# NATURAL CONTROL IN CABBAGE ROOT FLY POPULATIONS AND INFLUENCE OF CHEMICALS

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Dit proefschrift met stellingen van

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*De Rector Magnificus der Landbouwhogeschool,*
W. DE JONG

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# NATURAL CONTROL IN CABBAGE ROOT FLY POPULATIONS AND INFLUENCE OF CHEMICALS

(MET EEN SAMENVATTING IN HET NEDERLANDS)

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD
VAN DOCTOR IN DE LANDBOUWKUNDE
OP GEZAG VAN DE RECTOR MAGNIFICUS IR. W. DE JONG,
HOOGLERAAR IN DE VEETEELTWETENSCHAP,
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VAN EEN COMMISSIE UIT DE SENAAT
VAN DE LANDBOUWHOGESCHOOL TE WAGENINGEN
OP VRIJDAG 5 FEBRUARI 1960 TE 16 UUR

DOOR

I. K. ABU YAMAN

H. VEENMAN & ZONEN N.V. - WAGENINGEN - 1960

# THEOREMS

I

Predators most likely play a minor part in larval mortality in the cabbage root fly. (*Erioischia brassicae* Bché)

II

The main factors responsible for the severe damage by the cabbage root fly observed in *Brassica* crops in spring time are:
*a.* Strong infestation.
*b.* Low temperature, reducing the recovery power of the plants.

III

Progress in biological control is much hampered by a lack of knowledge of numerical data on plant pests.

IV

The recent method for the determination of the *in vivo* inhibition of acetylcholinesterase in insects poisoned with an organophosphorus insecticide is insufficient to establish what is the relation between this inhibition and the accompanying accumulation of acetylcholine.

V

In several cases, the summer sprays as currently practised against plant diseases and pests in Lybia, could be successfully replaced by dormant sprays.

VI

Especially in arid regions, crop rotation and killing vines at harvest may be considered of great importance in controlling Late Blight (*Phytophthora infestans*) of tomato and potato.

VII

The recent discovery of a plant virus which causes harm to its insect vector does not support the theory of an insect origin of certain plant viruses.

VIII

In view of the soils and root-stocks as used in citriculture, the virus disease, "quick decline" is a standing threat to this industry.

IX

To obtain better economical yield of banana grown in the Jordan River Valley (El-Ghor), Jordan, the use of windbreaks (e.g. *Casuarina equisetifolia*) and the removal of male-flower clusters is highly recommended.

X

The separation between the student societies as well as their very fixed traditional ways make it difficult for most foreign students to adapt themselves to Wageningen student life.

XI

Agricultural projects as a mean to solve the Palestine-Arab problem will fail because of the resistance of the refugees against measures which will keep them away from the restoration of their integral rights.

# NATURAL CONTROL IN CABBAGE ROOT FLY POPULATIONS AND INFLUENCE OF CHEMICALS

THESIS

IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF
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ON FRIDAY 5 FEBRUARY 1960 AT 16 O'CLOCK

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# NATURAL CONTROL IN CABBAGE ROOT FLY POPULATIONS AND INFLUENCE OF CHEMICALS

*(met een samenvatting in het Nederlands)*

by

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CHAPTER I

## INTRODUCTION

The intensive use of chemicals in the control of phytophagous pests, and the resulting undesirable effects of most of these chemicals (resurgences, development of man-made pests, and the selection of resistant strains) necessitate the limitation of chemical control.

In most insect populations in their natural environment, a very high mortality occurs without any deliberate treatment. This mortality is caused by the "natural resistance factors". It seems appropriate, therefore, to make more use of these factors in controlling pests.

In order to obtain information on the importance of these factors for agricultural pests, we must study the natural mortality of the insects under field conditions. This can be done only by population counts.

When the natural resistance factors and their effects are known, we may try to find ways to improve them (culture methods, choice of varieties etc.).

Insecticides and fungicides are merely "new" resistance factors. Therefore, it is of great importance to know whether they:

*a.* are harmful to other resistance factors and, if so, to what extent. This refers especially to biological control factors.
*b.* promote multiplication of the pest (stimulate egg production, stimulate growth and survival e.g. by improvement of leaf quality).

In economic entomology we are interested in regulation of the population density of a pest at a low level. Under the conditions of practice, this can be achieved successfully, only by the combination of chemical and biological control methods. A change in the balance between a pest and its natural enemies in favour of the last is very important. For this purpose, two things must be combined:

1. Selective insecticides – the discovery of many more of them is essential.
2. "Density dependent" factors, for they may regulate the population density.

Since, so far, no selective insecticide has been discovered for the control of our phytophagous insect, the cabbage root fly, it seemed important to study the effects of the two most recommended insecticides, Aldrin and Chlordane, on its control and on the abundance of its natural enemies.

In the experimental field of the Laboratory of Entomology at Wageningen, the abundance of different stages of the cabbage root fly has been followed over a period of five successive years (1955–1959). Started as a series of short investigations by graduate students, the work has been continued by the present author since 1957. In this paper the results obtained during the five years period are summarized. In addition, a preliminary experimental analysis of the mortality factors has been carried out.

CHAPTER II

## GENERAL REMARKS ON THE CABBAGE ROOT FLY AND ITS DAMAGE

The cabbage root fly, *Erioischia* [1]) *brassicae* BOUCHÉ, belongs to the Family *Anthomyiidae;* Order Diptera. The larvae of many species of this family affect agricultural and horticultural crops. Many species can only be identified in the adult male. The cabbage root fly and some other species can be identified by larval characters.

LUNDBLAD (1933) gave descriptions of the adults and immature stages of 13 species of the Anthomyiids attacking crucifers in Sweden, among them the cabbage root fly.

DE WILDE (1947) surveyed the morphological characteristics of all stages.

MILES (1952) described the immature stages.

The distribution of the cabbage root fly is restricted to the temperate zone of the holarctic region (35°–60° N.L.) (DE WILDE, 1947).

SCHOEN (1916) and METCALF & FLINT (1933) mentioned in the U.S.A. that below 40° N.L. it causes no damage. The same holds for Europe, below 45° N.L.

[1]) For using the genus name *Erioischia*, a name which is now in common use in the English applied entomological literature, I based myself upon the "check list of British Insects" by KLOET & HINCKS (1945).

According to a private correspondence with Dr. W. J. KABOS, Dipterologist, the only other genus name for *brassicae* is *Delia*, when one thinks that the characters which the species *D. brassicae*, *D. pilipyga* and *D. floralis* have in common, are too small to erect a valid genus for them.

The attacks by the cabbage root fly develop every season in much the same way. Between 15 April and 15 May the adult flies emerge from hibernated puparia. After a pre-oviposition period of 3–4 days, the females lay their eggs in the ground at or near the stalk of the plant. Oviposition takes place at air temperatures above 15 °C (MILES, 1955). Upon hatching, the first instar larvae move down along the main root, feed mostly on the cortex, and make grooves and passages with their hookshaped mouth-parts (plate Ia). As a result they destroy the feeding system of the plant. The plant remains small and looses its turgidity, and when heavily damaged, the whole root system decays and the plant dies (plate Ib).

At the end of the third instar, the larvae crawl a few centimeters horizontally into the soil to pupate. These pupae give flies of the first generation which according to DE WILDE and MILES is more numerous than the over-wintering generation.

The number of generations varies from one country to another. It ranges between 1 and 5 per year.

LUNDBLAD (1933) in Sweden mentioned that there are at least 2 generations.

DE WILDE (1947) in Holland recorded 3 generations and a partial 4th.

CARLSON *et al* (1947) in U.S.A. mentioned 4–5 generations.

BROOKS (1951) in Canada mentioned 3–5 generations.

SEMENOV (1953) in the arctic regions of U.S.S.R. mentioned only one generation.

WAGN (1955) in Denmark mentioned 3 generations.

MILES (1955) in England mentioned 2 generations and a partial third.

LEIN (1956) in Norway mentioned 2 generations.

Locally, the appearance of the cabbage root fly in cultivated crucifer fields shows strong annual fluctuations. In some years the damage is comparatively small, in others the pest may be called epidemic. For example, in the years 1929 and 1956 losses were severe, while in 1930 and 1955 the damage was insignificant. In addition to the standing threat of such epidemics, the loss of yield is considerable in more normal years.

The above-ground system of the damaged plants may show the following symptoms:

1. *Light damage:* wilting of the outer leaves due to lack of water, with ready recovery.
2. *Moderate damage:* wilting followed by colour change of the leaves. Recovery possible only under favourable weather conditions.
3. *Severe damage:* total wilting of the plant and usually collapse because of the entire loss of the root system.

CHAPTER III

# MATERIALS AND METHODS

## A. MATERIALS

Cauliflower transplants of the local commercial varieties (Alpha and Lecerf) were used in this study. The investigations were carried out under field conditions in the experimental plot of the Laboratory of Entomology at Wageningen.

