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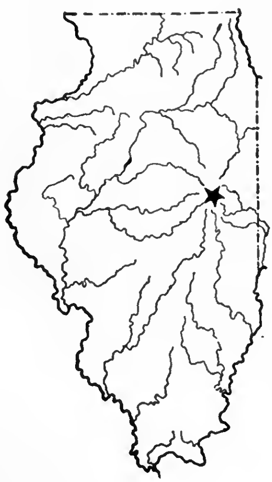
BULLETIN NO. 98.

THE CURCULIO AND THE APPLE.

By CHARLES S. CRANDALL.



URBANA, FEBRUARY, 1905.

Summary of Bulletin No. 98.

1. The investigations reported in this bulletin were undertaken because of serious and widespread injury to the apple crop by curculios. Page 468

2. The larvæ of the plum curculio develop in very small apples, and the fall of the fruit is necessary to their development. The time from oviposition to the emergence of the larvæ from the fruit varies from sixteen to thirty-nine days, the average in 1903 being twenty-six days, and in 1904 twenty days. Page 475

3. The mortality of plum curculio larvæ in the fruit is due to crushing by growth of the fruit tissue, and to the action of the sun. Page 479

4. The depth of pupation of the plum curculio varies from one-fourth inch to three and one-half inches; 93.69 percent of the 824 pupæ recorded were at depths of two inches or less. Page 480

5. The time the plum curculio spends in the ground ranges from nineteen to forty-eight days, the average being twenty-eight days. In 1904, 87 percent were in the ground between July 10th and August 8th, and 97 percent between July 10th and September 1st. Page 487

6. The first plum curculio beetle emerged from the ground July 17th, and the last on November 7th, a period of one hundred and fourteen days. The newly emerged beetles feed freely upon the fruit and do great damage. Page 490

7. The beetles of the plum curculio hibernate, and appear the next spring early in May. No evidence was found of their feeding upon leaves or buds in the orchard. Page 495

8. Oviposition of the plum curculio begins while the apples are very small, and may continue until September. The largest number of eggs laid by one individual was 263, and the longest period during which one individual laid eggs was one hundred and five days. Page 498

9. The habits and life history of the apple curculio differ from those of the plum curculio. Page 515

10. The period of oviposition of the apple curculio is about sixty days. The number of eggs laid by twenty females varied from four to one hundred and twenty-two for each individual. Page 521

11. The larvæ of the apple curculio change to pupæ within the fruit, and the adult beetles emerge directly therefrom. Page 515

12. The plum curculio and apple curculio each have certain characteristics whereby they can be readily distinguished. Page 528

13. Various means of controlling curculios have been tried. Page 530

14. Experiments at Barry in 1903 showed practically no gain from spraying. The results were affected by weather, location, and abundance of insects. Page 533

15. Spraying experiments in 1904 resulted in a range of benefit from 14.14 percent to 60.96 percent. Four or five applications will probably control from twenty to forty percent of the possible injury. Page 541

16. Cultivation of the ground aids greatly in the repression of curculios. Page 553

17. Conclusions. Page 556

THE CURCULIO AND THE APPLE.

By CHARLES S. CRANDALL, Assistant Chief in Pomology.

INTRODUCTION.

In all sections of the State of Illinois where orchard fruits are grown may be found fruits that are more or less defaced by deformities, by curiously made surface cuts, and by small cylindrical excavations. These marks are found upon plums, peaches, apples, and less commonly upon pears and quinces. The same marks are common on fruits of the wild plum, wild crabapple, and of the red-fruited hawthorn so common in native woodland. The marks referred to are made by two species of curculio, and from reports received by the Horticultural Department of the Experiment Station, and also from observations made by representatives of the Station, it appears that during the last two or three years there has been a decided increase in the amount of injury resulting from the attacks of these insects.

The amount of injury done to the apple crop is not the same every year, nor is the damage equally distributed over the state. In some counties the fruit is comparatively free from injury, while in others the damage practically amounts to the loss of the whole crop.

From personal inspection of orchards, it appears that no section is entirely free from attack, but there are certain factors of location and of orchard treatment that in great measure account for differences in the amount of injury inflicted in different sections. Orchards in close proximity to bodies of timber suffer more than do those remote from wooded parts, and orchards where clean cultivation is practiced are remarkably free from injury when compared with orchards in which grass and weeds grow undisturbed.

The injuries to apples which are to be considered in this bulletin are not new. The same trouble has been complained of for many years; but there have been periods when, from natural causes, the work of the insects has been minimized, and now that this period of comparative immunity has been followed by an ascending movement towards maximum injury, the difficulty is brought to the notice of many fruit-growers for the first time, and to them it is new and strange. As far back as 1860, serious injury to plums and peaches was reported from southern counties, and in 1867 and 1868 not only the plums, peaches, and apples of the southern counties, but the apples of northern counties, were seriously injured.

The insects reponsible for the injuries above referred to are:

The Plum Curculio—*Conotrachelus nenuphar*, Herbst.

The Apple Curculio—*Anthonomus quadrigibbus*, Say.

There is a third species—the Plum Gouger, Anthonomus prunicida—which, though in the main confining its work to the plum, has been reported as attacking the apple; but, as in our work with the apple in the past two seasons not a single specimen of the gouger was found, nothing further need be said of this species.

The two species of curculio to be considered differ in appearance, in habits, and in development, and there is a corresponding difference in the character of the injury they inflict. Both are natives that have lived on and bred in native food plants for unknown generations. The apple curculio once lived exclusively upon fruits of the wild cra-bapple and the hawthorn. With the introduction of cultivated fruits of congeneric species, it took kindly to them, and is now as much at home on our best orchard apples as on the less inviting wild crab. The plum curculio, supposed to have been originally confined to the native wild plums as food plants, has evidently developed new tastes, for it feeds on and breeds in both wild crab and hawthorn as well as in wild plum.

Among cultivated fruits, while it is generally understood that the plum curculio belongs to and prefers the plum, it has a well-developed taste for peaches and cherries, seems perfectly satisfied with the apple, and will under necessity accept pears and quinces.

Our present consideration of the insects relates to the apple only. Both species feed upon and breed in it, and they both do it injury. In general, it is the plum curculio that does the greater amount of damage, but from some of the southern counties it is reported that the apple curculio is the more destructive of the two.

WHY AN INVESTIGATION OF CURCULIO WAS UNDERTAKEN.

In October, 1902, Messrs. Albert Blair and John R. Williams, proprietors of extensive orchards near Barry, in Pike County, appealed to the Station authorities for assistance in determining the cause of, and in finding a remedy for, very destructive work done in their orchards. Their crop in 1902 was practically ruined, and previous crops had been in some degrees injured. Reports of similar injuries were received also from other fruit-growers of the same section. Specimens of injured apples were shown which fully supported the reports of injury done. The gentlemen mentioned represented over two hundred and sixty acres of orchard, nearly half in full bearing, the rest approaching bearing age. The trouble was not confined to a few orchards, but was general throughout the county. The apple industry of Pike County is a large one; orchards of commercial size are numerous, and the aggregate acreage is extensive. The losses sustained, while not equal in all orchards, were everywhere serious, and would together represent a large sum.

These facts together with the reported losses from the same cause from other and widely separated counties served to show that the problem was of importance to the whole state; therefore it was a problem falling legitimately within the province of the Experiment Station.

After full discussion with the Director of the Station and the Department of Entomology it was decided that the Department of Horticulture should undertake an investigation of the difficulty.

It was perfectly plain from inspection of injured apples that the destructive work was done by curculios, but there was then some doubt as to whether one or more species was responsible, and, if more than one, which did the greater damage. A preliminary examination of the orchards was made in November, 1902, at which time specimens of both plum curculio and apple curculio were found in hibernating quarters. The investigation was commenced in April, 1903, carried through the season, and continued through the season of 1904, along two principal lines. First—Spraying with arsenical poisons. Second—Inquiry into the life histories and habits of the two insects with a view to the possible discovery of vulnerable points which might suggest new lines of attack.

Because of the differences between the two species already alluded to, it will be necessary, or at least advisable, to consider them separately, and precedence must be accorded the plum curculio, not only because it is best known and has been longest known, but because it is usually the more destructive to apples. Both insects are to be considered in their relations to the apple only.

THE PLUM CURCULIO.

HISTORICAL.

The plum curculio was first discovered, named, and given systematic position by Herbst in 1797, but the insect was known as injurious to plums and cherries long before this. The first published account of the habits of the insect appeared in the "Domestic Encyclopædia" published at Philadelphia in 1803, and was written by Dr. James Tilton of Wilmington, Delaware.* This article, in an enumeration of the fruits attacked, includes not only the stone fruits, but the apple, pear, and quince as well. It appears from this that the habit of attacking the apple is an old one and not a development of recent years as some have suggested.

*Harris. Insects Injurious to Vegetation. Page 76.

Through the early years of the nineteenth century agricultural journals made numerous references to the injuries done by the curculio and to the success or failure of the remedies tried. About 1830, a lady in New Jersey started a movement to raise $2,000 by subscription to be offered as a premium for the discovery of an effective means of destroying the curculio. A committee of the Massachusetts Horticultural Society appointed to consider the proposition recommended that $200 be appropriated for the purpose by the society and that subscriptions should be opened to add to the amount. It is not known that any person ever claimed this premium.* March 5, 1842, the Massachusetts Horticultural Society voted to offer a premium of $100 for a successful method of destroying the insect, and an equal amount was added to this sum by subscription.†

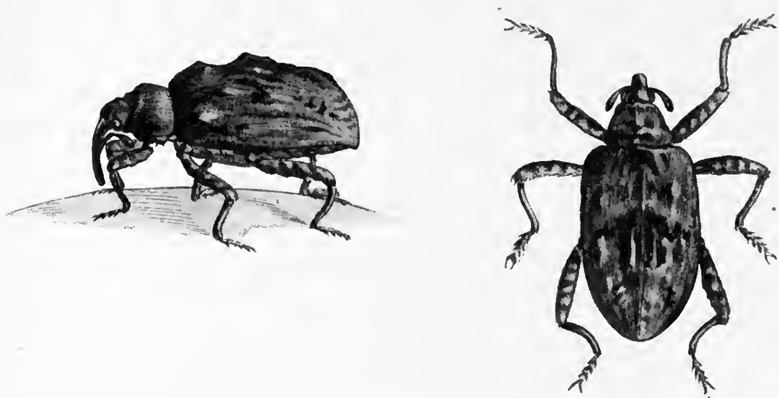


PLATE 1. THE PLUM CURCULIO, ENLARGED.

It appears that, although there were several applicants, this premium was never paid, for the reason that no method presented was thought sufficiently successful. The paper most highly commended was one by Dr. Joel Burnett, giving something of the habits and life history of the curculio and recommending the now well-known jarring process as a remedy. This paper was published in the proceedings of the society for 1843, and also in Hovey's Magazine for the same year.

Kenrick (New American Orchardist, 2d Ed., 1835, page 49), refers to the plum curculio as "the most destructive of all enemies to fruit," and includes the apple and pear in the list of fruits attacked. Of the apricot, nectarine, and plum he says: "The destruction is usually almost total in those parts of the country where this insect abounds," but the apple "usually survives, although disfigured in its form and lessened in its size."

*History Massachusetts Horticultural Society. Page 257.
†History Massachusetts Horticultural Society. Page 256.

The organization of horticultural societies and the establishment of journals devoted especially to horticultural questions kept pace with advances in fruit growing and afforded means of recording experiences and discussing theories regarding curculio. These sources supply many references to the curculio, and when collected and digested, these references exhibit marked uniformity in tone. They refer mainly to losses sustained, or detail the failure or successful application of some remedy. Discussions of treatment are frequent and often bring out statements of results directly opposed to each other, although based upon identical treatment. Some new remedy is heralded as the salvation of fruit-growers one year and is bitterly condemned the next. It does not appear that there was any marked advancement towards perfectly successful control. In some sections, plum culture was abandoned and, in general, fruit men were not encouraged to plant on a commercial scale.

Most of the early testimony concerning the insect has reference to the plum only, or to the stone fruits. Few make serious complaint of injury to the apple, but enough to show that the curculio did work on the apple, though usually not causing such serious loss as to discourage growers.

The natural food plant of the plum curculio is indigenous to the timbered portions of Illinois, and we may fairly assume that the plum curculio was present in the state before the introduction of cultivated fruits. The insect probably attacked stone fruits soon after their cultivation began, but no date can be assigned for the first depredations. The earliest reference to curculio thus far found is by John A. Kennicott, chairman of the committee for Illinois, who reported on the horticultural interests of this state to the "American Pomological Congress," assembled at Syracuse, New York, September 14, 1849. Of the curculio he says: "The plum tree succeeds to admiration on our deep prairie soils and 'sets' enormous crops of fruit. But, alas, the curculio makes sad havoc, and often leaves us scarce a single unmarked specimen. Most of our best soils are light 'sandy loam' and this is the proper home of this 'hump-backed little Turk,' where he winters unharmed and breeds and multiplies to an extent which threatens the ultimate abandonment of this and other beautiful and delicious fruits of its class, unless a more practicable remedy than any now attempted should be discovered."*

All early references to the plum curculio convey the idea that it is an old offender, and there appears to be no doubt that from the beginning of fruit culture in the state the curculio regularly preyed upon all stone fruits and frequently did serious injury to the apple. Mr. D. B. Walsh, one of the editors of the American Entomologist, writes in that journal for 1868 of a trip around the state, and among other things says: "Noth-

*Patent Office Report. Agriculture, 1849. Page 441.

ing in the course of this Southern tour surprised me more than the wholesale manner in which pip-fruit in the South is punctured and ruined by various kinds of snout beetles. In the North it is quite unusual to see an apple bearing the well-known crescent cut of the common curculio, but in the South I estimated that, upon an average, every apple bore three such cuts. When I got to Lacon, which lies but little to the south of Rock Island, the comparative immunity of the apple crop from this grievous pest became apparent at once, but in Madison County, in Jersey County, in Macoupin County, in Union County, in Pulaski County, and in Champaign County, the apples seemed to be almost universally crumpled and gnarled by the punctures of fruit borers."*

Mr. Walsh divides the injury between the two species here considered, and undoubtedly his list of counties where injury was apparent would have been longer had he visited more counties. The published proceedings of the state and local horticultural societies for this period and for a few succeeding years show that the curculio was regarded as a serious pest by all fruit-growers.

GEOGRAPHICAL DISTRIBUTION.

As the plum curculio is native, it may reasonably be supposed that its distribution would nearly coincide with the distribution of its native food plants. The original and natural food plant of the plum curculio is the wild plum, although it frequently feeds upon and oviposits in fruit of the wild crab-apple and the hawthorn. The distribution of the insect is nearly, but possibly not quite so extended as is the distribution of the wild plum. The insect is known from Canada to the Gulf and from the Atlantic west to the one hundredth meridian, and possibly in some places west of this line. It had not appeared in Colorado up to the spring of 1902.† It has not reached the Pacific coast states, and with one exception has not, so far as the writer has been able to ascertain, been reported west of the Continental Divide. This exception is a report in the spring of 1902 of its appearance in the Bitter Root Valley in Montana.‡

*American Entomologist, October, 1868, page 36.
†Gillette. Colorado Station Bulletin 71, page 14. April, 1902.
‡Experiment Station Record 13, page 805.

HABITS AND LIFE HISTORY OF THE PLUM CURCULIO.

In order to combat intelligently any injurious insect, it is essential that the habits and characteristics be known. Every detail of the full life cycle, from deposition of the egg to the maturity and death of the perfect insect, must be inquired into, and special effort given to the correct interpretation of the observed habits of those insect forms or stages directly responsible for the injury done. If there are vulnerable points in the economy of any particular insect, study of habits will reveal them; then, knowing the weak points, means can be devised for attack.

The life cycle of the plum curculio is as follows: At about the time in early spring when vegetation resumes activity and buds begin to push, curculios, which have hibernated under rubbish on the ground, under the rough bark of trees and in other secure hiding-places, emerge from concealment and seek the fruit plants upon which they feed and breed. About the time the trees bloom, mating begins and as soon as the young fruit enlarges the deposition of eggs begins. Apples no larger than small peas often bear from one to three of the characteristic crescent marks made by this curculio. The deposition of eggs goes on most rapidly during the month of June, but continues through July and August, gradually growing less and less as the beetles die. The majority of the beetles of this generation do not live beyond the month of July, but a few may survive until September, or in rare instances until late fall. During the season both males and females feed upon the same fruits in which eggs are deposited, making small, usually cylindrical, punctures. The eggs hatch in from four to six days and the young larvæ start tortuous burrows through the fruit. Development of the larvæ causes the fruit to fall within a few days. In about twenty days the larvæ mature, cease feeding, bore out of the fruit, and at once enter the ground where they complete their transformations and in about twenty-eight days emerge as perfect beetles. The newly emerged beetles usually remain quiet for a day or two, allowing the body wall, beak, and jaws to harden; then they fly into the trees and begin feeding upon the fruit. Beetles of this new generation do not (except possibly in rare cases) pair and no eggs are laid during this first season. The fruit is freely punctured for feeding purposes and the amount of this work increases as the season advances. It is this feeding of the new generation that causes the greatest injury to the fruit crop. Feeding continues as long as fruit remains upon the trees. Late in the fall the beetles leave the trees and hide away in secure places for the long winter period of hibernation. Such in brief is the life history of the plum curculio.

STAGES IN THE DEVELOPMENT OF THE PLUM CURCULIO CONSIDERED IN DETAIL.

Having stated the main points in the life of the insect, we will now take up the various stages for more detailed consideration, embodying such facts as have been gleaned from the writings of others, together with our observations as made during the two seasons 1903 and 1904.

THE EGG.

The egg of the plum curculio may be described as oblong-oval in shape, and from several measurements made, is found to vary between .025 inch and .04 inch in length with a transverse diameter equal to about one-third the length. When fresh laid the egg is shining white, but within a short time becomes dingy and even yellowish. Sometimes the egg cavities are not of sufficient depth to cover the egg fully, and in such cases the portion exposed to light and air assumes a dark brown color and becomes more or less corrugated from loss by evaporation.

Regarding the duration of the egg period, writers on curculio, so far as consulted, give only general statements, which place the time between four and seven or more days. June 13, 1904, the exact time of oviposition was recorded in six cases, and subsequent observations were made to determine the exact time of hatching. Discarding fractions of hours, it was found that one egg hatched in 96 hours or four days, one in 105 hours or four days and nine hours, and four in 108 hours or four and one-half days. This was in the laboratory under inside conditions. Without doubt temperature and other weather conditions influence the time and may cause considerable variation.

FAILURE OF EGGS TO HATCH.

The data at hand are an insufficient basis for a definite statement regarding the proportion of eggs that fail to hatch, but it may be safely stated that the number of failures is considerable. In several instances, where apples containing eggs were placed in vessels for periodic examination, certain of the eggs failed to hatch. These eggs usually remained plump for several days, gradually assumed a yellow color, then began to shrivel, as was indicated by the minutely convoluted condition of the shell, and finally collapsed. No development of embryo could be detected and it is assumed that such eggs were infertile. Some eggs are destroyed, presumably by insects. It is not uncommon to find egg cavities containing shells from which the contents have been eaten. It seems probable also that some at least of the cavities found entirely empty had contained eggs which had been removed entire. In connection with a test of egg-laying capacity, which will be recorded in detail on another page, record was made of the number of mature larvæ obtained from a known number of eggs. Apples, 793 in number, which contained 1,474 eggs, deposited at intervals during a period of about three months, were examined two or three times daily and the larvæ removed as they emerged. The total number of larvæ thus secured was 1,238. It follows that 236 or 16.08% of the eggs failed to produce mature larvæ. It is probable that some of the eggs failed to hatch and equally probable that a considerable number of larvæ died after leaving the egg. Our figures then, have only indirect bearing upon the question of the proportion of eggs hatching, in showing that the loss from oviposition to maturation of larvæ is in this case surprisingly small. But this work was under laboratory conditions where protection was afforded from predatory insects and from adverse weather conditions. It is highly probable that under natural outside conditions a much larger percentage of loss in the egg stage would occur.

THE LARVA.

The larva of the plum curculio is footless, sluggish in movement, white or sometimes yellowish in color, has a distinct light brown head, and when fully developed is, as averaged from measurement of ten individuals, .32 inch in length and .078 inch in thickness. The course taken by the larvæ on emerging from the egg has been traced in a number of apples and is found to be variable. In one apple examined, the bore proceeded straight from an egg cavity near the basin to a point just beneath the skin on the border of the cavity; another bore was traced in a spiral two and one-half times around the fruit; other bores were found to be tortuous, but in no apple examined did the early bore extend to the core. Later, as development proceeds, increased size is accompanied by increased capacity for eating. Apples have frequently been found from which the pulp had been entirely eaten out. Early in the season eggs are frequently found in apples so small that it appears impossible for larvæ to obtain from them sufficient nourishment for development; doubtless some do fail from this cause to reach proper maturity; but actual trial has shown that some very small apples, if kept moist and not exposed to strong light, will bring larvæ to full maturity. By "very small apples" we mean such as are from one-fourth to three-eighths of an inch in transverse diameter and still thickly covered with the white pubescence belonging to young apples.

No case has been found of the full development of a plum curculio larva in fruit remaining upon the trees. It seems to be necessary to larval development that the fruit fall. Sometimes the larvæ complete development before decay of the fruit begins; more frequently development of larvæ and decay go on together. Badly decayed apples have in most cases furnished the largest and most vigorous larvæ, and we have come to regard the rotten pulp as the food most acceptable to larvæ of the plum curculio.

TIME REQUIRED FROM OVIPOSITION TO MATURATION OF LARVA.

The length of time that the insect remains in the fruit, as egg and larva, is of considerable importance, and an effort has been made to determine this period. No attempt was made here to separate the egg stage from the larval stage, but simply to record the time from deposition of the egg to the full maturity of the larva; in other words, the time spent in the fruit. The work was carried on in the laboratory under conditions favorable to rapid development and it is probable that the periods as recorded may be a little shorter than they would have been had the work been done under perfectly natural and generally less favorable conditions.

June 22, 1903, twenty-five plum curculios were placed in a vessel with three apples. These apples were each one and one-quarter inches in diameter and had not been previously punctured. The insects had been in confinement for forty-eight hours without food and were hungry. The apples were attacked voraciously and oviposition began within a short time. In forty-eight hours the apples were removed, placed separately in numbered vessels and left undisturbed. Larvæ emerged as follows:

	July 14.	July 15.	July 18.	July 20.	July 25.	Total.
Apple No. 1	4	2	2	1	0	9
Apple No. 2	3	1	1	0	6	11
Apple No. 3	0	0	2	0	2	4
	7	3	5	1	8	24
Days	22	23	26	28	33	—

The period between oviposition and maturation of larvæ here ranges from 22 to 33 days, provided the eggs were all laid on the first day, but, as some of the eggs were probably laid on the second day, the range may be between 20 and 33 days. The average time is 26 days. It may be noted that the two apples which harbored nine and eleven larvæ respectively were completely eaten out; nothing remained but the skin, the seeds, and the inedible portion of the core. In four additional cases in 1903, the exact time when the eggs were deposited was noted. Two larvæ from these eggs emerged from the fruit in 24 days, one in 25 days, and one in 27 days. The average time for the four is 25 days. During the season of 1904, the period between oviposition and full development of the larvæ was determined under laboratory conditions for 1,238 individuals. The first larva of the season was found, emerged from a fallen fruit, on June 16th. The first larva of our laboratory series emerged June 19th, sixteen days from deposition of the egg, June 3d. At the

TABULATION OF RECORDS ON LENGTH OF PERIOD FROM DEPOSITION OF EGG TO EMERGENCE OF LARVÆ FROM FRUIT.

Number of Larvæ emerged by months. Period	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	Total
June		1	3	8	22	46	77	55	34	6	1	1																				254
July		1	13	30	43	75	115	134	100	50	37	24	11	8	8	9	1		1	1				1								662
Aug.	2		1	4	8	16	18	28	43	26	37	16	23	14	10	9	5	2	4	2	1	1	1		1							272
Sept.								2	2	7	2	4	4	5	4	5	2	5	4					1				1		1	1	50
Totals	2	2	17	42	73	137	210	219	179	89	77	45	38	27	22	23	8	7	9	3	1	1	1	2	1			1		1	1	1238

other extreme, one larva emerged September 29th, thirty-nine days from deposition of the egg, August 21st. It is possible and probable that some larvæ emerged a few days earlier than the one found on June 16th, and also that some may have completed development later than the last we have recorded, but the season covered by definite record is between the dates given and embraces a period of one hundred and six days.

The following tabulation gives the records obtained during the season of 1904 on length of time in the fruit.

The records tabulated are separated by months in order to show distribution through the season and to bring out the fact that more than half of the larvæ came out of the fruit during the month of July. The percentages for each month are as follows:

June	254 or	20.52%
July	662 or	53.47%
August	272 or	21.97%
September	50 or	4.04%
	1238	100.00%

It will be noted that there are a few precocious individuals completing the period in 12 and 13 days; also that there are some laggards spending an unusual time in the fruit, but the great majority in all four months emerged within a comparatively few days. For the month of June, 234, or 92.12% of the larvæ emerging in that month, came out in the five days, 16th to 20th, inclusive. For July, 474, or 71.60% of the larvæ for the month, came out in the five days, 17th to 21st, inclusive. For August, 157, or 57.72%, came out in the five days, 19th to 22d and 24th; and in September, 26, or 52% emerged on the 21st, 23d, 25th, 27th, and 29th. The maximum emergence is, for June, 77 on the 18th day; July, 134 on the 19th day; August, 43 on the 20th day; September, 7 on the 21st day.

Considering the totals for the season, the maximum is 219 on the 19th day, and almost 90% emerged on the days, 15th to 23d, inclusive. In obtaining an average, it appears that the period is shortest early in the season and that it gradually lengthens as fall approaches. The average length of the period is as follows:

In June	18.07 days.
In July	19.15 days.
In August	21.55 days.
In September	26.00 days.

For the whole season the average is within a small fraction of 20 days. Without doubt, the period under consideration is subject to variations from various causes. Length of the period will be influenced by weather conditions, by location, and by conditions that chance to surround the fruit when it falls; but the averages given are believed to approximate closely the normal time between oviposition and emergence of the larvæ.

The instinct of the plum curculio larvæ on emerging from the apple is to bury themselves as quickly as possible in the earth. They may do this on the spot where they fall, or they may crawl several inches, apparently searching for a suitable place to enter. Action is greatly influenced by time of day, by weather conditions, and especially by intensity of light. On bright days, if not in very deep shade, frantic haste to get below the surface is shown; at evening or on cloudy days movement is more moderate and time may be spent in choosing the exact spot for entrance. The time required to burrow out of sight depends upon the compactness of the soil and varies, according to our observations, from one to ten minutes. The behavior of larvæ at the time of emerging from the fruit has been closely watched on many occasions, both in the orchard and in the laboratory, and multiplied observations confirm the conclusion that exposure to the open air is very distasteful to them: that strong light distresses them; and that direct sunlight is very quickly fatal. It seems probable that many larvæ emerging in the daytime perish from exposure before they can burrow beneath the surface. It might be supposed that larvæ would choose night as the best time for emerging, but apparently time of day makes little or no difference. A record obtained in 1903 for sixteen larvæ gave six emerging during the night and ten during the day; of these latter, five emerged between the hours of 10:00 A. M. and 1:00 P. M. For the season of 1904, the record for 1,238 larvæ shows that 558, or 45.07% emerged between the hours of 7:00 A. M. and 7:00 P. M., while 680, or 54.93%, emerged between 7:00 P. M. and 7:00 A. M. Of this latter number, some, it is true, emerged in early morning before record was made, and between the hour of record and darkness in the evening, but we know that a very large portion of the number emerged during the dark hours of the night. It is concluded from the observations made that the larvæ emerge from the fruit whenever ready, without making any distinction with reference to the light conditions prevailing at the time.

MORTALITY AMONG LARVÆ IN THE FRUIT.

