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The Action and Efficacy of Soil Fumigants Directed Against the Current Fruit Fly, *Epochra canadensis* Loew (Diptera: Trupaneidae)

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H.P. Richardson

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I. INTRODUCTION

The currant fruit fly, *Epochra canadensis* Loew, a native insect, is an important factor limiting the production of currants and gooseberries in the greater part of Canada, and in parts of the United States of America. Studies have shown this insect to be vulnerable in the adult stage to stomach and contact insecticides. Investigations to control the adult fly with contact and stomach insecticides have culminated in the recommendation of DDT (Andison *et al* 1951).

The possible destruction of the maggot and emerging adult with contact insecticides, and the immobile pupae with soil fumigants, has received attention by some workers, but without any notable success. The development of newer soil fumigants and insecticides has provided opportunity for further study on this phase of the control problem. The present paper presents results obtained from the use of the fumigants ethylene dibromide and DD and the insecticides BHC and dieldrin, tested in the laboratory, against dormant currant fruit fly pupae, and the insecticides BHC, DDT, and chlordane, tested in the laboratory, against the larvae entering the soil. The fumigant ethylene dibromide was further tested in the field against dormant, prediapausing and diapausing pupae at different rates, depths, and under conditions of cultivation and no cultivation.

The effect of the soil temperature and soil moisture on the efficacy of ethylene dibromide was considered.

Studies concerning the inception and completion of the pupal diapause of the currant fruit fly were made to obtain information necessary to plan and to evaluate the fumigation studies. Three tests were made in the laboratory and one in the field involving several temperatures, maturity dates, periods of time, and media, at a nearly constant relative humidity.

The studies were carried out in Brandon and Morden, Manitoba, during the years 1948 to 1951.

II. ACKNOWLEDGEMENTS

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III. LITERATURE REVIEW

No literature has been found reporting on the use of ethylene dibromide or 1,2 dichloropropane 1,3 dichloropropene for the control of the currant fruit fly. Ethylene dibromide in combination with benzene hexachloride was reported by Handford (1949) to be highly successful for the control of the carrot rust fly, *Psila rosae* (Fab.). Both fumigants have been used extensively for control of wireworms and other soil-inhabiting organisms.

Investigations were conducted by Allen (1943) and Morrison (1943) in which they tested a series of compounds against the currant fruit fly.

Allen (1943) tested 6 compounds, in 1/2-gallon glass jars, against the emerging fly. The effect, if any, of the compounds against the pupae 1 inch below the soil surface was noted. The chemicals used were:

1. DN sulphur dust -- Dinitro cyclohexyl phenol not less than 0.8 per cent.
2. Neocid -- DDT 10 per cent, pyrophyllite 90 per cent.
3. Dinitro-ortho-cresol 10 per cent, flour 90 per cent.
4. Derris dust, commercial, 0.75 per cent rotenone.
5. Calomel.
6. Corrosive sublimate.

The dust compounds with the exception of corrosive sublimate were applied at the rate of approximately 1 ton per acre. Eleven decimal two pounds of corrosive sublimate dissolved in 1792 gallons of water were applied per acre.

The chemicals tested did not suppress emergence of pupae from the puparial cases. The compounds Derris, Neocid, and DN sulphur were considered effective against the adults and worthy of field trial.

Morrison (1943) tested a long series of chemicals against the pupae in the soil. The chemicals tested were: naphthalene, paradichlorobenzene, mercury bichloride, mercurous chloride, kerosene, cyanamide, lubricating oil, lead arsenate, carbon bisulphide, sulphur, tar oil (dormant spray), soap (Sunlight), sodium chloride, formaldehyde, nicotine sulphate, rotenone, ethylene dichloride, dichlorethyl ether, and carbon disulphide. The promising chemicals, naphthalene, paradichlorobenzene, dichlorethyl ether, carbon bisulphide, and ethylene dichloride were retested. Naphthalene at 300, 750, and 1500 pounds per acre and paradichlorobenzene at 150, 300, and 1500 pounds per acre gave 100 per cent control in the laboratory.

Naphthalene was field tested. The general infestation was considered to have been reduced 40 per cent below that in previous years.

IV. STUDY OF THE DIAPAUSE OF E. CANADENSIS

A dearth of information concerning the time of inception and completion of diapause in the pupal currant fruit fly, necessary for the evaluation of soil fumigation work, necessitated the diapause studies.

A. PREVIOUS DIAPAUSE STUDIES

Studies involving the diapause of the pupal currant fruit fly have been conducted by several workers, but the information obtained from these studies did not provide all the essential details. Severin (1917) kept a number of puparia, about a month old, in moist sand in the insectary. Seventeen adult flies emerged during August. Two females had emerged by August 19. Of the 17 flies, 11 appeared normal and 6 were abnormal; the wings did not expand normally. Several flies emerged during September. No flies emerged from pupae in the field.

Severin's results show that, although some flies will emerge shortly after they pupate when kept in an abnormal environment, they do not emerge in the field.

Morrison (1943) on the basis of his studies states that winter diapause occurred in the adult stage, which was reached within the puparium in the early fall. He further states that cages of pupae brought in to the laboratory on various dates during the winter, commencing in October, gave no emergence when brought in prior to December 1.

Morrison's results would tend to show that the diapause is obligatory and that in the field the diapause is not completed by December 1.

Allen (1943) successfully overwintered pupae in the laboratory. The puparia were sifted from the sand of rearing flats August 1, placed in moist sawdust on ice until October 20, and then transferred to a refrigerator running at 35°F., with relative humidity approximately 80 per cent. The puparia were removed February 28 and placed in moist sand. During the period of March 9 to 24 emergence of 68.3 per cent occurred.

A similar type of experiment was conducted by the writer (Richardson 1949). The puparia were sifted from the sand of the rearing flats August 1 and placed in a sealed, waxed-paper carton. They were kept thus in an office until September 25 when sand was added to the carton and the whole placed in a constant temperature room at 35°F., relative humidity 90 per cent, until April 1. The unit was then shut off and the temperature rose to 50-55°F. The puparia were removed to the office on May 9. The adult flies commenced emerging May 15. From 600 puparia an emergence of 69.5 per cent occurred.

In Allen's experiment the pupae were held 7 months at a temperature of approximately 35°F.; and in the experiment by Richardson the pupae were held approximately 6 months at 35°F. and 1 month at 50-55°F. Although the results of the two experiments show that the conditions of temperature, relative humidity, and time met the requirements of diapause, no precise information concerning the date of inception and completion of diapause was obtained.

B. INCEPTION AND COMPLETION OF PUPAL DIAPAUSE IN THE LABORATORY

1. EFFECT OF MATURITY, TEMPERATURE, AND TIME ON PUPAL DEVELOPMENT

a. Materials

(i) Pupae. The pupae for the experiment were obtained by placing infested berries on 1/8-inch mesh wire screen over moist sand. The mature larvae had commenced to emerge from the fruit July 10, the date the fruit was picked, and ceased July 25. The larvae crawled through the screen into the sand where they formed puparia in which they pupated. The sand was sifted and the puparia removed.

(ii) Containers. One-half pint, waxed-paper cartons were used to contain each test group of pupae, and the medium.

(iii) Medium. Fine sand was used as the medium for the pupae. It was thought that the caking tendencies of loams on drying out would be detrimental to the pupae and would hinder emergence of the adults.

(iv) Equipment. Constant temperatures of 34°, 36°, 40°, and 70°F. were required for the experiment. The 34° and the 36°F. constant temperature rooms were located at Morden, and the 40° and 70°F. constant temperatures at Brandon, Manitoba. A refrigerator was used to provide the 40°F.; a cabinet fitted with a heater thermostatically controlled provided the temperature of 70°F.

The relative humidity, determined by a wet and dry bulb thermometer, in the 34° and 36°F. constant temperature rooms remained constant at 90 per cent. The relative humidity in the refrigerator was constant at 83 per cent. This was increased by weekly additions of water to the cartons. In the 70°F. constant temperature cabinet, pans of water were provided to raise the relative humidity, and also, the media of the cartons were kept moist.

b. Experimental procedure

In setting up the experiment to obtain information concerning the inception and completion of the state of diapause three points were considered. They were:

1. The maturity of the pupae. The dates of August 1, August 15, September 1, and September 15 were taken as the maturity dates in the experiment. August 1 was picked as the commencement date because the last larvae emerged from the infested red currants and entered the soil July 25, and according to Morrison (1944) it requires 8 days for the larva to change to a pupa in the puparium. Although many of the maggots pupated earlier, the majority did so between July 15 and 25. The remainder of the dates were picked to fall before September 25, since according to Richardson (1949) pupae placed at a constant temperature of 35°F. on September 25 produced from 600 pupae an average adult emergence of 69.5 per cent.

2. The temperature to which the pupae were subjected. The temperatures 34°, 36°, and 40°F. were used, firstly, because they were the only constant temperatures available, and secondly, because they were acceptable, since Allen (1943) and Richardson (1949) successfully reared pupae at 35°F. A lower temperature, 32°F., was preferred in place of 34°F.,

but since it was not available, and since Mail (1932) showed in his studies of winter soil temperatures in Montana, U.S.A., that with snow cover the soil temperature at the soil surface and 2-inch level varies only a few degrees from 32°F., the lack of a 32°F. temperature was not considered detrimental to the experiment.