It is an old arable land, moderately dry deep blackish-brown gravel sand. About sixty centimeters blackish-brown top soil. Humus content is low (± 2 %). Water table is about twenty meters from soil surface. The pH is 5.6–5.8.

### B. Arrangement of experimental field

With the intention of following the abundance of stages of the cabbage root fly through the growing season, several fields were utilized in succession to synchronize with the generations. The first transplantation was made before the appearance of adults from hibernated puparia; later transplantations at the end of the oviposition period of each generation (fig. 10–14). Each experimental field was divided into 9 plots of 60 plants each, separated by rows of broad beans (Vicia faba). The plant distance and shape of plots were as shown in fig. 1.

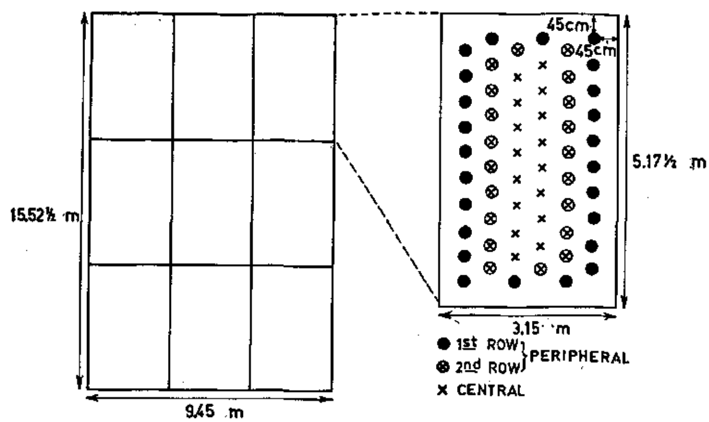



Fig. 1. Diagram of experimental field for population count. Peripheral (1st and 2nd rows) and central plants.

### C. Counting methods

The number of eggs collected on two successive days from 50 plants chosen at random over the whole field, was taken as a sample for egg density. Prior replications of such sampling had shown it gave a representative mean.

The density of larvae and pupae was determined by digging out a certain number of plants scattered over the 9 plots on two successive occasions. The first sample was taken about 6 weeks after the first ovipositions took place, as within this time-interval most larvae would have reached the pupal stage. About 2–4 weeks later, counting was repeated on a series of other plants.

The density of adults emerging was determined by means of catching-boxes in 1955 and by cone-cages in 1958 and 1959.

1. *Counting of eggs:*

Eggs were counted by means of the "washing method". A circle of soil about 10 cm. in diameter and 1 cm. deep was collected with a table spoon into a 250 cc. glass crystallizing dish, from around the base of each plant. The area sampled was based on preliminary experiments the results of which are given in fig. 2. The dishes were then put in a wooden box for safe carriage (plate IIa).

In the laboratory, the dishes were taken out, filled with tap-water, stirred with a glass rod, and left for a few hours to settle. After this they were examined for eggs (Plate IIb). This was carried out every other day throughout the season. When the eggs were not needed for further studies, a drop of caprylic alcohol added to each dish was of great help in clearing the surface and removing foam.

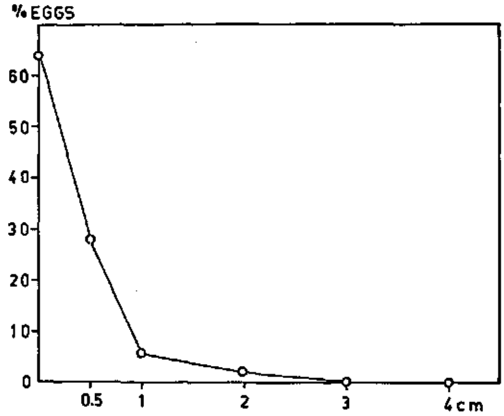


FIG. 2. Percentage of eggs collected at various distances from the stalk.

Error of egg counting: To determine the efficiency of egg recovery by the washing method, 100 eggs mixed with the normal amount of soil were put in a glass dish, and treated and counted by the usual method. This was repeated 10 times. The mean percentage recovery was 99.2. We therefore refrained from applying a correction factor for egg counts.

2. *Counting of larvae and puparia:*

The "auger" method was used. It is known that the maggots restrict themselves to the roots and only in the third instar crawl away for a few centimeters to pupate in the soil. This necessitates the examination of the root system as well as the soil around the plant. An auger (fig. 3) was therefore used for digging out the plant with the soil around its roots, after removing its head. Its dimensions (20 cm high, lower aperture 16 cm. wide) were based on the fact that no 3rd instar larva or pupa are found beyond a distance of 8 cm. from the plant (fig. 4). The soil was sieved with two sieves of different mesh (Plate IIIa). The first (25 meshes/inch) retained the root system, big stones and particles of other materials, while the second (256 meshes/inch) retained puparia, lärvae and other particles of similar size. The sieved soil was spread out on a zinc tray and searched for small larvae. The root system was dissected for larvae inside tunnels (Plate IIIb).

Only larvae of the 2nd and 3rd instar and puparia were found by this procedure. Larvae of the 1st instar were not found. The accuracy of the method depends on the examiner and the weather.

Errors in sampling larvae and puparia in dry soil: It is difficult to determine the error in finding larvae in the roots; we therefore checked only the error of collecting larvae from the soil. Fifty 3rd instar larvae and 50 puparia were counted. Each stage was dealt with separately. The 50 larvae were mixed with the normal amount of soil in a zinc tray. After that, they were counted again by the usual method. This same was done with the 50 puparia. The mean percentage obtained with larvae was 99.0, and with puparia 99.4. The error of counting was thus very small and has been neglected.

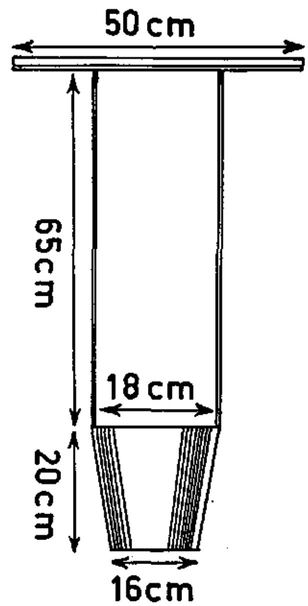



FIG. 3. Auger used for sampling sub-soil stages.

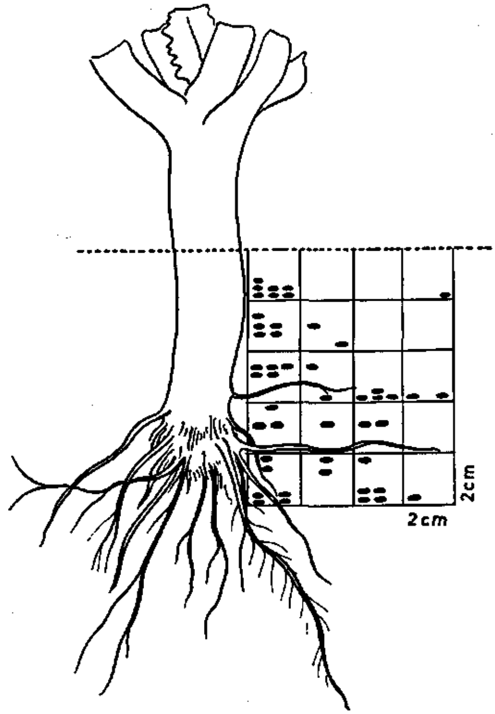



FIG. 4. Natural position of puparia near the root system (after DE WILDE 1947).

In the case of the 2nd instar larvae we used another method of estimating the error: the "brine" method, employing a saturated solution of sodium chloride. The larvae float on the surface owing to the high specific gravity of the solution and can easily be counted. However, because of practical difficulties this method was used only for one check of our standard method. For that purpose, 20 plants grown in pots were infested each with 20 1st instar larvae. After a week, 10 of them were examined by the brine method, and the other 10 by the usual method. The 2nd instar larvae found were 131 and 127 respectively. Even if the error had been considerably greater, it could have been neglected in the light of our practical experience, since 2nd instar larvae were usually few compared with other stages.

3. *Adult emergence*

Two methods were used for counting adults:

*a.* The "catching-boxes" (fig. 5a) with a wire-gauze top-cover were used in 1955 to determine the number of adults emerging in the field. A known number of plants were dug out with the soil around their root systems and covered with boxes, and the number of adults emerging in each box was counted.

*b*. "Cone-cages" (VAN DINTHER, 1953) (fig. 5b), were used in 1958 and 1959 instead of the catching-boxes. This type of cage was preferred because it interferes much less with the micro-climatic conditions, especially temperature and air humidity. As a rule, 20 cone-cages were used, each placed over a randomly chosen plant in the field at the time of larva and puparium sampling. The adults emerging in each cage were counted daily.

