in Ohio. Ohio. Agr. Exp. Sta. Bul. 404. 1927.

31. Knowlton, H. E. and Sevy, H. P. The relation of temperature to pollen tube growth in vitro. Proc. Am. Soc. Hort. Sci. 22:110-115. 1925.

32. Kosemanoff, S. Zur Kenntniss der Aufbewahrung des Pollens der Süss-und Sauerkirschen (Vorl. Mitt) Arb. d.Mleew. Gartenbau-Versuchs. Stat. Mleew. Sekt. f. Obstbau. Nr. 14. 1929. 77-81. (Russian with German summary) Abs. in Bot. Centrbl. 160:334. 1931.

33. Kraus, E. J. The self-sterility problem. Jour. Heredity. 6:549-557. 1915.

34. Kraus, E. J. and Kraybill, H. R. Vegetation and reproduction with special reference to the tomato. Ore. Agr. Exp. Sta. Bul. 149. 1918.

35. Kraybill, H. R. Effect of shading and ringing upon the chemical composition of apple and peach trees. N. H. Agr. Exp. Sta. Tech. Bul. 23. 1923.

36. Lamberg, G. Uber die Blutenbildung von Sempervivum, Flora, N. F. B. 11/12 (111/112) Festschrift Stahl p. 128-151. 1918.

37. Leeds & Northrup Co. Philadelphia. The Macbeth Illuminometer. Bul. 680. 1928.

38. Lewis, C. I. and Vincent, C. C. Pollination of the apple. Ore. Agr. Exp. Sta. Bul. 104. 1909.

39. MacDaniels, L. H. An evaluation of certain methods used in the study of the pollination requirements of orchard fruits. Mem. Hort. Soc. N. Y. 3:139-150. 1927.

40. MacDaniels, L. H. and Heinicke, A. J. Pollination and other factors affecting the set of fruit, with special reference to the apple. Cornell Univ. Agr. Exp. Sta. Bul. 188. 1929.

41. Marshall, R. E. et al. The pollination of orchard fruits in Michigan. Mich. Agr. Exp. Sta. Spec. Bul. 188. 1929.

42. Müller-Thurgau, H. Abhängigkeit der Ausbildung der Traubenbeeren und einiger anderer Früchte von der Entwicklung der Samen. Landw. Jahrb. Schweitz.12: 135-205. 1897.

43. Murneek, A. E. Fruit pollination. Mo. Agr. Exp. Sta. Bul. 283. 1930.

44. Osterwalder, A. Blütenbiologie, Embryologie und Entwicklung der Frucht unserer Kernobstbäume. Landw. Jahrb. 39:917-998, 1910.

45. Petri, L., Cited from Chandler, W. H. (5), Studi sulle malattie dell' olivo-v. Ricerche sulla biologia e patologia fiorale dell' olivo. Mem. R. Staz. Patol. Veg. Roma. (1914), 5-64. 1914.

46. Philp, G. L. and Vansell, G. H. Pollination of deciduous fruits by bees. Cal. Agr. Exp. Sta. Ext. Cir. 62. 1932.

47. Quisumbing, F. A. and Thomas, A. W. Conditions affecting the quantitative determination of reducing sugars by Fehling solution. Elimination of certain errors involved in current methods. J. Am. Chem. Soc. 43:1503-26. 1921.

48. Reinecke, O. S. H. Field and laboratory studies of the pollination requirements of varieties of deciduous fruit trees grown in South Africa. Univ. of Stellenbosch, South Africa. Sci. Bul. No. 9. 1930.

49. Roberts, R. H. Sour cherry fruiting. Wis. Agr. Exp. Sta. Bul. 415. 1930.

50. Roberts, R. H. and Langord, L. Faulty nutrition responsible for poor set of cherries during cloudy weather. Ann. Rpt. Wis. Agr. Exp. Sta. Bul. 421. pp. 73-74. 1932.

51. Sandsten, E. P. Some conditions which influence the germination and fertility of pollen. Wis. Agr. Exp. Sta. Res. Bul. 4, pp. 149-172, 5 fig. 1909.

52. Sax, K. Studies in orchard management. II. Factors influencing fruit development in the apple. Maine Agr. Exp. Sta. Bul. 298. 1921.

53. Schuster, C. E. Pollination and growing of the cherry. Ore. Agr. Exp. Sta. Bul. 212. 1925.

54. Shirley, H. L. Light sources and light measurements. Plant Physiology 6:447-66. 1931.

55. Shoemaker, J. S. Cherry pollination studies. Ohio. Agr. Exp. Sta. Bul. 422. 1928.

56. Tufts, W. P. and Philp, G. L. Pollination of the sweet cherry. Cal. Agr. Exp. Sta. Bul. 385. 1925.

57. Waugh, F. A. Problems in plum pollination. Vt. Agr. Exp. Sta. Rpt. 10:87-98. 1897. Rpt. 11:238-62. 1898. Rept. 12:189-209. 1899.