3. The period of time the pupae were kept at the various temperatures. The pupae were kept for periods of 4, 5, 6, and 7 months at each temperature. The period of 7 months was chosen because in previous work by both Allen (1943) and Richardson (1949) emergence occurred after the pupae were subjected to a constant temperature of 35°F. for 7 and 6 months, respectively. The period of 4 months was selected so that the pupae commencing August 1 would be removed December 1, because according to Morrison (1943) pupae brought in to the laboratory from the field prior to December 1 would not emerge. The periods of 6 and 5 months were chosen to provide information as to the effect of periods of a month on the pupal development at any one of the three temperatures.

The pupae, sifted from the sand of the rearing flats, were divided into groups of 100; each group was placed in a 1/2-pint, waxed-paper carton half filled with sand. The sand was kept moist until the cartons were placed in the constant temperature rooms.

On August 1, the date the experiment commenced, 4 cartons each containing 100 puparia were placed at temperatures of 34°F., 36°F., and 40°F. This was repeated for the dates of August 15, September 1, and September 15. Of the 4 cartons placed at each temperature on each of the 4 dates, 1 was kept there for a period of 4 months, 1 for 5 months, 1 for 6 months, and 1 for 7 months. At the end of the 4, 5, 6, and 7-month periods the cartons were removed and placed in a constant temperature cabinet at 70°F. The sand in the cartons was kept moist until emergence ceased.

The cartons were checked daily and the flies removed and recorded. At cessation of emergence the sand was sifted and the number of empty pupal cases noted.

c. Results and discussion

A daily record of the flies that emerged through the sand medium was kept for each carton in the test. The summarized results are presented in Table I. Mould growth occurred in 3 of the cartons, preventing normal emergence of the flies. In support of this, Table II shows the currant fruit fly emergence based on the number of empty pupal cases present in the sand following cessation of emergence. The number of empty pupal cases in each instance was checked against the number of puparia from which no adults had emerged. A comparison of Tables I and II shows that emergence from the exposed puparia was generally greater than from puparia covered by sand. Due to such factors as mould growth and cementing of the sand a number of flies died in the medium. Table II is considered to represent the actual emergence more accurately than Table I. The results of Table II are graphically represented in figures 1, 2, and 3, which show clearly the trend of the results.

An analysis of variance was performed on the results presented in Table II. The results of the analysis of variance showed that the temperatures at which the pupae were kept, the dates on which the pupae were placed at the temperatures, and the number of months the pupae were kept at each temperature had significant effects on the emergence of the adult currant fruit fly (Table III). The results were further analysed to determine whether there were significant differences between the effects of the individual temperatures, dates, and months. For the temperatures the results of the analysis showed that there is a significant difference at the 1 per cent level between 34° and 36°F. but not between 36° and 40°F.

The analysis of the data to determine the individ-

Table I

Emergence of adult *E. canadensis* from sand medium based on 100 pupae per carton

Dates	Temperature											
	34°F.				36°F.				40°F.			
	Months											
	4	5	6	7	4	5	6	7	4	5	6	7
Aug. 1	1	0	4	26	12	11	21	64	18	27	49	57
Aug. 15	12	21	42	16	39	49	61	73	39	52	56	74
Sept. 1	35	61	65	14	36	69	64	67	48	41	47	67
Sept. 15	37	46	55	72	55	65	66	73	46	61	35	83

Table II

Total emergence of adult *E. canadensis* based on number of empty pupal cases

	Temperature											
	34°F.				36°F.				40°F.			
	Months											
Dates	4	5	6	7	4	5	6	7	4	5	6	7
Aug. 1	1	1	15	30	16	18	26	70	18	30	58	63
Aug. 15	15	24	49	51	42	48	69	78	49	52	56	80
Sept. 1	35	61	66	27	36	69	73	71	48	62	56	69
Sept. 15	39	56	59	73	59	71	80	80	54	70	70	88

Table IIA

Tables of emergences derived from Table II

1.

	No. months in storage					
Temp.	4	5	6	7	Totals	Avgs.
34	90	142	189	181	602	37.62
36	153	206	248	299	906	56.62
40	169	214	240	300	923	57.68
Totals	412	562	677	780	2431	
Avgs.	34.33	46.83	56.41	65.00		

2.

	No. months in storage					
Dates	4	5	6	7	Totals	Avgs.
Aug. 1	35	49	99	163	346	28.83
Aug.15	106	124	174	209	613	51.08
Sept.1	119	192	195	167	673	56.08
Sept.15	152	197	209	241	799	66.58
Totals	412	562	677	780	2431	
Avgs.	34.33	46.83	56.41	65.00		

3.

	Dates of introduction					
Temp.	Aug.1	Aug.15	Sept.1	Sept.15	Totals	Avgs.
34	47	139	189	227	602	37.62
36	130	237	249	290	906	56.62
40	169	237	235	282	923	57.68
Totals	346	613	673	799	2431	
Avgs.	28.83	51.08	56.08	66.58		

4. Differences necessary for significance between means of:

	12 variates	16 variates
5% point	8.09	6.81
1% point	11.35	9.37

Fig. 1. Emergence of currant fruit flies, *Epochra canadensis* Loew, from puparia kept at 34°F. for periods of 4, 5, 6, and 7 months.

EMERGENCE OF CURRANT FRUIT FLIES FROM PUPARIA
KEPT AT 34° F. FOR DIFFERENT PERIODS OF TIME

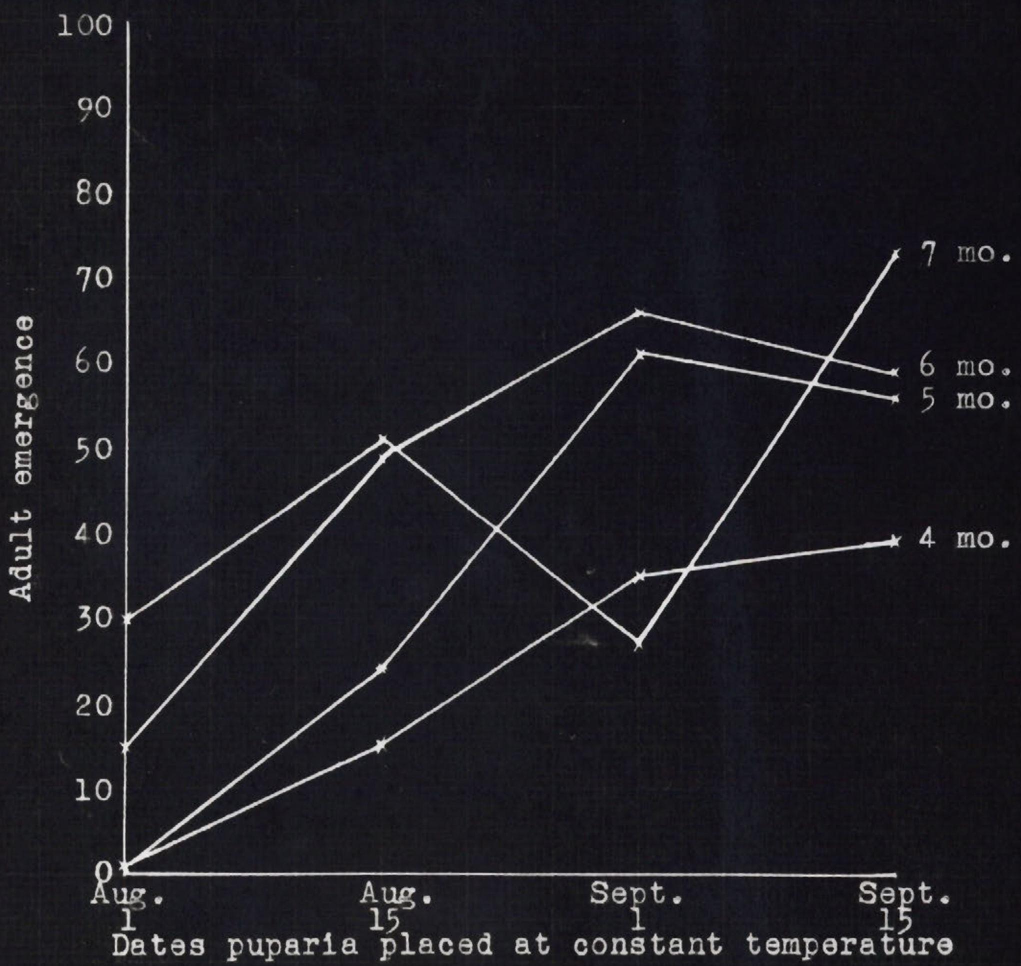

Fig. 2. Emergence of currant fruit flies, *Epochra canadensis* Loew, from puparia kept at 36°F. for periods of 4, 5, 6, and 7 months.