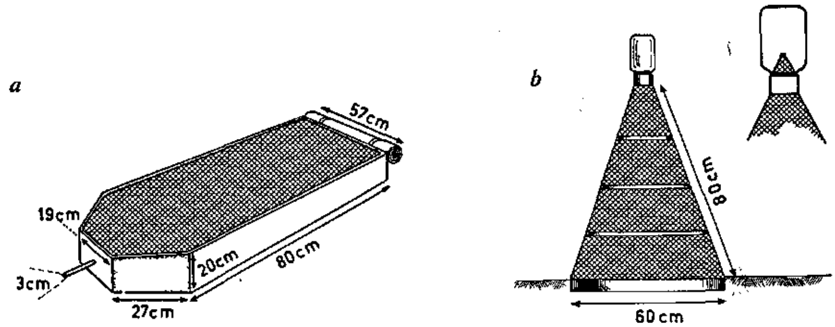



FIG. 5. Catching-box (a) and cone-cage (b) as used for studying adult emergence.

CHAPTER IV

## DISTRIBUTION OF *ERIOISCHIA* POPULATIONS

It is known from the literature that phytophagous insects are by no means evenly distributed over the area covered by their hostplants. Many factors can be responsible for this.

The types of insect distribution according to their biological significance were fully discussed by ULLYETT (1947) and can be summarized as follows:

1. "Contagious distribution" in which the distribution is not random in any one generation but depends on the distribution of individuals of the previous generation.
2. "Attractional distribution" governed by the condition of the hostplant (healthy or in certain growth stage).
3. "Migrational distribution" effected by a source of infection near the crop attacked.
4. "Directional distribution" effected by directed "drift", e.g. western winds.

Since we were dealing with *Erioischia*, a mobile insect in the adult stage, it was of importance to check our method of sampling with the distribution of the eggs deposited per plant in the field. For this purpose, central and peripheral plants were compared, as well as eastern to western and northern to southern plots (fig. 1).

### A. METHOD

The experimental block was divided into 9 plots of 6 × 10 plants each. Fifty plants were selected at random over all plots. The size of the sample taken was about 9 % of the total. Records were kept of egg population on individual plants. In this way the pattern of infestation over the whole field could be mapped. This was done in two different fields on two different dates. The number of eggs deposited at each plant was used as a parameter for distribution.

Migrational distribution was studied by the use of the data obtained in the first field with reference to the location of the different plants from a cauliflower field of the previous season. The same was done in the second field with reference to the location of the first field.

Attractional distribution as related to the size and age of the plant was studied and fully discussed on pages 19–22 of this paper. It has little influence on the distribution over the whole field as plants were planted randomly with regard to size.

## B. Results

The results obtained are shown in table 1.

TABLE 1. *Summarizing distribution of eggs deposition of the 1st and 2nd field in 1959*

*a.* Location of the plants (peripheral and central)

| Field | Examination of the whole field | | | | Examination per plot | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1st row | 2nd row | centre | | 1st row | 2nd row | centre |
| I | eggs/plant (mean) | 254 | 305 | 200 | eggs/plant (mean) | 230 | 247 | 190 |
| | $s_x$ | 136 | 72 | 66 | | 109 | 84 | 40 |
| | $s_{\bar{x}}$ | 43 | 24 | 12 | | 22 | 20 | 14 |
| II | eggs/plant (mean) | 23 | 37 | 33 | eggs/plant (mean) | 32 | 34 | 32 |
| | $s_x$ | 10 | 38 | 27 | | 25 | 38 | 26 |
| | $s_{\bar{x}}$ | 4 | 12 | 5 | | 5 | 11 | 8 |

*b.* Infestation mean for the 9 untreated plots per field

| Field I | | | | Field II | | | |
|---|---|---|---|---|---|---|---|
| | | | (means per row) | | | | (means per row) |
| 222.7 C3 | 206.0 A3 | 197.0 B3 | (209.2) | 36.5 C1 | 27.8 B1 | 53.6 A1 | (39.1) |
| 220.2 B2 | 161.6 C2 | 265.3 A2 | (218.8) | 24.2 A2 | 57.3 C2 | 38.2 B2 | (39.9) |
| 260.5 A1 | 269.5 B1 | 251.0 C1 | (260.9) | 30.4 B3 | 15.6 A3 | 9.3 C3 | (17.9) |
| (235.3) | (215.4) | (239.5) | | (30.4) | (35.1) | (32.5) | |
| (means per column) | | | | (means per column) | | | |

## C. Conclusions

In field I, there were no significant differences found between:

1. different plots of the field (different rows placed from North to South and different columns placed from East to West).

2. the peripheral plants (1st row), the peripheral plants (2nd row), and the other plants of the field.
3. the peripheral plants (1st row), the peripheral plants (2nd row) and the other plants of every plot.

For field II, we may conclude:

1. There were some differences between the mean infestations of the 9 plots. Except for the difference between $C_2$ and $C_3$ [1]), these were not significant.
2. There are no significant systematic differences in the directions N–S and E–W.

These conclusions do not mean that the flies are distributed at random among the individual plants, with special reference to plant size. We will deal with this subject in Chapter VI.

## CHAPTER V

# ABUNDANCE OF DIFFERENT STAGES IN THE COURSE OF THE SEASON

## A. EGGS

The results obtained during the growing seasons of 1955, 1956, 1957, 1958 (part) and 1959, are presented in figs. 6–10 and summerized in table 2. They indicate that the accumulative number of eggs deposited per 50 plants of the sampling in each generation increased towards the end of the season in 1955, while in 1956, 1957 and 1959, it decreased gradually. In 1958, the egg counts started late (about the middle of the season) so they comprised part of the eggs deposited by the 2nd generation during the period of 30/7–26/8 (793 eggs counted) and all of those deposited by the 3rd generation (656 eggs counted). It follows that

TABLE 2. *Abundance of larvae and puparia as compared with the accumulated number of eggs of same generation during the seasons of 1955–1959. Numbers refer to samples of 50 plants.*

| Year | Field I | | Field II | | Field III | |
|---|---|---|---|---|---|---|
| | Eggs | L+P | Eggs | L+P | Eggs | L+P |
| 1955 | 4/5–1/6<br>4430 | 8/6<br>844 | 6/7–2/8<br>5880 | 9/8<br>520 | 16/8–9/9<br>9420 | 16/9<br>265 |
| 1956 | 3/5–3/6<br>17800 | 10/6<br>469 | 5/6–18/8<br>8800 | 25/8<br>779 | 4/8–18/9<br>5960 | 25/9<br>286 |
| 1957 | 5/4–31/5<br>10657 | 7/6<br>2122 | 21/5–8/7<br>6512 | 15/7<br>894 | 18/7–22/9<br>3114 | –<br>– |
| 1958 | few<br>few | 8/7<br>86 | –<br>– | 25/8<br>305 | 28/8–29/9<br>642 | 6/10<br>150 |
| 1959 | 15/4–25/5<br>9940 | 1/6<br>348 | 22/6–30/7<br>1567 | 7/8<br>52 | 25/8–30/9<br>142 | 6/10<br>135 |

[1]) The plants in this plot were very weak and small due to soil deterioration in the plot in the dry summer of 1959.

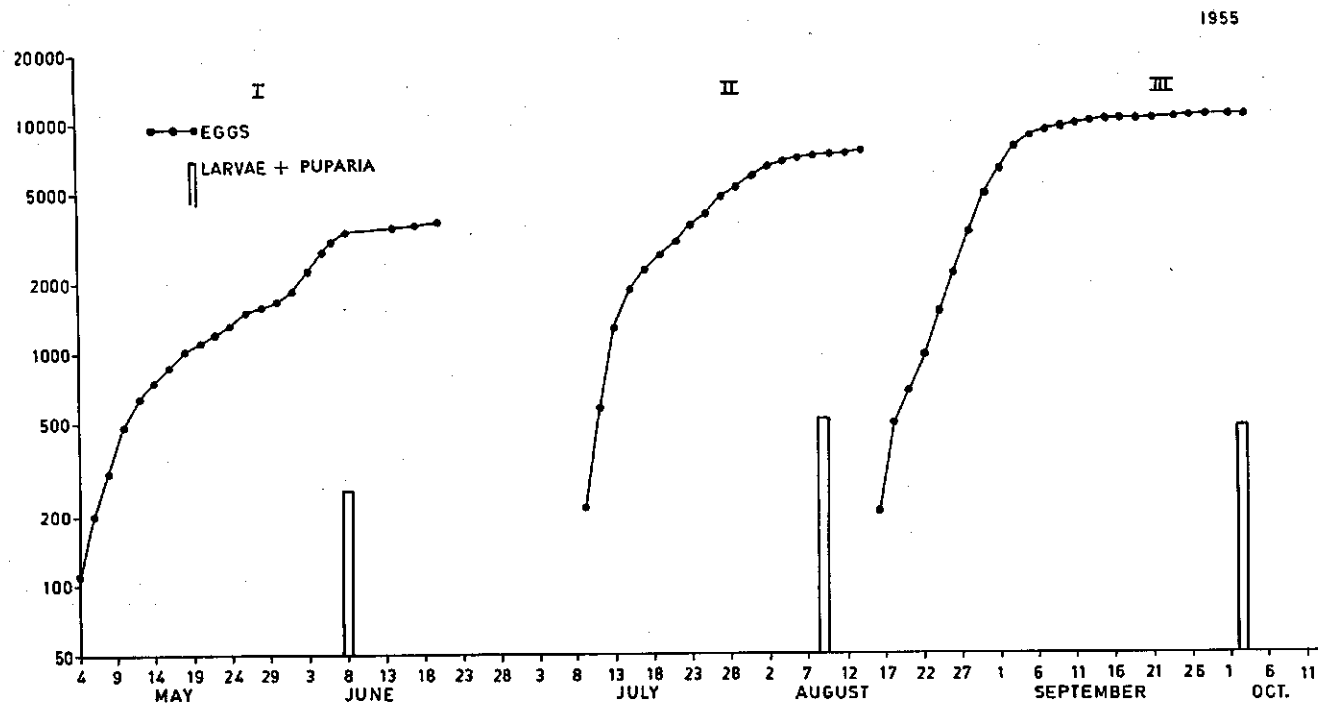



FIG. 6. Accumulated number of eggs and larvae & puparia per fifty plants in 1955–1959 (in 1958 only the third generation was sampled).