It has been noted throughout the period of this investigation that there is a considerable mortality among larvæ while within the fruit. Most of the larvæ found dead in the burrows were less than half grown, and many were not more than two or three days from the egg. In an examination on various dates of 716 fallen apples, 169 plum curculio larvæ were found, 103 of which were dead. Here is an apparent loss of nearly 61% and, as many of the living larvæ were quite young, it is presumable that the percent of loss would have been still further increased. Reasons for this mortality have not been established, and from the nature of the problem an actual demonstration would be extremely difficult. Extended observations through two seasons point to two possible causes.

First—Crushing by growth of fruit. The writer holds the opinion that some larvæ die from this cause, and this opinion is based upon microscopical examination of larvæ found dead in the burrows, and examination of the fruit tissue surrounding these larvæ. Many larvæ thus found have a flattened, crushed appearance. This, taken in connection with the fact that newly formed fruit cells closely encompassed the larvæ and completely closed the burrows behind them, is looked upon as fairly good evidence that death resulted from pressure from growing fruit cells. The eggs of the plum curculio are deposited in apples on the trees. If the apples fall at the time the eggs hatch or soon after, growth of the fruit is arrested, and development of the larvæ may proceed; but if the fruit fails to fall, growth of tissue continues and the formation of new cells may be so rapid and strong that the weak, newly hatched larvæ cannot overcome it and hence are crushed. Additional evidence that tardy falling of fruit has much to do with the death of larvæ is found in the records of larvæ developed from fruit which was off the trees at the time the eggs were laid. From 793 apples in which were deposited 1,474 eggs, there emerged 1,238 fully developed larvæ. In this case, 83.92% of the eggs deposited resulted in mature larvæ. The loss from all causes, including the possible failure of some of the eggs to hatch, is here only 16.08%, and it appears reasonable that this low percentage of loss is largely due to the fact that the newly hatched larvæ did not have to contend against the strong growing fruit tissue. It has been the accepted belief for many years that the plum curculio makes the crescent puncture in order to undermine the egg and thus prevent its being crushed by development of fruit tissue. The newly hatched larva is almost as delicate an organism as the egg, and its resisting power is exceedingly small, even though it can eat and has some power of moving. Probably it is the weaker ones that succumb, but be that as it may, the growth of fruit tissue is believed to be the real cause of much of the mortality found.

Second—The action of direct sunlight upon fruit. Considerable evidence has been gathered tending to show that sunlight on fallen apples is destructive to the contained larvæ. No living larvæ were found in fallen apples that had been exposed to the sun for a few hours, while apples taken from under the shade of trees gave a fair proportion of living larvæ. This was tried repeatedly and always with the same result. An experiment regarding pupæ to be detailed in another place, may be referred to here as bearing directly upon this question of exposure to sunlight. A quantity of fallen apples gathered under trees was divided into lots and placed in bottomless boxes over earth; in one box in the shade of a tree were placed 200 apples, in another in full exposure to the sun were placed 250 apples. Conditions surrounding the two boxes were in every way the same except in the matter of exposure to sun. From the earth below the box in the shade, forty-two pupæ were taken; from the earth below the exposed box three pupæ were taken. This last box yielding in the same proportion as did the other, should have yielded fifty-two pupæ, but only three were found. The larvæ died mostly in the fruit and no reason can be ascribed other than the action of the sun. Just how the action of the sun causes death is not clear. Death may result directly from elevation of the temperature beyond the endurance of the larvæ, or it may be the indirect result of the action of high temperature upon juices of the fruit. In any event, it is plain that direct action of the sun is destructive to larvæ in the fruit, and from this fact we may draw the practical conclusion: namely, that the system of orchard management that allows free access of sunlight, and that keeps the ground free from weeds, so that the sun can act upon fallen fruit, will be most helpful in reducing the number of these insects.

THE PUPA.

DEPTHS TO WHICH LARVÆ GO FOR PUPATION.

The larvæ, following a natural instinct, go into the earth to pupate and complete their transformations. How deep do they go? This is a question of practical importance and during our study of the insect considerable thought and much labor has been directed towards answering it in definite terms. In searching the written testimony, we find apparent differences of opinion as to the depths of pupation. One writer says "two to three inches"; one says "a few inches"; one "a short distance"; two say "several inches"; six say " four to six inches"; and one says "fifteen to thirty-six inches."

Dr. C. V. Riley (Illinois State Horticultural Society, 1869, page 84) says, "When the grub has once become full grown, however, it forsakes the fruit it has ruined, and burrows from four to six inches in the ground," and again on page 93 of the same volume, "Individually I never found plum curculio larvæ at a greater depth below ground than six inches, and my efforts to find them in the winter under trees from which infested fruit had fallen during the previous summer have so far been fruitless."

According to the above statements, it appeared possible to find pupæ at depths ranging from two to thirty-six inches, with possibilities in favor of finding the greater number at from four to six inches. Early in July, 1903, we began making excavations under infested trees. The soil was sifted and carefully searched, but for some time no pupæ were found, and the labor seemed profitless. At length a few pupæ were found. This encouraged further effort and more were found. Digging under trees finally gave records of depth for seventy-eight pupæ. To supplement the digging, to concentrate the insects and incidentally to test the behavior of larvæ in loose as compared with undisturbed soil, and to test the influence of light and shade, boxes were prepared on July 20th. One box twelve inches square and fourteen inches deep, without bottom, was sunk over a core of undisturbed blue-grass sod under the shade of a tree in the orchard. In this were placed 200 apples gathered from the ground. A second box of the same size was sunk in like manner in cultivated soil in an exposed situation; that is, not shaded by trees. In this were placed 250 apples. A third box was set in an excavation in shade under a tree and filled with loose soil. In this were placed 200 apples. The apples used were all picked up at the same time and divided between the boxes in numbers as stated. The three boxes were then covered closely with cheese cloth and left undisturbed. On August 7th, the box over blue-grass sod was removed and the core of earth shaved up. Pupæ to the number of forty-two were found and accurate depth measurements made for each. The remaining boxes were lifted and the earth examined on August 8th. The one in cultivated soil exposed to the sun gave three pupæ; the one under a tree in which loose soil had been placed yielded thirty-four pupæ; for each of which depth record was made. A pupa in its burrow one inch below the surface is shown in Fig. 2, Plate 2. In addition to the above, records were obtained for twenty-two individuals in breeding cages in the laboratory. Thus in 1903 we secured accurate depth records for a total of 179 pupæ. The depths as found are given in tabular form below—

Where found.	No.	Depth in inches.						
		½	¾	1	1¼	1½	1¾	2
In undisturbed earth under trees	78	12	21	22	10	10	2	1
In earth in box over sod, in shade	42	19	15	7	1			
In earth in box in cultivated soil in sun	3	1				2		
In box of loose soil in shade	34	9	10	6	5	3	1	
In earth in laboratory cages	22	4	9	5	3	1		
Totals	179	45	55	40	19	16	3	1

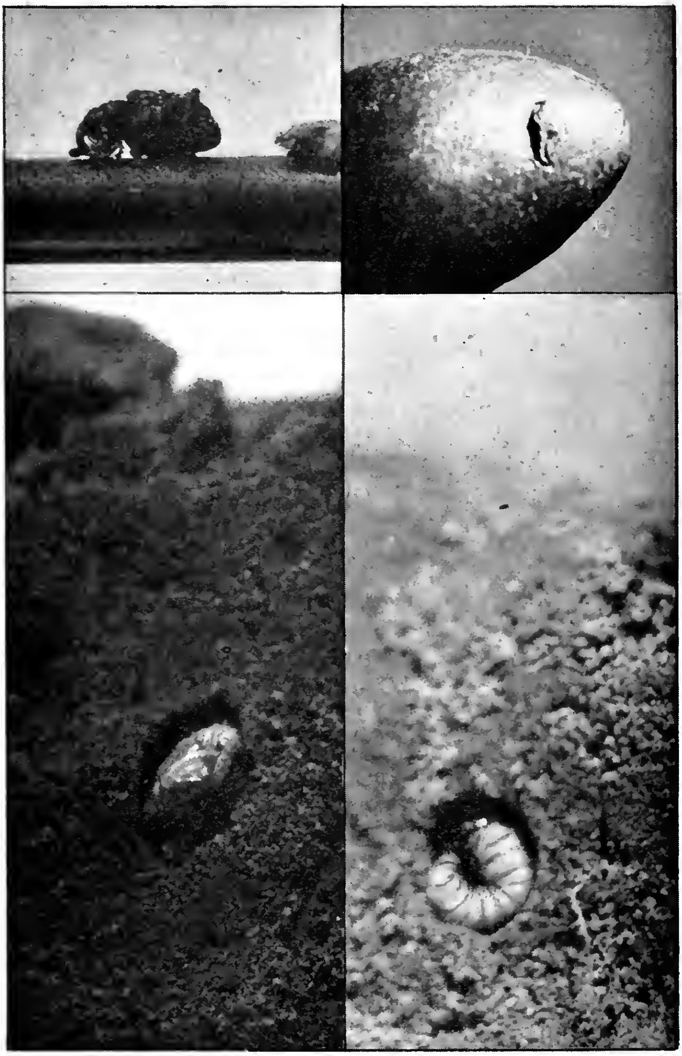


PLATE 2. FIG. 1—PLUM CURCULIO LARVA IN BURROW. x 3½.
FIG. 2—PLUM CURCULIO PUPA IN BURROW. x 3½.
FIG. 3—PLUM CURCULIO RESTING POSITION. x 3½.
FIG. 4—PLUM CURCULIO CRESCENT PUNCTURE. x 3½.

The number at each depth with its percentage of the total follows:

At a depth of ½ inch	45	or	25.14%
At a depth of ¾ inch	55	or	30.73%
At a depth of 1 inch	40	or	22.35%
At a depth of 1¼ inches	19	or	10.61%
At a depth of 1½ inches	16	or	8.94%
At a depth of 1¾ inches	3	or	1.67%
At a depth of 2 inches	1	or	.56%
	179		100.00%

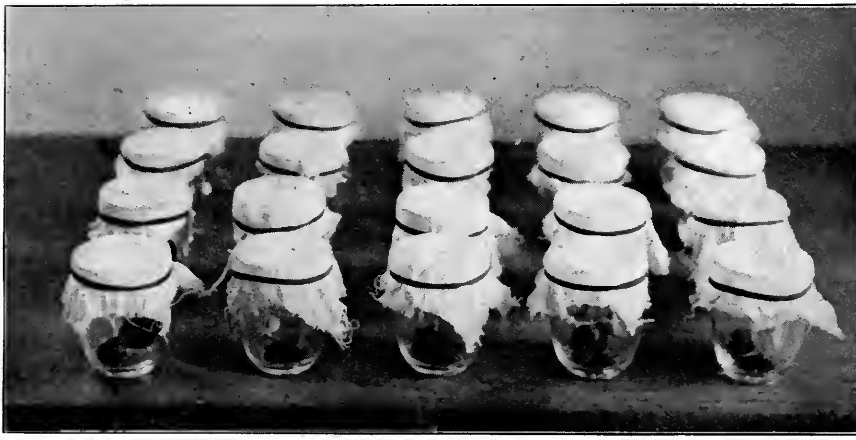


PLATE 3. GLASSES USED IN EGG-LAYING TEST.

During the season of 1904 depth records were obtained for 645 pupæ. Digging in the earth under trees gave twenty-four. From earth in boxes in which apples had been placed, 298 records were obtained. These boxes were six in number, but depth records were obtained from only five of them. Each box contained fallen apples gathered from one plat. They were placed in position as shown in Plate 4, on different days between July 8th and 14th. On July 29th and 30th the boxes were lifted and taken to pieces. The contained blocks of earth were then shaved down in thin slices with a flat knife, and, as pupæ were uncovered, the depth was measured and recorded. Measurement was made, in all cases, from the surface of the soil to the bottom of the burrow. Depth record for 323 individuals was obtained in the laboratory. Of these, seventeen were from a small box which had been filled with moist, compact earth, and which was used as a repository for surplus larvæ that came to us in various ways and were not wanted for other purposes. The remaining 306 records were obtained from pupæ in tubes. Apples used in our test of egg laying capacity (to be treated of in another place), were

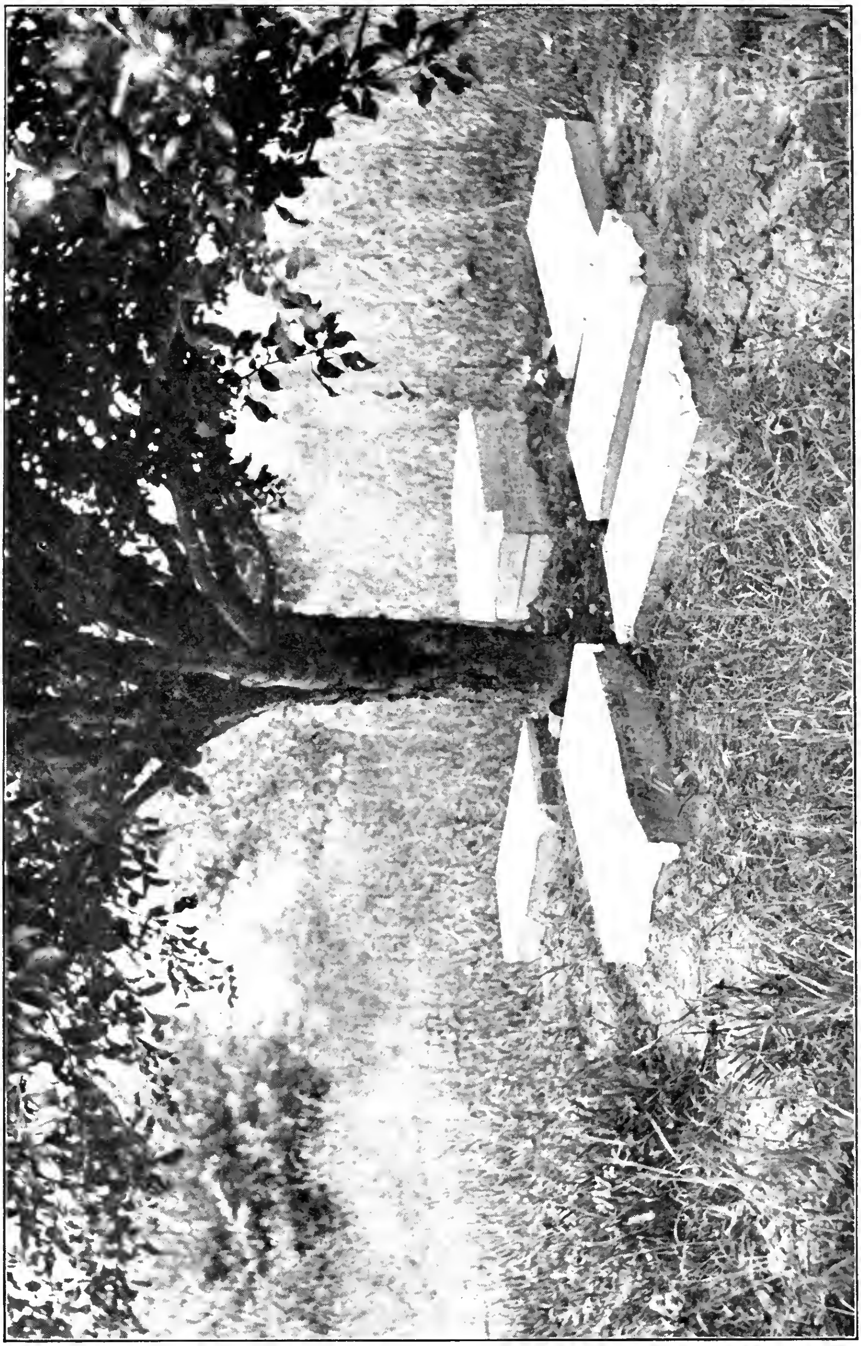


PLATE 4. BOXES USED IN DETERMINING DEVELOPMENT OF CURCULIOS.

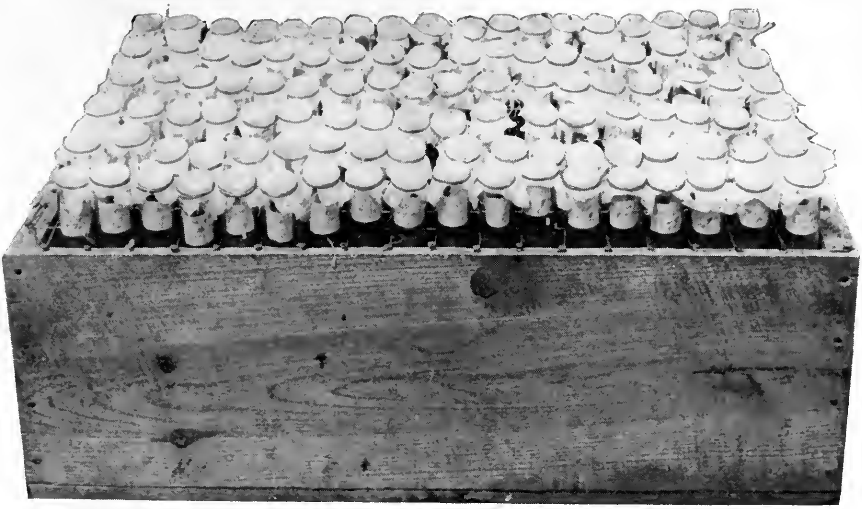


PLATE 5. BOX OF TUBES USED FOR PUPATION RECORD.

placed in jelly glasses such as are shown in Plate 3, and as the larvæ completed their feeding and emerged from the fruit they were placed separately in glass tubes one inch in diameter and six inches in length. These tubes were prepared by filling one end with earth which was made very compact to the depth of one inch; then they were filled with sifted earth to within one and one-half inches of the top. This earth was made moderately firm. As they received larvæ the tubes were labeled, covered with cheese cloth, and placed in boxes partly filled with moist earth. The open bottom in contact with moist earth was designed to maintain proper conditions of moisture throughout the tubes. One of the tubes is shown in Fig. 1, and a box filled with tubes in Plate 5.

FIG. 1.—Tube used in work on pupation.

In the following tabulation depths are recorded by differences of one-fourth inch; totals are given for each depth as found in the laboratory and under outside conditions, with percentages for each depth. It may be noted that some of the laboratory records show unusual depths. This is due to the fact that earth in some of the tubes was rather too dry and not sufficiently compact. It appears to have been necessary for the larvæ to go deeper than usual in order to find earth sufficiently moist to admit formation of the burrows.

The least depth at which pupæ were found is one-fourth inch and at this depth we record forty-eight. The extreme depth in boxes, under outside conditions, was two and three-fourths inches. In the laboratory, eight were recorded at a depth of three inches, one at three and one-

DEPTH OF PUPATION—RECORDS OF 1904.

Depth in inches	¼	½	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	
Outside	25	78	60	48	31	43	18	12	1	3	3				322
In laboratory	23	59	40	43	19	34	21	39	13	12	9	8	1	2	323
Totals	48	137	100	91	50	77	39	51	14	15	12	8	1	2	645
Percent for each depth	7.44	21.24	15.51	14.11	7.76	11.94	6.01	7.91	2.17	2.33	1.87	1.24	.16	.31	

fourth inches, and two at three and one-half inches, but as already explained these went to unusual depths from force of circumstances rather than from choice.

The records obtained outside the laboratory show 315 or 97.82% at depths of two inches and under, and two-thirds of these were at and under one inch. Considering the totals for the season, we find 593 or 91.94% at depths of two inches and less with more than half or 59.29% of the total at one inch and under. Bringing together the records of the two seasons we find the number and percentages for each depth to be as follows:

Depth in inches.	Number of pupæ.	Percent.
¼	48	5.82
½	182	22.09
¾	155	18.81
1	131	15.90
1¼	69	8.37
1½	93	11.29
1¾	42	5.10
2	52	6.31
2¼	14	1.70
2½	15	1.82
2¾	12	1.46
3	8	.97
3¼	1	.12
3½	2	.24
	824	100.00

The total number of records is 824, and of this number 772, or 93.69%, were at depths of two inches or less, and 516, or 62.62%, were at depths of one inch and less. From these figures the conclusion is reached that the great bulk of the new generation of plum curculio may at the proper time be found as pupæ very near the surface. Larvæ stop at the depths given, not because of any adverse circumstances, but because of natural instinct. In our boxes of loose soil, out of doors, larvæ had every opportunity to go deeper had their instincts prompted them to do so, but they went no deeper than did the larvæ in undisturbed and very compact soil. It is interesting to note that while boxes placed in shade under trees yielded, respectively, 42 and 34 pupæ, the box exposed to the sun yielded only three, although it contained fifty more apples than did either of the other boxes. It appears from this that shade is a more important factor than degree of compactness in ordinary soils. In this box exposed to the sun, most of the larvæ died in the fruit before attaining full development. Death was surely not due to dryness, for the apples were sufficiently juicy; nor to scarcity of rotten pulp, for most apples were more or less decayed. As regards conditions likely to influence larval development and emergence from the fruit, there were no differences between the three boxes except that the one yielding only three pupæ was exposed to the sun. The failure of larvæ to mature under this exposure, coupled with the fact, frequently observed, that larvæ are extremely sensitive to direct sunlight, warrants the conclusion that the mortality here found was directly due to the action of the sun. If this is true, it follows that fallen fruit under trees will have most of the contained larvæ killed if the ground is clean and not so densely shaded as to exclude sunlight. If shade is very dense immediately about the trees, it would be well to rake fallen fruit to exposed middles and thus accomplish the same end, so far as plum curculio is concerned, that would be attained if the fruit were gathered and destroyed.

THE PERIOD OF PUPATION.

The period of pupation, or, more correctly, the time spent by the insects in the ground, has been determined for a considerable number of individuals. Record of time of entering the earth was made for 1,724 larvæ. Of these, 1,264 or 73.26 percent, emerged as beetles, while 460, or 26.74 percent, failed to come out. These latter, either as larvæ, pupæ, or beetles, died in the burrows. Details of emergence are given in the tabulation on page 488.

At the top of the tabulation is given the number of days; below are given the records obtained in 1903, followed by those obtained in 1904. The latter are separated into those obtained from tubes in the laboratory and those obtained from jelly glasses which were kept under the shade of a tree in the orchard, where natural conditions were more nearly approximated. The shortest time recorded is 19 days for one individual. At the other extreme, one beetle emerged 48 days from the time the larva entered the ground. It will be noted that all the very tardy ones, those appearing from the 37th to the 48th day, came from tubes in the laboratory. This is due to the fact that, as the season advanced, the use of the glasses in the field was abandoned, and all the later appearing larvæ consigned to the tubes. No larvæ were placed in glasses after August 22d. In the matter of time in the ground, we found no appreciable difference between those kept in the laboratory and those outside. The long periods appear to be a natural consequence of low temperatures through the latter part of September and the month of October. The

PLUM CURCULIO. TIME IN THE EARTH.

No. of days	Beetles emerged in laboratory, 1903	Beetles emerged, tubes in laboratory, 1904	Beetles emerged, glasses, outside, 1904	Totals
19		1		1
21		5		5
22		11	2	13
23	7	31	12	50
24		91	22	113
25	2	111	39	152
26		101	62	163
27	6	49	85	140
28		48	99	147
29		44	79	123
30		31	66	97
31		38	47	85
32		21	24	45
33	3	26	14	43
34		22	8	30
35		8	4	12
36		8	1	9
37		3		3
38		4		4
39		5		5
40		2		2
41		4		4
42		4		4
43	1	5		6
44		3		3
45		1		1
46		1		1
47		2		2
48		1		1
Totals	19	681	564	1254

beetle having the longest period, 48 days, emerged October 30th. One came out November 2d, with a record of 46 days in the ground. Some of the later larvæ were noted to be undersized and evidently weaker than those maturing early in the season. The beetle recorded in 1903 as emerging the 43d day was from a larva so small and weak that it was not thought possible for it to pass through the transformations, but it lived, and the beetle, although of small size, was otherwise normal.

The maximum number appearing for any one period was 163 the 26th day. Leaving out of consideration the very early and the very late ones, we find that the period from the 22d to the 36th day, inclusive, covers 1,222 out of the 1,264 beetles, or 96.67%. Computing an average time based on all the beetles emerging, we find that this average is 28 days.

The causes of death in the 460 cases where larvæ failed to come forth as living beetles are probably several. Some enter the ground weak, not well nourished, and have not sufficient vitality to live through. Not infrequently the larvæ and pupæ are found in the burrows, dead and thickly covered with mycelial threads of fungi. Whether these fungi are parasitic or simply saprophytic, attacking after death, is undetermined. Sometimes minute parts of larvæ or pupæ are found, suggesting the work of predatory insects. That larvæ often pass through all the transformations and then, as beetles, die from the attacks of other insects, is shown by the frequency with which half-eaten beetles are found in burrows.

Our observations lead to the conclusion that a very large part of the mortality occurring after the larvæ leave the fruit and before the beetles emerge may be ascribed to insect enemies, and of these insect enemies ants are the most numerous, active, and destructive. A small red ant and the common black ant were both frequently observed in the act of carrying off curculio larvæ and pupæ. An effort to ascertain the number of larvæ obtainable from a known number of punctured apples was seriously interfered with because ants carried off the larvæ as fast as they emerged, and in our outside pupating boxes we are confident that the number of pupæ found would have been very much greater had it been possible to exclude the ants. Ten pupæ placed in the center of the cloth cover of a box which projected four inches above the ground surface were discovered by ants, killed, and removed from the box within thirty minutes. Other similar tests all serve to show that ants have great capacity for the destruction of curculio larvæ and pupæ.

THE BURROWS.

The burrows in which pupæ are found are oval in form, with smooth walls, and are not lined with web-work. They are made by the larvæ, probably, as Riley suggests, "by turning round and round until the right size and degree of smoothness is attained."* A larva in its burrow one inch below the surface is shown in Fig. 1, Plate 2. The burrows are oblique to the surface and the pupæ always rest with the head up. No record was obtained of the time spent in pupa form, but it surely is several days shorter than the period spent in the earth. Probably two or three days may be required by the larvæ after entering the earth, before they change to pupæ, and, at the end of the pupa stage, two or three days elapse between the casting of the pupa skin and the emergence of the beetle. Beetles fresh from the pupa stage are reddish in color and quite soft-bodied. It required a few days to assume natural colors and attain sufficient hardness of body to enable them to reach the surface. Newly emerged beetles have a bright, fresh appearance that serves to distinguish them from those that have hibernated.

THE FULL PERIOD FROM DEPOSITION OF THE EGG TO THE EMERGENCE OF THE MATURE BEETLE.

The life cycle of the plum curculio, or the period from deposition of the egg to the emergence of the mature beetle, as observed in this investigation, may have an extreme range of from 31 to 90 days, by adding the shortest period in the fruit to the shortest observed period in the ground for the minimum and adding the other extremes in the same way for the maximum. But a long period in the earth is not necessarily preceded by a long period in the fruit, nor is a long period in the fruit usually followed by an abnormal period in the earth. It

*Transactions Illinois Horticultural Society, 1869, page 84.

is not probable that any curculio completed the life cycle in the mimimum time of 31 days, or that any required the extreme time of 90 days. As a matter of fact, the beetle recorded as emerging in 48 days, had a period in the fruit as egg and larva of only 24 days, making the whole period from oviposition to final emergence only 72 days. One curculio recorded as emerging on the 41st day has a record of only 20 days in the fruit, making the full time 61 days. The average time in the fruit, 20 days, added to the average time in the ground, 28 days, gives an average time from oviposition to emergence of the beetle of 48 days, and the great majority of the individuals for which we have record will come within a few days, one way or the other, of this average.

BETWEEN WHAT DATES ARE MOST PUPÆ IN THE EARTH?