EMERGENCE OF CURRANT FRUIT FLIES FROM PUPARIA
KEPT AT 36° F. FOR DIFFERENT PERIODS OF TIME

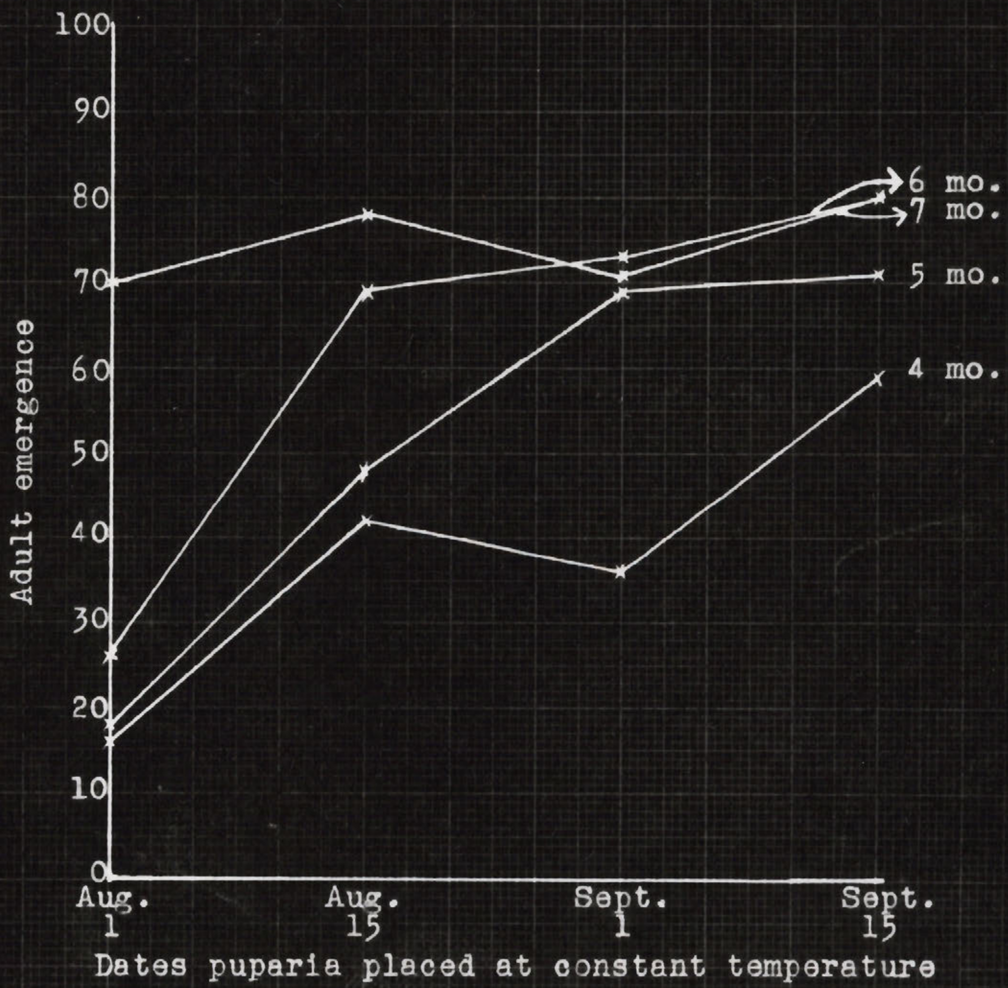

Fig. 3. Emergence of current fruit flies, *Epochra canadensis* Loew, from puparia kept at 40°F. for periods of 4, 5, 6, and 7 months.

EMERGENCE OF CURRANT FRUIT FLIES FROM PUPARIA
KEPT AT 40° F. FOR DIFFERENT PERIODS OF TIME

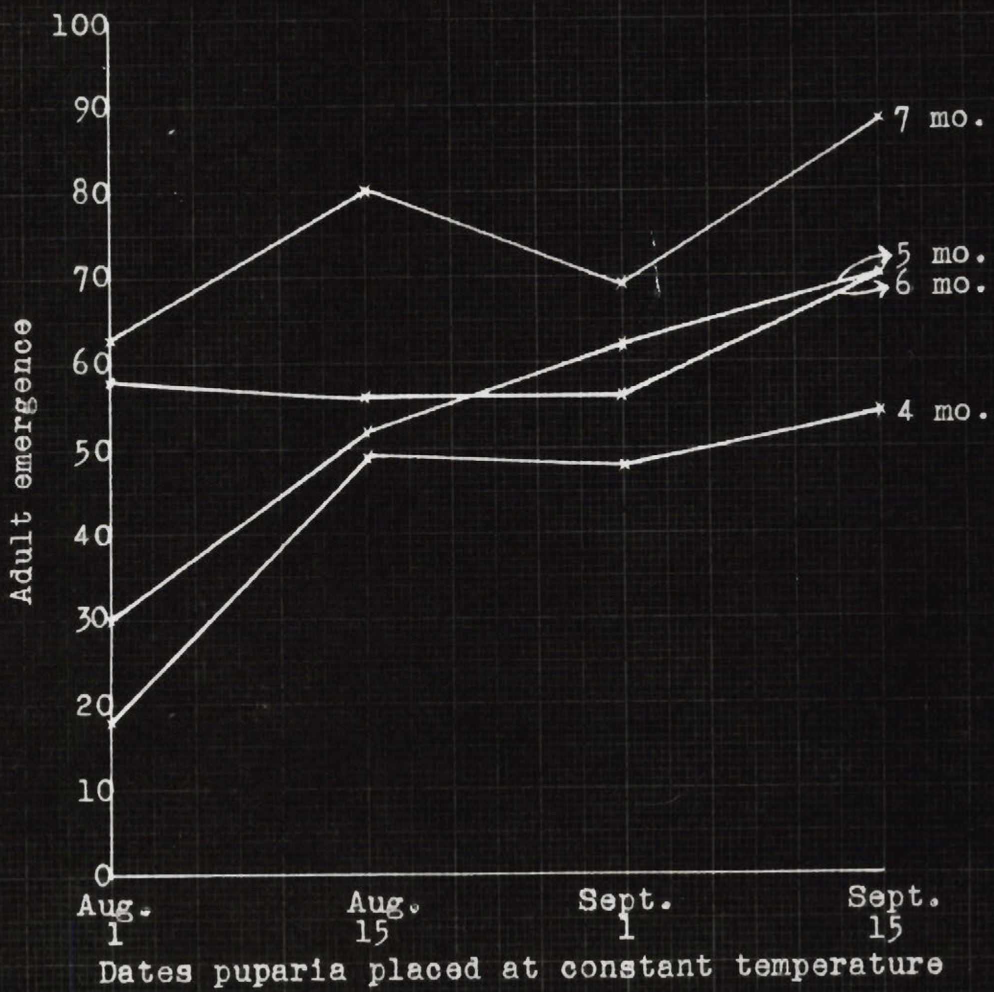

Table III

Analysis of variance of results of Table II

Source of variation	Degrees of freedom	Sum of squares	Mean of squares
Temperatures	2	4078.04	2039.02xx
Dates	3	9114.56	3038.18xx
Months	3	6239.73	2079.91xx
D x M	9	1918.69	213.18x
T x D	6)		
T x M	6)		
T x D x M	18) 30 error	2477.96	82.60
Total	47	23828.98	

xx Beyond the 1% level of significance.

x Beyond the 5% level of significance.

ual effect of the months shows that the difference between 4 and 5 months, and 5 and 7 months, is significant at the 1 per cent level, but the difference between 5 and 6 months, and 6 and 7 months, is not significant at the 1 per cent level.

The difference between the dates of August 1 and August 15, and between August 15 and September 15, according to the analysis is significant at the 1 per cent level, but the difference between August 15 and September 1, and between September 1 and September 15, is not significant at the 1 per cent level.

On the basis of the analysis performed it would appear that a significantly greater number of pupae had reached a state of development by August 15 than by August 1, enabling them to withstand the temperatures to which they were subjected. Reference to Table IV shows, however, that the earliest date at which 50 per cent or more of the pupae produced adults in the shortest period of time was September 1 for the temperatures of 34^{o} and $36^{o}F$. If the development of the pupae by September 1 permits only a slightly greater than 50 per cent emergence, it is quite probable that the state of development of the pupae in the

Table IV

The earliest date at which 50 per cent or more of the pupae produced adults in the shortest period of time at 3 constant temperatures

Temperature F.	Date pupae placed at temperature	Date pupae removed from temperature	No. months at temperature
34°	Sept. 1	Feb. 1	5
36°	Sept. 1	Feb. 1	5
40°	Aug. 15	Jan. 15	5
40°	Sept. 15	Jan. 15	4

field would not be such as to enable 50 per cent of the pupae to withstand temperatures of 32°F. and lower, which occur in the soil during the winter (Mail 1932).

In the experiment conducted, the analysis showed that a temperature of 36° or 40°F. is more effective for wintering pupae than 34°F.

The periods of 5 or 6 or 7 months, according to the analysis, were more productive than a period of 4 months at any one temperature. Table IV shows that a period of 5 months commencing September 1 at 34° and 36°F. and August 15 at 40°F., and 4 months commencing September 15 at 40°F. met the requirements of at least 50 per cent of the pupae. At the conditions shown in Table IV it appears that the state of diapause is completed in 4 to 5 months and ends between January 15 and February 1 for at least 50 per cent of the pupae.