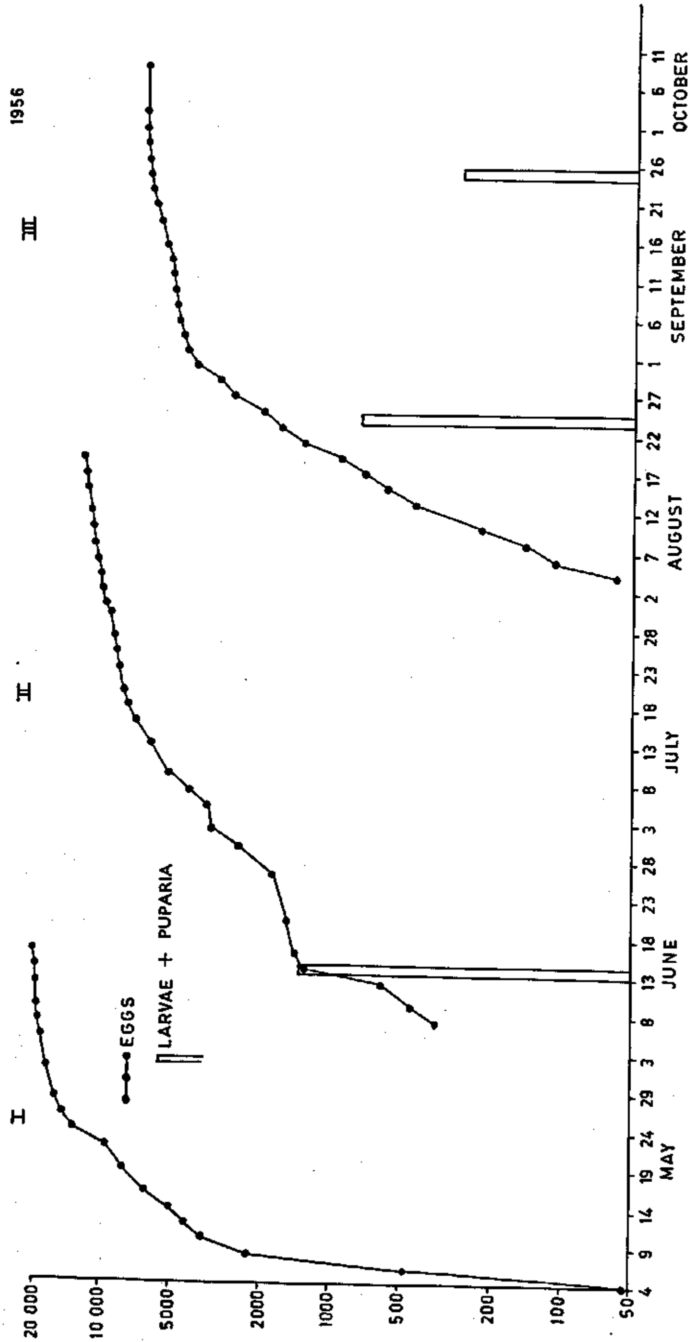



FIG. 7. Explanation see fig. 6.

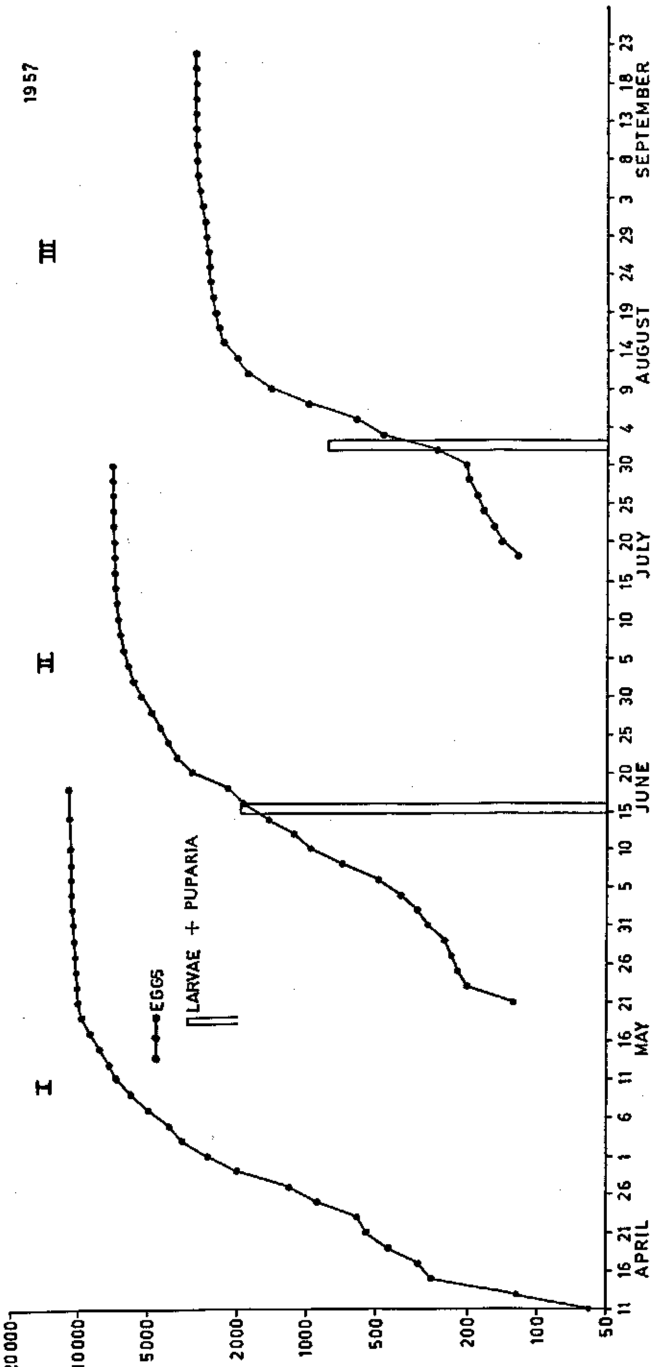



FIG. 8. Explanation see fig. 6.