From what has preceded regarding depth for pupation and time spent in the ground, it appears that the new generation of the plum curculio is in the earth, mostly within two inches of the surface, for a period of about four weeks during the summer. If all eggs were laid on the same day, or within a few days of each other, so that the whole crop for the season would be in the ground at the same time, the problem of control by attack during pupation would be greatly simplified; but, unfortunately, the period for depositing eggs is greatly prolonged, as has been shown. It follows that beetles of the new generation come from the earth and are at work on the fruit long before the older generation has ceased laying eggs. While our records show a period of 143 days between June 17th, when the first larva entered the ground, and November 7th, when the last beetle emerged, there must be some shorter period that, while not including the precocious individuals nor the laggards, would cover a great majority of the insects. Commencing with July 17th, the day of the first emergence of beetles, let us consider a period of 30 days, which would include August 15th. Up to this last date, 1,536, or 90%, of our 1,700 larvæ had entered the ground; but the time between June 17th, when the first larva entered the ground, and the emergence of the first beetle, on July 17th, is 29 days, one day more than the average time spent in the ground; and, as many beetles emerged in less than the average time, a considerable number would likely escape before July 17th. To guard against this, we will shift the thirty-day period and consider it as extending from July 10th to August 8th. There have entered the ground up to this last date 1,479, or 87%, of the total number of larvæ, and the number likely to emerge and escape before July 10th would be very small. If we make the period 40 days, and extend the time to include August 18th, we have 1,565, or 92.06%, of the 1,700 larvæ in the ground. Lengthen the time still further to include the whole month of August, a period of 53 days, and we cover 1,645, or 96.76%, of larvæ entering the ground.

For this season of 1904, the date for commencing operations against the curculio in the ground may be given as July 10th. The percentage of the crop controlled or destroyed would then depend upon how long work was continued, with probabilities that operations extended over thirty days would affect 87%, forty days, 92%, and fifty-three days, nearly 97% of the curculio crop. The date given for commencing work applies only to the one season of 1904. It must be moved one way or the other according as the season is late or early. In relation to the date of full bloom, which for 1904 occurred on May 10th, our date of July 10th comes sixty-one days later. In 1903 the date of full bloom was April 22d. Adding sixty-one days, the date for commencing would fall on June 22d, eighteen days earlier than for 1904.

It is not intended to convey the idea that there is a positive relation between the blooming period and curculio pupation; other factors may intervene to vary the time, but in a general way the period of full bloom may serve as a basis from which to calculate. The dates given above as possible limits to the period during which effort may be directed against curculio in the ground, are intended to be only approximate, but they have been named only after careful study of the situation as found in central Illinois during the last two seasons, and are believed to be as nearly correct as it is possible to make them with the information at hand. In the northern part of the state they would vary but little, but in the south, where egg laying begins earlier, the period would begin from ten to fifteen days earlier. To definitely establish this period is important in connection with the treatment to be given. This treatment will be suggested in considering means of repression.

THE BEETLE FROM EMERGENCE TO HIBERNATION.

Emergence of plum curculio beetles is governed in great part by weather conditions. Dryness of the soil retards movement to the surface, and without doubt extreme drouth proves fatal to many, either in the pupa state or at the time of transformation to beetles. A shower brings the beetles out in great numbers, and, in general, moist conditions of soil are favorable to emergence. Precocious individuals, developed from the first eggs deposited, began to emerge as beetles on July 16th; but the earliest to appear among those under control in the laboratory came out on July 17th. From this date, beetles continued to emerge throughout the summer and until late in the fall. With July 17th as the earliest date of emergence, and November 7th as the date of the last emergence, we have a period of 114 days during which beetles may emerge. It is an interesting coincidence that the period during which larvæ entered the ground is exactly the same as the period during which beetles emerged, 114 days. The first larva entered the ground on June 17th;

the last on October 9th. There are twenty-nine days between the entrance of the first larva and the emergence of the first beetle, and also twenty-nine days between the entrance of the last larva and the emergence of the last beetle. But this is merely a coincidence, and has no bearing upon individual periods in the ground, as is shown by the fact that, while 1,039 larvæ, or 61.11%, of the total number entered the ground during the first twenty-nine days, or before any beetles emerged, only twenty-nine, or 2.28%, of the beetles emerging came out during the last twenty-nine days, or after the last larva entered the ground. The maximum number emerging on any one day was ninety-one on July 27th. The number emerging by months is as follows:

Month.	Number.	Percent.
July	592	46.69
August	449	35.41
September	188	14.83
October	34	2.68
November	5	.39
	1268	100.00

Newly emerged beetles usually remain quiet for a time, apparently to allow complete hardening of the body wall and appendages. Then they seek the food plants and, so far as the evidence at hand indicates, spend the rest of the season in eating and sleeping.

Beetles that came from the earth early in the season were kept in cages and supplied at frequent intervals with fresh apples. They ate voraciously, but did not breed and no eggs were laid. Early writers held diverse opinions as to the number of broods of the plum curculio, and the question was much discussed until 1870, when Riley, by careful experiments, established the fact that there is but one brood. In the Transactions of the Illinois Horticultural Society for 1870, Riley says: "But as there seem to be exceptions to all rules, so there are to this; yet the exceptions are just about sufficient to prove the rule, for as far south as St. Louis, not more than one percent of the beetles lay any eggs at all, until they have lived through one winter; or in other words, when one female will pair and deposit a few eggs the same summer she was bred, ninety-nine will live on for nearly ten months and not deposit until the following spring. In more northern latitudes I doubt if any exceptions to the rule will be found." Eating is the principal business of the beetles from the time they emerge until the fruit is gone, and it is during this period in late summer and fall that the greatest amount of injury to apples is done. Feeding punctures made early in the season, or during May and June are usually small; simply shallow cylindrical holes that commonly are nearly obliterated by the later growth of the apple, so that eventually they constitute but slight surface blemishes. The later punctures are larger and remain as permanent blemishes, destroying the value of the fruit. The character of these late punctures is shown in Plate 19. Not only are the cylindrical cavities somewhat deeper and larger, but they are further enlarged by excavation back beneath the skin as far as the length of the beak will allow. When completed, the opening through the skin may be about one-sixteenth of an inch in diameter, while the cavity in the pulp below may be one-fourth of an inch across and one-eighth of an inch deep. As evaporation takes place, the skin that has been undermined shrinks back, thus enlarging the opening. It also becomes discolored, appearing as a dark brown ring about the opening.

PLATE 6. APPLE SHOWING COLLAPSED AREA.

Not infrequently excavations are so numerous that several run together causing the surface of a considerable area to collapse, working utter ruin to the fruit. Plate 6 is from a photograph of an apple affected in this manner. There are twenty-one punctures on the surface shown; thirteen of these were so excavated that they ran together undermining the skin; as a consequence the surface collapsed.

For additional data on the feeding habits of newly emerged beetles, ten were placed separately in glasses as they came from the earth, on August 26th, and supplied with apples. Five of these were given fresh apples daily for fifty-one days, or until October 21st, and as apples were removed record was made of the punctures. The remaining five were given fresh apples about once each week for the same period and similar record made from the fruit removed.

Those supplied with fresh apples daily gave the following record:—

Number of beetle	1	2	3	4	5
Total punctures made	35	8	49	68	72
Number of days on which punctures were made	24	5	30	32	32
Number of days on which no punctures were made	27	40	21	19	19
Greatest number of punctures made in one day	6	3	5	7	4

No. 2 made only eight punctures and died on the forty-fifth day. With the others, there were periods of from three to seven days during which no punctures were made. With all, the number of punctures diminished as the season advanced, and few were made during the last two weeks of the period. The five examined at less frequent intervals gave the following record:—

Number of beetle.	Dates when record was made.							Total.
	Sept. 2.	Sept. 9.	Sept. 16.	Sept. 23.	Oct. 3.	Oct. 10.	Oct. 21.	
1	8		7	5	3	2	3	28
2	22	7	8	6	20			63
3	24	19	19	11	24	5	9	111
4	21	7	5	2	8		4	47
5	20	9	3	5	7		4	48

This record discloses marked individual differences in the number of punctures. The beetles also differed in general activity. Some seemed content to lie for days at a time with the appendages drawn close to the body; others, even when not feeding were moving about much of the time and rested for short periods only.

From about the middle of August as long as the apples remained upon the trees, the beetles used these excavations, to a considerable extent, as resting-places, spending the time when not feeding safely housed and often entirely hidden from view. In the summer of 1903, beetles were first taken from cavities on August 11th. Frequently beetles fed from the interior of these cavities, often increasing the size of the excavation to three or four times the size attained by work from the outside.

Of fifty-four beetles taken from fruits, August 21 and 22, 1903, thirty-two, or 59.26%, were in cavities, while twenty-two, or 40.74%, were on the outside of the fruits. Of forty-five taken October 1st and 2d, 38, or 84.44%, were in cavaties, and 7, or 15.56%, were on the outside. As the season advanced, the tendency to hide in the cavities increased greatly. In two cases beetles were found in cavities of fallen fruit, but those above recorded were all in apples upon the trees. Curculios found in cavities do not willingly leave them. Jarring apparently does not disturb them, and often they will not move at all until forced to. They rest with legs drawn close up to the body and will remain for hours without sign of life. As many as four have been taken from a single cavity.

As the fall temperatures get lower the beetles become less and less active. Finally they leave the trees and seek places to hibernate. The place most commonly chosen for hibernation is on or very near the ground under grass, or such other rubbish as may be present. It is recorded that they also hibernate, "under the rough bark of both fruit and forest trees and under the shingles of houses." Diligent search for the beetles among grass and weeds under orchard trees was made in November,1902, in March, 1903, and again in November of the same year, and several specimens were taken, all of them under dead grass in immediate contact with the earth. Search was also made in woods adjoining an orchard, but no beetles could be found.

That they do hibernate in woods, however, seems at least very probable because it is so universally the case that orchards in close proximity to woodlands are most infested in those portions nearest the woods. The difference in infestation, between parts of the orchard near and those remote from woods, is most marked in cultivated orchards. When kept free from weeds and grass, orchards do not offer so good shelter for hibernating insects. They are naturally driven to seek shelter elsewhere and woods afford ample opportunities for secure shelter.

When orchards are not cultivated, as is the case with many in Pike County, the work of the plum curculio is more evenly distributed over the orchard, but even here the fruit on rows adjoining bodies of timber generally shows greater injury than does the fruit on trees further away.

THE BEETLE IN SPRING.

In the spring of 1903 the earliest search for hibernating curculios was made on March 31st; nearly the whole day was given to the work, but no beetles were found. Search was again made on April 14th, and at intervals up to April 27th, on which date the first beetles were discovered. Only a few specimens were secured and these were found, as were those found in the fall, in contact with the ground under dead grass. In view of the abundance of the insect in 1902, it was disappointing to meet with such ill success in finding the hibernating beetles, because more detailed information is desired regarding hibernating habits and situations most chosen. To be sure the area available for hibernating was large, and the area actually searched in detail small, but it seemed reasonable to expect to find more than were found. However, the beetles were present somewhere, as was shown by their abundance on the trees a month later. So far as found, the beetles were single; apparently they are not gregarious in hibernating. During the spring, the trees were carefully searched at frequent intervals, with a view to ascertaining when the beetles first went into them, but no beetles were found on the trees until May 10th. They appeared to come all at once. None could be found on the trees May 9th, but May 10th they were abundant. Apple buds began opening April 16th. Trees were in full bloom April

22d, and the petals had practically all fallen by May 4th. It was, then, one week after the end of the blooming period when beetles were first found upon the trees. The apples had at that time begun to form, and some could be found that were one-fourth of an inch in diameter.

In the spring of 1904, attempts were again made to locate the beetles in hibernating quarters, and to ascertain the date of first appearance on the trees, but no new information was secured regarding hibernating quarters, as no beetles could be found. The first curculio of the season was taken by Mr. J. R. Shinn from a cluster of blossom buds on a Siberian crab tree near a dwelling, April 30th. April 28th, the systematic shaking of selected apples trees was commenced. A sheet twenty-four feet square was spread under the trees from one to three times daily. The trees were jarred and shaken and record made of the curculios captured. Tree No. 1 was located at the southwest corner of the orchard adjoining a tract of woodland. Tree No. 2 was located diagonally across the orchard near the northeast corner. Other trees in the body of the orchard were shaken frequently, but with less regularity. The first curculio secured in this way was taken from tree No. 1 the evening of May 4th. Others from the same tree were taken as follows—one, May 5th; five, May 7th; one, May 10th; one, May 12th; two, May 13th; one, May 15th; one, May 18th; and three, May 19th. From tree No. 2, the first curculio was taken May 17th followed by one May 18th. The first from other trees was taken May 7th, followed by captures of one, two, and three at intervals during the month. From our records, it appears that beetles were taken from trees six days earlier in 1904 than in 1903. Gauged by blooming dates, the appearance of the beetles upon trees was fully two weeks earlier this season than last. Apple buds in 1904 began bursting about May 3d. Trees were in full bloom May 10th, and the petals had practically all fallen by May 15th.

The date of the first appearance of the beetles in spring, and their feeding habits previous to the setting of fruit are matters of importance because they bear directly upon the early application of insecticides. If the beetles feed freely upon buds, young leaves, and flowers, early spraying should kill many of them.

In the eleventh report of the State Entomologist of New York for 1895, page 122, Dr. Lintner says: "The Plum Curculio (*Conotrachelus nenuphar*) enters upon the scene at least two weeks before its first crescent cuts are made in the fruit, ready and free to devote all its energies to obtaining the supply of food needed for the development of its eggs and for the labors attending its complicated and painstaking method of oviposition." Dr. Riley gives his testimony as to early appearance as follows: "In central Illinois and in central Missouri the beetles may be found in the trees during the last half of April, but in the extreme southern part of Illinois they appear about two weeks earlier, while in the extreme northern part of the same state they are fully two weeks later. Thus, in the single State of Illinois, there is a difference of about a month in the time of the curculio's first appearance on your fruit trees; and I need hardly remind you that the time will vary with the forwardness or lateness of the season. As we shall see from the sequel, it is very important that we know just when first to expect Mrs. Turk, and I, therefore, lay it down as a rule applicable to any latitude, that she commences to puncture peaches when they are the size of small marbles or of hazelnuts, though she may be found on your trees as soon as they are in blossom."* There are other writers giving like testimony regarding the early appearance of beetles upon the trees. I am not aware of any peculiar conditions tending to retard the appearance of beetles upon the trees, either in the spring of 1903 or in 1904, in Pike County, where our observations were made; but we utterly failed to find any trace of them upon the trees previous to May 10 in 1903, and May 4 in 1904. After May 10 in 1903, beetles were found on branches, twigs, leaves, and fruit without trouble. If they were there before, they certainly eluded diligent and persistent search. Regarding spring feeding habits of the beetles, it has been demonstrated by several experimenters that they will accept leaves and the leafy parts of flowers, as well as fruits. Dr. Forbes in 1888 and 1889 found† that beetles confined with plum leaves made excavations in midribs and petioles; supplied with fruit and leaves, both were eaten; the fruit perhaps the more freely. As between leaves and blossoms, the beetles showed preference for the latter, eating the leafy parts. Given roses in bloom, the petals and later the calyx and peduncle were eaten, and they also fed upon the flowers of the honeysuckle and snowball.

In our work during the two seasons, it has been found that beetles confined with fresh apple leaves fed upon these leaves very sparingly; supplied with both leaves and fruit, only an occasional small puncture was made on midribs and petioles of leaves while the fruit was freely punctured. It has, however, been frequently noted that beetles feed upon the stems of apples to some extent. When pairs have been confined with apples, the male has been observed puncturing the stem while the female was ovipositing upon the apple, and it has been thought possible that this was the exercise of an instinct operating to insure the fall of the apple, but examination of a large number of apples has failed to bring to light anything in support of this idea.

All records consulted that bear upon this matter of early feeding deal with beetles in confinement; no reference to observations made upon the work of free insects, in the trees, has been found. It is a perfectly natural inference that insects when free will feed the same as when

*The American Entomologist, 2: 130, 1870.

†17th Report State Entomologist, Illinois, for 1889-1890, pages 21, 22 (1891).

confined; direct evidence, however, would be desirable. Prolonged search for such evidence has been made, but none has been found. In 1903, fruits had commenced development before any beetles were found in the trees; from the time the beetles were found they worked industriously, but so far as our observations went the work was confined entirely to apples. No puncturing of leaves or twigs was discovered, although beetles were frequently found resting upon both twigs and leaves.

Actual demonstration of the use of succulent parts for food before the fruit was formed, would point to the early application of some insecticide as a possible effective means of reducing the number of beetles, but thus far we have failed to secure evidence warranting a recommendation of spraying for this particular purpose.

In 1903, after May 10th, the date of the first appearance of the beetles, feeding punctures on apples multiplied rapidly and crescent punctures became daily more numerous. Fruits at this time had but just begun to enlarge and many were very small. Apples less than one-fourth of an inch in diameter frequently were marked with two or three crescents and as many cylindrical feeding punctures. These apples were thickly covered with the normal white pubescence, and all examinations of punctures were of necessity made under a lens. Three or four days after puncturing began, apples began to fall in considerable numbers. Whether this was directly attributable to the work of the curculio or not, has not been determined. Many early punctured fruits persisted until well into the summer, and some remained on the trees through the season, but practically all the fruit that fell was more or less punctured. It is expected that a certain portion of very young fruits will fall, either because of imperfect fertilization, unfavorable weather conditions, or some cause outside of insect work; so that it is not possible to ascribe the drop here referred to wholly to the action of curculio.

OVIPOSITION.

Mating begins soon after the beetles come from their hibernating quarters, and deposition of eggs by what Dr. Lintner refers to as "its complicated and painstaking method of oviposition," follows soon after. The beetles do not wait for the apple to develop, but begin almost as soon as the petals have fallen. The procedure in oviposition is a matter of no great practical importance, but cannot help being of great interest to any student of insect habits and instincts. It is only a detail in the life of the insect, but the observer sees in it some importance, because it exemplifies that principle of scientific investigation which demands for it the same accurate observation and clear expression that would be accorded larger and more general matters. It should be borne in mind that each detail is but a link in the chain that makes possible the deduction of a right conclusion or the broad statement of fact or principle. I have before me statements of this process of oviposition compiled from twenty-two different writers. These statements exhibit considerable variation in method of work and in sequence of acts, and the question naturally arises, how many of these statements are founded upon actual observation? Some surely are so founded, others leave one in doubt, and still others are quite evidently repeated from some printed source. Below are eight of the twenty-two statements, numbered as in my list.

1. "As soon as the plums are the size of peas, the weevil commences the work of destruction by making a semi-circular cut through the skin with her long, curved snout, in the apex of which cut she deposits a single egg."

2. "In doing this, the beetle first makes a small, crescent-shaped incision with its snout in the skin of the plum, and then, turning round, inserts an egg in the wound."

3. "Having taken a strong hold of the fruit, the female makes a minute cut with the jaws, which are at the end of her snout, just through the skin of the fruit, and then runs the snout under the skin to the depth of one-sixteenth of an inch, and moves it back and forth until the cavity is large enough to receive the egg it is to retain. She next changes her position and drops an egg into the mouth of the cut; then, veering round again, she pushes it by means of her snout to the end of the passage, and afterwards cuts the crescent in front of the hole so as to undermine the egg and leave it in a sort of flap."

5. "Alighting on the young fruit, she stings or punctures with her pincer-like jaws the tender, immature fruit, forces her snout under the skin, puncturing and moving it about until, with its aid, a sufficiently deep and smooth cavity has been formed for the reception of her egg. * * * * After oviposition, turning about, with the aid of her snout, the egg is pushed to the bottom of the hole made for its reception. This important task performed, she makes with her mandibles a slight incision on one side of the cavity where the egg now lies, and the piece thus formed, is shoved forward, completely covering the egg, affording it protection from the hot sun, and hiding it from the preying eye of procto-tupid and other parasites."

6. "As soon as the plums, peaches, cherries, and apples are set, the curculio commences operations, imprinting the familiar crescent and placing an egg inside."

7. "When the young plums are set, the female makes the well-known crescent-shaped cut and deposits an egg in the cavity eaten out."

16. "She makes a crescent-shaped cut and then separates and elevates a small flap, into which the egg is inserted."

17. "When the young fruits are formed they are visited by the

female, who cuts a crescent-shaped flap in the skin and deposits an egg under the flap."

Observations on oviposition were attempted many times, but the records preserved are for the most part fragmentary; that is, they do not cover the whole operation, from the first puncturing of the skin to the departure of the insect from a completed work.

Observations of this character must be made under a lens and it is extremely difficult to bring the lens to focus and then maintain the position for from fifteen to twenty minutes without disturbing the insect. Usually, when preparing to oviposit, or engaged in any of the details of the process, the females are very sensitive to jar or motion of any kind, and will cease work and change position on very slight provocation; but occasionally they are so intent upon the work that nothing disturbs them or causes them to stop until the last detail is completed.

On several occasions the process, from deposition of the egg to the final details of egg protection, has been watched; other records cover in some cases the preparation of the cavity, in some the act of ovipositing, in still others the final acts only. In only three cases have our observations been complete, covering every detail from beginning to end.

In the first observation, the female moved about the apple for several seconds, keeping the end of her beak in contact with the surface, as if seeking a favorable spot. When the exact spot was decided upon, the minute jaws at the end of the snout began a rapid movement which quickly made an opening through the skin. This opening was no larger than necessary for admission of the tip of the beak. No skin was removed; it was simply torn and thrust aside to give access to the pulp below. Later, as the excavation proceeded, the broken skin was seen as a sort of fringe around the beak at the surface of the fruit. As soon as excavation in the pulp was commenced, the beak was deflected backward so that the work was carried on under the insect, just beneath the skin and nearly parallel with the surface. As the work advanced, the opening through the skin became slightly enlarged by lateral motions of the beak. The pulp was all eaten as excavated. During the process the beak was not once withdrawn, nor was there any cessation of motion. When the excavation of the cavity was completed the beak was withdrawn by a quick motion, the insect turned about, adjusted the tip of the abdomen to the opening and deposited an egg, which was forced to the extremity of the excavation by the ovipositor. The insect now rested without motion for two minutes; then, turning again, proceeded to cut the crescent in front of the egg. This crescent puncture was not wholly a separate puncture, but, starting in the original opening through the skin, was cut laterally in either direction, partly by the jaws and partly by crowding the beak, first one way and then the other. The direction of the beak was but little deflected from the perpendicular and the cut was made as deep as the length of the beak would allow. The pulp torn away in making the crescent was eaten, just as was done in excavating the egg cavity. The crescent completed, the insect walked away, drew the legs closely under the body and settled down, apparently to sleep. The time occupied in the process described was distributed as follows:

Excavating egg cavity	9	minutes.
Deposition of egg	1	minute.
Rest	2	minutes.
Cutting the crescent	3½	minutes.
Total	15½	minutes.

The egg cavity was cylindrical, with a rounded bottom, and by measurement was found to be .04 inch in depth. The egg when deposited very nearly filled the cavity.

The second observation of the complete process was nearly identical with the one described. The insect spent no time in choosing the exact spot, but went to work at once. It worked in a more leisurely way and did not excavate as deep an egg-cavity. Eleven minutes were spent on the cavity, two in depositing the egg, two minutes in rest, and four minutes in cutting the crescent, a total of nineteen minutes. The egg-cavity measured .035 inch in depth and was completely filled by the egg. On completion of the process the insect moved a short distance and immediately began a second cavity.

Essential differences from procedure in the two preceding cases were noted in the third complete observation. Excavation of the egg-cavity was the same, except that it was deeper in the pulp and of greater depth. After depositing the egg, the beetle turned and with her beak worked the egg back to the bottom of the cavity. Then she began tearing off bits of skin and pulp, which were carefully packed in, above the egg, until the cavity was full. Following this, the crescent was cut in much the same manner as in the preceding cases. Then she appeared to make a final inspection, and added some further packing above the egg. Finally the work appeared to be satisfactory and she walked away and began a second puncture. The time consumed in this process was longer than in the others, and was divided as follows:

Excavating egg cavity	12	minutes.
Depositing egg	1½	minutes.
Placing the egg with the beak	2	minutes.
Packing the cavity	4	minutes.
Cutting the crescent	4	minutes.
Finishing touches	3	minutes.
Total	26½	minutes.

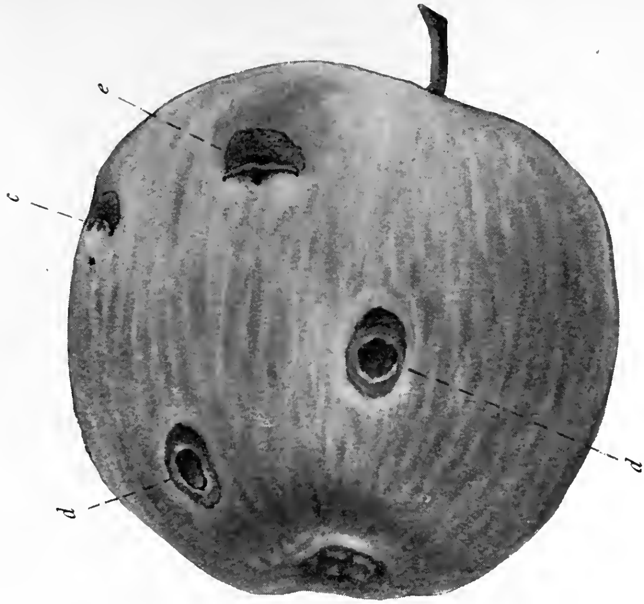
Among the many cases where only part of the process was observed some anomalies were noted. In two cases the insect walked away immediately after depositing the egg and made no crescent cut. In three cases, beetles were seen to cut crescents and, moving a short distance, begin other punctures. These crescents had no egg cavities and no eggs were deposited in them. In two cases, eggs were found deposited directly in crescent cuts, neither of which had the usual egg cavity. Marked variation in depth of the egg cavity was frequently observed. Not infrequently the cavity is so shallow that the tip of the egg protrudes, and sometimes its depth is nearly equal to twice the length of the egg. Packing the egg-cavity with pieces of pulp is a common, but not universal practice; often this is neglected, even where the cavity is deep. A section through a packed cavity is shown in Fig. 5, Plate 8. Section of a deeper cavity, not packed and somewhat diagramatic, may be seen at (é) Fig. 2, Plate 7. External appearance of crescent punctures is shown in Figs. 6 and 7, Plate 8, and at (e) and (c) Fig. 1, Plate 7.

When reading of the various processes and acts in insect economy, as observed and recorded in published life histories, it is quite natural to suppose that these processes are fixed, absolute, and unchangeable; while, as matter of fact, many of them are subject to modifications. Sometimes these variations have apparent reason in surrounding conditions, and again they can only be ascribed to individual peculiarity. The acts and habits of an insect as observed upon one food plant may not entirely accord with those of the same insect when on another food plant. They vary under different climates and under different seasonal conditions. It seems entirely possible that, in the course of generations, new or modified habits may appear as apparently fixed characters that differ from those observed when the life history was first recorded. So it seems reasonable and practical to regard modifications from accepted and understood procedure as appearing in the natural course of things, rather than to look upon them as strange or abnormal.

A crescent puncture is usually supposed to represent an egg or an attempt at egg laying, but this does not always hold true because, as stated above, some crescent cuts are made without the accompaniment of egg laying. On May 27, 1903, fallen apples, twenty-five in number, were picked up at random for examination of the crescent punctures. Nearly all were more or less punctured by the apple curculio, but these punctures are not here considered. Two fruits bore apple curculio punctures only, so that the number examined for crescent marks was twenty-three. On these twenty-three apples were fifty-eight crescent marks, or 2.52, to each apple. There were also thirty-five feeding punctures made by the plum curculio. Of the fifty-eight crescent cuts, fourteen, or 24.14 percent, had no egg-cavities and contained no eggs. The remaining forty-four crescent cuts had forty-five egg-cavities. Some

PLATE 8

1 Fruit of *Cratægus,* showing one egg puncture (above) and one feeding puncture (below). Made by apple curculio. Natural size.
2 Portion of surface of same fruit, showing external appearance of punctures enlarged.
3 Longitudinal section through the egg puncture, showing egg, enlarged.
4 Longitudinal section of the feeding puncture enlarged.
5 Section of egg cavity and crescent of plum curculio, showing egg packed in, on apple. Somewhat enlarged.
6 Crescent of plum curculio, showing external appearance, enlarged.
7 Crescent of plum curculio, showing external appearance, enlarged.