The number of days from date of transfer of the pupae from the three temperatures to 70°F. to the date emergence commenced is shown in Table V. It is evident from the results that for the 4-month period for the dates of August 1, August 15, and September 1, at any of the three temperatures, the number of days before the adults began to emerge is greater than for the date of September 15. In relation to this, the emergence, Table II, for the

Table V

Number of days from removal from constant temperature cabinets until commencement of emergence of adult E. canadensis from soil

	Temperature											
	$34^{o}F.$				$36^{o}F.$				$40^{o}F.$			
	Months											
Dates	4	5	6	7	4	5	6	7	4	5	6	7
Aug. 1	100	0	14	16	64	30	10	17	46	30	8	12
Aug. 15	48	26	17	17	34	16	16	11	42	20	13	9
Sept. 1	35	22	20	7	33	6	16	7	32	3	14	4
Sept. 15	17	20	15	11	24	18	15	11	30	17	12	9

same dates, temperatures, and period does not exceed 50 per cent. It is evident that a 4-month period of conditioning at the above dates and temperatures is not sufficient to effect 50 per cent emergence.

2. EFFECT OF MEDIUM ON PUPAL DEVELOPMENT AND EMERGENCE

a. Materials

(i) Pupae. The pupae, 2,300 in number, were reared from infested berries placed on a screen over sand. The larvae left the fruit and crawled through the screen into the sand where they formed their puparia. The sand was sifted and the puparia removed.

(ii) Containers. The puparia were stored in a closed waxed-paper carton. Petri dishes with plaster of Paris in the bottoms were used for the pupae at the final rearing temperature.

(iii) Equipment. Constant temperatures of 40° and 70°F. were used in the experiment. A refrigerator was used to produce the 40°F. temperature and a constant temperature cabinet thermostatically controlled provided the temperature of 70°F.

The relative humidity in the refrigerator remained constant at 83 per cent. In the constant temperature cabinet, pans of water were provided to raise the humidity. The plaster of Paris in the petri dishes was kept moist.

b. Experimemtal procedure

The puparia, when sifted from the sand, were placed in a pint-sized, waxed-paper carton and on August 15 were placed in the refrigerator. The temperature of the refrigerator averaged 40°F. and the relative humidity 83 per cent. On the 1st and 15th of January, February, March, and April, samples of puparia were removed from the carton and placed in a petri dish, the bottom of which was covered with plaster of Paris and kept moist. The petri dishes containing the puparia were placed at a constant temperature of 70°F. The puparia were kept under these conditions until emergence ceased. The number of emergents was recorded daily.

c. Results and discussion

The results presented in Table VI compare closely with the results of Table II for the same date, temperature, and number of months. The difference between the two tests

Table VI

Emergence of E. canadensis adults from puparia held at 40°F. commencing August 15

No. months	4½	5	5½	6	6½	7	7½	8
No. puparia	39	40	56	68	69	100	107	154
No. emergents	20	20	27	46	39	69	66	88
% emergence	51.3	50.0	45.7	67.6	49.2	69.0	61.6	57.1

Table VII

Number of days from removal from constant temperature cabinets until commencement of emergence of adult E. canadensis

No. months	4½	5	5½	6	6½	7	7½	8
No. days pre-emergence	27	20	16	15	14	12	7	8

lies in the use of sand in the previous experiment. The emergence of 51.3 per cent of the flies after 4 1/2 months commencing August 15 shows that the sand media had no apparent effect on the pupal development or emergence.

On the basis of the results of the experiment, Table VI, at least 50 per cent of the pupae entered the state of diapause by August 15. The duration of the diapause period of at least 50 per cent of the pupae was 4 1/2 months. Diapause was completed by January 1.

The number of days from the time of removal from the constant temperatures until emergence commenced, shown in Table VII, compares with the data presented in Table V for the same time, date, and period of months.

3. EFFECT OF CONSTANT TEMPERATURE OF 70° FAHRENHEIT ON PUPAL SURVIVAL

a. Materials

(i) Pupae. The 200 pupae used in the experiment were reared from infested berries.

(ii) Containers. Petri dishes with the bottoms covered with plaster of Paris, were used to hold the pupae.

(iii) Equipment. A constant temperature of 70°F.

was required for the duration of the test. The temperature was provided by a thermostatically controlled constant temperature cabinet located at Brandon, Manitoba.

The relative humidity was maintained by pans of water, and moisture was added to the petri dishes.

b. Experimental procedure

The pupae, when sifted from the sand, were divided into 2 groups of 100 pupae each. Each group of pupae was placed in a petri dish with a thin layer of sand. The sand was used to keep the pupae more or less separate from each other to prevent spread of moulds. The petri dishes were covered, and placed in the constant temperature cabinet at 70°F. The pupae were retained at the above conditions from August 1 until April 1.

c. Results and discussion

No flies emerged from the currant fruit fly puparia retained at 70°F. from August 1 until April 1.

The negative results would indicate that a period at a low temperature is necessary to satisfy the diapause requirements of the pupae. Severin (1917), however, did obtain adults from month-old puparia kept in moist sand in the insectary during August and September, but 6 of the 17 flies that emerged in August were abnormal. The fact that adults did not emerge in the soil from pupae in the field shows that the emergence obtained must have been abnormal. The abnormal flies obtained in Severin's experiment would tend to support the thought that a period of low temperature is necessary for normal development.

C. DATE OF COMPLETION OF DIAPAUSE IN THE FIELD

1. MATERIALS

a. Pupae

The pupae for the experiment were sifted from the soil around the bases of currant bushes on September 21.

b. Containers

Cages, 2 by 4 by 4 inches, were made of 14-mesh wire screen to hold the pupae and medium.

c. Medium

Clay loam was used as the medium.

2. EXPERIMENTAL PROCEDURE

The currant fruit fly pupae, when sifted from the soil, were divided into lots of 25. Each group was placed in soil in a cage. The cage was closed and buried in the ground so that the pupae were 3 inches below the soil surface. On the 1st and 15th of December, January, February, March, and on the 1st of April a cage containing pupae was dug up and taken to the laboratory. The pupae and medium were transferred to a waxed-paper carton and placed at a temperature of 40°F. for 1 day to condition the pupae to the temperature change. They were then placed in the constant temperature cabinet at 70°F. The soil was kept moist. The emergence was recorded daily and at cessation of emergence the soil was examined for empty pupal cases and puparia.

3. RESULTS AND DISCUSSION

The results of the experiment, Table VIII, show that emergence to the extent of 20 per cent occurred when the pupae were removed from the soil on December 1, 32 per cent emergence occurred when removed December 15, and 52 per cent emergence occurred when removed January 1. It would appear from these results that by January 1 the

Table VIII

Per cent emergence of adult *E. canadensis* from 25 pupae on basis of number of empty pupal cases

	Date pupae removed from field								
	Dec. 1	Dec. 15	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1
No. emergents from soil	2	7	10	16	13	12	14	15	13
No. empty pupal cases	5	8	13	18	15	12	14	15	13
Per cent emergence	20	32	52	72	60	48	56	60	52

Table IX

Number of days from date of removal from soil until adult *E. canadensis* commenced to emerge from medium

	Date pupae removed from field								
	Dec. 1	Dec. 15	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1
No. days	111	53	39	33	36	33	25	14	23

diapause requirements of at least 52 per cent of the pupae in the field are met.

The number of days pre-emergence, Table IX, shows that, although 20 per cent of the pupae produced adults when removed from the soil December 1, it required 111 days before the flies began to emerge. The time factor evens off for the pupae removed January 1, at 39 days. These data further support the evidence of Table VIII that the diapause requirements of at least 52 per cent of the pupae in the field are met by January 1.

V. SOIL FUMIGATION STUDIES

A. ON LARVAE ENTERING THE SOIL

1. LABORATORY TEST

a. Materials

(i) Larvae. The larvae for the experiment were reared from infested fruit. The method consisted of placing the infested fruit on a 1/8-inch mesh wire screen over moist fine gravel contained in a flat. The larvae on leaving the fruit fell through the screen onto the gravel, which they entered to pupate. The larvae were taken from the flats before they entered the gravel, or by heavy application of water the larvae that had entered the gravel were caused to return to the surface to be picked up.

(ii) Containers. The containers consisted of waxed-paper, pint cartons having a diameter of 3 1/2 inches, a height of 4 inches, and an end area of 9.6 square inches or 1/15 of a square foot. The carton tops were not used in the experiment.

(iii) Medium. Garden loam composed largely of clay served as the medium.

(iv) Insecticides. The insecticides DDT, hexachlorocyclohexane, and chlordane were tested in the experiment.

Each insecticide was in the form of a wettable powder that contained 5 per cent of the active ingredient. The fumigants ethylene dibromide and DD were not tested. Their persistence in the soil in the laboratory, ethylene dibromide at excessive rates 14+ days and DD 2 days (Stark and Lear 1947), did not exceed the period of 16+ days (Allen 1944) over which the larvae entered the soil in the field.

b. Rates

The insecticides were each applied at 5 and 2.5 pounds of the active ingredient per surface acre.

c. Experimental procedure

The cartons were filled to a depth of 3 inches with the clay loam. The insecticides were scattered on the soil surface and mixed in the soil to a depth of half an inch. Following this the currant fruit fly larvae, obtained from the rearing flats, were placed on the soil surface. A total of 15 larvae were placed in each carton. Applications of water were made at intervals to keep the soil moist.

The cartons, 24 in number, comprising the three test insecticides each at two levels of treatment, triplicated, and six check cartons, were kept in the insectary.