A B

Fig. 1. (A) Tree enclosed with wire screen to exclude bees.
(B) Check tree with screens underneath to catch the daily drops.

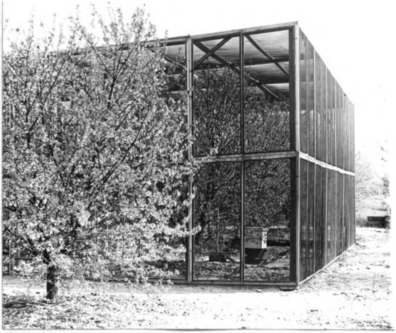

Fig. 2. Large wire screen cage over two trees with colony of bees for pollination.

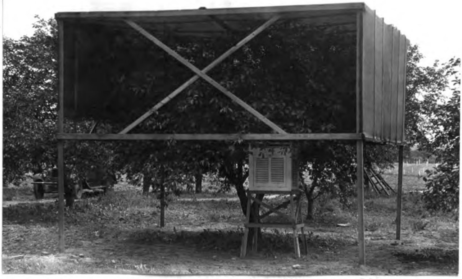

Fig. 3. Burlap shade (1930) with instrument shelter for hygrothermograph. The north side of the frame was not covered.

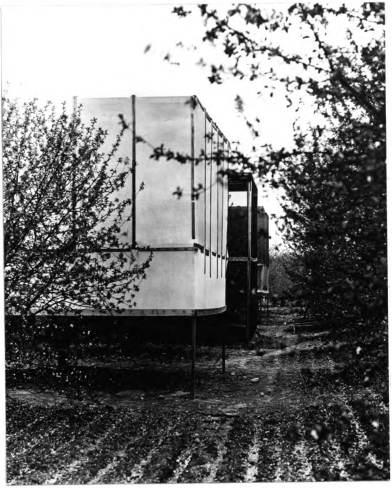

Fig. 4. Part of the set up in 1931 showing muslin shade, in the foreground, wire screen (with bees), and burlap shade. In the adjacent row is also shown part of the screen under the check tree.