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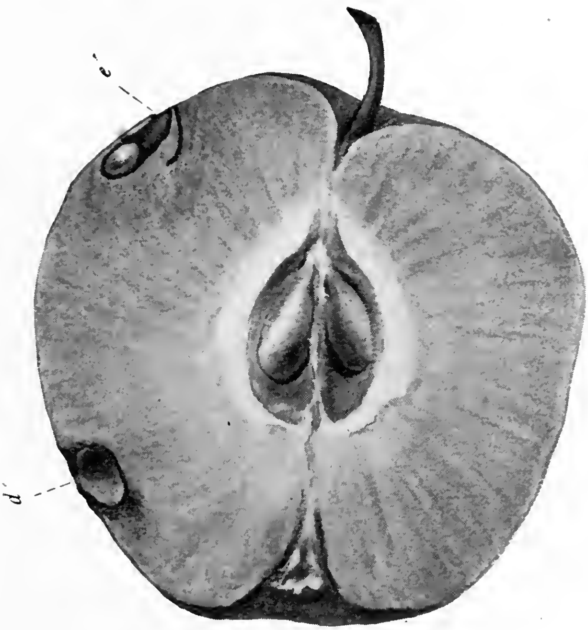


2

PLATE 7. FIG. 1—EXTERNAL APPEARANCE OF CRESCENT CUT.
FIG. 2—SECTION OF CRESCENT CUT.

variation in the location of the egg-cavities was observed; usually they occupied the center of the crescent, but some of these were not so situated. Of the forty-five egg-cavities, thirty-four, or 75.56 percent, were located at or near the center of the crescent; eleven, or 24.44 percent, were located near the ends of the crescents. In one case there were two egg-cavities within one crescent, one on each side half way between the center and tip. By another modification one of the egg-cavities, instead of being excavated from the surface, was excavated from the bottom at the center of a crescent cut. It was of usual dimensions, extended back obliquely towards the surface, and contained an egg. Evidently in this case the crescent was cut first and the cavity excavated afterwards.

Newly made egg-cavities, even with crescent attachment, are quite inconspicuous and would escape notice on casual examination; but within a few hours, evaporation causes that part of the pulp containing the egg-cavity to shrink and turn outward; at the same time it becomes discolored and is then readily seen.

As the egg-cavity shrinks back, it often brings the egg into a perpendicular position and not infrequently the end of the egg is fully exposed to view. Twenty-one of our forty-five egg-cavities contained eggs; twelve had contained eggs, but the eggs had hatched as was indicated by the larval burrows. Twelve were empty and there was no way of ascertaining whether eggs had been laid in them or not.

The statements we have quoted regarding the details of oviposition of the plum curculio, together with the observations recorded, indicate variation in details sufficient to confuse the layman, and even to puzzle the expert, if he seek to cover rightly any detail with a general statement that will fit all cases. Two conclusions are open; either some individual insects have faulty instincts, or there is more than one acceptable way of performing several of the details of oviposition. The writer accepts the latter conclusion.

PERIOD OF OVIPOSITION AND NUMBER OF EGGS.

The length of the period during which oviposition continues, and the number of eggs laid by each female are matters of some importance. Riley believed "That the stock of eggs of the female consists of from fifty to one hundred; that she deposits from five to ten a day, her activity varying with the temperature," also "That the period of egg depositing thus extends over more than two months."* This estimate has often been quoted and has been generally accepted.

In 1901, Professor A. L. Quaintance and Mr. R. I. Smith of Maryland obtained very interesting records regarding number of eggs and length of period of oviposition.† Ten females, taken in copula, were confined

*First Missouri Report, 1869, page 54.

†Division of Entomology, U. S. Dept. Agr. Bul. 37, June, 1902.

separately in four-ounce bottles, supplied each day with fresh plums, and record made of eggs laid. One of the beetles proved to be a male, and one escaped after seventeen days, so that the final complete record is for eight individuals running from May 14th to the death of each beetle. The record is as follows:

No.	Date of death.	No. of days li ing.	No. of days on which eggs were laid.	Total No. of eggs.	Range of eggs laid per day.
1	Aug. 2	81	70	276	1 to 15
2	June 20	38	32	235	1 to 15
4	June 19	37	36	294	2 to 17
5	Aug. 2	81	74	436	1 to 18
6	July 10	58	37	270	2 to 15
7	May 28	15	10	62	2 to 12
9	July 31	79	64	396	1 to 19
10	July 26	74	57	348	1 to 15

This gives a maximum period of oviposition of eighty-one days which holds for two of the beetles. The average for the eight beetles is nearly fifty-eight days. Of the two living longest, No. 1 laid on seventy days a total of 276 eggs, an average of 3.94 per day; while No. 5 laid on seventy-four days a total of 436, an average of 5.89 per day. No. 4 lived thirty-seven days, laid on thirty-six days a total of 294 eggs, or at the rate of 8.16 eggs for every working day. The number of eggs laid each day by each beetle ranges from one to nineteen in the case of No. 9; one to eighteen, for No. 5; two to seventeen, for No. 4; one to twelve and fifteen for the others. The maximum was reached about the last of May, after which the number per day diminished rapidly. This record is an excellent exposition of the egg laying capacity of this insect, and shows clearly that oviposition extends over a long period.

During the season of 1903, very little information was obtained that bore directly upon these questions of egg laying capacity and length of egg laying period. The first eggs were found on May 12th, two days after the discovery of beetles upon the trees; the last egg of which we have record was deposited on July 12th. The time difference is here sixty-one days, but various observations, notably the finding of young larvæ in September, clearly indicated that the period was much longer. In the spring 1904, provision was made for testing the egg laying capacity and for ascertaining the length of the egg laying period. The appearance of the beetles was so tardy that enough for our purpose were not secured until May 23d. On that date, nineteen pairs were obtained, all taken in the act of mating. Each pair was placed in a jelly glass; the glasses were numbered, supplied with apples, and covered with squares of cheese-cloth held in place by rubber bands. Three days later, on May 26th, an additional pair was secured, making twenty in all. The glasses were arranged on a table in our laboratory, as shown in Plate 9, and were not disturbed except at regular intervals when the apples were changed,

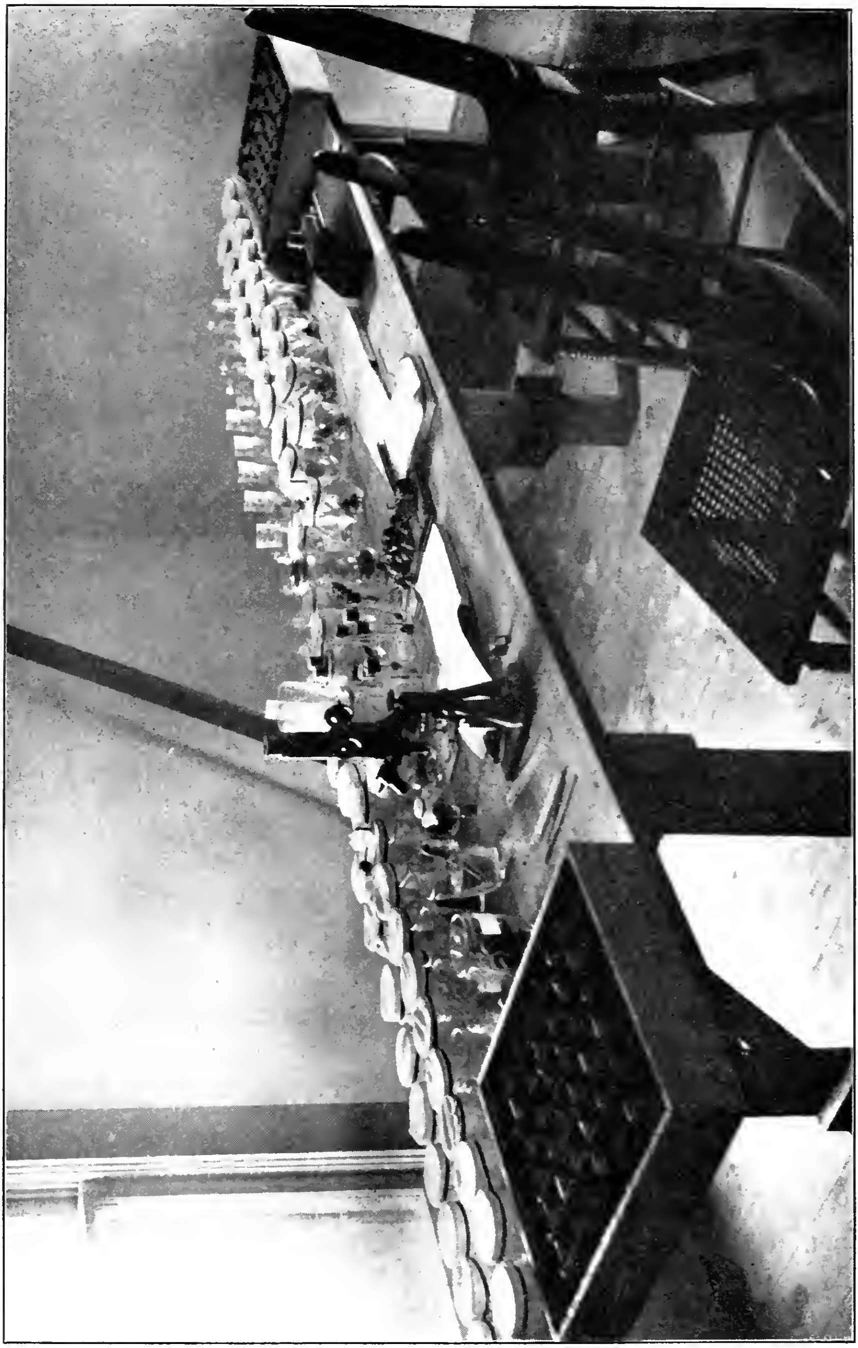


PLATE 9. LABORATORY TABLE AT GRIGGSVILLE.

The hours for change of fruits were fixed at 6:30 in the morning and at 8:30 in the evening, and were closely adhered to throughout the season. The female of pair No. 8 deposited only eight eggs as follows: two on May 30th, one each on June 16th, 25th and 27th, two on July 1st, and one on July 4th. The pair was as active as others, and both lived to August 15th. One died then and the remaining one lived to September 19th, but the egg production is so far below all others that we discard the pair from our tabulation of results. The female of pair No. 12 laid two eggs on May 27th, and died on June 1st; this eliminated the pair. Up to June 18th no egg had been laid by the female of pair No. 14, and on that date she was removed and a new one substituted. This new one laid two eggs the day she was placed in the glass, but none after that day, although she lived until August 10th. The male did not die until September 10th. These two pairs, No. 12 and No. 14, are also excluded from our tabulated record, so that we have remaining but seventeen pairs. The record of two of these is incomplete. No. 5 escaped on June 16th and No. 11 on June 26th. All others are recorded for the duration of life.

The tabulation on page 508 brings into compact form the details recorded for each pair.

The apples as removed were carefully examined under a lens and record made of eggs and punctures found. Use of the knife was generally necessary to determine the presence of eggs, because external appearances cannot be depended upon, and no egg was recorded until seen. The number of eggs without crescents and the number of crescents without eggs are recorded, as showing the frequency of departure from what is generally regarded as normal procedure. Thus No. 18 made a total of 311 crescents, sixty-five of which were unaccompanied by egg-laying; she also laid three eggs that had no accompanying crescent. No. 2 made 263 crescents, forty of which were not accompanied by eggs and twelve out of her 235 eggs had no crescents appended. The total number of crescents made by the seventeen females is 2,206 and of these 307, or 13.92%, were unaccompanied by eggs. On the other hand, fifty-four eggs were found unaccompanied by the usual crescent; this is 2.76% of the 1,954 eggs laid.

Wide differences in the egg laying capacity of individuals appear. Thus our maximum number of eggs, 263, was laid by No. 10 on sixty-nine of the one hundred days in confinement, while No. 16 laid only thirty-four eggs on twenty-five out of her 102 days under observation, and No. 20 in her eighty-seven days, oviposited on only eleven days, and has a total of only fourteen eggs.

The time between deposition of the first egg, May 25th, and deposition of the last egg September 9th, or 107 days, may be taken as the duration of the egg laying period, but there is great variation in individuals and this full period was reached by none. The nearest approach is by No. 17.

PLUM CURCULIO. NUMBER OF EGGS. PERIOD OF OVIPOSITION.

Number of the individual.	Date of death of female.	Number of days under observation	Eggs and Crescent Punctures. Date of first egg.	Date of last egg.	Number of days on which eggs were laid.	Number of days between first and last egg.	Number of eggs.	Number of crescents.	Number of crescents with eggs.	Number of crescents without eggs.	Number of eggs without crescents.	Maximum number of eggs in 24 hours.	Day. Number of eggs laid between 6:30 A. M. and 8:30 P. M.	Night. Number of eggs laid between 8:30 P. M. and 6:30 A. M.	Feeding Punctures. Number of feeding punctures.	Number of days on which feeding punctures were made.	Day. Feeding punctures made between 6:30 A. M. and 8:30 P. M.	Night. Feeding punctures made between 8:30 P. M. and 6:30 A. M.	Maximum number of feeding punctures in 24 hours.
1	July 24, P. M.	63	May 25	July 10	32	45	84	98	81	17	3	9	40	44	207	49	94	113	11
2	Sept. 15, A. M.	115	May 26	Sept. 3	84	99	235	263	223	40	12	8	116	119	375	95	182	193	13
3	July 20, P. M.	59	May 26	July 8	37	42	119	122	116	6	3	9	67	52	301	57	153	148	12
4	Sept. 10, P. M.	111	May 26	July 17	14	51	31	32	31	1		5	15	16	251	74	125	126	12
5	June 16, P. M.	25	May 30	June 13	9	13	12	13	11	2	1	2	6	6	198	25	100	98	19
6	Sept. 26, A. M.	127	May 25	Aug. 5	12	72	18	22	16	6	2	3	12	6	299	95	117	182	15
7	June 23, P. M.	32	May 26	June 22	22	28	44	54	42	12	2	4	24	20	156	32	77	79	11
8																			
9	July 26, P. M.	65	May 25	July 1	15	35	19	25	18	7	1	2	8	11	167	54	84	83	12
10	Aug. 30, P. M.	100	May 26	Aug. 10	69	75	263	300	259	41	4	9	121	142	615	97	251	364	22
11	June 26, P. M.	35	June 3	June 25	22	21	98	104	98	6		8	63	35	180	33	75	105	16
12																			
13	Sept. 6, A. M.	106	May 26	Aug. 30	78	97	197	226	192	34	4	6	101	96	454	92	202	252	24
14																			
15	Aug. 9, P. M.	79	May 26	Aug. 1	59	67	160	170	154	16	6	8	95	65	393	77	188	205	15
16	Sept. 1, P. M.	102	May 27	Aug. 17	25	81	34	36	29	7	5	3	17	17	428	91	195	233	14
17	Sept. 23, A. M.	123	May 27	Sept. 9	87	105	252	282	246	36	6	9	137	115	507	112	239	268	15
18	Aug. 10, P. M.	80	May 25	Aug. 4	62	70	249	311	246	65	3	9	137	112	484	78	225	259	21
19	July 23, P. M.	62	June 2	July 17	42	46	125	133	123	10	2	8	70	55	378	59	204	174	24
20	Aug. 20, P. M.	87	June 10	July 18	11	37	14	15	14	1		2	8	6	238	72	83	155	15

This insect deposited the first egg May 27th and the last September 9th, a period of 105 days. The next longest period between first and last days is for No. 2, May 26th to September 3d, or ninety-nine days; then follows No. 13 with ninety-seven days, No. 16 with eighty-one days, and No. 10 with seventy-five days. Leaving out the two incomplete records, No. 7 has the shortest period, twenty-eight days, but this is within four days of her total time. No. 9 has a period between first and last eggs of only thirty-five days. Her last egg was deposited July 1st, and she lived until July 26th. Including all of the seventeen insects under observation, the average time between first and last egg is 57.88 days while the average time under observation is 80.64 days. Several of the insects lived for from ten to twenty days after their last eggs were deposited, and those having long periods attain this record because intervals of three to seven days between eggs were common after about the first of August.

Fresh fruits were supplied twice each day in order to ascertain the distribution of the work over day and night. Did oviposition continue at night, and if so to what extent? Results indicate a nearly even distribution, although the twenty-four hours were not divided equally. The number laid in the daytime is 1,037 as against 917 laid at night. As the season advanced and the days lengthened there would be a period of daylight before examination in the morning, and to insure darkness between the examination at night and the next morning the glasses were placed upon a cloth mat and covered with tin cans so that the insects were in absolute darkness during the night period. This practice was continued for several weeks, but as it apparently made no difference was finally discontinued. The greater number of feeding punctures were made at night. Of the 5,631 feeding punctures recorded, 2,594 were made during the day period and 3,037 during the night, an excess of 443 in favor of night as a time for feeding.

Comparing our record of eggs laid, with the results obtained by Professor Quaintance, wide differences appear. His eight females produced a total of 2,317 eggs, while our seventeen gave only 1,954. The average in one case is 289.62, in the other 114.94. His most prolific insect laid 436 eggs, ours produced but 263. The differences in number of eggs laid may in part account for the differences in length of life. In the Maryland experiment the last insect died on August 2d after eighty-one days confinement. Our No. 6 died on September 26th after 127 days in confinement.

It is possible that the plums supplied in Maryland were more acceptable to the insects than were the apples furnished the insects in Illinois, but we are inclined to regard differences in climate as the more probable cause of the differences in number of eggs and period of oviposition shown by the two records. High temperatures and great humidity are factors tending to accelerate egg production. It was frequently observed during the summer that oviposition was most rapid on warm days and that very few eggs were laid during periods when the temperatures ran low. The summer throughout was cool, there were few warm days, and none of the excessively hot days that characterized the summer of 1903.

It is presumable that Maryland temperatures were relatively higher and that the prevailing humidity was greater than in Illinois. In the absence of definite data it is only possible to suggest probable causes of difference, but whatever the causes may have been, the records show the fact of wide differences in the two sets of insects.

NUMBER OF PUNCTURES FOUND ON FALLEN APPLES.

At intervals during the summer of 1903, fallen fruit was gathered, critically examined, and record made of the number and purpose of the punctures, and number of eggs and larvæ. The results of this examination are tabulated below as an illustration of the extent of the work done by the plum curculio:

Date.	No. of apples.	Total punctures.	Crescent punctures.	Feeding punctures.	Eggs.	Larvæ.	
						Living.	Dead.
May 14–18	405	753	286	467	144	31	32
June 17–18	285	969	649	320	5	32	64
July 10–30	26	517	102	415	9	3	7
Totals....	716	2239	1037	1202	158	66	103

Every apple here examined had been visited by the plum curculio, and the total of 716 apples bore 2,239 punctures. The average for the apples examined in May is 1.86 punctures to each fruit; for apples examined in June, 3.40 punctures to each fruit; and for the few examined in July, 19.88 punctures to each fruit. A little more than half the total number of punctures, or 1,202, were distinctively for feeding. On the apples examined in May and June these feeding punctures were small, cylindrical excavations extending straight into the fruit at right angles to the surface, and were seldom enlarged below. Feeding punctures on the apples examined in July were for the most part enlarged below, so that the excavation in the pulp was from three to four times the diameter of the surface opening.

The crescent punctures numbered 1,037, or, given in percentages, 46.32% of the punctures were crescents, and 53.68% feeding punctures. Division of punctures by percentages for the different months would be as follows:

May, 37.98% crescents and 62.02% feeding punctures.
June, 66.97% crescents and 33.13% feeding punctures.
July, 19.73% crescents and 80.27% feeding punctures.

These figures simply help to illustrate what has been generally observed, that crescent punctures multiply most rapidly during June, and that, as the season advances, feeding punctures become proportionately more numerous.

Our tabulation above records 158 eggs and 169 larvæ, a total of 327. Associate each one of these with a crescent mark and we still have 710 crescents which must be accounted unproductive. These would include crescents made without the accompaniment of egg laying, those whose accompanying eggs had been destroyed, and those whose eggs had hatched, the larvæ having developed and left the fruit. An effort was made to separate these classes, but so many uncertainties were encountered that the attempt was abandoned. However, it may be stated with certainty that the number of crescents cannot be taken as an index of the egg laying capacity of the insect. August 5, 1904, seventy-three apples were collected in an unsprayed orchard near Griggsville and examined for curculio punctures. Seventy of these apples bore 393 crescent punctures, and on 63 of the lot 422 feeding punctures made by the plum curculio were found. Apple curculio injury was much less common. Twenty-one of the apples bore 27 egg punctures, and 29 carried 112 feeding punctures.

August 24, 471 apples were picked from trees in another orchard that had not been sprayed and in which the conditions for insect development were very favorable. One of these apples was free from puncture. On 417 of these apples 1,762 crescent punctures were counted. This is 4.22 punctures for each apple punctured. The feeding punctures made by plum curculio numbered 4,264, and were distributed on 457 apples, or at the rate of 9.33 punctures for each apple.

The apple curculio injury was unusually small; seven apples bore eight egg punctures and 31 apples bore 47 feeding punctures. In gathering these apples they were taken at random as they came to hand, and the lot fairly represents the whole orchard, which is about ten acres in area.

The following figures bearing upon the extent to which apples are punctured and the proportion of crescent marks as compared with feeding punctures are given by Mr. E. S. G. Titus, then assistant to the State Entomologist, and were obtained from an examination of apples on the trees at three different places in southern Illinois in the spring of 1902.* In one lot of 104 apples, 27, or 25.96%, were marked by 58 punctures, 12, or 20.69%, of which were crescents. In a second lot of 100 apples, 68 were marked by 249 punctures, one-third of which were crescents. Of the third lot of 50 apples, 23, or 46%, were marked by 38 punctures, 26, or 68.42% of which were crescents. Further, regarding plum curculios supplied with apples in confinement, Mr. Titus

*Transactions Illinois State Horticultural Society, 1902, page 158.

says: "Four females made in four days 46 egg punctures and 161 feeding pits. Eight females made in this time 48 egg punctures, in which were 19 eggs, and 203 feeding pits. Three males made 63 feeding punctures in two days. Four pairs, males and females, made in four days 327 feeding pits, and the females of these pairs made 28 egg punctures in the same time."

Professor F. M. Webster reports,* finding 158 egg punctures on 136 apples examined, and from these apples eight adult curculios were bred.

The figures above given are sufficient to illustrate the wonderful industry of the plum curculio. The work of making punctures begins as soon as apples begin forming, and continues as long as the fruit remains upon the trees. Each puncture means a blemish, greater or less, according to the purpose of the puncture and the season when made. The great majority of the apples punctured for egg-laying purposes fall early. Such as remain on the trees are ruined by the abundant feeding punctures, especially by those made in late summer and fall. Not infrequently the whole side of a fruit will collapse, owing to running together of the excavations in the pulp. One such fruit examined under a lens showed 61 punctures within the borders of the collapsed area; seven of these were made by the apple curculio and 54 by the plum curculio. This same fruit had 31 separate and distinct punctures outside the area first examined; nine of these were made by the apple curculio and 22 by the plum curculio. Here were 92 punctures, all made for feeding purposes, on one Ben Davis apple that measured one and one-fourth inches in transverse diameter. This apple was taken from the tree July 10th. Other apples selected as being badly punctured were examined August 24th, and gave, 54, 28, 63, 47, and 38 punctures, respectively. In 1903 apples were examined in several orchards in the neighborhood of Barry, and these apples were everywhere found to be badly punctured. The crop was light and undoubtedly punctured worse than would have been the case had the trees borne a full crop, but there were enough apples to demonstrate the abundance of the insects and their capacity for doing injurious work.

ADDITIONAL NOTES ON CRESCENT PUNCTURES.

Differences in feeding punctures have already been referred to. There are also differences in crescent punctures, modifications from the normal form which frequently appear in the latter part of the season, and seem to be due to circumstances rather than to individual peculiarities or any direct influence of season. Observations on the crescent cuts made by the seventeen females kept in confinement during the past season show that the several forms may, at different times, be made by any individual. Upon plums, the crescent, so far as my observation goes, is very uniform

*Purdue University Experiment Station Bulletin 33, October, 1890.

in shape, appearing usually as in Fig. 4, Plate 2; only slight variations have been seen; but on the apple the modification from the usual crescentic form is often considerable. So far as external appearance is concerned, this modification commonly consists in a shortening of the horns of the crescent, often to such an extent that the cut appears perfectly straight; or the cut may be reduced to an irregular form or be perfectly circular. But whatever the external appearance, if the cut was designed to serve the purpose of a crescent cut, it goes deep and extends back underneath the egg-cavity. This cut backward is also true of those perfectly made, but apparently purposeless crescents referred to as unaccompanied by egg-cavities or eggs. If an egg deposited in a normal cavity accompanied by the crescent cut fails to hatch, or if the larva dies soon after hatching, development of the apple usually continues. In these cases the crescent puncture frequently grows out in such manner that it finally leaves only a more or less irregularly shaped russet-colored spot upon the surface of the apple. Such a spot is illustrated by Fig. 3, Plate 18. This mark cannot be regarded as a serious blemish.

From observation of the beetles at work, the conclusion is formed that modifications from the normal crescentic form are not due to faulty instinct, or lack of care on the part of the insect, but to circumstances under which the work is done. In making punctures, the force necessary to press the jaws at the end of the beak into the skin or pulp is mainly derived from the pull by the legs, and this can not be exerted unless the feet are securely anchored. On several occasions beetles have been seen to waive the attempt to make punctures because of inability to anchor the feet. Young apples, still covered with thick pubescence, afford secure anchorage at any point, and here the crescents are found to be quite uniform in shape. Later in the season, as the apples enlarge, the surface presents less curvature, and, unless marked by some defect, becomes perfectly smooth, and the beetle, unable to gain secure footing, has difficulty in making any puncture at all, and often leaves the work incomplete or of altered form. If the apple is slightly wilted or has a slightly roughened surface, beetles have no trouble in anchoring the feet securely, and under these circumstances punctures of normal size and form are made. Very old beetles, even though securely anchored, are often unable, either from weakness due to old age or from injury to the jaws, to make a puncture at all, and no doubt many die from starvation because of inability to puncture the skin and gain access to the edible fruit pulp.

THE APPLE CURCULIO.

The apple curculio has been known as injurious for a much shorter period than has the plum curculio, and it has never been so serious a menace to fruit crops, never has developed the interest or received the attention that has been accorded the plum curculio. It follows that the published accounts of the apple curculio are as meager as the accounts of

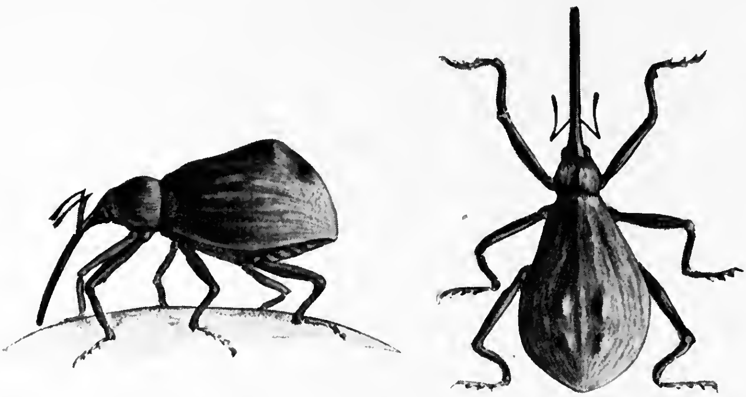


PLATE 10. THE APPLE CURCULIO, ENLARGED.

the plum curculio are voluminous. There is very little of historical matter regarding the insect.