The results were obtained by dissecting and examining the pupae. The larvae, if healthy, at the date of examination had completed their pupal development and were easily distinguished from the affected insects. The affected insects had either failed to produce puparia or had died in the puparia and had dried up.

d. Results and discussion

The results presented in Table X show that of the three insecticides tested, only BHC had an effect on currant fruit fly larvae as they entered the soil. Its degree of control, 45.4 per cent, was not satisfactory. DDT and chlordane had no apparent effect on the larvae.

Table X

The percentage mortality corrected by Abbott's formula effected by DDT, chlordane, and BHC on _E. canadensis_ larvae, 15 per replicate, entering the soil

Material	Rate	Replicate	No. dead	% Ave. mortality
BHC 5% gamma	2.5 lb. gamma/ac.	A B C	9 6 6	45.4
BHC 5% gamma	5 lb. gamma/ac.	A B C	5 6 10	45.4
DDT 5%	2.5 lb. actual/ac.	A B C	0 0 1	0.0
DDT 5%	5 lb. actual/ac.	A B C	0 1 0	0.0
Chlordane 5%	2.5 lb. actual/ac.	A B C	0 0 0	0.0
Chlordane 5%	5 lb. actual/ac.	A B C	0 0 0	0.0
Check 1		A B C	0 0 1	0.0
Check 2		A B C	0 0 1	0.0

B. ON PREDIAPAUSING PUPAE

At the time, August 20, 1950, that the prediapause experiment was conducted, the only information available as to the approximate date that the currant fruit fly entered the state of diapause was that diapause occurred in the adult stage, which was reached within the puparium in early fall (Morrison 1943). Diapause studies, discussed earlier, completed during the winter of 1950-51 showed that by September 1, 50 per cent of the pupae had reached a state of development or diapause enabling them to withstand a temperature of 34°F. It is quite probable though that by September 1, 50 per cent of the pupae would not be able to withstand a temperature of 32°F. or lower, which would occur in the field during the winter. The test to be discussed can probably be considered a predominantly prediapause experiment.

1. FIELD TEST

a. Materials

(i) Plots. The experiment was conducted on an east-west row of red currants located on the Dominion Experimental Station, Morden, Manitoba. The row was isolated by 1/2 mile from other plantings. The bushes were pruned to facilitate fumigation, and the soil on either side of the row and between bushes was cultivated to a depth of 3 inches.

(ii) Equipment. A machine consisting essentially of a "Planet Junior" seeder with a 3-inch tine, and a tank replacing the seeding attachment, was used to apply the fumigant. A copper tube was attached to the bottom of the tank and opened at the heel of the tine. A valve on the copper tubing controlled the rate of flow of the fumigant. A similar machine for application of soil fumigants is handled by Innis, Speiden & Co., U.S.A.

Cone-type cages, each covering 1 square foot of soil, were used to trap the emerging flies on the plots. The base of the cage consisted of a 4-inch band of galvanized sheet iron. To the band, a 14-mesh wire screen cone was attached to provide ventilation and facilitate observation. The tip of the cone was removed and a cloth sleeve attached in its place to allow access to the cage for removal of emergents. The height of the cage was about 1 foot.

(iii) Soil fumigant. A 40 per cent ethylene dibromide solution supplied by Dow Chemical Co. Ltd., U.S.A., was cut with carbon tetrachloride to make a 20 per cent solution.

b. Rates

The 20 per cent ethylene dibromide solution was applied at the rate of 2 and 4 gallons actual per acre.

c. Method

The fumigant was applied in an east-west direction along the length of the row of currants on both sides. The application was made as close to the crown of the bushes as possible, a distance of 6 inches intervening. The succeeding applications were made at 1-foot intervals from the first application.

The first 45 bushes commencing at the west end of the row were treated differently. In addition to the application of the fumigant along the length of the row, fumigant was applied between the bushes at 1-foot intervals. This had the effect of increasing the rate from 2 to 4 gallons of ethylene dibromide per acre.

The following spring before the flies commenced to emerge, 3 cages were placed at random on each plot beneath the overhang of the currant bushes. The base of each cage was forced into the soil to prevent the emerging flies from escaping.

The cages were examined daily for emergents.

At cessation of emergence the cages were removed and the soil covered by each cage, to a depth of 4 inches, was sifted. The number of puparia and empty puparial cases was noted.

In several cages where no emergents were recorded, remains of adult currant fruit flies were found on the soil surface. Ants and spiders were suspected of killing the emergents. To obtain as accurate a set of data as possible the number of emergents and the number of empty puparial cases for each cage were compared and the higher of the two figures taken to represent the number of emergents. It was thought that this method would compensate for flies lost through destruction and possible escape and empty puparial cases lost in sifting. The raw data showed instances where the number of emergents equalled the number of empty puparial cases, and other instances where the emergent figures were greater or less than the figures for the empty puparial cases.

d. Results and discussion

The results presented in Table XI show that the 4-gallon rate was almost twice as effective as the 2-gallon rate of application. The fruit was as heavily infested as in previous years. On the basis of the results and observations recorded in a later experiment with dormant pupae, the per cent mortality obtained at either the 2- or 4-gallon rate against the prediapause pupae would not produce an adequate control.

The soil temperatures taken during the experiment are presented in Table XII.

Table XI

Mortality of prediapause E. canadensis pupae in the field fumigated August 20 with ethylene dibromide, 1950

Rate per acre	No. emergents	No. dead puparia	Per cent emergence	Per cent ave. mortality
4 gal.	5	12	29.4	73.7
	4	11	26.6	
	6	19	24.0	
2 gal.	12	8	60.0	37.5
	5	3	62.5	
	18	10	64.5	
Check	10	0	100.0	0.0
	7	0	100.0	0.0

Table XII

Record of soil temperatures taken at 3-inch level at 3.30 P.M., 1950

Date	Ave. temperature F.
Aug. 20	60.0°
21	67.2
23	74.1
25	78.3
26	61.7
30	70.0
31	70.5
Sept. 1	69.3
Average	68.8

C. ON DIAPAUSING PUPAE

The experiment was set up on September 22, 1950, by which date it was thought the currant fruit fly pupae would have entered diapause, and also when soil temperatures effective for volatilization would still probably occur. Diapause studies mentioned earlier showed that the pupae enter diapause on or about September 1.

1. FIELD TEST

a. Materials

(i) Plots. The experiment was conducted in an east-west row of red currants located on the Dominion Experimental Station, Morden, Manitoba. Two plots were used; one plot was located on the south side of the row and the other on the north side. Either plot consisted of an area about 3 feet wide by 20 feet long. Four red currant bushes were located between the 2 plots. The bushes were pruned to facilitate fumigation. The south side of the row was cultivated to a depth of 3 inches and the north side left uncultivated but kept free of weeds.

(ii) Equipment. An iron bar was used to make holes in the soil at intervals of 1 foot. The fumigant was measured into the holes with a pipette.

Cone-type cages each covering 1 square foot of soil were used to trap the emerging flies.

(iii) Soil fumigant. A 40 per cent solution of ethylene dibromide was cut to 20 per cent ethylene dibromide with carbon tetrachloride.

b. Rates

The fumigant was applied at a rate of 2 gallons actual ethylene dibromide per acre at a depth of 3 inches in the soil.

c. Method

The 2 plots were marked at intervals of 1 foot. A hole 3 inches deep was made at the intersections, and the fumigant pipetted into it. The hole was then closed with soil.

The following spring, 3 cone-type cages were placed at random beneath the overhang of the currant bushes on each plot. The cages were checked daily for emergents. At cessation of emergence the soil covered by the cage, to a depth of 4 inches, was sifted. The number of puparia and empty puparial cases was recorded. To obtain the correct emergence data the higher of the 2 figures, number of emergents and number of empty puparial cases for each cage, was taken to represent the actual number of emergents.

The soil temperature was recorded only for the day of the fumigant application.

d. Results and discussion

The results presented in Tables XIII and XIV show that ethylene dibromide applied in the fall for the control of diapausing pupae did not produce an average mortality of 50 per cent. The similarity of the results presented seems to indicate that cultivation or the lack of it does not affect the efficacy of ethylene dibromide applied in the fall.

The soil temperature at the 3-inch level on the date of application was 60.0°F. It was not possible to obtain further soil temperature data; weather conditions similar to the day of application held for at least a week and it is assumed that the soil temperatures averaged near 60°F. Such a temperature causes effective volatilization of ethylene dibromide.

The actual precipitation for September was 2.76 inches compared with the normal precipitation of 1.88 inches. The precipitation for the summer season was above normal, the soil was quite moist and presumably in a condition favoring effective fumigation.

Table XIII

Mortality of diapausing *E. canadensis* pupae in cultivated soil fumigated September 22 with ethylene dibromide at 2 gal. per acre

Cage No.	Number emergents	No. dead pupae	Per cent mortality	Per cent ave. mortality
1	9	2	18.2	40.4
2	15	14	48.3	
3	7	5	41.7	
Check 1	10	0	0.0	0.0
2	7	0	0.0	

Table XIV

Mortality of diapausing E. canadensis pupae in uncultivated soil fumigated September 22 with ethylene dibromide at 2 gal. per acre

Cage No.	Number emergents	No. dead pupae	Per cent mortality	Per cent ave. mortality
1	12	7	36.9	42.4
2	13	6	31.6	
3	5	9	64.3	
Check 1	9	0	0.0	0.0
2	11	0	0.0	

D. ON DORMANT PUPAE

Studies of the diapause of the currant fruit fly pupae discussed earlier in this paper show that the diapause stage of the pupae is completed about January 15. It is probable that the pupae remain in a dormant state until temperatures suitable for further development are reached. The term, dormant pupae, is used to refer to pupae which have completed their diapause and are capable of developing to the adult state when the proper temperatures are provided.