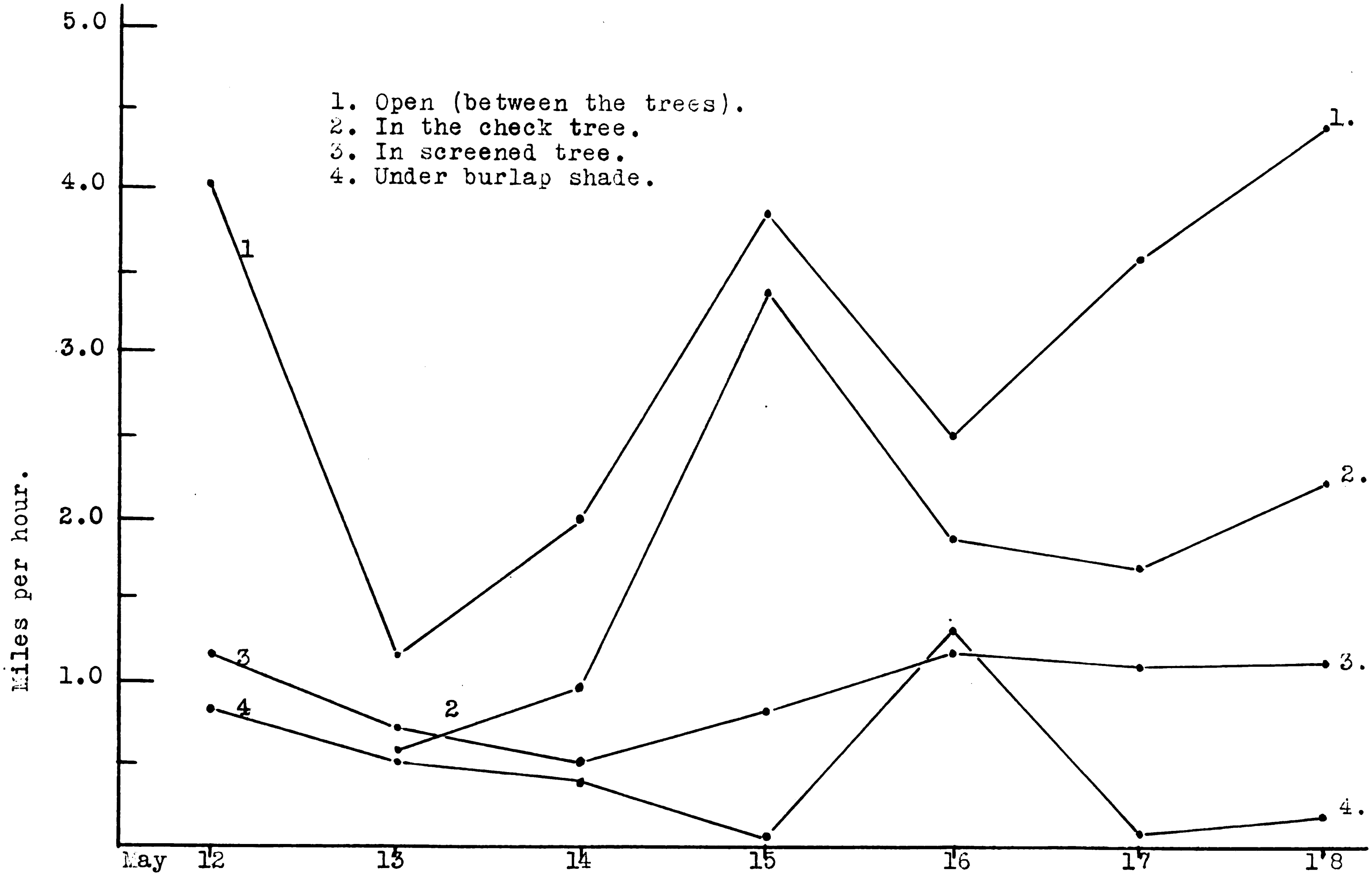

Fig. 5. Wind velocities under the several cages and in the open.

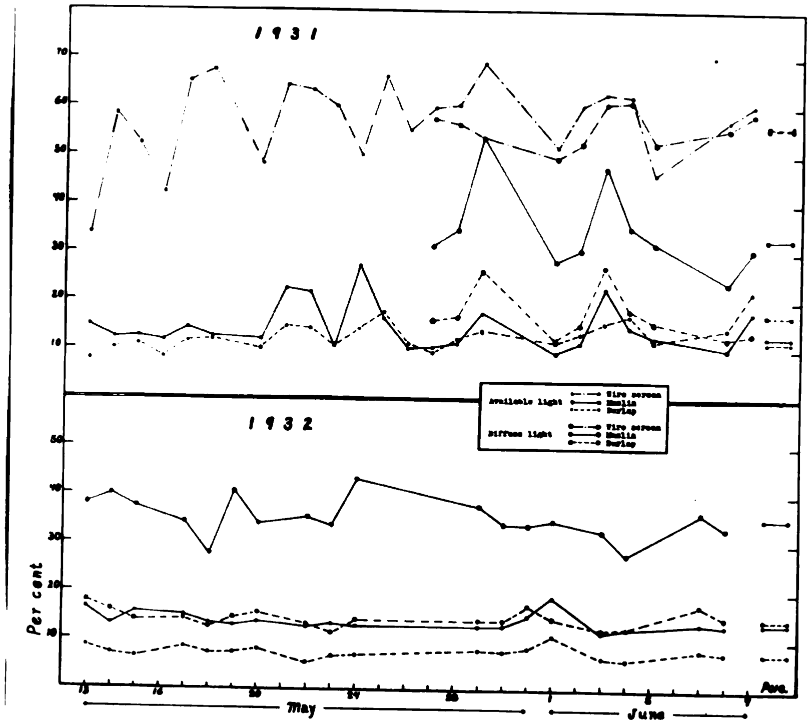

Fig. 6. Graph showing the amount of available light transmitted by the different screens and amount of diffuse light or light on vertical plane under screens as compared with the same in the open.