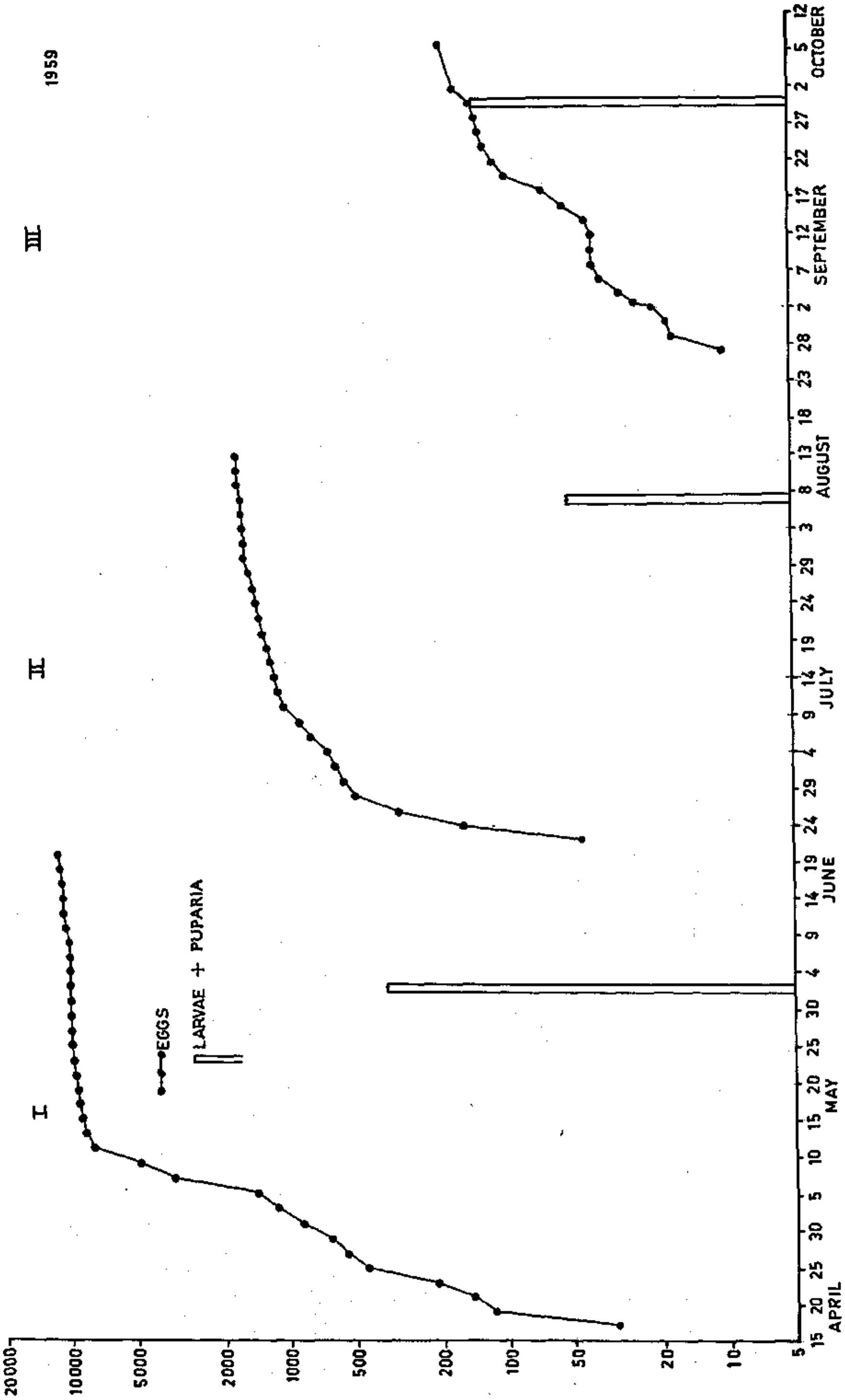



FIG. 10. Explanation see fig. 6.

in 1958, the total number of eggs produced by the 2nd generation must have been greater than that of the 3rd generation. Therefore, it seems that in 1958, there had been a decrease in the number of eggs towards the end of the season.

It is clear also that there are considerable differences between the total numbers of eggs deposited by similar generations of different years.

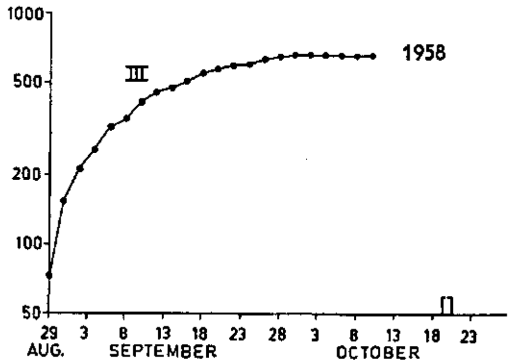



FIG. 9. Explanation see fig. 6.

## B. LARVAE AND PUPARIA

If we examine the foregoing table 2 for the total numbers of larvae and puparia per 50 plants as counted about 6 weeks after the beginning of the first egg deposition, we see that in 1956, the highest number was that of the 2nd generation, while in 1955 and 1959, the first generation was most numerous. In 1957, of the two generations sampled, the 1st generation was more abundant. In 1958, the 2nd generation was the more numerous.

From this it appears that the relative increase in the number of larvae and pupae took place in the beginning or in the middle of the season, and in no case at the end. In this respect the number of larvae and puparia does not run parallel with the number of eggs. The latter showed a tendency to decrease towards the end of the season in 4 years, a tendency to increase up to the 3rd generation only in 1955, and in no case showed a maximum in the middle of the season.

## C. ADULTS

The results obtained, as presented in table 3, show that the percentage of adults emerging as found by the catching-box method, are different from one

TABLE 3. *Adults emergence in catching boxes and cone-cages in 1955, 1958 and 1959 as compared with density of larval stages*

| Method | Field | Plant | L+P per 50 plants | Cages placed at: | Number of adults | Percentage |
|---|---|---|---|---|---|---|
| C.-boxes 1955 | I | Point.H.Cabb. | ± 500 | 15/6/'55 | 205 | 41 |
| | II | Caulif. | ± 500 | 11/8/'55 | 100 | 20 |
| | III | Caulif. | ± 250 | 22/8/'55 | 20 | 8 |
| Cone-cages 1958 | I | Caulif. | ± 103 | 14/6/'58 | 45 | 43.7 |
| | II | Caulif. | ± 305 | 26/8/'58 | 90 | 29.6 |
| | III | Caulif. | ± 100 | 20/10/'58 | 4 | 4 |
| Cone-cages 1959 | I | Caulif. | ± 263 | 8/6/'59 | 75 | 28.5 |

generation to another (even if the adults originated from about the same number of larvae and puparia, as it appears from the figures of the 1ste and 2nd generations of 1955). This was also confirmed by the results obtained by the cone-cage method in 1958. Also, these percentages varied between similar generations of the same year. It is clear, further, that this percentage showed a sharp decrease towards the end of the season during the two years of study despite the use of two different methods. This may be ascribed to three causes:

*Firstly*, this decrease ran parallel with that of egg deposition, as was proved in four successive years of our investigations (1956–1959), as has been discussed before.

*Secondly*, most of the puparia found later in the season will enter diapause until the next season. As a result, only part of them will emerge.

*Thirdly*, the percentage of parasitism of the puparia is highest at the end of the season as is shown in Chapter VI (p. 35).

Comparing the total number of eggs deposited per 50 plants with the number of larvae and pupae developed from these eggs in all generations during the five years of our investigations (figs. 6–10 and table 4), we observe that only a small fraction of the eggs develops to the pupal stage. This fraction of survivors indicates that very great losses are suffered during the earliest stages. It is also clear that these losses were maintained at about the same level over the five different years.

TABLE 4. *Density of eggs, larval stages and calculated survival of the latter during the five years of our observations. Fields synchronizing with generations. Eggs counted up to one week before larval sampling.*

| Year | Field I | | | Field II | | | Field III | | |
|---|---|---|---|---|---|---|---|---|---|
| | Eggs | L+P | % | Eggs | L+P | % | Eggs | L+P | % |
| 1955 | 4430 | 844 | 19.0 | 5880 | 520 | 8.8 | 9420 | 265 | 2.8 |
| 1956 | 17800 | 469 | 2.6 | 8800 | 779 | 8.8 | 5960 | 286 | 4.8 |
| 1957 | 10657 | 2122 | 19.9 | 6512 | 894 | 13.7 | 3114 | – | – |
| 1958 | few | 86 | – | – | 305 | – | 642 | 150 | 23.3 |
| 1959 | 9940 | 348 | 3.5 | 1567 | 52 | 3.3 | 142 | 135 | 95.1 |

Since this great mortality took place in the field under natural conditions, we call it "*natural mortality*", and since it is highest in the earliest stages, the term "*juvenile mortality*" seems appropriate.

The observations mentioned above raise the following questions:

1. *What are the causes of this high natural mortality? Are they biotic or abiotic factors?*
2. *Which stage or stages are affected most?*

The following chapters will deal with these problems.

## CHAPTER VI

## FACTORS INFLUENCING ABUNDANCE

The percentage mortality in the field up to the larval and pupal stages during the years of our investigations is summarized in table 5.

We found that the overall percentage of juvenile mortality in the different generations was very high in all years. It is also evident that this juvenile mortality remained at about the same level during the course of climatically very different years.

Similar results have been found in other insects studied. BODENHEIMER (1958) brought out the importance of juvenile mortality by studying the distribution of the total mortality over the different stages of the desert locust (*Schistocerca gregaria* FORSKÅL) in outdoor cages. ULLYETT (1947) found the same when he studied the mortality of the diamondback moth (*Plutella maculipennis* CURTIS).

In this chapter we will make an attempt to analyse the factors influencing the abundance of different stages.