1. LABORATORY TESTS

Two tests were made using dormant pupae. Test 1 was made in 1949 and test 2 in 1950.

a. Materials

(1) Pupae. For the 1949 test, several thousand pupae were reared from infested fruit during the previous summer. Infested berries were placed on a 3/16-inch mesh screen which was suspended in a waxed-paper carton. The larvae emerged from the fruit and fell to the bottom of the carton, where they pupated. The pupae were placed in a covered carton and kept until September 25. On this date,

fine gravel was added to the pupae, and the carton and its contents was placed in a constant temperature room. The temperature ranged between 35° and 40°F., and the relative humidity averaged 90 per cent. The room remained at the above conditions until April, at which time the cooling unit was shut off and the room allowed to find its own temperature at 50° to 55°F. On May 9, the pupae were removed from the holding room and placed in the office at a temperature ranging between 40° and 70°F. On May 15, adult flies began to emerge. With the viability of the pupae attested, 24 groups of 100 pupae each, were selected from the stock for the experiment. Selection was made on the basis of uniformity in size, freedom from obvious injuries such as cracks in the puparium, and from puparial deformities.

The pupae for the 1950 experiment were sifted from the soil surrounding the base of 5 currant bushes on June 4 to 6 of the same year. On this date the imagos were commencing to emerge.

(ii) Containers. Waxed-paper pint cartons measuring 3 1/2 inches in diameter by 4 inches in height, with an end area of 9.6 square inches or 1/15 square foot, were used as containers in both tests. The waxed-paper tops of the cartons were replaced with a 14-mesh wire screen to provide ventilation and facilitate observation.

(iii) Medium. A clay loam served as the medium in 1949. It was not entirely satisfactory, as it hardened on loss of moisture. In 1950 a sandy clay loam was used in its stead.

(iv) Soil fumigants and insecticides. In the 1949 and 1950 experiments the soil fumigants ethylene dibromide and 1,2 dichloropropane 1,3 dichloropropene (DD), and the insecticide hexachlorocyclohexane (BHC), were compared. Dieldrin was included also in the 1950 tests. The ethylene dibromide and DD, crude, were supplied undiluted and were used as such in the 1949 tests. In 1950 the ethylene dibromide and a 50 per cent solution of DD were cut to 10 per cent with carbon tetrachloride and used in the diluted form. The BHC, 5 per cent gamma isomer, was supplied as a wettable powder. It was used as supplied in 1949, but it and dieldrin, 25 per cent wettable powder, were diluted with talc to 0.25 per cent active ingredient in 1950.

b. Rates

The fumigants ethylene dibromide and DD, in 1949, were each applied at the rates of 14.4 and 28.7 gallons actual per acre. The BHC applications were made at the rates of 5 and 10 pounds gamma isomer per acre.

In 1950, ethylene dibromide and DD were applied at the rates of 1, 2, and 4 gallons actual per acre. The insecticides BHC and dieldrin were applied at the rates of 2, 4, and 8 ounces of active ingredient per acre.

c. Experimental procedure

The cartons, in 1949, were filled to a depth of 1 1/2 inches with garden loam. The selected pupae, 100 per carton, were then scattered over the soil. Two inches more of the loam were added to each carton to give an overall soil depth of 3 1/2 inches. In 1950, the cartons were filled with soil to a depth of 1 inch. Twenty-five pupae, unless otherwise indicated, were scattered on the soil in each carton. Three inches more of the soil were added. The soil fumigants, ethylene dibromide and DD, were placed at the 3-inch level in the soil in the cartons in 1949, and at the 2-inch level in 1950. This was done by inserting a pencil to the required depth and pipetting the fumigant into the hole remaining after the pencil was removed. The hole was then filled with soil.

The BHC in 1949, and the BHC and dieldrin in 1950, were incorporated into the top 1 inch of soil in the cartons. The chemicals were spread on the soil surface and then mixed with the soil to the depth of 1 inch.

Each level of treatment, in 1949 and 1950, was triplicated.

In 1949 the cartons were kept at a temperature which ranged from 50° to 60°F.; in 1950 the cartons were kept in the office at a temperature which fluctuated from 40° to 70°F.

The cartons were examined daily, and all emergents were recorded and removed. At cessation of emergence in 1950 the soil was examined to determine the fate of the remainder of the pupae.

d. Results and discussion

The results of the 1949 and 1950 laboratory experiments with dormant pupae are discussed herewith.

Ethylene dibromide, Tables XV, XVI, and XVII, at the rates of 14.4 and 28.7 gallons of fumigant per acre, was 100 per cent effective against the dormant pupae. A second test at lower rates, Table XVIII, shows that the fumigant was 100 per cent effective at 4 gallons per acre. At 1 and 2 gallons per acre, ethylene dibromide was, Table XVIII, 74.3 and 97.1 per cent effective, respectively. Examination of the puparia in the cartons of the ethylene dibromide test, Tables XV and XVI, showed that no emergence from the puparia occurred, partial or otherwise. The effect of the fumigant apparently was to kill the dormant pupae within the puparial cases. This is evident also in Table XVIII where the 4 gallons per acre rate gave complete control of the dormant pupae; examination of the puparia failed to show any partially-emerged flies. The 1 and 2 gallons per acre allowed some emergence but here again the majority of the pupae died in the puparial cases.

The DD tests, Table XVII, at the rates of 14.4 and 28.7 gallons per acre produced a mortality of 49.6 and 73.6 per cent, respectively. The results of DD tests at lower rates, Table XIX, show that DD, at these rates, is practically ineffective against dormant pupae. The results, Tables XV and XVI, show that either the effect of the DD dissipated after a short period of time or that the DD was ineffective against the dormant pupae. Both would seem to be true. The DD at the rate of 14.4 gallons per acre suppressed emergence for a period of about 9 days, and at the 28.7 gallons per acre suppressed emergence for approximately 12 days. The emergence of the flies after the suppression periods compares with the check emergence. According to Stark and Lear (1947) DD mixture (crude) has a relative persistence in the soil of 2 days. The persistence of the fumigant in the soil was determined by the number of days after treatment that wheat seed could be planted without injury.

That DD is ineffective against the dormant fruit fly pupae is evident from Tables XV and XVI. Had the fumigant been effective against the dormant pupae it is logical to suppose that emergence would not have been suppressed for a definite period but that the emergence of the survivors would have been dispersed over the period rather than occurring at the end of the period. It is probable that the DD, used at the excess rates of 14.4 and 28.7 gallons per acre in a rather impermeable waxed-paper carton at temperatures of 40° to 70°F., would take longer to dissipate than indicated by Stark and Lear (1947). Under the conditions described, the DD probably remained insecticidal for the periods of 9 and 12 days as the results show. The results of the diapause studies, Table V, show too that the periods of 9 and 12 days are sufficient to permit pupae, after the diapause requirements have been met, to break dormancy and emerge.

Examination of the puparia at cessation of emergence showed that the majority of the dead pupae died within the puparia while the remainder died partially emerged from the puparia. A record of the number of dead pupae and adults in the soil would probably have shown that the number of dead pupae is less than indicated by total emergence figures and that a large number of adults died in the soil. This statement is prompted by the results presented in Tables XIX and XXII, which show that in the DD and check cartons approximately 1/7 of the flies died in the soil.

The evidence presented would appear to show that DD, during its period of insecticidal persistence, is effective against adults in the soil, adults as they emerge from the puparial cases, and probably against those pupae which have broken dormancy within the puparial cases.

The results of the BHC tests, Tables XV, XVI, XVII, and XX, show that BHC had no significant effect on the dormant currant fruit fly pupae.

The effect of dieldrin, Table XXI, against the dormant pupae also appears negligible.

Table XV

Daily emergence of E. *canadensis*, totalled at 3-day intervals, from 100 dormant pupae per replicate, treated in the laboratory, 1949

Date	DD 14.4 gal. per acre			EDB 14.4 gal. per acre			BHC 5 lb. per acre			Check		
	A	B	C	A	B	C	A	B	C	A	B	C
May 19-21	1						1	3	1	1		2
22-24							2	1		1	1	2
25-27	1						7	8	7	7	13	8
28-30	9		7				27	20	28	17	23	18
May 31-June 2	21	12	22				27	15	11	25	17	18
June 3-5	3	6	6				4	8	8	8	9	10
6-8			2				3	8	5	5	6	4
9-11	4	2	4				1	5	4	3	8	4
12-14	2	1	2				1	2	1	1	1	
Total	41	21	43	0	0	0	73	70	65	68	78	66

Table XVI

Daily emergence of *E. canadensis*, totalled at 3-day intervals, from 100 dormant pupae per replicate, treated in the laboratory, 1949

Date	DD 28.7 gal. per acre			EDB 28.7 gal. per acre			BHC 10 lb. per acre			Check		
	A	B	C	A	B	C	A	B	C	A	B	C
May 19-21										1	2	3
22-24								1			1	
25-27							5	7	2	9	4	4
28-30							18	26	28	25	19	27
May 31-June 2	1	2	18				31	15	25	19	21	11
June 3-5			6				6	6	5	6	6	4
6-8	2		4				5	3	2	5	4	6
9-11	4	2	11				4	3	4	6	8	8
12-14	2	2	1				3			2	1	3
Total	9	6	40	0	0	0	72	61	66	73	66	66

Table XVII

Per cent mortality, corrected by Abbott's formula,*
of dormant *E. canadensis* pupae
treated in the laboratory, 1949

Material and rate	Total emergence	Per cent mortality
DD 14.4 gal./acre	105	49.6
DD 28.7 gal./acre	55	73.6
EDB 14.4 gal./acre	0	100.0
EDB 28.7 gal./acre	0	100.0
BHC 5 lb. gamma/acre	208	0.2
BHC 10 lb. gamma/acre	199	4.5
Check	208.5**	30.5

* Abbott, W.S. 1925. A method of computing the effectiveness of an insecticide. Jour. Econ. Ent. 18:265-267.