The apple curculio, *Anthonomus quadrigibbus*, was named and described by Say, in 1831. He gives the habitat as the United States, and the food plant upon which it breeds as *Crataegus*. The earliest record which we have been able to find indicating injury to the apple by this nsect is that by B. D. Walsh in the Prairie Farmer for August 27,1864, and this account appears to have been first published in the Valley Farmer.

Mr. Walsh here states that the insect has long been known to infest the wild crab, and ascribes the discovery that it would breed in cultivated apples to Mr. William Cutler, of Beverly, Illinois. Mr. Cutler reported that the first punctures were noticed May 26th, and that June 12th fully half the fruit on trees that promised ten to fifteen bushels per tree had been punctured.

In succeeding years there are occasional notices of injury done by these insects. These reports come mainly from Illinois, Missouri, Iowa, and Wisconsin, but injury is also reported from Connecticut, New Jersey, Pennsylvania, North Carolina, and other Southern states.

The native food plants of the apple curculio are the wild crab and the hawthorn (*Cratægus*). Both these plants are widely distributed; the former represented by about four species, the latter by fifteen species. Whether the apple curculio breeds in all species or not does not appear to be known, nor is its geographical range at all well defined.

In Pike County the insect was found ovipositing in fruits of the Western crab-apple, *Malusiensis*, and of the scarlet haw, *Crataegus coccinea*, but it was very much more abundant upon the haw than upon the crab-apple.

Dr. Le Baron says, "Records lead to the conclusion that this insect is rather a Southern species, more abundant South than North." * This is probably true as far as injuries to apples are concerned, for most of the reports of injuries by this insect made since Le Baron wrote the above come from southern localities. That the insect is distributed well to the north is indicated by the following from Saunders: "But in most of the Northern states and in Canada, although common on thorn bushes and crab-apples, it seldom attacks the more valuable fruits to any considerable extent." †

HABITS AND LIFE HISTORY.

The main facts in the life history of the apple curculio are well established, and were first clearly set forth by Riley in his Third Missouri Report in 1871. Oviposition begins in the spring, while the fruits are quite small. The larvæ feed on the pulp, pupate in the cavity excavated, and emerge from the fruit as perfect beetles. This new generation of beetles for the most part hides away in secure places until late fall, then hibernates until time for ovipositing in the spring.

Very few definite data regarding the length of the various stages—egg, larva, pupa, and beetle—are to be found in the written accounts of this insect. Of the larva Riley says, "It feeds for nearly a month," and of the pupa he says, "After remaining in this state from two to three weeks, it undergoes another moult, and the perfect beetle state is assumed." The difficulty in obtaining exact data on these matters is appreciated when we consider that all of the changes occur while the insect is sealed within the fruit, and cannot be examined without disturbing natural conditions.

During the two seasons of 1903 and 1904, over which this investigation of curculios in relation to the apple in Pike County has extended, the main effort was directed against the plum curculio, as much the more injurious of the two species, but some facts regarding the apple curculio have been gathered and may properly be given place here.

In the spring of 1903, search was made for the beetles April 15th, and

*Prairie Farmer, 1873, 209.

†Insects Injurious to Fruits, 135.

at frequent intervals after that date. None, however, were found until April 27th, and then only a single specimen taken among dead leaves of grass in close contact with the ground. Search among rubbish on the ground was continued, and trees were carefully examined, but no more beetles were found until May 10th. On this date, two specimens were taken from a Ben Davis tree. The next day others were found and the 12th beetles were very common. They appeared to come all at once in company with the plum curculio. May 13th hawthorn trees in woodland adjoining the orchard were observed to be much infested, and several specimens were taken from fruits of the wild crab-apple. The insects were mating, oviposition was in progress, and feeding punctures were multiplying rapidly.

In the spring of 1904, search for beetles in hibernating quarters was unsuccessful; none were found. The first beetle found was taken from an apple tree May 2d; a second was taken May 12th. Several were taken May 19th, and at various times after that date, but throughout the season they were much less abundant than in 1903. In fact, for most of the season the beetles were rare upon orchard trees. May 19th, beetles were taken in considerable numbers from fruits of hawthorn in adjoining forest, and for several weeks the insects were abundant on these native trees. This was the source from which we drew our supplies of this insect for laboratory purposes.

THE EGG.

The eggs of the apple curculio are quite uniform in size, and from measurements of ten are found to be about .04 inch in length and .02 inch in transverse diameter. When first laid they are of a pearly white color. Apparently they swell somewhat by absorption of the juices in the cavity, and within a day or two after being deposited assume a dingy yellowish color.

The length of the egg stage was determined to the hour for eight individuals, and the range is from one hundred hours to one hundred and seven hours, with an average of one hundred and five hours, or four days and nine hours. Without doubt high temperatures accelerate and low temperatures retard the hatching of eggs.

OVIPOSITION.

The first and only description of the process of oviposition of the apple curculio that has been found is that recorded by Professor C. P. Gillette in Bulletin No. 11, of the Iowa Experiment Station, issued in November, 1890. This record accords closely with our observations made in Pike County.

The apple curculio, like the plum curculio, varies the form of the puncture considerably and individuals differ greatly in the time required to complete the process. The position of this insect when engaged in excavating the egg-cavity is shown in Fig. 1, Plate 11. The apple curculio is much less shy than the plum curculio, and no difficulty was experienced in bringing under observation insects engaged in the act of oviposition. Twigs bearing fruits upon which curculios were working were removed from trees and arranged in positions convenient for observation without causing any cessation of work. Bringing the working insects into focus of the lens necessitated getting close to them, but this did not disturb them nor cause them to stop work. The complete operation of making the egg-cavity, depositing the egg, and sealing the cavity was observed and timed in ten cases. In twelve additional cases the latter part of the operation, that is to say, the deposition of the egg and the sealing of the cavity, was in like manner observed under a lens. In the ten cases where the entire process was observed, the work was identical, except in the matters of the time consumed, form of the cavity, and in the fact that five of the beetles rested for a time after completing the cavity and before turning to place the egg. The time consumed in each operation is given below:

APPLE CURCULIO—TIME CONSUMED IN OVIPOSITION.

Date of observation.	No.	Excavating cavity.	Rest in minutes.	Ovipositing.	Sealing.	Total time.
May 13, 1903	1	1 hr. 10 min.		4 min.	2 min.	1 hr. 16 min.
May 13, 1903	2	1 hr. 16 min.	9	5 min.	1 min.	1 hr. 31 min.
May 13, 1903	3	2 hr. 20 min.		8 min.	2 min.	2 hr. 30 min.
May 14, 1903	4	1 hr. 40 min.	2	5 min.	2 min.	1 hr. 49 min.
May 14, 1903	5	1 hr. 24 min.	5	4 min.	3 min.	1 hr. 36 min.
May 15, 1903	6	1 hr. 22 min.		4 min.	2 min.	1 hr. 28 min.
June 4, 1904	7	40 min.		2 min.	1 min.	43 min.
June 4, 1904	8	1 hr. 13 min.	1	6 min.	2 min.	1 hr. 22 min.
June 7, 1904	9	59 min.		6 min.	2 min.	1 hr. 7 min.
June 7, 1904	10	1 hr. 6 min.	2	5 min.	3 min.	1 hr. 16 min.

The average time is about one hour and twenty-eight minutes.

No. 3 was an exceptionally small beetle and consumed an unusual time in the operation. No. 7 was extremely active and strong and completed the process in less than half of the average time. The insect begins work by tearing the skin of the fruit sufficiently to give access to the pulp. Little or no skin is removed; the particles torn generally remain attached and as the beak is worked into the fruit appear as an irregular fringe about the point of entry. For the first fifteen or twenty minutes, the beak is worked slowly downward with no lateral motion; then it is partially withdrawn and worked downward along one side with an interrupted chisel-like motion. This is repeated, and as the cavity enlarges, the head is twisted more and more to one side or the other. This motion slightly enlarges the surface opening. The depth of the excavation is as great as the length of the beak will allow, and towards the end of the

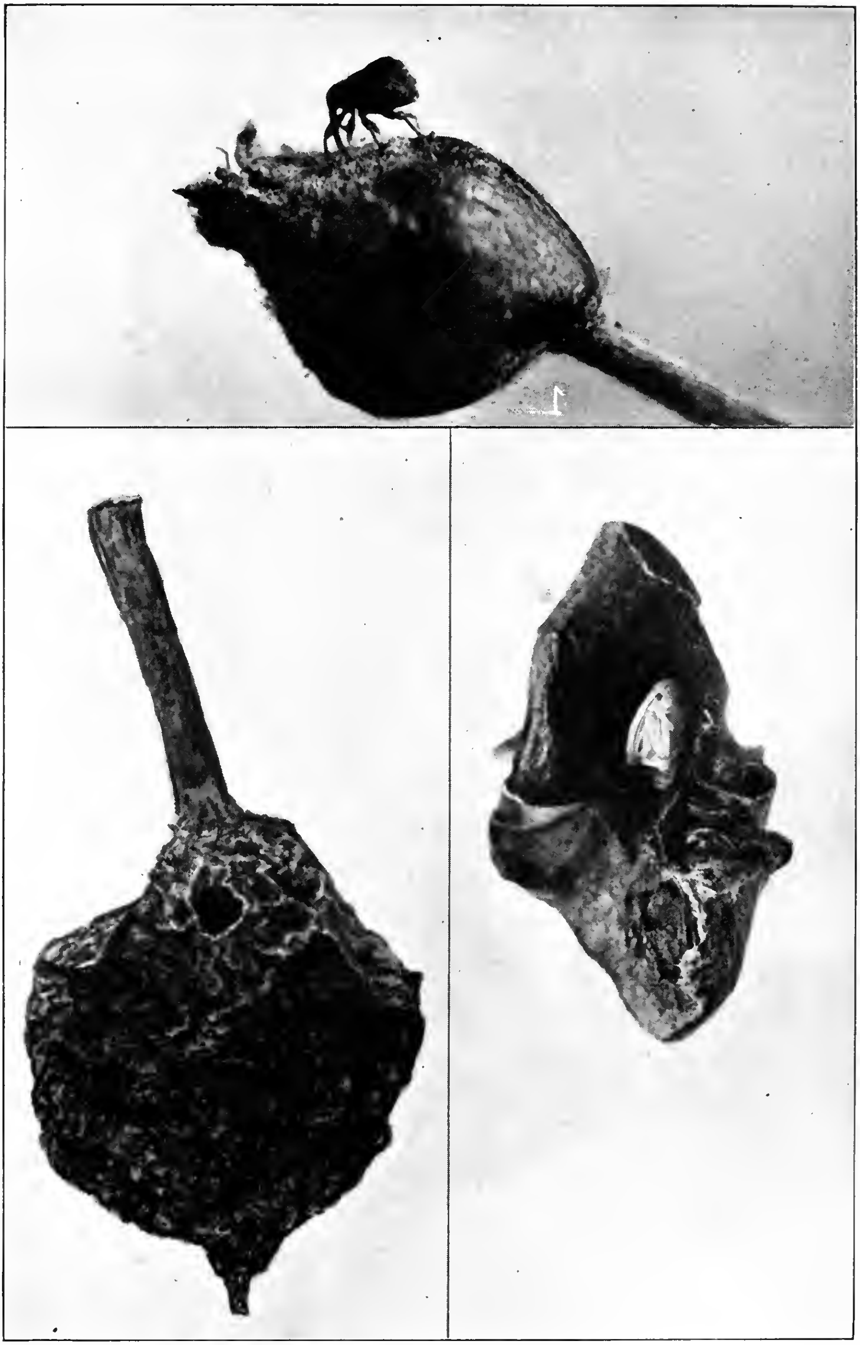
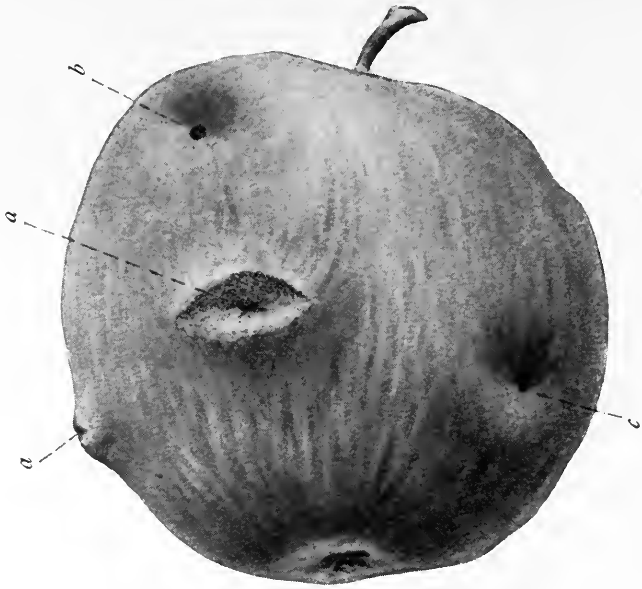


PLATE 11. FIG. 1—APPLE CURCULIO MAKING EGG PUNCTURE. x 3½.
FIG. 2—EXIT HOLE OF APPLE CURCULIO IN SMALL APPLE. x 3½.
FIG. 3—APPLE CURCULIO PUPA IN APPLE. x 3½.

work the head is pressed into the opening until the eyes are half buried, the antennæ being pressed back against the beak with only the ultimate joints protruding. Unless greatly disturbed the beak is at no time wholly withdrawn until the excavation is complete. The pulp as excavated is eaten by the insect and, in each case observed, copious excretion occurred from eight to twelve times during the operation. The excavation completed to the satisfaction of the insect the beak is withdrawn. In five cases the insect turned at once, applied the tip of the abodomen to the opening and deposited an egg. In the other five cases the insect rested without motion for from one to nine minutes before turning to deposit the egg. Almost immediately after the egg is dropped, the insect deposits over the opening a mass of excrement which is greenish in color and of viscid appearance. By an up-and-down motion of the tip of the abdomen this matter is crowded into and plastered down over the opening, effectually sealing it, then the insect quickly walks away. In three of the ten cases, after a short period of rest the insect took wing and flew into a near-by tree; two, after resting, began other punctures; the others were still resting when the observations were discontinued. When an insect leaves after oviposition, there is so little surface evidence of the work that it would not be noticed, and can only be detected by careful examination. In a few hours, however, the plug becomes brown and finally black; in drying it hardens. It effectually seals the opening and remains permanently. Figures 1, 2, 3, and 4, Plate 8, serve to illustrate punctures of the apple curculio. Fig. 1 is a hawthorn fruit natural size, in which are two punctures appearing as minute black dots; Fig. 2 is a portion of the fruit showing the dots enlarged. The upper is the sealed egg-cavity, the lower, the open feeding puncture. Figures 3 and 4 show these cavities in section, enlarged. Other apple curculio punctures are shown in figures 1 and 2, Plate 12.

With one exception the cavities made by the insects observed were of practically the same dimensions, as follows: surface opening, .03 inch in diameter; depth, .12 inch; greatest diameter of enlarged portion, .08 inch. Most of the excavations were nearly cylindrical at the surface end, gradually broadening below, with the egg-cavities various in form. The cavity made by No. 3, a very small beetle, was only .09 inch deep, with a surface opening .02 inch in diameter.

Oviposition by the apple curculio does not necessarily cause the fruit to fall, but it does, as a rule, completely arrest growth at the point punctured. Surrounding parts continue to develop and soon the sealed opening appears at the bottom of a more or less deep depression. Early spring punctures made when the fruit is very small commonly involve the ovary and not infrequently the ovules are eaten out and the egg dropped directly into the ovule cavity. Where this is the case, marked deformity commonly follows. While the plugged opening is left in a depression, it is at the



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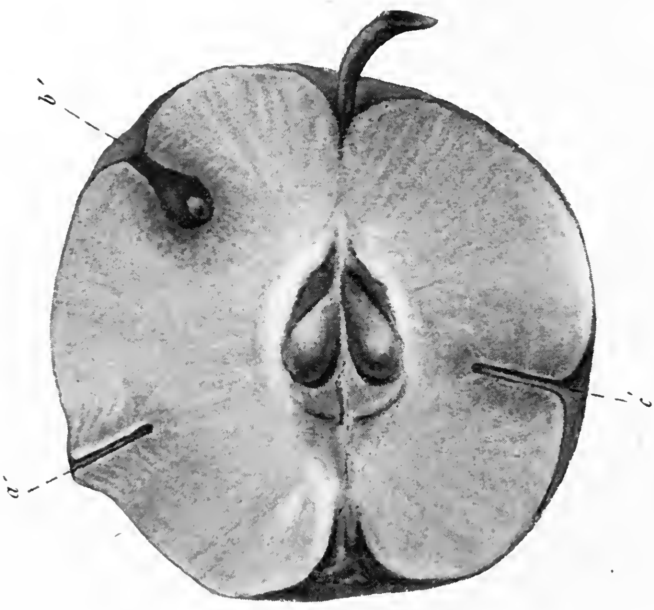


2

PLATE 12. FIG. 1—EXTERNAL APPEARANCE OF APPLE CURCULIO PUNCTURES
FIG. 2—SECTION THROUGH APPLE CURCULIO PUNCTURES.

same time raised away from the core, greatly lengthening the channel leading to the egg-cavity. This channel may become one-half inch to more than an inch in length, and in long section appears filled with brown, granular matter, or as is frequently the case, the channel is completely closed by thick-walled fruit cells and appears as a more or less green line that is compact and hard in texture. Figures 1 and 2, Plate 18, illustrate the punctures here referred to. Egg punctures made a little later in the season when the apples are an inch or more in diameter, do not, of course, reach the core, but they produce the same deformities, and if the egg hatches and the larva begins development, the apple is affected to such an extent that the presence of the developing insect can be detected with considerable certainty by external appearances. Besides the deformity, the infested fruit appears stunted and frequently more or less shriveled. After the beetles leave them, these apples often become dry and remain on the tree indefinitely. An exit hole of the apple curculio in a small, shriveled and dry apple is shown in Fig. 2, Plate 11.

In three cases beetles were observed to spend more than one hour in excavating egg-cavities, and then walk off, without depositing eggs, and begin new punctures. In one case a beetle completed an egg-cavity, turned about, and deposited an egg on the surface near the opening, then turning again, she attacked the egg, devoured it, and after racing about the fruit for a short time, began a new puncture. This was the only case of egg-eating seen, but if the practice is at all common, it may account for some of the many empty cavities found.

PERIOD OF OVIPOSITION. NUMBER OF EGGS.

During the season of 1903, no definite information was obtained regarding the number of eggs deposited, and but little was learned of the length of the period over which oviposition extended. The first eggs were found May 13th, the last July 9th. In the two weeks following July 9th, considerable time was given to the search for eggs, or beetles engaged in ovipositing, but none were found. Beetles were occasionally found resting upon apples, but there were no evidences of any attempt to deposit eggs. The conclusion was reached that oviposition ceased about the middle of July, and that the duration of the period for this work was about sixty days.

In the spring of 1904, plans were laid for securing more definite and detailed information regarding the period for egg laying and number of eggs. In furtherance of these plans, twenty pairs of apple curculios were captured as early in the season as they could be found, and confined in the same manner as were the plum curculios previously mentioned. Fresh apples were supplied daily, at 6:30 in the morning and at 8:30 in the evening. The punctured apples removed were examined; record made of eggs and punctures, and then the apples were placed in glasses and retained, for determination of the period of development. This work was continued until the last beetle died, August 14th. The data accumulated have been brought together in the tabulation on page 523.

PERIOD OF OVIPOSITION.

The first egg was laid May 23d, the last July 22d, so that the egg laying season for this year extended over sixty days. The longest time between the first and last egg for any individual is fifty-six days for No. 8. This insect deposited the last egg July 22d, and died July 27th. Some of the insects lived a much longer time after depositing the last egg than did this one, for example No. 1. This insect lived until August 14th, eighty-seven days from date of capture, deposited the last egg June 23d, but did not die until fifty-two days later. Another, No. 6, was in confinement for eighty-three days, laid a total of only four eggs, the last June 2d, and lived for seventy-two days beyond this, or until August 14th.

This, No. 6, represents one extreme. The other extreme is represented by No. 2. This insect deposited, on forty-eight of the fifty-six days in confinement, a total of one hundred and twenty-two eggs. There were fifty-two days between the first and last egg, and she died July 17th, within twenty-four hours of depositing the last egg. Some of the averages for the twenty females are:

Number of days in confinement	51.6
Number of days on which eggs were laid	27.9
Number of days between first and last egg	34.6

NUMBER OF EGGS.

The total number of eggs recorded was 1,316, an average of 65.8 for each female. Individual records range from 4 to 122. Of the total number of eggs laid, 799, or 60.71 percent, were deposited during the day period, and 517, or 39.29 percent, during the night. This distribution of oviposition between day and night is not so nearly equal as with the plum curculio, but enough eggs are laid at night to indicate a distinctly nocturnal habit.

Departures from normal procedure in oviposition are seen in the thirty-seven egg punctures which were left without eggs, and in the eighteen eggs laid on the surface of the fruit and not accompanied by egg punctures. These eggs on the surface range from one to five each for nine individuals. They were all laid towards the end of the egg laying period, and were probably left on the surface because of inability to make the punctures. It was frequently observed that old beetles experienced difficulty in breaking the skin of the fruit. This may have been because of general debility from age, exceptional smoothness or toughness of the fruit skin, accident to the jaws, or the loss of parts of one or more of the anterior legs. The beak of the apple curculio is so long in proportion to the body that, when starting punctures, it is necessary that the body be

APPLE CURCULIO. EGGS LAID. PERIOD OF OVIPOSITION.

No. of the individual.	Date and time when confined.	Date of death of female.	Number of days under observation.	Eggs and Egg Punctures.									Day.	Night.		Feeding Punctures.		Day.	Night.	
				Number of days on which eggs were laid.	Date of first egg.	Date of last egg.	Number of days between first and last egg.	Number of egg punctures.	Number of eggs.	Number of egg punctures with eggs.	Number of egg punctures without eggs.	Number of eggs on surface with no punctures.	Number of eggs laid between 6:30 A.M. and 8:30 P.M.	Number of eggs laid between 8:30 P.M. and 6:30 A.M.	Maximum number of eggs in 24 hours.	Number of days on which feeding punctures were made.	Number of feeding punctures.	Number of feeding punctures bet. 6:30 A.M. and 8:30 P.M.	Number of feeding punctures bet. 8:30 P.M. and 6:30 A.M.	Maximum number of feeding punctures in 24 hours.
1	May 23, A.M.	Aug. 14, A.M.	83	33	May 23	June 23	31	74	71	71	3		37	34	5	60	319	183	136	19
2	May 23, A.M.	July 17, P.M.	56	48	May 24	July 16	52	121	122	120	1	2	84	38	6	51	345	227	118	22
3	June 13, P.M.	Aug. 11, A.M.	58	12	June 17	July 5	18	18	18	18			14	4	3	42	249	151	98	29
4	May 23, A.M.	June 24, P.M.	33	29	May 24	June 23	29	92	88	88	4		58	30	5	31	167	101	66	14
5	May 23, A.M.	Aug. 10, P.M.	80	28	May 30	July 13	44	53	53	52	1	1	24	29	4	66	362	263	99	19
6	May 23, A.M.	Aug. 14, A.M.	83	4	May 27	June 2	6	4	4	4			4		1	61	182	121	61	11
7	May 23, A.M.	June 3, A.M.	41	37	May 24	June 30	37	108	108	107	1	1	63	45	5	37	120	70	50	7
8	May 23, A.M.	July 27, P.M.	66	34	May 26	July 22	56	66	65	63	3	2	37	28	6	62	414	252	162	21
9	May 23, A.M.	June 20, A.M.	28	20	May 24	June 17	24	60	58	58	2		37	21	6	26	206	110	96	19
10	May 24, P.M.	July 23, P.M.	60	34	May 29	July 8	41	69	68	68	1		40	28	4	55	415	262	153	31
11	June 5, P.M.	July 18, P.M.	43	28	June 6	July 10	35	59	59	59			31	28	4	39	480	279	201	28
12	May 26, P.M.	July 18, P.M.	53	27	May 27	July 8	42	56	52	51	5	1	26	26	6	53	413	229	184	29
13	May 26, P.M.	June 25, P.M.	30	18	May 27	June 18	22	38	34	34	4		24	10	5	30	243	138	105	23
14	May 26, P.M.	July 22, P.M.	57	32	May 29	July 16	48	70	68	63	7	5	43	25	5	50	551	363	188	36
15	May 26, P.M.	June 29, P.M.	34	25	May 27	June 24	27	72	70	70	2		41	29	5	34	241	146	95	20
16	May 27, P.M.	July 22, P.M.	56	34	May 28	July 6	38	86	85	85	1		50	35	5	47	328	194	134	20
17	May 28, P.M.	July 27, P.M.	60	35	May 28	July 16	48	76	78	76		2	39	39	5	54	344	226	118	26
18	May 28, P.M.	July 17, P.M.	50	34	May 30	July 8	39	89	90	87	2	3	58	32	5	48	409	253	156	31
19	May 28, A.M.	July 13, A.M.	45	32	May 29	July 7	40	94	95	94		1	65	30	6	44	490	290	200	32
20	June 8, A.M.	June 24, A.M.	16	14	June 8	June 23	15	30	30	30			24	6	4	16	163	90	73	22

raised as high above the fruit as the length of the legs will allow (see Fig. 1, Plate 11), and secure anchorage for the feet is necessary in order to press the beak against the fruit with sufficient force. On fruit that is large and perfectly smooth, beetles fail to secure that anchorage for the feet, without which it is impossible for them to break the skin. The apple curculio is even more helpless than the plum curculio in this regard.

The maximum number of eggs per day of twenty-four hours varies from one to six for the different insects, and the average maximum is four and three-fourths. This is considerably below the average maximum for the plum curculio; but, as the apple curculio requires more time in preparing a cavity, probably the working time of the two insects for an equal period would not be very different. The season of oviposition for the plum curculio is, however, considerably longer than for the apple curculio.

FEEDING PUNCTURES.

The total number of feeding punctures made by the twenty pairs of apple curculios is 6,441. Of these, 3,948, or 61.29 percent, were made during the day period, and 2,493, or 38.71 percent, during the night period. These percentages are in close accord with the division of egg laying, and serve to confirm the fact that the species is nocturnal as well as diurnal.

The major portion of the feeding punctures are made by the male. It would seem that the female, who eats more than her own bulk of apple pulp every time she prepares to deposit an egg, would not need other food, and it is believed she seldom makes other punctures during the season of oviposition. She does, however, sometimes wholly complete egg-cavities and then leave them without placing an egg, as has been observed on several occasions.