TABLE 5. *Summarizing the natural mortality percentage in the field up to the larval and pupal stage during the seasons of 1955 to 1959.*

| Year | First generation | | | Second generation | | | Third generation | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1st Count % | 2nd Count % | Mean % | 1st Count % | 2nd Count % | Mean % | 1st Count % | 2nd Count % | Mean % |
| 1955 | 81.0 | 80.9 | 81.0 | 91.2 | 89.5 | 90.4 | 97.2 | 95.7 | 96.5 |
| 1956 | 97.4 | – | 97.4 | 91.2 | – | 91.2 | 95.2 | 96.5 | 95.9 |
| 1957 | 89.0 | 82.4 | 85.7 | 86.3 | 88.5 | 87.4 | – | – | – |
| 1958 | – | – | – | – | – | – | 76.7 | 91.2 | 84.0 |
| 1959 | 96.5 | 98.3 | 97.4 | 96.7 | 97.1 | 96.9 | 4.9 | – | 4.9 |
| Mean per generation | | | 90.4 | | | 91.5 | (except 1959) | | 92.1 |
| $S_x$ | | | 8.3 | | | 4.0 | ,, | | 7.1 |
| $S_{\bar{x}}$ | | | 4.2 | | | 2.0 | ,, | | 3.5 |

| Generations | Mortality limits at P = 0.95 |
|---|---|
| First | 77% and 100% |
| Second | 85% and 98% |
| Third | 77% and 100% |

## A. ADULT CONDITION

As it has been observed in most cases that the overwintering generation produces the greatest number of eggs, the question arises whether the fly is most fertile at relatively low temperatures. Therefore, it is very important to know the influence of temperature on the rate of oviposition and longevity of the flies of different generations. This can only be studied under controlled conditions.

### 1. *Methods*

Flies from a stock of puparia were liberated in an insectary (fig. 11a). In this insectary 3–4 young plants had been planted for oviposition. An artificial flower (fig. 11b), made of a small glass "carbon disulphide pot" and yellow and blue coloured pieces of card, was mounted on top of a small stick. The "flower" was filled daily with a fresh solution of sugar and casein (1 : 1). A piece of cotton wool was dipped into the solution to enable the flies to suck. The insectary was placed before a north window to avoid exposure to direct sunlight and to give a more constant air temperature. The temperature was measured daily at 2.00 p.m. The soil at the base of the plants was removed regularly and examined for eggs by the usual washing method.

To count the flies inside the insectary is rather difficult because they are active and often hide under the leaves. Therefore, a cage (fig. 11c) covered with cellophane was used to trap them by darkening the insectary. The flies were then separated by means of diaphragms and in this way could be counted easily.

Since it was impossible with our method to determine longevity and fertility of individual females separately, we counted the total number of eggs laid by a group of females; this number was counted daily. Females were placed in the insectary on the day of emergence and fed on sugar and casein solution. Observations were continued until the last fly had died. In this way the total number of fly/days was known. Divided on the number of eggs, this gave the mean egg deposition per female/day. Divided by the total number of females added to the cage, it gave the mean longevity per female.

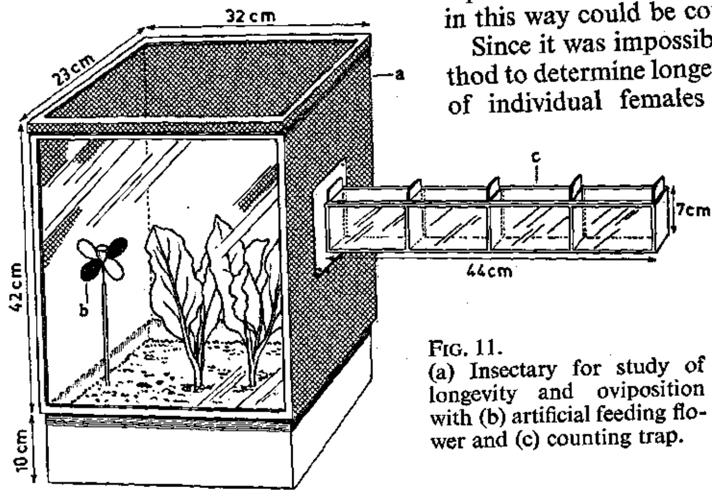



FIG. 11.
(a) Insectary for study of longevity and oviposition with (b) artificial feeding flower and (c) counting trap.

2. *Results*

The results obtained by following these methods on the over-wintering, first, and mixed (second and third) generations are presented in table 6.

3. *Discussion and Conclusions*

The egg laying capacity of the over-wintering generation was greater than that of the first generation at the same temperatures (19° and 24 °C). At 19 °C temperature we found that the egg laying capacity of the over-wintering generation was 87 eggs/female, while it was 42 eggs/female in the mixed (2nd and 3rd) generations.

The longevity of the flies of the over-wintering generation was greater at 19° than at 24 °C.

At the same time, the longevity of the over-wintering generation was much greater than that of the 1st generation at the same temperatures (19° and 24 °C).

At 19 °C longevity of the over-wintering generation was 33 days in insectary A, while it was 20.6 days in the mixed (2nd and 3rd) generations.

In most cases the females live about 2.5 days longer than the males.

TABLE 6. *Longevity and egg laying capacity of flies of different generations when reared in insectaries kept at different temperatures*

a. Spring experiments

| Generation | Insectary | Flies ♂♂ | Flies ♀♀ | Mean temperature | Average eggs/♀ | Calculated mean longevity in days |
|---|---|---|---|---|---|---|
| Over-wintering generation | A | 18 | 16 | 19 °C | 87 | 33 |
| | B | 16 | 14 | 24 °C | 54 | 30 |
| 1st generation | C | 13 | 8 | 24 °C | 24 | 16 |
| | D | 7 | 17 | 24 °C | 20 | 14 |

b. Summer experiments

| Generation | Insectary | Period of breeding | Mean temperature | Average eggs/♀ | Average longevity in days ♂ | Average longevity in days ♀ |
|---|---|---|---|---|---|---|
| Mixed 2nd and 3nd gen. | 1 | 19/8–17/9 | 22.9 °C | 40 | 12.8 | 18.6 |
| | 2 | 17/9–16/10 | 17.5 °C | 42 | 19.1 | 20.8 |
| | 3 | 25/9–31/10 | 17.6 °C | 41 | 24.7 | 24.1 |
| | 4 | 29/9–31/10 | 17.6 °C | 38.4 | 20.7 | 24.2 |
| Total | | | 75.6 °C | 166.4 | 77.3 | 87.7 |
| Mean | | | 18.9 °C | 41.6 | 19.3 | 21.9 |

## B. OVIPOSITION

It is clear from our egg counts that there are differences in the total number of eggs deposited on different plants at different dates. These differences, upon which the abundance of other stages may depend, necessitate the study of the factors affecting oviposition.

### 1. *Plant size*

To study the effect of plant size the following parameters were compared:

*a.* Plant height (length of longest leaf).

Twenty-five plants were selected at random in an untreated experimental field. The total number of eggs deposited per plant in successive intervals was recorded. At the end of the intervals, the plants were measured (fig. 12a).

The results obtained are shown in table 7.

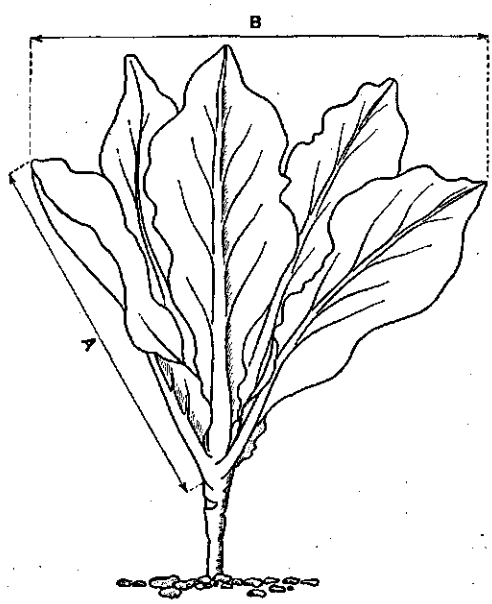



FIG. 12. Way of measuring plant size (a) length of leaf (b) plant diameter.

TABLE 7. *Relation between the length of the highest leaf and the number of eggs deposited in 1955*

| Plant No. | Number of eggs | Length of blade in cm | Note |
|---|---|---|---|
| 1 | 22 | 11 | |
| 2 | 33 | 11 | |
| 3 | 26 | 12 | |
| 4 | 32 | 12 | |
| 5 | ? | - | |
| 6 | 31 | 13 | |
| 7 | 16 | 14 | |
| 8 | 23 | 14 | |
| 9 | 20 | 15 | r = 0.33 |
| 10 | 25 | 15 | 0,95 > P > 0.90 |
| 11 | 34 | 15 | |
| 12 | ? | - | |
| 13 | 53 | 15 | |
| 14 | 21 | 16 | |
| 15 | 28 | 16 | |
| 16 | 30 | 16 | |
| 17 | ? | - | |
| 18 | 31 | 16 | |
| 19 | 46 | 16 | |
| 20 | 63 | 16 | |
| 21 | 81 | 17 | |
| 22 | 12 | 18 | |
| 23 | 25 | 18 | |
| 24 | 68 | 18 | |
| 25 | 43 | 21 | |

From this table we may conclude that at P = 90 % there is some positive correlation, but at P = 95 % the correlation is not significant.