** Average total emergence from check of Tables XV and XVI.

Table XVIII

Effect of ethylene dibromide on dormant
E. canadensis pupae in the laboratory, 1950

Rates of replicates	1 gal./ac. A	B	C	2 gal./ac. A	B	C	4 gal./ac. A	B	C
No. pupae	25	25	25	25	25	25	25	25	25
No. dead pupae	20	15	22	24	25	24	25	25	25
No. adults dead in soil	2	1	1	1					
No. adults dead in carton	2	4							
No. adults surviving	1	5	2			1			
Total emergence	5	10	3	1		1			
% total emergence	20	40	12	4		4			
% average mortality* corrected by Abbott's formula	74.3			97.1			100.0		

* In Tables XVIII to XXI, inclusive, based on average emergence of check Table XXII.

Table XIX

Effect of dichloropropane dichloropropene on dormant *E. canadensis* pupae in the laboratory, 1950

Rates	1 gal./ac.			2 gal./ac.			4 gal./ac.		
Replicates	A	B	C	A	B	C	A	B	C
No. pupae	25	25	25	25	25	25	25	25	25
No. dead pupae	1	3	6	3	7	1	5	5	2
No. adults dead in soil	8	3		7	1	6	3	3	5
No. adults dead in carton									
No. adults surviving	16	19	19	15	17	18	17	17	18
Total emergence	24	22	19	22	18	24	20	20	23
% total emergence	96	88	76	88	72	96	80	80	92
% average mortality corrected by Abbott's formula	7.1			8.5			10.0		

Table XX

Effect of hexachlorocyclohexane (0.25% gamma isomer) on dormant *E. canadensis* pupae in the laboratory, 1950

Rates	2 oz. gamma isomer/ac.			4 oz. gamma isomer/ac.			8 oz. gamma isomer/ac.		
Replicates	A	B	C	A	B	C	A	B	C
No. pupae	25	25	25	25	25	25	25	25	25
No. dead pupae	6	2	3	2	0	2	1	1	5
No. adults dead in soil	3	12	6	0	3	1	3	2	4
No. adults dead in carton	2	3	3	3	7	4	7	7	5
No. adults surviving	14	8	13	20	15	18	14	15	11
Total emergence	19	23	22	23	25	23	24	24	20
% total emergence	76	92	88	92	100	92	96	96	80
% average mortality corrected by Abbott's formula	8.5			0.0			2.8		

Table XXI

Effect of dieldrin (0.25% actual) on dormant
E. *canadensis* pupae in the laboratory, 1950

Rates	2 oz. actual per acre			4 oz. actual per acre			8 oz. actual per acre		
Replicates	A	B	C	A	B	C	A	B	C
No. pupae	20	20	20	25	25	25	25	25	25
No. dead pupae	5	2	2	2	2	3	2	2	3
No. adults dead in soil	2	7	2	5	3	7	5	7	7
No. adults dead in carton	1	3	4	4	6	5	2	3	5
No. adults surviving	12	8	12	14	14	10	16	13	10
Total emergence	15	18	18	23	23	22	23	23	22
% total emergence	75	90	90	92	92	88	92	92	88
% average mortality corrected by Abbott's formula	8.7			2.8			2.8		

Table XXII

Adult emergence from dormant E. *canadensis* pupae

Replicates of check	A	B	C
No. pupae	25	25	25
No. dead pupae	1	1	3
No. adults dead in soil	4	5	1
No. adults dead in carton			
No. adults surviving	20	19	21
Total emergence	24	24	22
% total emergence	96	96	88
% average mortality corrected by Abbott's formula		0.0	

2. FIELD TESTS

Three field trials were made with dormant pupae. The 1950 and 1951a experiments were used to obtain information concerning the efficacy of ethylene dibromide against the pupae at different rates, depths, and conditions of cultivation. The purpose of the 1951b test was to determine the efficacy of the fumigant where the whole planting was fumigated.

a. Materials

(i) Plots. The plots of the 1950 and 1951a experiments were located within east-west rows of red currants growing on the Dominion Experimental Station, Morden, Manitoba. The 1951b experiment was made in the currant and gooseberry planting of Mr. Godfrey, Morden, Manitoba.

(ii) Equipment. For the application of the fumigant in 1950 an iron bar for making the holes and a pipette for measuring the fumigant comprised the fumigation equipment. In the 1951a and 1951b experiments a mechanical injector termed "Fumigun" was employed. It was supplied by Innis, Speiden & Co., U.S.A. The injector was capable of delivering quantities of fumigant accurately as low as 1 cubic centimeter per stroke.

Cone-type cages, each covering an area of 1 square foot, were used to trap the emerging flies.

(iii) <u>Soil fumigants</u>. Ethylene dibromide was the only fumigant used in the 3 field experiments. The fumigant supplied in the 1950 test was a 40 per cent solution, and in the 1951 tests an 85 per cent solution. In both years the fumigant solution was cut to 20 per cent ethylene dibromide with carbon tetrachloride.

b. Rates

In the 1950 and 1951b tests, the ethylene dibromide was applied at the rate of 2 gallons per acre. In the 1951a test, it was applied at the rates of 2, 3, and 4 gallons per acre.

c. Methods

In 1950, a section of a row of red currants, measuring about 6 feet wide by 40 feet long, was selected for fumigation. The area was marked off at 1-foot intervals. Holes to a depth of 3 inches were made at the intersections with the iron rod. The fumigant was pipetted into the holes and the holes closed with soil. Six cages were placed at random in the fumigated area beneath the overhang of the currant bushes. The cages were checked daily and emergents removed.

The 1951a experiment, located in an east-west row of red currants, covered an area 6 feet wide by about 60 feet long. The soil on the south side of the row was cultivated with a spade to a depth of 3 inches. The north side of the row was left uncultivated but kept free of weeds.

The cultivated and uncultivated areas were each divided into 3 sections and each section into 3 plots. A plot was equal to the distance, about 6 feet, between two currant bushes in either the cultivated or uncultivated areas.

The 3 sections of cultivated or uncultivated soil were fumigated to a depth of 1, 3, or 6 inches, respectively. The 3 plots within each section of cultivated or uncultivated soil were fumigated at the rate of 2, 3, or 4 gallons per acre, respectively. Following the fumigation, two cages were placed on each plot to trap the emerging flies.

At cessation of emergence the cages were removed and the soil covered by the cage, to a depth of 4 inches, was sifted. The number of empty pupal cases and puparia were recorded. The higher of the two figures, number of emergents and number of empty puparial cases for each cage, was taken to represent the emergence figure.

The 1951b experiment was conducted in a private planting of currants and gooseberries. The entire planting was fumigated with ethylene dibromide to a depth of 3 inches. The mechanical injector was used to apply the fumigant. Two cages were placed on the fumigated soil beneath the overhang of the currant bushes. The cages were checked daily. At cessation of emergence the cages were removed, and the soil covered by the cage, to a depth of 4 inches, was sifted for empty pupal cases and puparia. The number of emergents and number of empty puparial cases obtained for each cage were compared and the higher of the two figures retained to represent the currant fruit fly emergence.

After the maggots of the current season had left the fruit and entered the soil, two soil samples, each 1 foot square by 4 inches deep, were sifted. The number of puparia obtained per square foot served as a check on the season's infestation for that planting.

d. Results and discussion

The results of the 1950 field experiment, Table XXIII, show that ethylene dibromide gave control of the dormant pupae in the field ranging from 50.0 to 100.0 per cent. The flies that did emerge, emerged at the beginning of the emergence period, a matter of 5 and 6 days after the fumigant was applied. Examination of the puparia sifted from the soil after cessation of emergence showed that a number of the pupae died partially emerged from the puparia. The early emergence, and the dead partially-emerged pupae, would seem to indicate that the fumigant application was late.

An analysis of variance was performed on the results of the 1951a experiment, Table XXIV. The results of the analysis showed that only the soil had a significant effect on the efficacy of the fumigant. The highest mortalities were obtained on the cultivated soils apparently at the 3-inch depth. The rates of application and the depth at which the fumigant was applied, according to the results of the analysis, failed to affect the efficacy of the fumigant.

In neither the 1950 nor the 1951a experiments could the effect of the soil fumigation on berry infestation be determined. The plots were located within rows of currants and easily accessible to gravid females from the remainder of the rows.