The feeding punctures made by the male are cylindrical, vary from .04 to .08 inch in depth, and are about .04 inch in diameter. The time spent on each puncture varies from ten to fifteen minutes, and sometimes two or three are made with but very short intervals of time between. These feeding punctures generally result in deformities which are as a rule less marked than are those caused by egg punctures. Sometimes the tissue surrounding a puncture develops in such manner as to elevate the puncture above the surface of the fruit, and it appears as a crater-like cavity at the summit of an elevation, as shown at (a) Fig. 1 and (á) Fig. 2, Plate 12. More frequently the growth of the surrounding tissue leaves the original puncture at the bottom of a more or less contracted deep depression, as shown at (c) Plate 12. Further illustration of the effects of apple curculio punctures is given in Plate 13. This plate is from a photograph of an apple picked from the tree August 20th. The apple is marked by nine apple curculio feeding punctures, eight of which caused deformities; five plum curculio feeding punctures, and nine plum curculio crescent punctures, a total of twenty-three punctures. On the face shown in the plate, twelve punctures are indicated. Numbers 1, 2, 3, 4, 7, and 9 are apple curculio feeding punctures; Numbers 5, 6, 8, 11, and 12 are plum curculio crescent punctures; and Number 10 is a plum curculio feeding

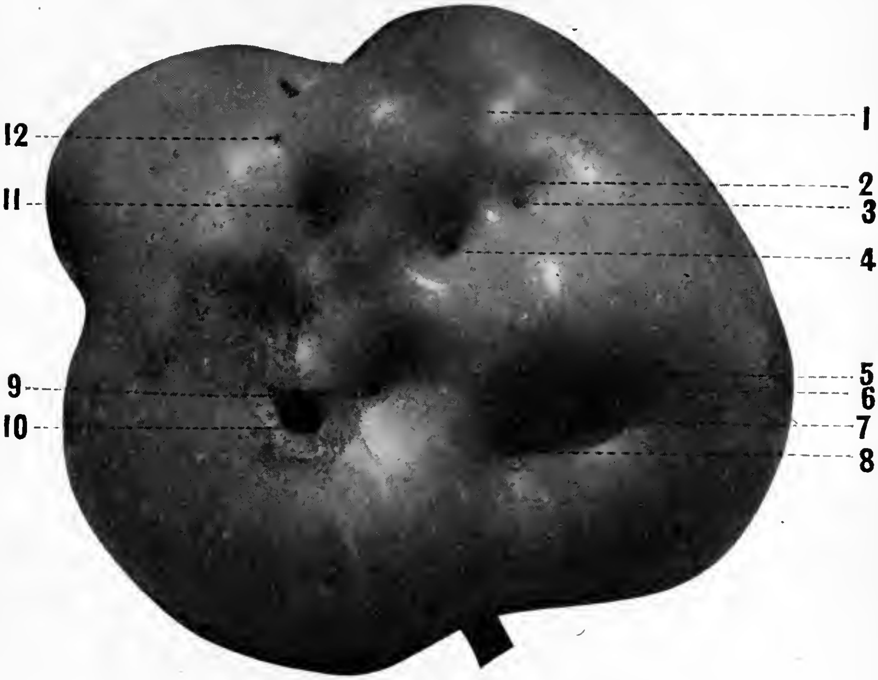


PLATE 13. DEFORMITIES CAUSED BY THE APPLE CURCULIO.

puncture. The egg-cavities with crescents, 5, 6, and 12, either contained no eggs or the eggs did not hatch. Larvæ from the cavities of 8 and 11 bored a short distance and died.

THE LARVA.

The larva of the apple curculio is footless, dingy or yellowish white in color, and owing to enlargement of some of the body segments, is of curved form and does not appear able to straighten out. This larva is very sluggish in movement, but as it pupates in the cavity eaten out, ability to move quickly or far is not essential.

Larvæ from eggs laid early in the season feed in and about the core because eggs deposited in the very small apples are placed close to, or, in many cases directly in, the core. Those from eggs laid at a later period when the apples are larger remain in the pulp; often they simply enlarge the original egg-cavity, or sometimes they eat out a new cavity which connects with the egg-cavity by a small opening. A pupa in a cavity in an apple is shown in Fig. 3, Plate 11.

Several determinations made to within a fraction of a day show that the time from hatching of the egg to the full development of the larva is from nineteen to twenty-one days. The average time in the larval stage may be given approximately as twenty days. Determinations in the same manner place the time as pupa at approximately seven days. Accurate determinations of the full period from deposition of the egg to emergence of the adult or beetle form were recorded for three hundred and thirty-five individuals, and range from twenty-seven days as the minimum to the maximum of forty-eight days.

Thirteen individuals emerged in the shorter period of twenty-seven days. At the other extreme, one appeared on the forty-fourth, one on the forty-seventh, and one on the forty-eighth day. The largest number to appear on any day was fifty-eight, on the thirty-first day.

During the ten days, twenty-seventh to thirty-sixth, inclusive, there emerged three hundred and ten, or 92.54 percent of the whole, leaving only twenty-five, or 7.46 percent coming out on days later than the thirty-sixth. The average period is then 31.8 days, or practically thirty-two days. The first beetles to emerge came out June 30th, the last August 28th, giving a period of emergence of sixty days; exactly the same as the period of oviposition. By months, four, or 1.19 percent, emerged in June, two hundred and ninety, or 86.57 percent, in July and forty-one, or 12.24 percent in August.

HABITS OF BEETLES AFTER EMERGENCE.

Observations made during the season of 1903 indicated that, unlike the plum curculio, the new generation of the apple curculio feed upon apples to a very limited extent, after emergence. Beetles coming out in breeding cages, although constantly supplied with fresh apples, made very few punctures, but remained hidden as much as possible under any shelter afforded. In 1903 beetles were numerous on apples in the orchard until about the middle of July. During the last half of the month they became quite rare and after the first of August none were found upon the trees. Search was then instituted to ascertain where the beetles could be hiding. On August 18th, eight specimens were found among leaves on the ground and two from close down near the roots in blue-grass sod. Other specimens were taken in similar situations on succeeding dates up to October 2. Their food habits during this period were not determined, but they did not feed upon apples. During the season of 1904, very few beetles of the new generation were taken in the orchard. They were at all times rare as compared with the previous season. Fallen fruit was closely picked up and the beetles emerging were captured in the boxes where the fruit was kept. Some emerged from apples on the trees, but no evidence of feeding upon fruits on the trees was found.

In the laboratory, five pairs of newly emerged curculios were placed in glasses at 9:00 a. m., July 4th, and with each pair was placed an apple; the feeding punctures made are here shown:

DATES OF EXAMINATION.

No.	July 5, 9:00 A. M.	July 7, 5:30 A. M.	July 8, 5:30 A. M.	July 9, 12:30 P. M.	July 10, 11:00 A. M.	July 11. 8:00 P. M.	July 13, 9:00 P. M.	July 14, 9:00 P. M.	July 16, 2:00 P. M.	July 18 6:00 P. M.	July 20, 6:00 A. M.	July 22, 8:00 P. M.	July 23, 8:00 P. M.
1	9	18	11	23	6	23			1	4	4	2	
2	13	15	12	21	10	25	7						
3	6	22	7	19	1	5				2			
4	5	11	10	15	2	8	2	2					
5	13	29	8	8		4	1						

All of the beetles fed freely during the first week. Two did no feeding after the tenth day; only one fed beyond the fifteenth day. No punctures were made after the two recorded for No. 1 July 22, the nineteenth day. No food other than apples was supplied. This test shows that under some circumstances beetles do make feeding punctures after emerging, but we have no evidence that they ever attack apples upon trees.

MORTALITY DURING DEVELOPMENT.

The twenty pairs of apple curculios in confinement produced 1,316 eggs. Two hundred and ninety-two eggs, or a little more than 22 percent, were destroyed in examination, so that the apples retained for determination of the period of development contained only 1,024 eggs. From these eggs, three hundred and forty-three living adults were reared. Eight of them were cut from the fruits and are not included in the record of three hundred and thirty-five that emerged voluntarily.

The beetles reared represent 33½ percent of the eggs, and the loss during development is therefore 66½ percent. The causes of this heavy loss are not all apparent. Some eggs failed to hatch; larvæ died at various stages of development; some transformed to pupæ and then died; while others reached the adult stage, but died before emerging. Loss cannot be ascribed to predaceous insects, because such insects were excluded. Only one cause is definitely known, and that is the drying up of some of the small apples early in the season. These apples became so dry and hard that processes of insect development could not proceed. In some cases where single apples contained five or six eggs, it is probable that the stronger larvæ used all the nourishment and that the weaker starved. It is probable also that some individuals were weak from the beginning, and although food was abundant, had not sufficient vitality to complete the transformations. During the season of 1903, considerable evidence was accumulated that pointed to strong growth of the fruit as a cause of mortality among apple curculio larvæ in fruit upon the trees. Many of the egg-cavities cut into were found to be more or less completely filled by intruding cell masses. These cell masses were quite firm in texture. Sometimes they invaded the cavity from the bottom, but often grew as wart-like excrescences from small areas on the sides of the cavities. In several instances, dead larvæ were found pressed close to the cavity wall by these intruding cell masses.

CHARACTERISTICS OF THE TWO SPECIES OF CURCULIO COMPARED.

Comparing the damage done by the two curculios under consideration it is quite plain that for northern and central Illinois, at least, much the greater injury is done by the plum curculio. This is due to numerical superiority, to longer period of work, and to the more destructive character of the punctures made. The greatest damage done to apples by the plum curculio is done after all injurious work by the apple curculio has ceased.

During the season of oviposition, when insects are upon the trees, the apple curculio is much less timid than is the plum curculio. It allows close approach without appearing disturbed, while the plum curculio when approached will at once seek a hiding place. The apple curculio is not so partial to dense shade, it endures strong light better, and is less given to hiding from sight. It has not the protective instinct of folding its legs and dropping, which is so characteristic of the plum curculio, although it occasionally does fall, and is taken in jarring over a sheet. A characteristic position taken by the apple curculio when disturbed is shown in Plate 14. The apple curculio more readily takes wing than does the plum curculio. This we have tested many times, always finding the plum curculio very reluctant to fly, either by day or by night, while the apple curculio will usually attempt flight rather than crawling off to hide. On two occasions, while jarring over a sheet, apple curculios have been observed to fall, spread the wings and fly before reaching the sheet. In flight, the apple curculio takes a straight course and flies with only moderate speed. The plum curculio, in all cases observed, took a zigzag course and traveled at high speed. It has been shown by records made during the past summer that both species are to quite a degree nocturnal in habits, so far as oviposition and feeding are concerned. Results of attempts to ascertain habits of movements at night were not sufficiently decisive, but indicate in a general way that the plum curculio does fly at night. In the summer of 1903, when the beetles were especially abundant, two trap lanterns were used for several weeks. The only curculio caught was an apple curculio, probably an accidental catch. Neither species fly to light. From July 17th to August 24th, several sheets of "Tangle-foot" fly-paper were suspended in trees to be examined morning and evening. In this way eighty-two plum cruculios and one apple curculio were caught. Of the plum curculios, sixty-nine were caught during the night period and thirteen during the day period. Examinations, however, were not made at perfectly regular hours, and there was always a period of daylight before the morning examination and after the evening examination, so that we do not regard the recorded division of the catch as absolutely correct. But making all due allowances, there was evidently a greater number of plum curculios on the wing at night than in the daytime. This conclusion is confirmed by one specific instance—the sheets examined at dark and again in the early morning gave a catch of nine plum curculios. The highest number for any day period was three. Readiness to take wing was also tested at night by use of a bullseye lantern. Search for beetles was made between the hours of nine and ten on a dark night; thirteen plum curculios were found resting on apples. Whenever the glare of light was directed upon a beetle, it quickly moved around the fruit into the shade; following with the light simply kept the beetle moving; in no case was flight induced, although in some instances beetles were followed by the glare of light for several minutes.

PLATE 14. APPLE CURCULIO ON APPLE, POSITION WHEN DISTURBED. x 3½.

Tests of willingness to fly by day were also made with much the same result. No amount of badgering induced flight; they would either drop or try to avoid the annoyance by crawling away.

The plum curculio is erratic about dropping when jarred. Sometimes beetles are seen to drop upon being approached and before a leaf of the tree is disturbed; sometimes the lightest touch upon an adjacent branch will cause them to fall, and again they will cling on through severe jarring. In one instance a small branch was grasped in hand about one foot below an apple on which a beetle was resting. The branch was then given a quick blow with a lead pencil, between the hand and the apple. The beetle made no movement. Blows were repeated at short intervals. At the fifth stroke the legs were drawn in close to the body, and the beetle assumed the position shown in Fig. 3, Plate 2. No further evidence of disturbance was seen until the eighteenth blow was struck, then hold of the fruit was released and the beetle fell. This test was repeated many times, and if the beetle did not fall when the branch was taken in hand, sometimes one, or more frequently six or eight blows were required to dislodge it.

REPRESSION.

MEANS OF CONTROLLING CURCULIOS.

What remedies possessing the qualities of efficiency, ease of application, and reasonable cost may be used against our two species of curculios? This is an important question, and one upon which various opinions have been expressed.

Jarring over sheets spread under trees, the old and still standard remedy for plum curculio on plums and cherries, while possible in young apple orchards just coming into bearing, cannot be recommended as practicable for orchards of commercial extent.

This method was thoroughly tested during the season of 1903 on trees sixteen years of age, using a sheet twenty-four feet square. The accompanying Plate (No. 15) illustrates this sheet in use.

Our average catch per tree up to July first was seventeen plum curculios and one apple curculio at each visit. As many as sixty plum curculios were taken at one time from a single tree, but the trees were too rigid to be properly jarred, and the spread so great that a sheet of sufficient size is not easily handled from tree to tree.

REPELLENTS.

Growers of plums and cherries many years ago tried various repellents, such as burning sulphur and coal tar, sprinkling with whale-oil soap, or soap and tar, and dusting with plaster, air-slaked lime, or car-

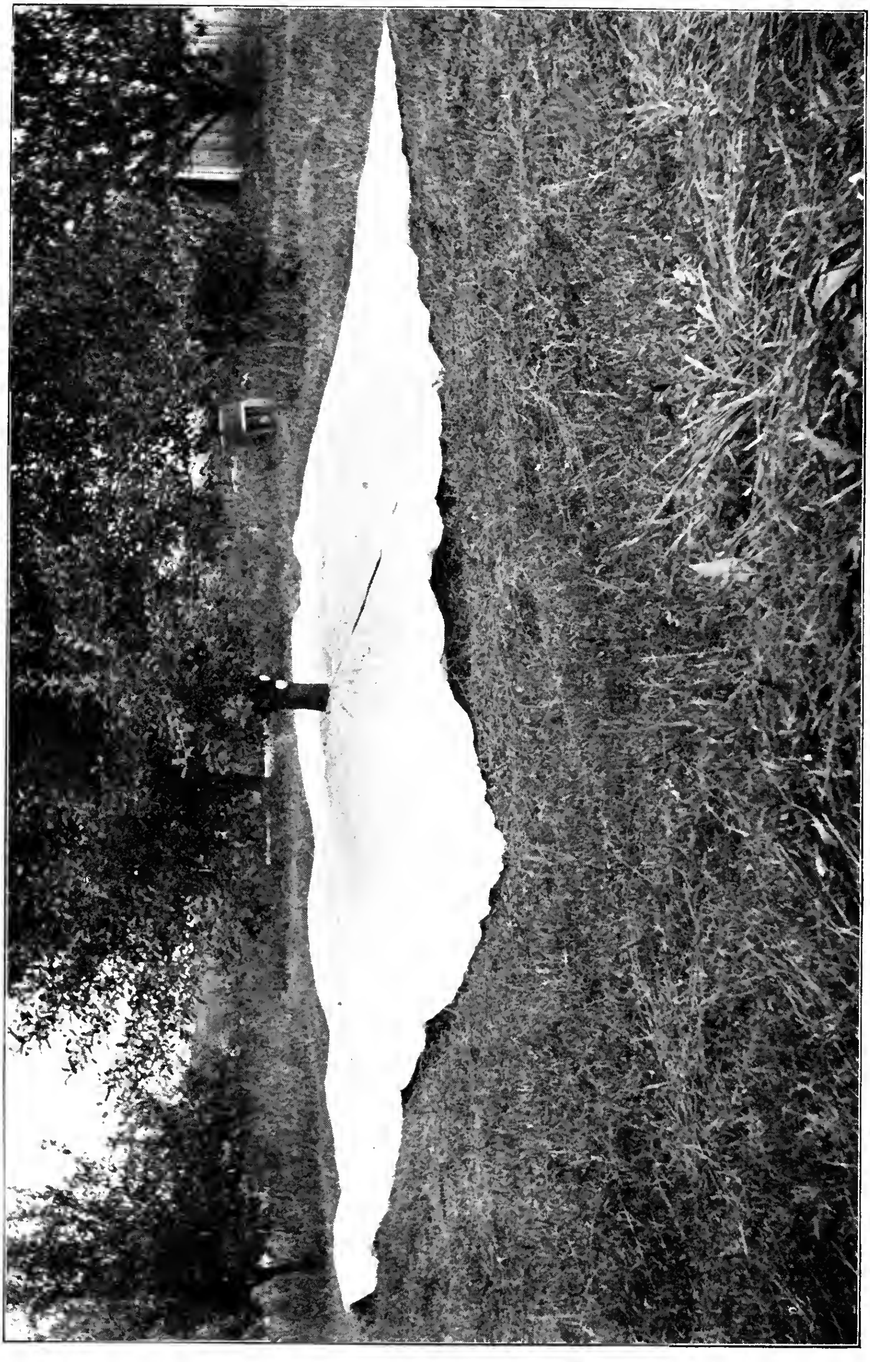


PLATE 15. SHEET USED IN JARRING WORK.

bolized lime. Transactions of various horticultural societies contain reports of the successful use of these repellents, but adverse reports are in the majority, and the fact that these remedies have not come into general use is sufficient evidence that they are ineffective.

ARSENICAL POISONS.

Spraying with arsenical poisons has been the subject of experiments during the last twenty years. Results of reported experiments have been various, but in the main favorable. While some have been entirely unsuccessful in diminishing the amount of injury, most have reported varying degrees of benefit. As high as 75 percent of possibly injury controlled is reported in one or two cases. No one has claimed perfect success, but in several cases the benefit has been sufficient to warrant commending the use of arsenites to the fruit-growers. Most of those who have experimented with the arsenites have worked upon stone fruits, and the most common recommendation is to jar and supplement this with spraying.

G. C. Brackett reports * that check trees gave as large a percent of sound fruit as did trees thoroughly sprayed with London Purple.

Prof. C. M. Weed, from experiments on cherries, concludes,† "First, that about three-fourths of the cherries liable to injury by the plum curculio can be saved by two or three applications of London Purple. Second, that a sufficiently large proportion of the plum crop can be saved by the same treatment to insure a good yield when a fair amount of fruit is 'set.'"

Prof. A. J. Cook says,‡ "I believe I am justified in the conclusion that spraying with the arsenites will never become a satisfactory remedy for the work of curculio."

The earliest and most complete experiments with arsenites for curculio injury to the apple were those conducted by Professor Forbes in 1885, and reported in the transactions of the Illinois State Horticultural Society for that year. In the experiments, five trees were sprayed, and for each sprayed tree a check was retained for comparison. Two trees, sprayed eight times with Paris green between June 9th and September 3d, had 27.3 percent of the fruit punctured by curculios, while the corresponding check trees showed 51.3 percent of injury. During the same period, eight applications of London Purple were made to one tree, which on final count of fruit gave 39 percent punctured, while the fruit of the check tree showed 48 percent. Two trees were sprayed with lime water, and of this treatment Professor Forbes says, "While producing some effect on the curculios, lessening the damage seemingly about one-fourth, lime is less

*Insect Life, December, 1888, page 193.

†Proceedings of the Society for the Promotion of Agricultural Science, 1889, page 107.

‡Proceedings of the Society for the Promotion of Agricultural Science, 1890, 23.

efficient in this respect than Paris green." Again, in conclusion, "Furthermore, if we must judge from results thus far reached, these various applications are of too slight effect upon the apple and plum curculios to make them worthy of use against these insects; Paris green diminishing curculio blemishes less than one-half, London Purple about one-fifth, and lime not far from one-fourth."

SPRAYING EXPERIMENTS AT BARRY IN 1903.

When this investigation of curculio injury was commenced in the spring of 1903, one of the first things done was to select blocks of trees for treatment by spraying with arsenical poisons. Two blocks of sixty trees each were selected. One was in the orchard of Mr. J. R. Williams; the other, twenty rods distant, in the adjoining orchard of Mr. Albert Blair. Both orchards were planted the same year, and were at this time (1903) eighteen years old. The trees stood twenty-four by twenty-eight feet, and so completely did they cover the ground that passage between them was difficult. In the Williams orchard, blue-grass sod covered a considerable portion of the ground, and the surface mulch of leaves and dead grass was heavy. In the Blair orchard, the trees were not so large, branches not so thickly interlaced, and passage between trees less obstructed. The ground was covered with a scattering growth of plants, representing a number of species, including several grasses, but there was no established sod. Dead leaves and grass were less abundant, and, in general, the ground was cleaner, affording less favorable hiding-places for insects than did the Williams orchard.

The blocks of trees were divided into six plats each, as shown in the diagrams on pages 534 and 535.

The plats were of ten trees each, except that, owing to vacancies, the check plat in each block (plat 3) contained only eight trees, and plat 6 in the Williams orchard was reduced in like manner to eight trees.

In order to control in some degree apple scab and reduce as far as possible the injury from codling moth, it was determined that all trees of both blocks should receive three early applications of Bordeaux mixture and Paris green. Following the third spraying, plats 1, 2, and 4 of each block were to receive a varying number of applications of Paris green. Plat 3 of each block was to be retained as a check, and given no further spraying. The plats numbered "5" were to be treated with arsenite of lime and those numbered "6" with arsenate of lead. A definite schedule was prepared on the plans as outlined above, and was closely followed throughout the season. The number of applications each plat received, with formulæ and dates of application, is given below:

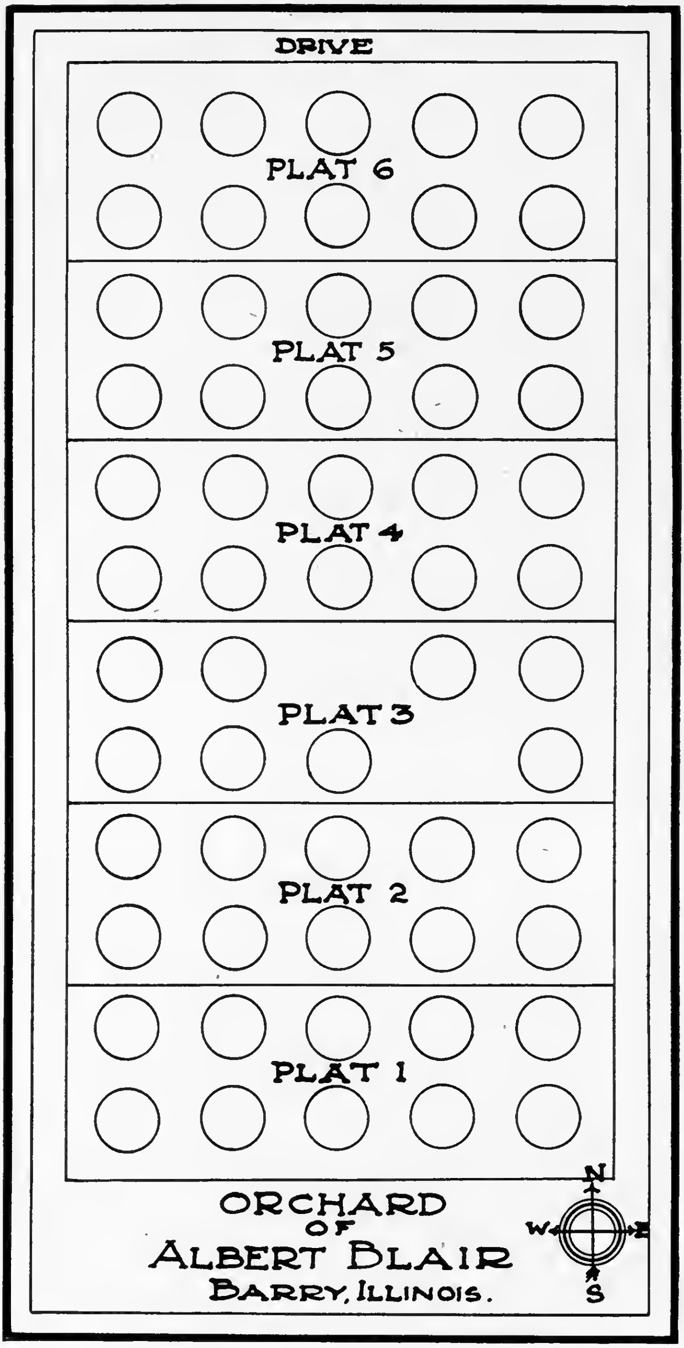

DRIVE
PLAT 6
PLAT 5
PLAT 4
PLAT 3
PLAT 2
PLAT 1
ORCHARD
OF
ALBERT BLAIR
BARRY, ILLINOIS.
N
W
E
S

PLATE 16.

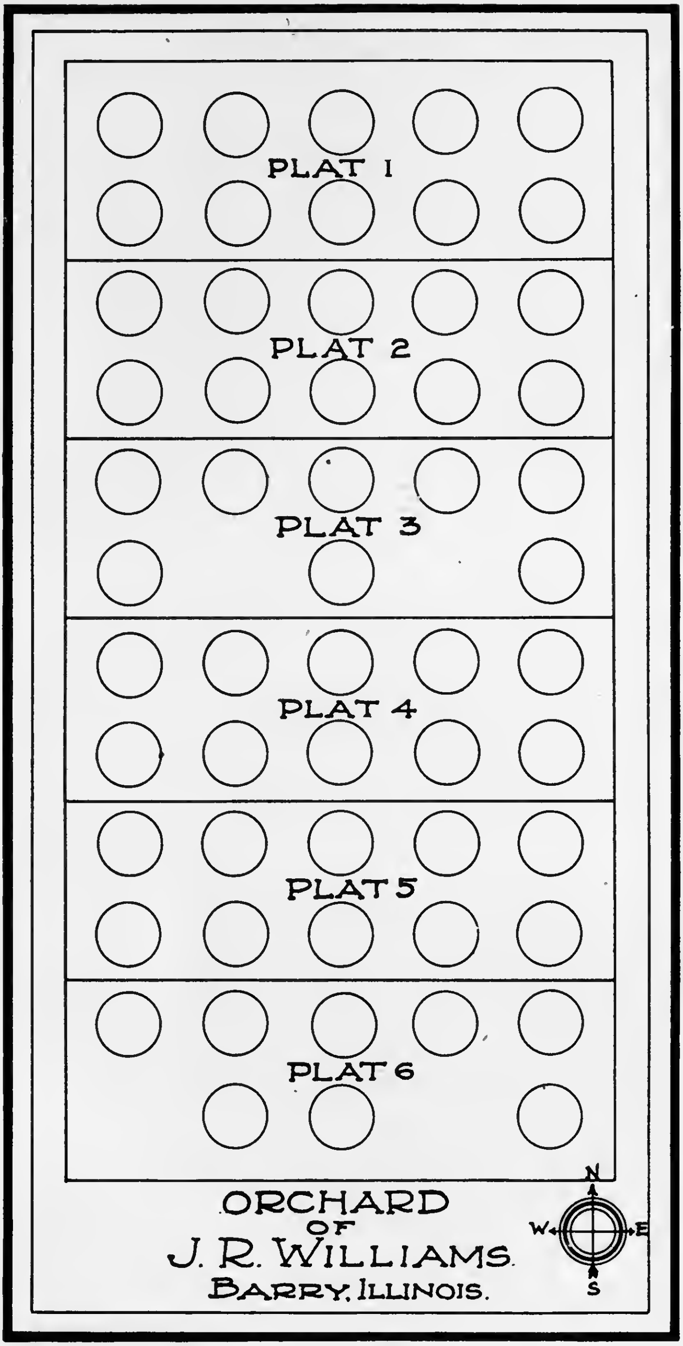

PLAT 1
PLAT 2
PLAT 3
PLAT 4
PLAT 5
PLAT 6
ORCHARD OF J. R. WILLIAMS. BARRY, ILLINOIS.
N
W
E
S

PLATE 17.

TREATMENT OF PLATS FOR CURCULIO.

Orchards of Albert Blair and John R. Williams, Barry, Pike County. Season of 1903.

All plats were given three applications for scab and codling moth, using Bordeaux mixture and Paris green. Formula, 4–4–¼–50.

First, when buds were bursting . . . . April 15th and 16th.
Second, just after petals had fallen . . . . . May 4th and 5th.
Third, one week later . . . . May 12th.

Plat 1.—This plat was sprayed once each week from May 15th to July 31st, and was given a final application two weeks later on August 15th. The dates of application were May 15th, 22d, 29th; June 5th, 12th, 19th, 26th; July 3d, 10th, 17th, 24th, 31st; August 15th.

The material used was Paris green, ½ lb.; lime, 6 lbs.; water 50 gallons.

The number of applications was thirteen, which, with the three applications of Bordeaux mixture and Paris green, makes a total of sixteen.

Plat 2.—This plat was sprayed on dates as given below, using the same formula as used on plat 1; May 15th, 22d; June 15th; July 6th, 27th; Aug. 17th; September 7th.