*b.* Plant diameter

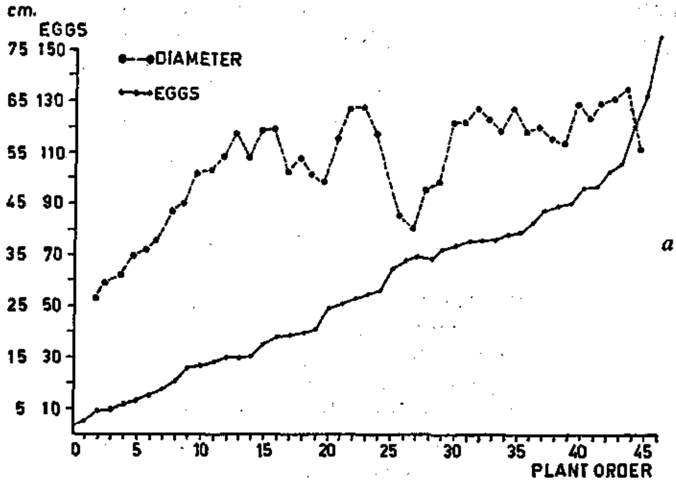
Two successive untreated fields were utilized to study the relation between the plant diameter and the total number of eggs deposited. The plants were selected at random and the number of eggs deposited per plant in successive intervals was recorded. At the end of the interval the plants were measured (fig. 12b).

The results obtained are shown in fig. 13a, b, c and table 8.

TABLE 8. *Summary of correlation coefficients of plant diameter and egg-number, and reliability intervals as observed in the experiments shown in fig. 13.*

| | P = 0.95 | P = 0.99 |
|---|---|---|
| *Field II (19 Aug. 1956)* | | |
| n = 47 r = 0.43 | 0.18 < r < 0.65 | 0.07 < r < 0.68 |
| n⁻ = 17 r = 0.86 | 0.66 < r < 0.94 | 0.50 < r < 0.97 |
| *Field III (4 Sept. 1956)* | | |
| n = 40 r = 0.66 | 0.45 < r < 0.80 | 0.35 < r < 0.84 |
| n⁻ = 12 r = 0.78 | 0.35 < r < 0.23 | 0.15 < r < 0.95 |
| *Field III (29 Sept. 1956)* | | |
| n = 48 r = 0.54 | 0.32 < r < 0.72 | 0.22 < r < 0.75 |
| n⁻ = 20 r = 0.79 | 0.53 < r < 0.91 | 0.43 < r < 0.93 |

n = total number of plants.
$n^-$ = total number of plants with the lowest numbers of eggs.



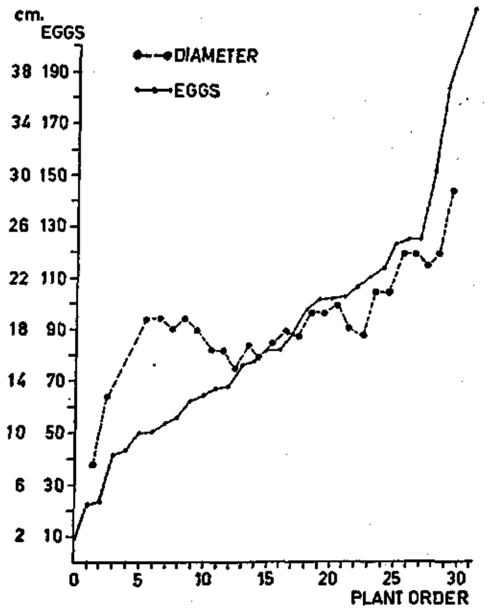
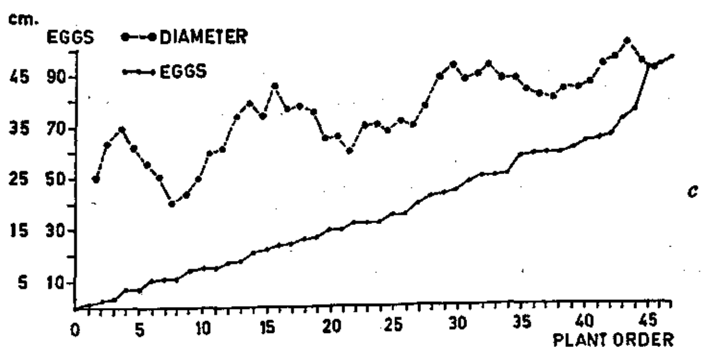




FIG. 13. Comparison of plant-diameter and egg number (plants arranged in order of increasing egg number).



As a conclusion, we may say that there is a positive correlation between plant diameter and the number of eggs deposited. In all cases the correlation coefficient is higher when calculations are based only on the plants with the lowest numbers of eggs.

It is evident now that the attractiveness of the plant is determined by its horizontal rather than its vertical dimensions. Attractiveness increases with increasing plant size.

2. *Plant age*

Comparing the attractiveness of different cabbage fields, we have as a rule to deal with plants of different planting date. Therefore, we want to find out if there is a difference between egg deposition near old and young plants which, apart from size, depends upon other factors.

The field of experimentation, designed to be planted at two different dates, was to contain alternating old and young cauliflower plants at the same time. The planting dates were the 1st and 15th of July, 1956. Egg counts were started three days after the last planting date. Young and old plants were chosen in turns for the experiment. The plants selected were marked.

Observations were made at different periods, viz.: 1) 11–14 August, 2) 29–31 August.

At the beginning of each observation period new plants were selected for examination. Young and old plants were very different in size during the first period of observation. Later on differences decreased.

The results obtained are presented in table 9.

TABLE 9. *Relation between plant-age and number of eggs deposited*

| Number of plants | First period (11–14 Aug.) | | Second period (29–31 Aug.) | |
|---|---|---|---|---|
| | Total eggs | | Total eggs | |
| | Young | Old | Young | Old |
| 25 | 78 | 47 | 125 | 85 |
| mean | 3.1 | 1.9 | 5.0 | 3.4 |
| $S_x$ | 4.2 | 3.1 | 6.1 | 5.3 |
| $S_{\bar{x}}$ | 0.84 | 0.62 | 1.2 | 1.06 |

It is clear that there are no significant differences between the mean numbers of eggs deposited near young and old plants. However, large plants are favoured over small ones of the same age.

3. *Seasonal conditions*

The number of eggs deposited every other day per 50 plants sampled was compared with the daily temperature and rainfall during the seasons of 5 different years.

The results obtained are represented in figs. 14–18.

The ideal situation, taking account only of the multiplication rate, would be as follows:

eggs of 2nd generation > eggs of 1st generation
eggs of 3rd generation > eggs of 2nd generation

Temperature and rainfall affecting this picture.

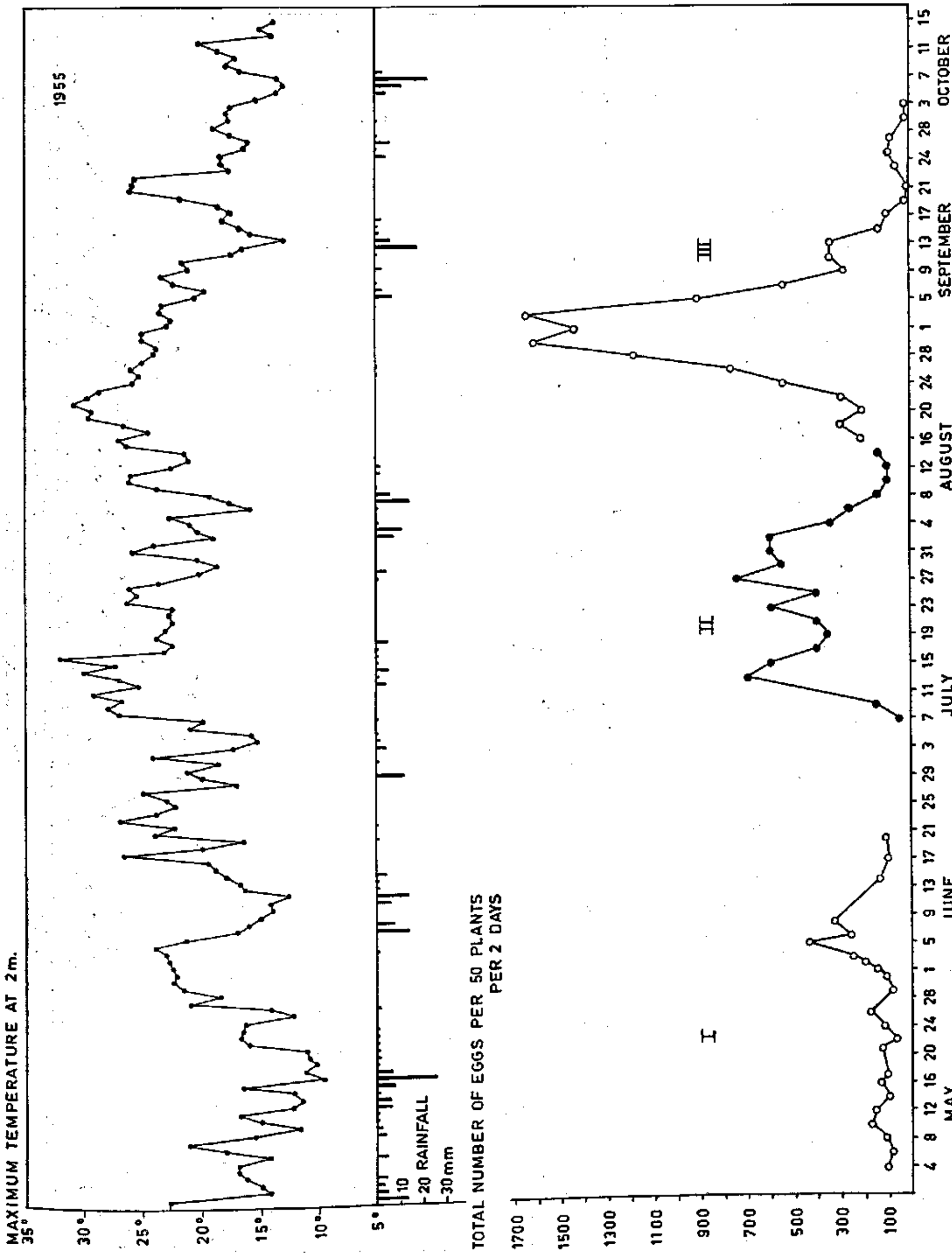



FIG. 14. Daily rate of oviposition, temperature (°C) and rainfall (mm) during the five years of our observations.