The results of the 1951b experiment, Table XXV, were obtained from a planting which was completely fumigated. The mortality of the fruit fly pupae was 52.9 and 80.0 per cent. Despite these mortalities the red currant infestation was estimated to range from 25 to 50 per cent. The red currants were not considered worth picking. The gooseberries and black currants were not as heavily infested. Two soil samples, each one foot square, taken from beneath the overhang of the red currant bushes after the maggots had left the fruit, showed an infestation of 60 and 53 puparia per square foot. The soil infestation per square foot was greater for the current season's infestation than for the fumigated infestation. Infestation of the planting from outside sources was considered negligible since the closest planting was over one-quarter of a mile distant (Severin 1917).

It is evident from the results that despite high mortality of the dormant pupae a sufficient number of flies survived to heavily infest the fruit.

Observations on the effect of ethylene dibromide on the currant bushes, weeds, and soil organisms were made. The fumigant, at the rates applied, had no apparent effect on the currant bushes, weeds, or grass. During the soil sifting operations after the currant fruit fly emergence had ceased, numerous dead adult scarabeids, strawberry root weevils (*Brachyrhinus ovatus* (L.)), larval wireworms and cutworms were noted in the soil, apparently killed by the fumigant. An infestation of the imported currantworm, *Nematus ribesii* (Scop.), occurred in the plots of the 1951a experiment; a number of the emerging adult sawflies were trapped by the cages. No dead pupae or adults were noted when the soil was sifted.

The fumigant had the effect of either killing the earthworm population or causing it to leave the area, since the earthworms disappeared. They reappeared in the treated area about a month after the fumigation.

Soil temperature and precipitation records were obtained for the 1950 and 1951a experiments. These are presented in Tables XXVI, XXVII, XXVIII, and XXIX. McClellan _et al_ (1949) state that temperatures as low as 61°F. are sufficient for the volatilization of ethylene dibromide. The temperatures of Table XXVI range from 53° to 78°F. with an average of 62.7°F. The average temperatures presented in Table XXVII are higher than those of Table XXVI. The temperatures presented are close to or above the temperature used by McClellan _et al_ (1949) and would provide conditions suitable for volatilization of the fumigant. This is shown by the mortality results of Tables XXIII and XXIV.

The precipitation records for the months of April and May of 1950 and 1951, are presented in Tables XXVIII and XXIX, respectively. The total precipitation for the two months in 1950 is about double the normal rainfall, and in 1951 about one-half the normal rainfall. The soil moisture conditions at the time of fumigation varied accordingly. The soil was very moist in 1950 and very dry in 1951. According to McClellam et al (1949) ethylene dibromide was more effective in damp soil than in dry. The effect of the moisture, or lack of it, on the efficacy of the fumigant is not apparent from the results presented in Tables XXIII and XXIV, although it is possible that the irregular results presented in Table XXIV may partially be caused by the droughty conditions that existed.

Table XXIII

Mortality of dormant _E. canadensis_ pupae fumigated with ethylene dibromide at 2 gallons per acre in the field, 1950

Cage No.	No. flies	No. dead pupae	% mortality based on total no. pupae
1	1	1	50.0
2	1	5	83.4
3	1	1	50.0
4	1	2	66.6
5	0	6	100.0
6	0	7	100.0

Table XXIV

Per cent mortality of dormant *E. canadensis* pupae, corrected by Abbott's formula,*
resulting from field fumigation with ethylene dibromide, 1951a

Rate/acre		Cultivated soil 1"	3"	6"	Uncultivated soil 1"	3"	6"
2 gal.	A	76.8	100.0	60.4	66.7	60.0	33.4
	B	69.6	100.0	21.7	55.6	0.0	55.6
3 gal.	A	47.8	100.0	79.1	66.7	55.6	66.7
	B	79.1	55.3	70.3	85.8	50.0	75.0
4 gal.	A	30.5	100.0	13.0	55.6	54.6	55.6
	B	75.0	81.1	43.1	25.0	71.5	33.4
Check	A) B)	4.2			0		

* Abbott, W.S. 1925. A method of computing the effectiveness of an insecticide. Jour. Econ. Ent. 18:265-267.

Table XXV

Mortality of dormant *E. canadensis* pupae fumigated in the field with ethylene dibromide at 2 gallons per acre, 1951b

Cage no.	Total emergence	No. dead pupae	Per cent emergence	Per cent mortality
1	12	14	47.1	52.9
2	9	36	20.0	80.0
Check 1	9	0	100.0	0.0
2	11	0	100.0	0.0

Table XXVI

Soil temperature, degrees Fahrenheit, recorded at 2-inch level at 3.30 P.M., 1950

Date	Temperature
May 29	62
June 1	64
2	53
6	78
7	60
8	59
10	55
12	64
14	70
Average	62.7

Table XXVII

Soil temperature, degrees Fahrenheit, recorded at 3.30 P.M., 1951a

Dates	Cultivated			Uncultivated		
	1 in.	3 in.	6 in.	1 in.	3 in.	6 in.
May 16	76	86	71	69	70	61
17	83	84	69	76	75	67
19	80	76	70	78	74	68
21	76	82	72	73	82	77
22	86	84	74	84	83	74
23	84	83	80	82	84	76
Average	80.8	82.5	72.5	77.0	78.0	70.5

Table XXVIII

Precipitation records for April and May, 1950

Month	Actual rainfall	Normal rainfall*
April	1.54 in.	1.28 in.
May	5.77 in.	1.94 in.
Total	7.31 in.	3.22 in.

*Normal rainfall - averaged precipitation from time first record kept for a particular period.

Table XXIX

Precipitation records for April and May, 1951

Month	Actual rainfall	Normal rainfall
April	1.20 in.	1.23 in.
May	0.39 in.	1.92 in.
Total	1.59 in.	3.15 in.

VI. DISCUSSION OF FUMIGATION STUDIES

The results of the experiments on the larvae, prediapausing, diapausing, and dormant pupae show that control of these stages is impractical with the materials used. Of the materials tested on the larvae, only BHC, 2.5 lb. and 5 lb. gamma isomer per acre, was effective, producing 45.4 per cent mortality at each rate. In the experiments on the prediapausing and diapausing pupae, ethylene dibromide at 2 gallons per acre failed to produce an average mortality of 50 per cent. The results of the experiment where the entire planting was fumigated for the control of the dormant pupae show that, despite an average mortality of 70.4 per cent, enough flies survived to infest 25 to 50 per cent of the fruit.

In addition to the high mortality required to obtain control, the use of fumigants has another weakness. With fumigants the grower has no control over surviving flies, or gravid females migrating from outside sources, in contrast to the recommended DDT treatment (Andison _et al_ 1951) where the flies are exposed to control conditions for at least 2 weeks. In comparison with DDT the fumigant application is more exacting and time-consuming. The ethylene dibromide plus diluent is also more expensive than the DDT required for 2 applications.

VII. SUMMARY

The diapause studies, necessary for evaluation of the soil fumigation work, showed that at least 50 per cent of the pupae had reached a state of development enabling them to withstand a temperature of 34°F. by September 1. Further work showed that the requirements of diapause were met by a period of 5 months at a temperature of 34°F., and complete by February 1.

The temperatures of 36° and 40°F. were shown to be more effective than 34°F. for overwintering currant fruit fly pupae in the laboratory.

In the field, diapause was complete in 52 per cent of the pupae by January 1.

The insecticides DDT, BHC, and chlordane were tested in the laboratory against larvae entering the soil. The BHC caused a mortality of 45.4 per cent. The DDT and chlordane had no apparent effect on the larvae.

In the tests against the prediapausing and diapausing pupae, ethylene dibromide at the rate of 2 gallons per acre at a depth of 3 inches caused a mortality of less than 50 per cent. In the diapause test, cultivation or the lack of it had no apparent effect on the efficacy of the fumigant.

The fumigants ethylene dibromide and DD, and the

insecticides BHC and dieldrin, were tested in the laboratory against the dormant currant fruit fly pupae. The ethylene dibromide caused mortalities of 74.3, 79.1, and 100 per cent at the rates of 1, 2, and 4 gallons per acre.

At the rates of 14.4 and 28.7 gallons per acre DD was only 49.6 and 73.6 per cent effective. The effect of the fumigant apparently was only upon those pupae which broke dormancy and commenced to emerge. At the rate of 1, 2, and 4 gallons per acre, DD was ineffective against currant fruit fly pupae.

The BHC and dieldrin had no apparent effect on the pupae.

Ethylene dibromide was tested in the field at rates of 2, 3, and 4 gallons per acre, at depths of 1, 3, and 6 inches, against dormant pupae. The rate of 2 gallons per acre was apparently as effective as 3 or 4 gallons per acre. The various depths had no apparent effect on the efficacy of the fumigant. The test showed that cultivation prior to fumigation improved the efficacy of ethylene dibromide.

The results of one test where the soil of the entire planting of currants and gooseberries was fumigated showed that despite an average mortality of 70.4 per cent enough flies survived to infest 25 to 50 per cent of the fruit.

The soil temperature and soil moisture conditions were noted in the field fumigation work. There was no apparent correlation between soil temperature or soil moisture, and efficacy of the ethylene dibromide.

The use of ethylene dibromide for the control of the currant fruit fly in the soil was considered impractical on the basis of results, cost, and precise application requirements.

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