Seven applications were given, or, adding the three early applications, a total of ten.

Plat 3.—Check, no spray after May 12th.

Plat 4.—This plat was sprayed with the same formula used for plats 1 and 2, on May 15th, 22d; June 15th; July 6th, 28th; five times, or, adding early applications, a total of eight.

Plat 5.—Arsenite of lime was applied to this plat four times as follows—May 23d; June 6th, 20th; July 6th.

The formula used was—White arsenic, 2 oz.; sal soda, ½ lb.; lime, 4 lb.; water, 50 gallons.

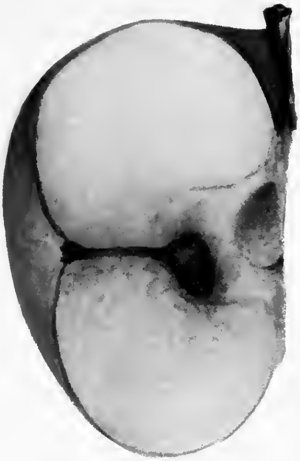
Add the three applications of Bordeaux and Paris green to the four of arsenite of lime and we have a total of seven applications.

Plat 6.—This plat was sprayed with arsenate of lead made on the following formula—Lead acetate, 12½ oz.; soda arsenite, 5 oz.; water, 50 gallons.

Four applications were made, May 23d; June 6th and 20th; and July 6th. The total number of applications is seven, the same as for plat 5.

The spraying outfit used for the early applications was a "Noxall" 250 gallon tank on which was mounted a Gould "Monarch" pump. Two lines of hose, each thirty feet long with Bamboo extension rods twelve feet long fitted with double Vermorel nozzles completed the outfit. Careful attention was given to the agitation of the mixtures, Nozzle caps with openings of the smallest size were used, and as high pressure as is possible with the hand pump was maintained. The quan-

1



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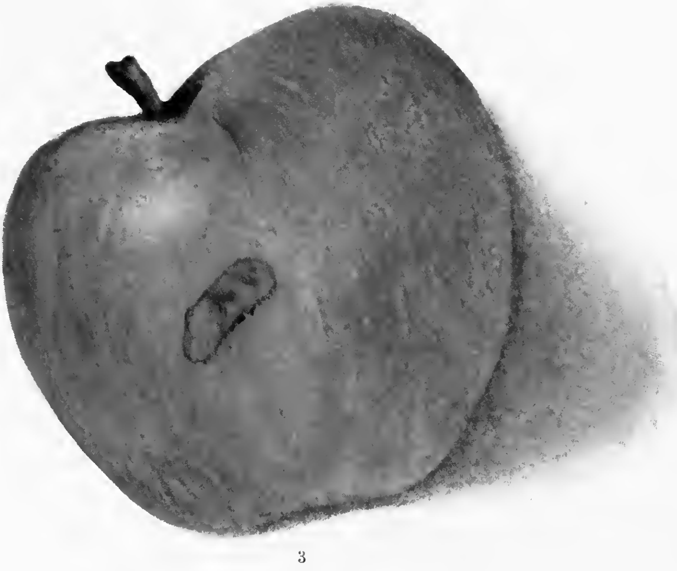


3

PLATE 18

1 Apple curculio egg puncture, showing how channel has lengthened with growth of apple.
2 Another example of apple curculio puncture.
3 Showing a crescent mark where egg has failed to hatch; the mark has grown out, leaving a russet spot as a surface blemish.

tity of material sprayed upon each tree was approximately three gallons at each application. For later applications, where only one or two plats in each block were sprayed at a time, the hose was coupled to a "Spraymotor" pump mounted on a fifty-gallon barrel. This outfit was as effective as the other, and was used because more easily portable. Constant care was exercised to secure even distribution, and, in general, to do the work in the best possible manner. A slight spotting of foliage followed some of the later applications of Paris green, but the injury was not serious.

Cultivation and breaking up of sod on the plats began about June 20th. For this purpose, two "Clark's Cutaway Harrows" were provided, one of which was extended by means of an oak plank to a spread of sixteen feet. This arrangement made possible the cutting of sod close to the tree trunks. After these tools had gone over the ground several times, a toothed-harrow was used to smooth the surface. These operations were repeated at intervals, until the surface was free from all vegetation. In July the ground under the trees was raked smooth in order to facilitate the gathering of fallen fruit.

Windfalls were gathered nine times during the season. Each lot of fruit gathered was carefully examined and record made of curculio punctures. The dates of gathering were as follows: June 18th, 19th; June 26th, 27th; July 3d, 4th; July 21st, 22d; July 28th, 29th; August 10th, 11th; August 28th, 29th; September 11th, 12th; and October 1st and 2d.

October 1st and 2d, the fruit remaining on the trees was picked, examined, and record of punctures made, as with the fallen fruit.

RESULTS.

On final computation, it was found that a total of 29,943 apples had been gathered and examined. Of these, 25,363, or 84.7 percent were gathered from the ground, and 4,580, or 15.3 percent were picked from the trees. The following tabulations show the numbers and percent of punctured and puncture-free apples taken from each plat in each of the two blocks.

DISCUSSION OF RESULTS.

A glance at the tabulations given discloses the fact that, so far as any favorable results are concerned, our labor of spraying was thrown away. Spraying in this instance did not control curculio injury. Apparently, frequent spraying had some influence, because the percentage of uninjured apples from the plats receiving sixteen applications is a little higher than for any other plats, but the differences are too small to warrant any claim of real benefit. During the season, the fruit on the sprayed plats and on the trees in all other parts of the orchards was critically examined many times, and at no time could there be detected any diminution of injury that might be attributed to the spray applied.

ORCHARD OF J. R. WILLIAMS, BARRY, 1903.

No. of Plat.	Total fruits picked		Total fruits windfalls.		Total.		Grand total.	Percent punctured.	Percent not punctured.
	Punctured.	Not punctured.	Punctured.	Not punctured.	Punctured.	Not punctured.			
I	880	36	3021	182	3901	218	4119	94.71	5.29
II	415	22	1767	81	2182	103	2285	95.49	4.51
III	411	10	2491	27	2902	37	2939	98.74	1.26
IV	742	29	3630	69	4372	98	4470	97.81	2.19
V	657	43	6094	93	6751	136	6887	98.03	1.97
VI	413	8	3696	88	4109	96	4205	97.72	2.28
Total	3518	148	20699	540	24217	688	24905	97.24	2.76

3,666 apples, or 14.72 percent, were picked from the trees.
21,239 apples, or 85.28 percent, were windfalls.

ORCHARD OF ALBERT BLAIR, BARRY, 1903.

No. of Plat.	Total fruits picked.		Total fruits windfalls.		Total.		Grand total.	Percent punctured.	Percens not punctured.
	Punctured.	Not punctured.	Punctured.	Not punctured.	Punctured.	Not punctured.			
I	118	24	399	75	517	99	616	83.93	16.07
II	100	19	330	30	430	49	479	89.77	10.23
III	67	11	234	22	301	33	334	90.12	9.88
IV	151	15	459	48	610	63	673	90.64	9.36
V	106	12	688	50	794	62	856	92.76	7.24
VI	281	10	1746	43	2027	53	2080	97.45	2.55
Total	823	91	3856	268	4679	359	5038	92.87	7.13

914 apples, or 18.94 percent, of total fruits were picked from trees.
4,124 apples, or 81.06 percent, of total fruits were windfalls.

The materials used in spraying were known to be of the best obtainable, and no fault could be found with the thoroughness of the applications. The experiments were reasonably extensive, and the spraying dates covered practically the whole season.

In considering possible reasons for the results obtained, there appear three factors of undoubted influence.

First.—Weather conditions of early spring and their bearing upon the crop.

Second.—Location of the plats treated in the midst of large orchards. These orchards are at several points contiguous to tracts of native woodland in which hawthorn, wild crab, and wild plum, native food plants of curculios, are abundant.

Third.—Unusual abundance of the insects.

The weather of early spring was mild and buds pushed forward rapidly. April 15th blossom clusters were open, and April 22d most trees were in full bloom. Then came a period of cloudy weather, with frequent cold rains, continuing until May 1st and followed on that date by a severe freeze. Blossoms and young fruits fell rapidly, and few were left upon the trees. The small average product per tree can be judged from the totals of fruit gathered, as shown in the preceding tabulations. This scarcity of fruit is certainly in some measure responsible for the high percentage punctured.

The possible influence of the second factor, the location of the plats in the midst of large orchards, was appreciated and discussed before work began, but there appeared no possible way of changing conditions in this respect. Curculios are winged insects. They fly. We may suppose that all curculios infesting a block of trees chosen for treatment are killed by applications of arsenical poisons; there is nothing to prevent invasion by a new army of insects from surrounding untreated trees, and this might go on indefinitely through the season. Practically, we know nothing of how many curculios were killed by poisons applied, nor do we know to what extent the suggested movement of curculios from untreated to treated trees took place. We do know that during the whole season the insects were very abundant on both treated and untreated trees.

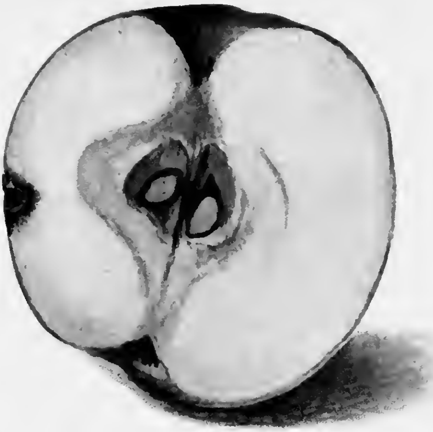
The third factor tending to raise the percentages of injury done, is the excessive abundance of the curculios. The year previous, 1902, was a year of abundant fruit. The insects were undisturbed throughout the season. They multiplied enormously and hibernated through a mild winter; hence their abundance in 1903. This abundance is illustrated by the fact that plum curculios needed for laboratory purposes were gathered by simply picking them from apples while feeding, ovipositing, or resting. There was never any trouble in obtaining plenty in this manner. Early in the season, the apple curculios were taken in the same way, but later they became rare, and late in July entirely disappeared.

The percentages of punctured fruit on the treated and check plats, as given in the tabulations, afford no evidence that any curculios died from poison. We do not know whether the arsenites applied killed many, few, or none. One attempt was made to gain information on this point. A tree bearing considerable fruit, located outside our treated blocks, was sprayed heavily with Paris green. Immediately afterwards a sheet, 24 x 24 feet, was spread underneath, and examined twice daily for eleven days. It was thought that if curculios took the poison they would become sick and fall upon the sheet below. Results were entirely negative. On first examination, two living and apparently healthy apple curculios were found. The fourth day three living and active plum curculios were taken. Subsequent examinations yielded nothing. No dead or ill curculios were at any time found. To be sure, there may be error in supposing that poisoned curculios would fall. They may cling in death agony to the tree, or, on experiencing the first pangs, take wing and fly away. Again, some might fall and be devoured by birds or insects in the intervals between examinations. In spite of these considerations, the most probable reason why no dead curculios were found is because none were killed.

Laboratory experiments show that Paris green will kill curculios, as it will any animal life, if taken internally in sufficient quantity. The great difficulty is in administering a sufficient dose to insects that in the early part of the season disturb so small a portion of fruit surface in their feeding and oviposition. In an experiment carried through by Mr. J. R. Shinn, one apple was treated with a mixture of Paris green and water at the rate of four ounces to fifty gallons; a second with a similar mixture at the rate of eight ounces to fifty gallons; a third with twelve ounces to fifty gallons; and a fourth with sixteen ounces to fifty gallons. These apples were placed in separate jars, and in a fifth jar was placed an untreated apple. Ten plum curculios were placed in each jar. In the jar containing the apple treated with four ounces to fifty gallons three were dead in four hours, five were dead at the end of six hours; no further fatalities resulted until the fourth day, when one more died, and all were dead at the close of the fifth day. The next stronger mixture gave but slightly different results. Two were dead in two hours, and five at the end of eleven hours. At the end of the fourth day, seven were dead. One more died on the fifth day, and the two remaining on the seventh day. Of the lot confined with the apple treated with twelve ounces to fifty gallons, one died in seven hours, six were dead at the end of eleven hours, and all were dead at the end of the third day. Where the apple was treated with the mixture of one pound to fifty gallons, all beetles died within twenty-four hours. Of the beetles confined with the untreated apple, one died on the fifth day, and eight were dead at the end of the seventh day. From the mortality here shown, we may infer that some at least of the later deaths in the other jars were due to natural causes, and not to the poison.

The results of this experiment simply indicate that if Paris green is applied and its presence maintained in sufficient quantity, so that the curculios are sure to take it when making punctures, we may be quite sure of good results in the destruction of the plum curculios.

With the apple curculio, however, results derived from a single test are not so promising. Two apples treated with Paris green in water at the rate of one pound to fifty gallons were placed in separate jars. In one, ten plum curculios were placed; in the other ten apple curculios. The plum curculios were all dead at the end of ten hours. At the end of six days the apple curculios were all living, and to all appearances in good health. This result strengthens a conviction derived from observation, that the apple curculio eats very little, if any, of the skin of the fruit. The punctures they make are minute. The skin is torn up, but commonly



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3

1

PLATE 19

1 Ben Davis apple, showing late feeding punctures of plum curculio. Natural size.
2 Section of the apple, showing section of one of the punctures. Natural size.
3 The puncture of Figure 2 enlarged.

the torn particles are not detached. Often in watching beetles at work it has been observed that the torn particles of skin stand erect as a sort of fringe about the beak at the point of insertion. On withdrawal of the beak, this broken skin sometimes falls back over the opening, completely closing it.

No doubt apple curculios sometimes eat small particles of apple skin, but the quantity is so minute that the chances of taking in poison that has been distributed over the surface are very remote.

Plum curculios are much more voracious feeders. They make larger holes, and eat more skin; hence there is greater probability that they will take in poison and succumb under its action.

But even with our most careful spraying in a commercial way, where Paris green is generally used at the rate of four ounces to fifty gallons, there are ample opportunities for curculios to puncture the fruit and still escape injury. The writer has examined a large number of apples taken from trees that had been thoroughly sprayed, and finds that, as a rule, many particles of the poison can be detected on the fruit surface, but no fruit has been seen that approached being completely covered. On all there are many areas where the curculio could work with impunity. Very young fruits catch and retain more particles of the poison than do older fruits. This is because of the pubescence. As the fruit grows, this pubescence is shed, and the poison of early applications largely goes with it. In later applications, some particles will find lodgment immediately about the stem or in the basin of the calyx, at which points the pubescence is more tardily cast off, but proportionately very few particles are caught and retained on the smooth surface of the fruit.

SPRAYING EXPERIMENTS IN 1904.

The character of the results of the spraying experiments in 1903, as detailed in the preceding pages, made repetition of the work under different circumstances, if not actually essential, at least desirable. It was determined to secure, if possible, the use of an isolated orchard, of such size that it could be treated entire. This plan would eliminate any possible modification of results from ingress to the plats of new insects from surrounding orchards. After examination of several orchards, which from size or situation were deemed unsuitable to our purpose, selection was finally made of the orchard of Mr. John Sawdon, situated two miles south of Griggsville and about eighteen miles distant from the orchards used in 1903. This orchard is a little over five acres in extent, and was planted twelve years ago with 260 trees; ten rows of twenty-six trees each. The four west rows are Ben Davis, the two central rows Wealthy, and the four east rows Milam. It is back some distance from the highway, and the nearest bearing orchard is nearly a half mile distant. The surface is somewhat uneven and broken by two gullies which cross it. The orchard had never been sprayed, and has not been cultivated for several years. It is now in grass, and a crop of timothy was removed last year.

Mr. Sawdon kindly placed the orchard in charge of the department for such experiments as might be decided upon, and work was commenced in April. Mr. James R. Shinn, who had charge of the work at Barry during most of the season of 1903, was placed in immediate charge of the work here, and remained with it until the close of the season. Many of the experiments undertaken involved details requiring infinite patience and close attention. Their successful termination is entirely due to the untiring persistence of Mr. Shinn.

The Ben Davis trees, occupying the four west rows, were chosen for curculio experiments, because they supplied in one body the desired number of trees, and would be comparable with the trees of the same variety treated last season. The rest of the orchard was taken in hand for an experiment testing the relative merits of liquid spray as compared with dust spray. Most of the trees were sprayed as often and as late in the season as were the trees in the curculio experiment, and we have no evidence that their presence in any way modified the results of the work against curculio.

The trees chosen were divided into six plats, as shown in the accompanying diagram, and the schedule of applications was the same as used at Barry in 1903. The dates of application, however, were different, owing to the fact that the season was two weeks later than in 1903.

THE WINDFALLS.

The first gathering of apples was commenced June 29th and finished July 12th. Examination of these small apples required infinite care and patience in order to determine and correctly record the character and number of punctures made. It was necessary to do the work under a lens. This consumed time, and, as fruit was picked up only as fast as the examination could be made, two weeks passed before the first picking was completed. Subsequent collections were made in much less time, because as the fruit grew larger, examination could be more quickly made. Fallen fruit was gathered nine times; the last time October 14th, just before commencing the final picking of fruit from the trees. The following tabulation gives the number of fallen apples by plats, and shows the extent to which they were punctured.

No. of plat.	No. of trees.	Times sprayed.	No. of apples.	Plum Curculio.				Apple Curculio.				Not punctured.
				Crescent punctures.		Feeding punctures.		Egg punctures.		Feeding punctures.		
				No.	Fruits.	No.	Fruits.	No.	Fruits.	No.	Fruits.	
1	13	3	5056	5599	2612	9366	2531	306	228	1395	506	1323
2	14	10	4281	3164	1696	4334	1572	289	237	1400	387	1634
3	13	16	2467	983	632	1577	776	77	66	639	221	1239
4	15	8	2831	1663	956	2393	992	141	111	885	289	1177
5	13	7	3255	1826	1073	3405	1267	181	152	1258	431	1197
6	12	7	6066	3458	2057	4124	1868	183	151	1451	474	2663
Totals....			23956	16693	9026	25199	9006	1177	945	7028	2308	9233

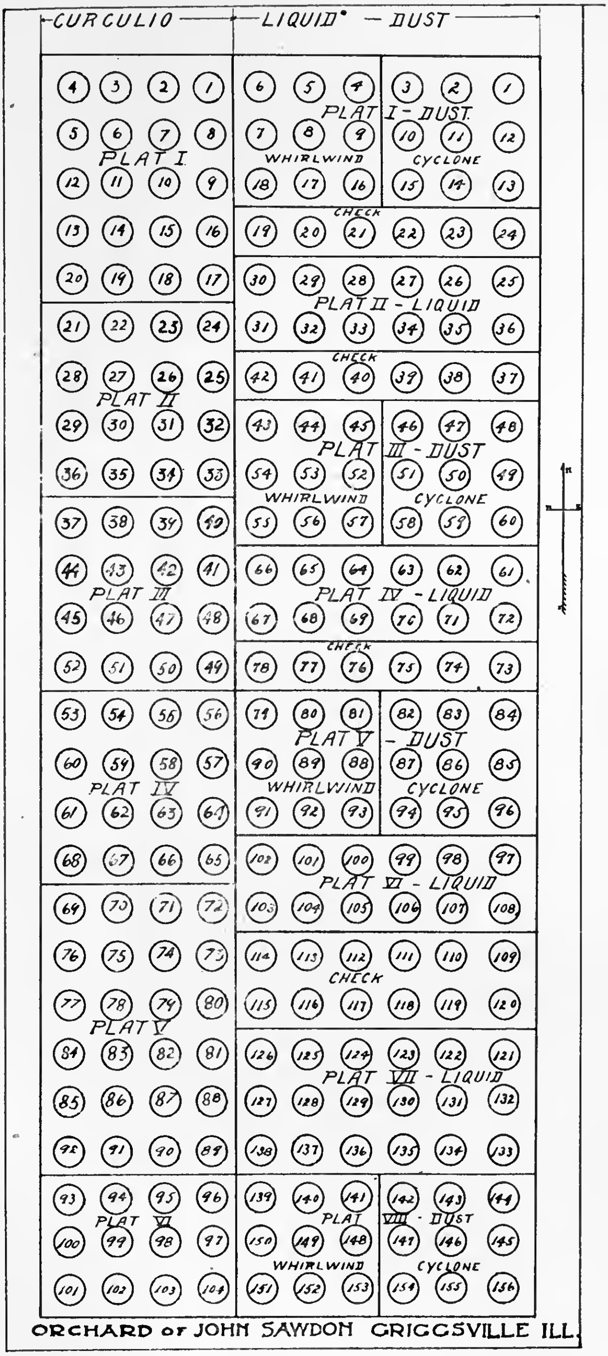
CURCULIO — LIQUID — DUST
PLAT I
PLAT I - DUST
WHIRLWIND
CYCLONE
CHECK
PLAT II - LIQUID
PLAT II
CHECK
PLAT III - DUST
WHIRLWIND
CYCLONE
PLAT III
PLAT IV - LIQUID
CHECK
PLAT V - DUST
PLAT IV
WHIRLWIND
CYCLONE
PLAT VI - LIQUID
CHECK
PLAT V
PLAT VII - LIQUID
PLAT VI
PLAT VIII - DUST
WHIRLWIND
CYCLONE
ORCHARD OF JOHN SAWDON GRIGGSVILLE ILL.

PLATE 20.

The tabulation shows a total of 23,956 windfalls, which number represents 32.85 percent of all the fruits borne on the plats. It will be noted that plat 1, receiving three applications of spray, shows a considerably greater percentage of punctured fruits than do the other plats, and that plat 3, which was sprayed sixteen times, shows the smallest percentage of punctured apples. It is also apparent that, comparing the two species of curculio, the plum curculio made much the greater number of punctures.

Of the total number of windfalls, 9,026, or 37.67 percent bore crescent punctures. Probably not all of these fruits fell because of these punctures, but assuming that they did, there remain 14,930 apples, or 62.33 percent that fell from causes other than puncture by curculio. The fall of a large part of these apples was due to an early development of scab that did not yield readily to the early applications of Bordeaux mixture. Some fell as a result of codling moth injury, and some were brought down by heavy winds. The 9,026 apples bore 16,693 crescents, nearly all of which may be assumed to have been accompanied by eggs, from a large proportion of which larvæ could develop. Destruction of this fallen fruit would, therefore, destroy many larvæ and thus materially aid in holding the insects in check. In this connection it is instructive to notice the distribution of windfalls throughout the season. Our 23,956 windfall apples were gathered as follows:

1st Picking	June 29 – July 12	12837	or	53.59%
2d "	July 28 – Aug. 1	1329	or	5.55%
3d "	Aug. 9	528	or	2.20%
4th "	Aug. 24 – 26	2338	or	9.76%
5th "	Sept. 1 – 2	606	or	2.53%
6th "	" 13 – 15	1005	or	4.20%
7th "	" 20 – 22	1243	or	5.19%
8th "	" 28 – 29	1156	or	4.82%
9th "	Oct. 14	2914	or	12.16%

The intervals are not regular, but in a general way the figures indicate the distribution over the season. The important fact is that more than half of the total number was gathered at the first picking. Of the 9,026 apples bearing crescents, 5,321, or 58.95 percent, were included in the first picking, and these apples carried 9,435, or 56.52 percent, of the total number of crescents. Apples gathered at the first picking were of small size, mostly very small, ranging from less than one-fourth inch to one inch in diameter, with the majority in the smaller sizes. In gathering, special effort was made to get everything that had the semblance of an apple. The ground under each tree was gone over several times until no more could be found. We have learned that no apple is too small to be punctured by the curculio, therefore no apple is too small to be included in our record.

The recommendation that fallen fruit be destroyed commonly conveys no idea of these first fallen apples. The mind turns to the tangible fruit of midsummer and fall, and where the recommendation is followed, the small apples that fall in early summer are entirely ignored. These same small apples are, however, an important factor, and should be considered in any systematic attempt to control the ravages of the plum curculio. At the beginning of this investigation, the development of larvæ in very small apples was looked upon as doubtful. It did not seem possible for an apple one-fourth inch or less in diameter to supply nourishment enough to bring a larva to full maturity, but it has been learned that larvæ can and do develop in just such apples. Several attempts were made to ascertain the number of larvæ that would emerge, and the number of beetles that would develop from known numbers of these small apples. Results from these efforts were seriously disturbed by the depredations of ants that carried off the larvæ as they emerged, so that in no case did we secure an accurate record. The results in the two trials that were least interfered with by ants are as follows:

In one case 1,576 small apples picked up under one tree on June 10th were placed on earth in a box which was partially sunk in the ground and then covered with cheesecloth held firmly in place by tacks. This lot of apples is shown in Plate 21. At the proper time daily examinations were commenced and kept up as long as beetles continued to emerge. From this box were taken 222 plum curculios and 64 apple curculios. Ants did not infest this box so much as they did some others, but there is no doubt that they destroyed some larvæ.

In another box similarly situated were placed 2,535 small apples picked up on the same date. From this we took 944 plum curculios and 39 apple curculios. Our test of egg-laying capacity given in detail in another place began May 23d. For some time the apples supplied each day were of necessity very small, but eggs were deposited in them as freely and larvæ developed as well as in the larger apples used later in the season. There is no doubt that plum curculio larvæ do develop in very small apples, and it follows that these apples should be considered in any plan for repression. To gather them would be impracticable, but if clean culture is practiced they and the larvæ they contain could be largely destroyed by use of the disk harrow or some other tool that would chop them up or bury them. If the ground is clean and the orchard sufficiently open, so that the sun can shine upon the apples as they lie on the ground, nothing further is necessary, because direct sunlight upon the apples will kill the contained larvæ.

THE PICKED FRUIT.

The final picking of fruit from the trees was commenced on October 14th and finished on October 20th. Following the same plan used with windfalls, each apple was examined, and record made of the number and character of punctures found. A force of eight men was necessary for this work. Three examined apples and called the punctures to three others who made the record on previously prepared forms. These forms were made for individual trees, and the tables were moved from tree to tree as the work advanced. Two men picked and kept the tables supplied with apples. Plate 22. The punctures found were separated,

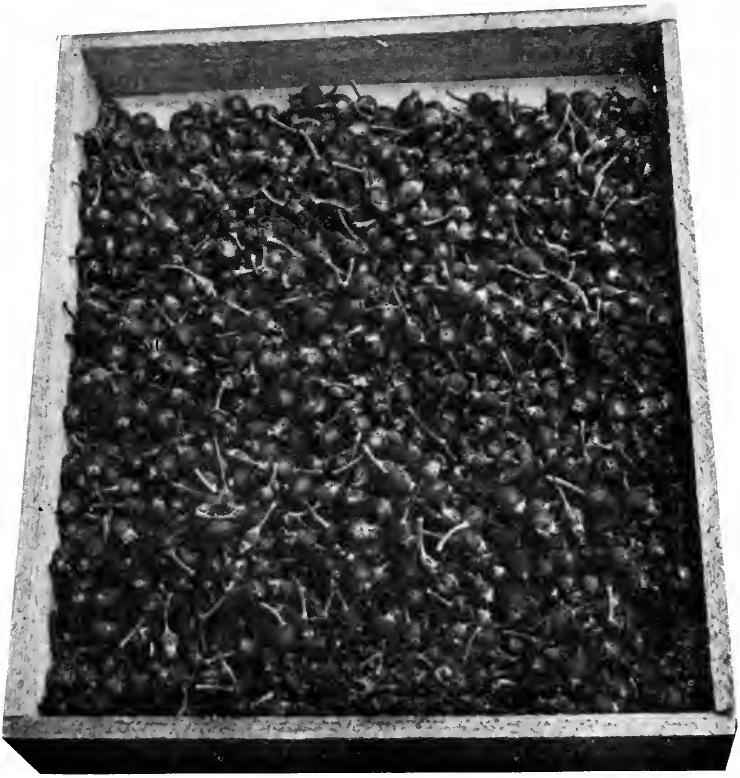

PLATE 21. BOX CONTAINING 1,576 SMALL APPLES.

according to purpose and the insect making them, into four classes as follows:

Plum Curculio	Crescents, usually accompanying oviposition.
	Feeding punctures.
Apple Curculio	Egg punctures, made for oviposition.
	Feeding punctures.