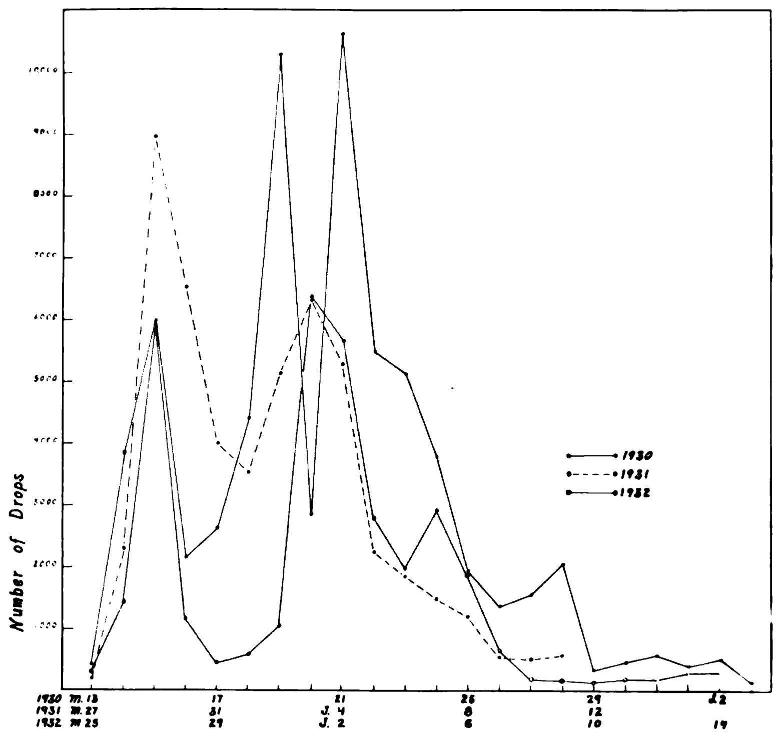

Fig. 7. Graph showing the daily drop of fruits for the first two waves of drops from the check tree for the years 1930, 1931, and 1932.

Legends for Plates

Plate I. Pollen tubes in stylar tissue at various periods after pollination: A, 9 hrs.; B, 12 hrs.; C, 24 hrs. (just above ovarian cavity); D, 24 hrs. (in ovarian cavity); E, 48 hrs. (in embryo sac); F, 3 days (endosperm, but not embryo, developing.) x 140.

Plate II. Embryo development four (A), eight (B), and ten (C,D) days after pollination. x 140.

Plate III. Embryo development: A, B, 15 days after pollination, showing increasing variation in size; C, normal embryo 21 days after pollination; D, aborted embryo 10 days after pollination. x 140.

Plate IV. Normal fruit (A) and aborting fruit (D) 8 days after pollination (x 13). B. Wrinkled integument and slow embryo development 10 days after pollination. C. Wrinkled integument and aborted embryo 21 days after pollination (x 140). Compare with 10 and 15 day normal embryos.

Plate I.

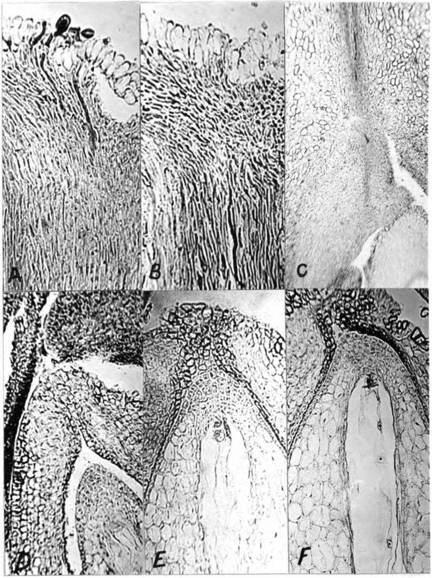

Plate II.

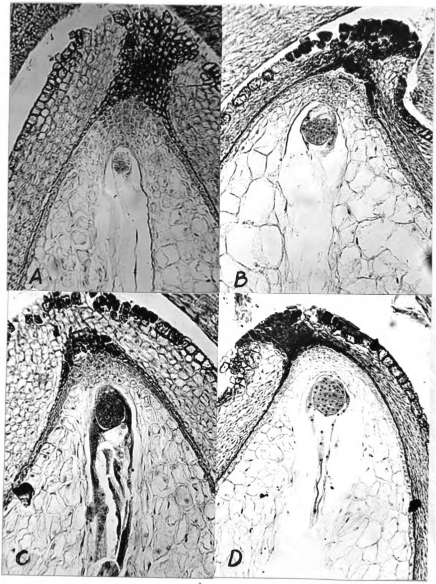

Plate III.

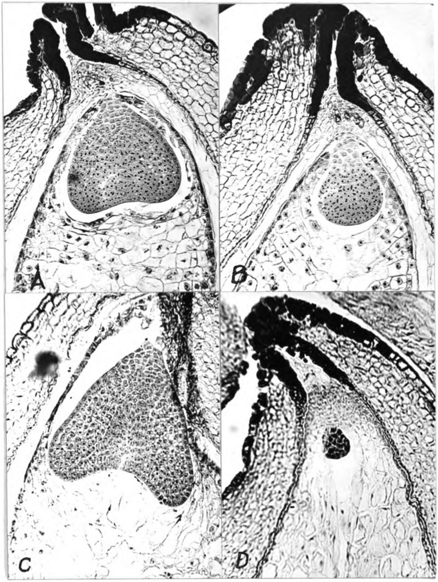

Plate IV.