The number of apples picked and recorded was 48,966, or 67.55 percent of all fruits borne by the trees. The number and the percent punctured, and the number and percent free from puncture is shown, by plats, in the following tabulation.

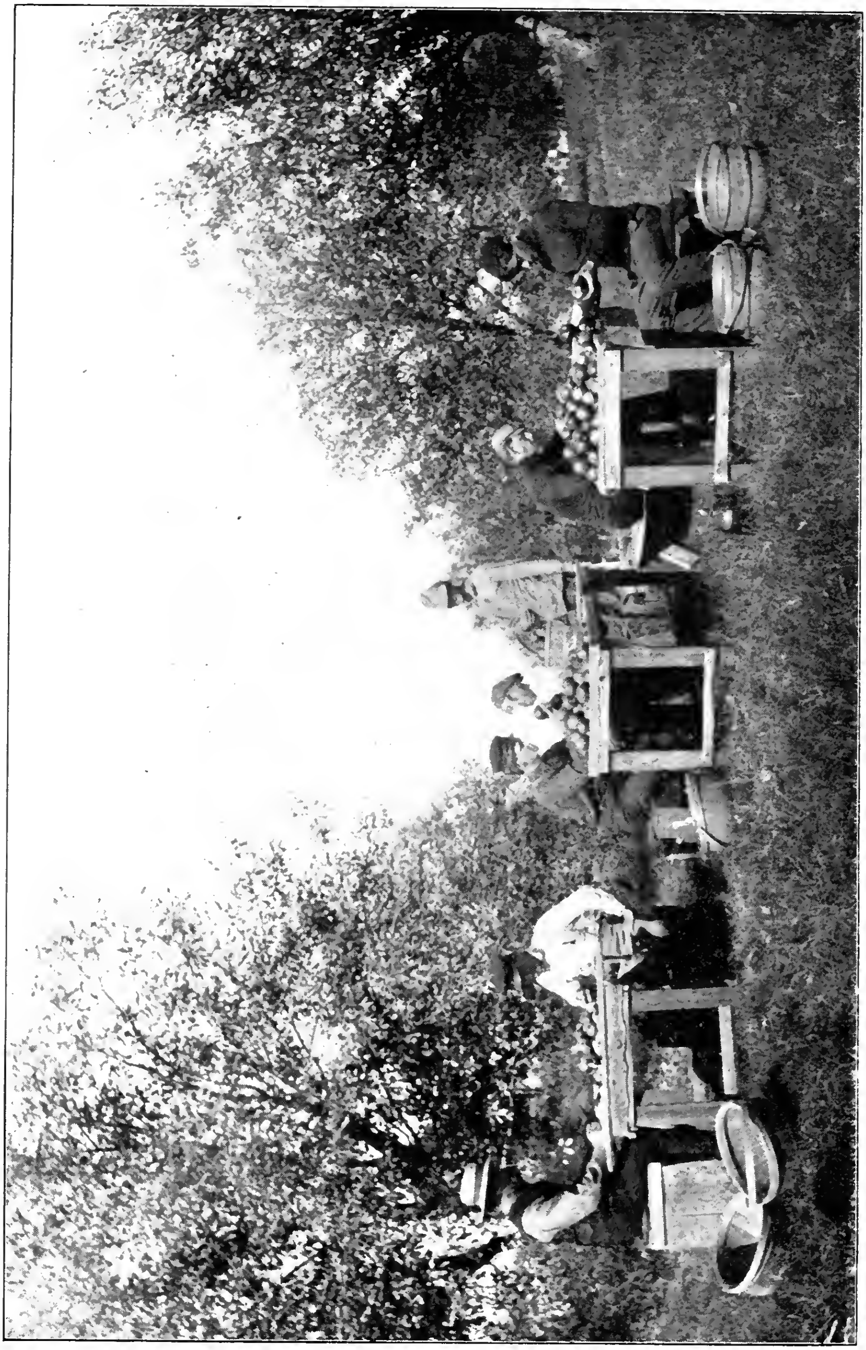

PLATE 22. MAKING THE RECORD.

RECORD OF PICKED APPLES.

No. of plat.	No. of Trees.	Times sprayed.	Punctured.		Not punctured.	
			Number.	Percent.	Number.	Percent.
1	13	3	3884	75.73	1245	24.27
2	14	10	5284	52.47	4787	47.53
3	13	16	2890	34.43	5504	65.57
4	15	8	5412	54.65	4492	45.35
5	13	7	4263	51.14	4074	48.86
6	12	7	3907	54.79	3224	45.21
Totals......................			25640	52.36	23326	47.64

By a simple computation based upon the percentage of fruit liable to puncture, as shown by the check plat, it is found that the percentages of fruit on the different plats saved from puncture by the treatment applied are as follows:

Plat 2 shows gain over the check plat of 30.71%
" 3 " " " " " 54.53%
" 4 " " " " " 27.83%
" 5 " " " " " 32.47%
" 6 " " " " " 27.65%

These percentages show, in close approximation, the relative efficiency of the treatment applied to different plats.

Of the 23,956 windfalls, 14,723, or 61.46 percent, were punctured, while 9,233, or 38.54 percent, were free from puncture. These figures show that the windfalls were punctured to a somewhat greater extent than were the picked fruits. Under perfectly natural conditions, however, it is believed the picked fruits would show a greater aggregate number of punctures than the windfalls. It will be understood that the majority of punctures for oviposition are made comparatively early in the season, while feeding punctures, more particularly those made by the plum curculio, multiply most rapidly late in the season. Fallen apples over the whole orchard were gathered, and no beetles developing from them were allowed to return to the trees. This reduction of the new crop of beetles without doubt greatly diminished the number of late feeding punctures which are the source of greatest injury to the apple crop.

The punctures found on the picked apples are classified in tabular form below:

No. of plat.	No. of trees.	Times sprayed.	No. of apples.	PLUM CURCULIO.				APPLE CURCULIO.				Not punctured.
				Crescent punctures.		Feeding punctures.		Egg punctures.		Feeding punctures.		
				No.	Fruits	No.	Fruits.	No.	Fruits.	No.	Fruits.	
1	13	3	5129	3611	2070	11090	3200	202	168	2493	722	1245
2	14	10	10071	3039	2079	9034	3621	339	275	3581	1020	4787
3	13	16	8394	1248	975	3506	1721	154	130	1899	591	5504
4	15	8	9904	1477	1187	10053	4252	218	186	2123	745	4492
5	13	7	8337	1125	938	6815	2996	272	241	3156	1006	4074
6	12	7	7131	937	759	8045	3171	173	154	2137	725	3224
Totals....			48966	11437	8008	48543	18961	1358	1154	15389	4809	23326

It will be seen that the number of punctures is large, aggregating many more than are shown on the windfalls, but the number of fruits is more than double and the percentage punctured somewhat less than for windfalls. Computing the number of punctures for each apple punctured, it is found that crescent punctures average 1.85 for each windfall and 1.42 for each picked apple. Feeding punctures average 2.8 for each windfall and 2.56 for each picked apple. Apple curculio egg punctures show the same relation, an average of 1.24 for each windfall and 1.17 for each picked fruit. With apple curculio feeding punctures the balance is the other way, windfalls have an average of 3.04 while picked apples average 3.20 punctures for each apple punctured. Some apple curculios of the new generation emerged from apples on the trees, and probably did some feeding on fruit before going into retirement. This may account for the greater number of feeding punctures on picked fruit.

Bringing all the apples together, and arranging the number and percent of punctured for comparison with the fruit not punctured, we have the following:

No. of plat.	No. of trees.	Times sprayed.	Punctured.		Not punctured.		Total apples.
			Number	Percent.	Number.	Percent.	
1	13	3	7617	74.79	2568	25.21	10185
2	14	10	7931	55.26	6421	44.74	14352
3	13	16	4118	37.92	6743	62.08	10861
4	15	8	7066	55.48	5669	44.52	12735
5	13	7	6321	54.53	5271	45.47	11592
6	12	7	7310	55.39	5887	44.61	13197
Totals			40363	55.35	32559	44.65	72922

In this consideration of all fruits, both picked and windfalls, the check plat which received only the three early applications shows 74.79 percent of the fruit punctured.

Plats 2, 4, 5, and 6 show striking uniformity in the percentages of fruit punctured, and plat 3 shows a marked gain over all other plats in the amount of fruit free from punctures. This plat received thirteen applications of spray after the first three, making a total of sixteen, and the relatively small percent (37.92) of punctured fruit is ascribed to these numerous applications, but how much of this freedom from puncture is due to an increased number of insects poisoned and how much to the repellent action of the frequent applications, is not determined. From the record of the check plat, which shows 74.79 percent of the fruit punctured, the percent of gain for each of the other plats is computed as follows:

Plat 2 with 10 applications shows gain over the check of 26.11%
" 3 " 16 " " " " " 49.29%
" 4 " 8 " " " " " 25.83%
" 5 " 7 " " " " " 27.08%
" 6 " 7 " " " " " 25.93%

In conducting the experiments in that portion of this orchard outside the curculio plats, certain check trees that received no treatment whatever were maintained. Record was made of all defects in fruits borne by these trees, and we find that 88.21 percent of the fruit was punctured by curculio. Comparing these trees with our curculio check plat, we find that the three early applications of spray effected a saving of 15.21 percent in amount of fruit punctured. Computing in like manner from the trees receiving no spray, our plat No. 3, which received sixteen applications, shows a gain of 57.01 percent.

It appears from the foregoing that when all fruits are considered, three applications of spray may effect a saving of 15.21 percent of fruit liable to puncture, and that sixteen applications may effect a saving of 57.01 percent. If we considered picked fruit only, the range of benefit lies between 14.14 percent and 60.96 percent, but the larger number of applications cannot be commended for commercial orchards because of the attending expense. Careful orchardmen would consider four or even five applications as possible, but beyond that most of them would not consent to go. This suggested possible number of applications would presumably effect a saving of from 20 to 40 percent of fruit liable to puncture, provided the conditions were as favorable as those surrounding our work during 1904.

Plate 23, from a photograph of tree No. 54 of plat 4, shows a fair average of the trees treated in this orchard. In Plate 24 the fruit from this tree is shown:

First, as separated into punctured and not punctured.

5 bushels not punctured	637 apples
5 bushels punctured	645 apples
Total apples	1,282

Second, as separated into market grades.

5 bushels No. 1	564 apples
4½ bushels No. 2	635 apples
½ bushel culls	83 apples
Total apples	1,282

The number of apples and the proportion punctured varies greatly with the trees on different plats.

Under the conditions prevailing in 1903, no benefit from spraying could be predicted. We may compare the two seasons, in parallel, as follows:

	1903.	1904.
Weather conditions in spring.	Bad. Cold rains and frost.	Season somewhat late, but in general favorable to fruit.
Crop.	Very few apples.	Good crop of fruit.
Location.	Small blocks in large orchards.	Small isolated orchard.
Curculios.	Excessively abundant.	Comparatively few.

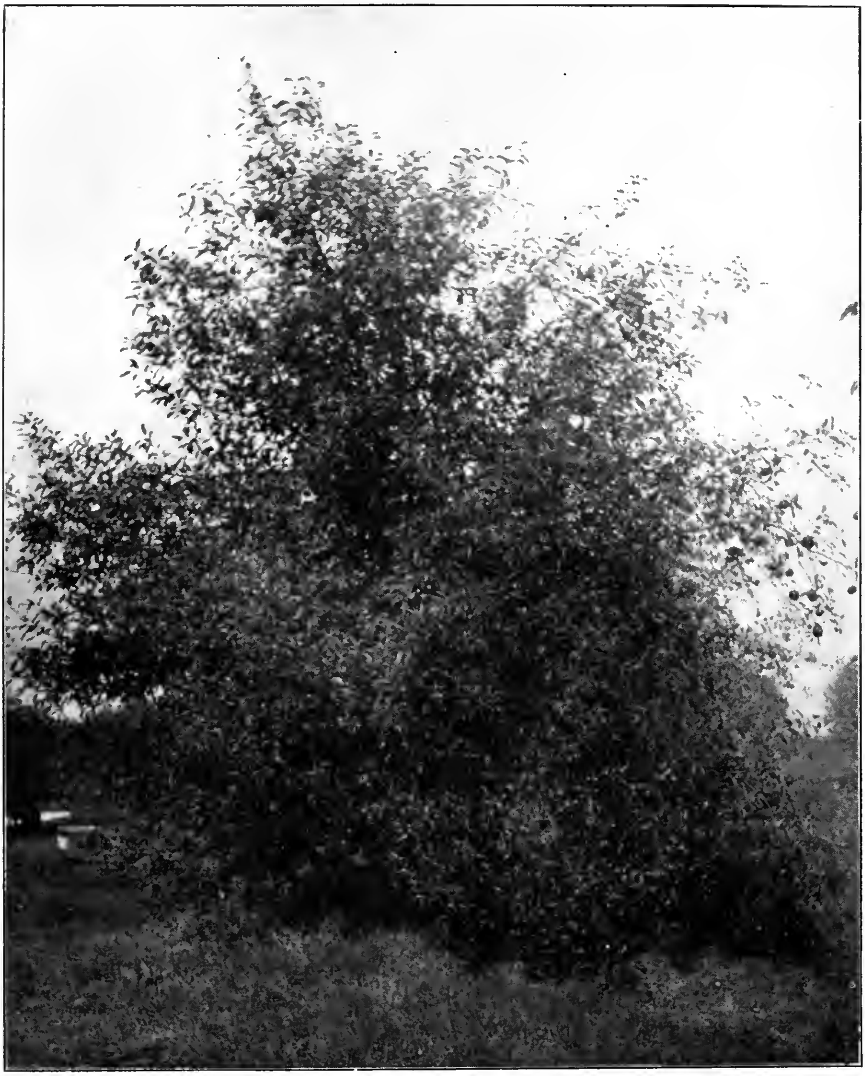

PLATE 23. TREE NO. 54 OF PLAT 4.

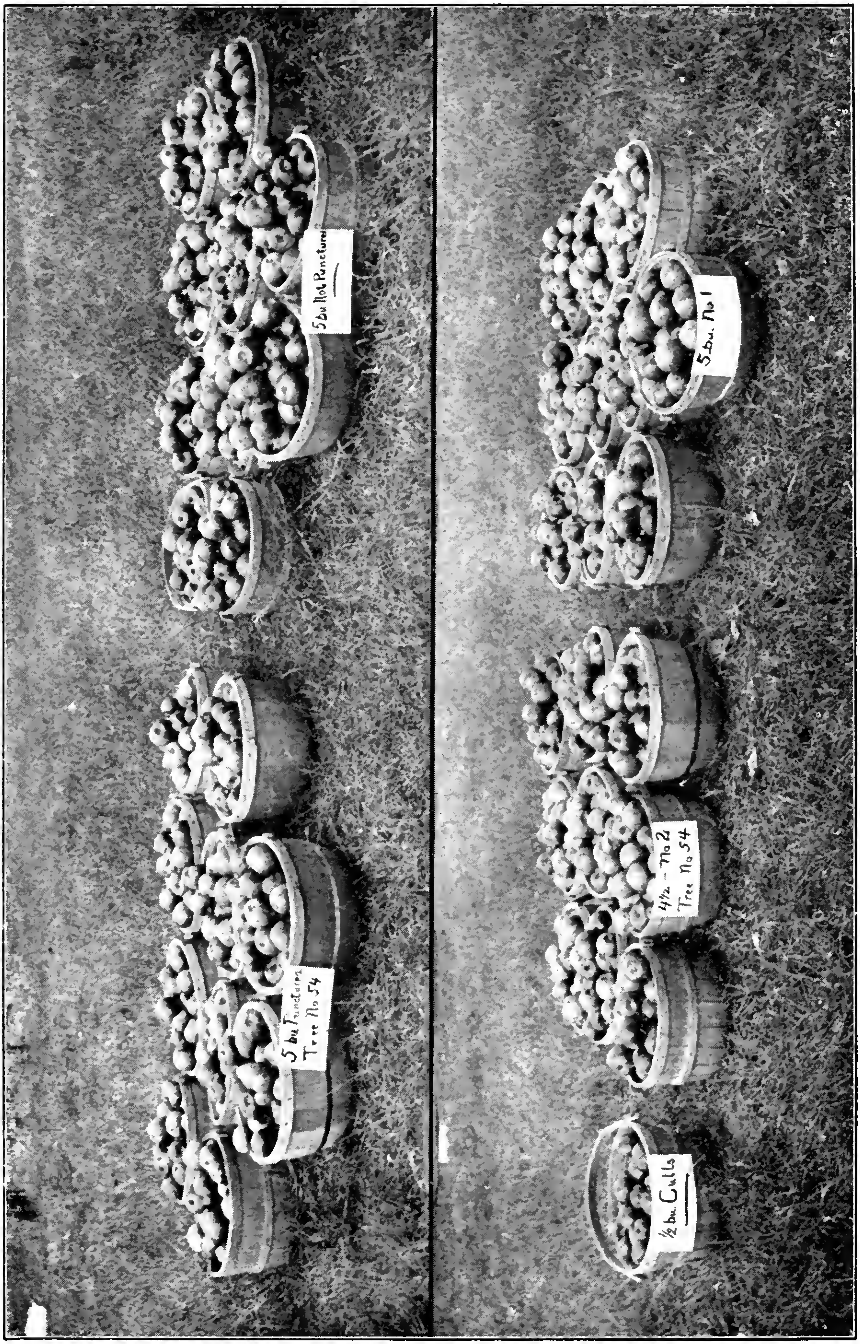

PLATE 21. FRUIT FROM TREE No. 54, PLAT 4.

Abundance of curculios is the most important factor influencing results, and in this respect the two seasons are not comparable. Had the curculios been as abundant in 1904 as in 1903, it is questionable if the work of spraying, which was identical with the work done in 1903, would have shown any better results than were obtained the previous year.

To sum up the whole matter of spraying for curculio, from the standpoint of results obtained during the two seasons of 1903 and 1904, it seems possible, under favorable conditions, and with a reasonable number of applications, to control curculios to the extent of from 20 to 40 percent of the possible injury. There is benefit to be derived from spraying, but not that degree of benefit which would warrant commendation of spraying as the one great panacea for the injury done by curculios. For satisfactory results, spraying must be supplemented by attack from other directions. Attention to fallen fruit has been already commented upon, and is a means of attack worthy of consideration.

The depth of pupation, and the period during which pupæ are in the ground, are matters that have been discussed on preceding pages. It has been shown that the major portion of the new generation of plum curculio is in the earth, within two inches of the surface, for a period of thirty days from July 10th. The common-sense method of attack that is at once suggested is *cultiv tion.*

CULTIVATION AS A MEANS OF REPRESSION.

Superficial tillage of the surface soil can be commended as an effective method of attacking curculio. This tillage should be carried on continuously or at frequent intervals for a period of from thirty to forty days, during which the great bulk of the new crop of plum curculios is in the ground. The object of tillage is to turn the pupæ out, kill some in the process, and expose the rest to the elements and to birds and insects that prey upon them. Pupæ of the plum curculio are extremely delicate, and they are incapable of moving about. In digging for pupæ it was observed that admission of air to the burrow invariably caused immediate distress; the pupæ would squirm and wriggle as if in pain. Actual trial proved that sunlight was quickly fatal, and that exposure on the surface in the shade, on a warm day, would kill in a few hours. It was also demonstrated that birds, ants, and other insects devour exposed pupæ greedily. In view of the results obtained in this work with pupæ, the definite statement is warranted that cultivation with disc or harrow will, in great measure, prevent the maturation of these insects and at less cost than by any other means.

For those orchards in which cultivation has been practiced, the treatment suggested would not be a serious burden, simply a prolongation or repetition of work easily and rapidly done, but for orchards that have not had the ground disturbed for several years, and are either heavily sodded or thickly grown up with weeds, the cultivation recommended is not so simple a matter. However, it is the grassy and weedy orchards that need the treatment most, because it is in such orchards that the curculio is doing the most damage. Observations made in a considerable number of orchards in various parts of the state make it plain that uncultivated orchards suffer greatest injury from curculio, and the reason seems equally plain. Grass and weeds offer hiding-places where curculios in the beetle stage are safe from most of their natural enemies, where fallen apples may slowly decay and nourish larvæ to full development, and where pupæ may rest securely until the transformations are complete and the perfect beetle ready to emerge. The conditions are ideal for bringing to adult form the largest possible percentage of the insects. They have things their own way, are correspondingly prolific, and there follows a corresponding amount of injury. To do away with these conditions, so favorable to insect development, to eradicate the grass and weeds, to clean, pulverize, and smooth the surface soil, and thus bring conditions least favorable to curculios, is a task demanding thoughtful planning and skillful execution. It means the outlay of time, labor, and money, proportionate to the size of the orchard and the length of time it has been neglected; and greater or less, according as the weather conditions are favorable or unfavorable, passage between trees unobstructed by drooping branches, and the ground free from dead brush and other rubbish too heavy for ordinary tools to contend with. In some orchards a severe pruning of lower limbs would be imperative before any attempt could be made at cultivation. Neglect of pruning usually accompanies neglect of cultivation, and too frequently the orchard becomes impassable for teams, necessitating considerable expenditure preparatory to the cultivation proposed. When orchards present conditions such as here referred to, owners are inclined to hesitate and count the cost. The dilemma presented is not attractive, for intelligent consideration is quite certain to resolve the question into a choice between grubbing out the orchard and placing it, at whatever cost, in condition again to give profitable returns. There are many orchards which present this problem, or would present it if judged according to actual existing conditions, and the choice of procedure is not easy. No fixed rule can determine how bad orchards must be to place them beyond possibility of renovation with reasonable expenditure, because no two orchards are alike, and conditions are various. The best course to pursue must be determined in each individual case by careful study. Then, if such study be supported by good judgment and knowledge of horticultural principles, it will be possible to bring many neglected and unprofitable orchards to a state of productiveness that will amply repay the effort and the cost.

Those who put in practice the suggested means of holding the curculio in check need apprehend no serious trouble from these insects in ordinary years unless injury results through invasion from neighboring orchards that are neglected and that serve as harbors and breeding places.

Years of excessive abundance of curculios will undoubtedly recur, but orchards that are pruned, cultivated, and sprayed are not likely to suffer serious injury. It is the neglected orchards, those affording ideal conditions for insect development, that will suffer most in these years of abundant insects.

Curculios, like many other insects, appear to run in cycles. Years of great abundance are, through natural causes, followed by years of comparative scarcity.

Persistent application of artificial means of repression will reduce injury to its lowest point in years of scarcity, make the recurrence of maximum injury less frequent, and greatly mitigate the injury in years when insects are most abundant.

It should be remembered that curculios are not the only orchard pests, and that means of repression directed against these insects are equally effective in controlling other insects which are more or less injurious every year.

Spraying is an essential practice for the control of apple scab and other fungous diseases. Arsenical poisons applied with the Bordeaux mixture add little to the expense and are even more effective in checking the ravages of codling moth, canker worm, and other leaf-eating insects than they are in destroying curculios. The practice of destroying fallen fruit commended as a means of attacking curculio is equally effective against codling moth and at the same time aids in preventing the spread of some destructive fungi.

Cultivation is an effective means for destroying plum curculio pupæ and for promoting conditions generally unfavorable to insects, but the benefits of cultivation do not end here. The physical condition of the soil is improved and plant food rendered available. Growth of both tree and fruit is stimulated and the increased vigor insures greater resistance to the ravages of insects and diseases. In view of the wide-reaching effects of the means commended for the destruction of curculio, the cost attending their application is not chargeable to curculio alone. To fight curculio is virtually to attack all orchard pests and to make right any conditions not favorable to the growth and productiveness of orchard trees.

CONCLUSIONS.

The primary cause of serious injury to apples by curculios can in the majority of cases be traced to conditions prevailing in the orchards. Neglect of the four cardinal principles of good orchard management, namely, pruning, cultivation, spraying, and fertilizing, engenders conditions favorable to the multiplication of curculios and also of other pests. Weeds and grass grow unrestrained, treetops become dense, and the consequent heavy foliage affords deep shade. The insects are undisturbed, they find protection against natural enemies, and their processess of development go on unchecked. As the insects multiply the injury increases until crops are utterly ruined.

The factor of location has an influence and will account for heavy losses from curculio injury that sometimes occur even in orchards that are given every attention. If cultivated orchards are in close proximity to badly neglected orchards, or to bodies of timber in which the native food plants, hawthorn, wild crab, and wild plum, are abundant, such orchards may be invaded by curculios and the fruit greatly injured. Such situations are unfortunate and usually cannot be changed or improved.

It seems possible to attack the curculio in three different ways.

First—By spraying with arsenical poisons. This method aims at the destruction of the adult or beetle stage of the insect only. This method as used in our experiments at Barry in 1903 proved ineffective as is shown by the tabulations on page 538. Reasons for these results are found in three factors or conditions:

A—Small amount of fruit borne by the trees.

B—Location of the treated plats in the midst of large orchards.

C—Excessive abundance of the insects.

The same treatment applied in 1904 in a small isolated orchard which bore a good crop of fruit and with the insects much less abundant resulted in saving from 27.65 percent to 54.53 percent of the picked fruit liable to puncture. The percentage of gain varied between the limits given, according to the number of times the trees were sprayed. But sixteen applications were required to attain the higher percentage and this involves too great an expense to warrant commending such procedure.

Under favorable conditions from twenty to forty percent of the fruit liable to puncture may be saved by five applications, and this treatment is regarded as profitable and practicable.

Second—By destruction of fallen fruit. This method of attack aims at the egg and larva stages of the insect. All fallen fruit must be taken into account, not only the larger fruits that fall in late summer, but more particularly the small apples that fall in June and early July. The early fallen fruit is usually ignored, but is really more important from the standpoint of attack on curculio than the late fallen fruit, because oviposition and larval development is at its highest early in the season. Experiments made during this investigation demonstrate conclusively that destruction of the small apples is important. Gathering them is regarded as impracticable because of small size and great numbers. If the orchard is sufficiently open and the ground clean so that the sun can act upon the apples the desired end will be accomplished because repeated trials have shown that action of the sun will kill larvæ contained in fallen apples. If shade under trees is too dense, the apples could be raked together in exposed spots at small expense and no doubt many of them would be destroyed during the cultivation necessary to keep the ground clean.

Third—Cultivation. This method of attack is directed against the insect in the ground and may affect the three stages, larva, pupa, and beetle, but is more particularly intended to destroy pupæ.

The experiments given have demonstrated:

First.—That the average time spent by the insect in the ground, based on the records for 1,264 individuals, is twenty-eight days.

Second.—That the period during which curculios were in the ground was for the season of 1904, 143 days, or from June 17th to November 7th.

Third.—That the majority of the new crop of insects are in the ground during July and August, and computing from the record of 1,700 larvæ entering the ground, a period of thirty days from July 10th will find 87% in the ground; forty days from the same date will affect 92% and fifty-three days nearly 97%.

Fourth.—That depths recorded for 824 pupæ range between one-fourth inch and three and one-half inches. At depths of two inches and less we find 772, or 93.69% of the total number, and at depths of one inch and less 516, or 62.62%.

Fifth.—That both larvæ and pupæ are very delicate and extremely sensitive to exposure to light and air.

Sixth.—That short exposures to direct sunlight are fatal to both larvæ and pupæ.

Seventh.—That ants and other predaceous insects, as well as birds, prey upon both larvæ and pupæ.

In the light of these facts superficial tillage for a period of thirty or more days from July 10th is commended as an efficient means of attacking plum curculios.

To advocate measures against curculios is in effect to urge the maintenance of better orchard conditions. The state of orchard culture most favorable to the production of profitable crops is correspondingly unfavorable to the development of insects and the spread of fungous diseases.

Best results can only be attained through intensive culture and to aim at these best results is simply to apply to the management of orchards that same business sense that brings success in other commercial ventures.

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