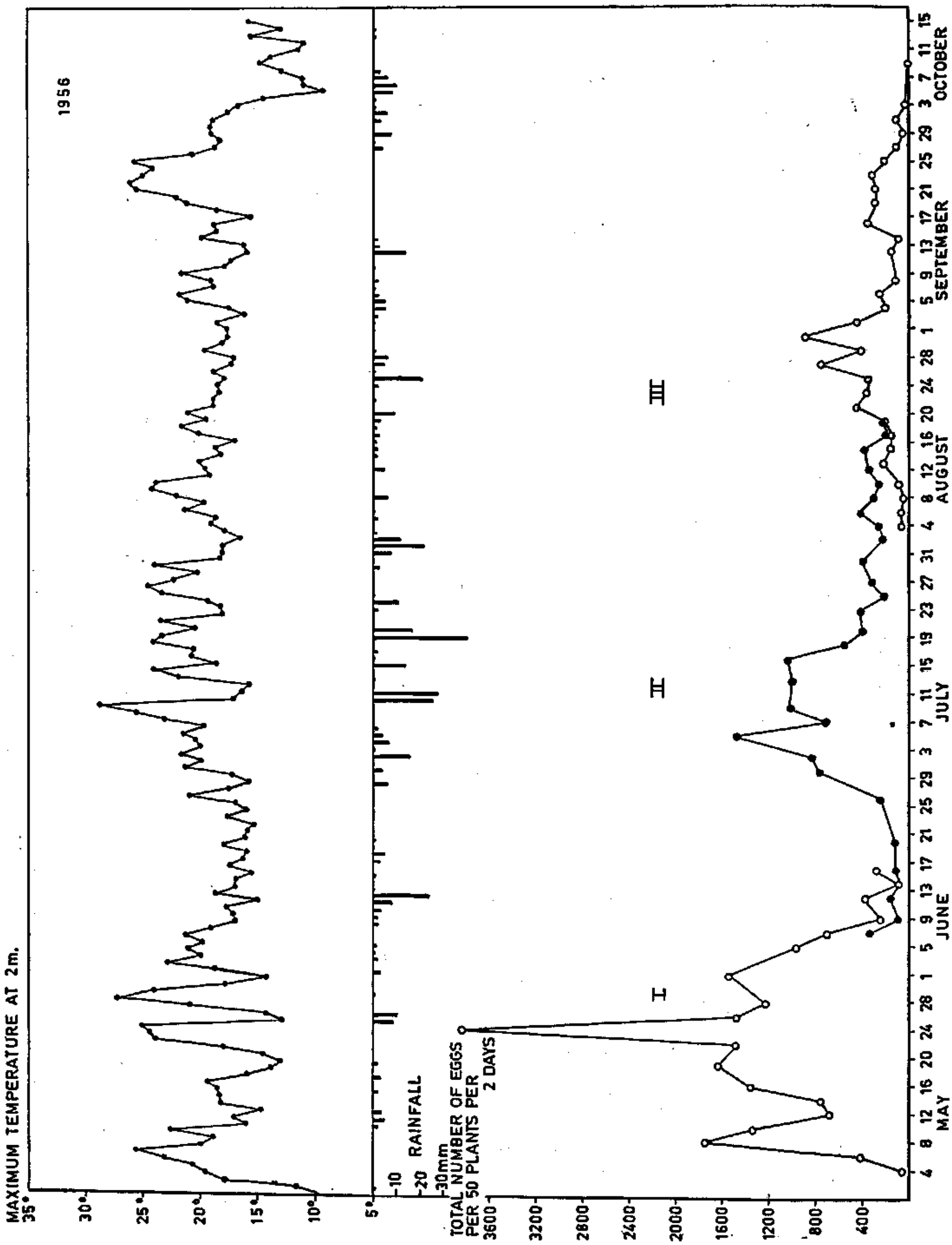



Fig. 15. Explanation see fig. 14.

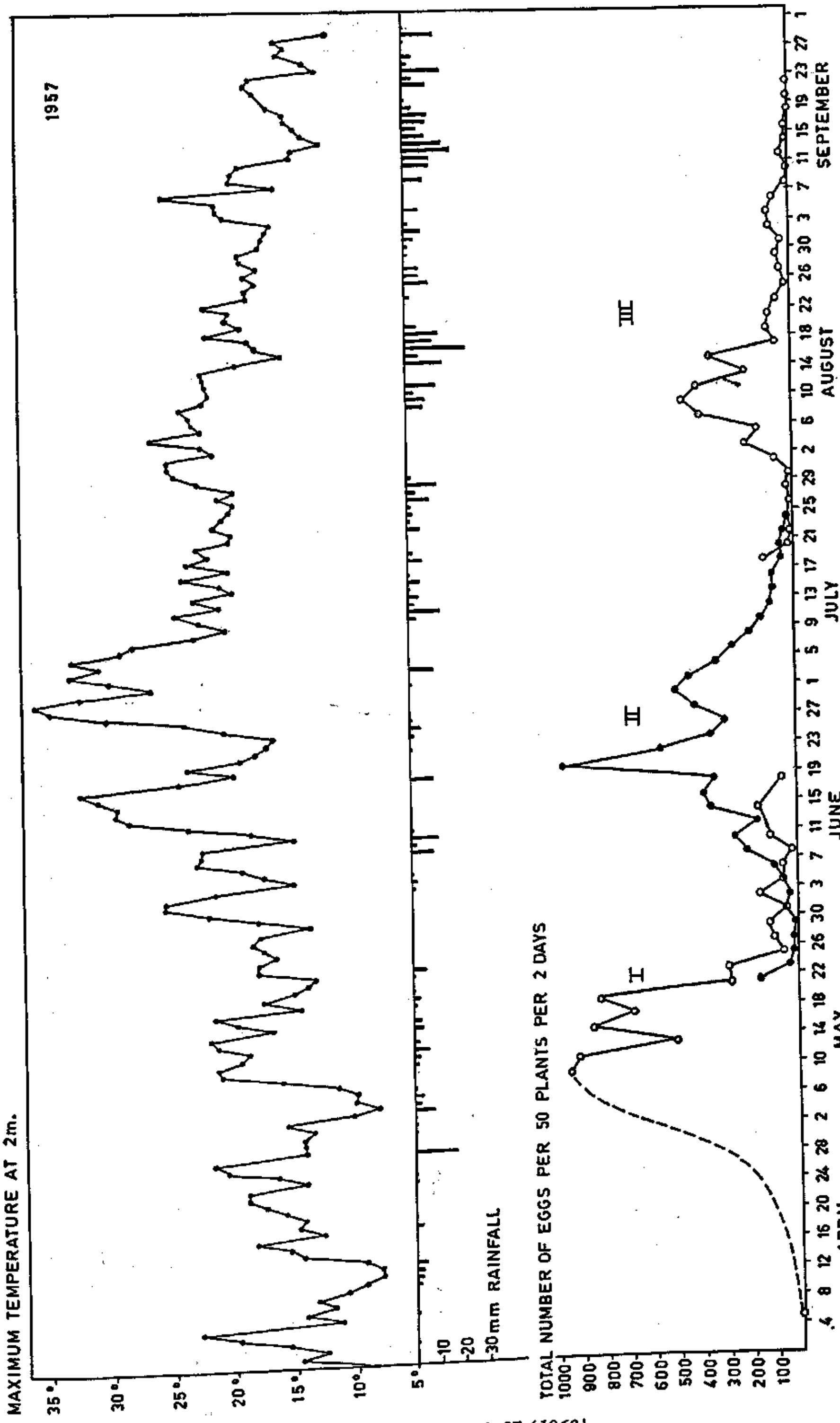



FIG. 16. Explanation see fig. 14.

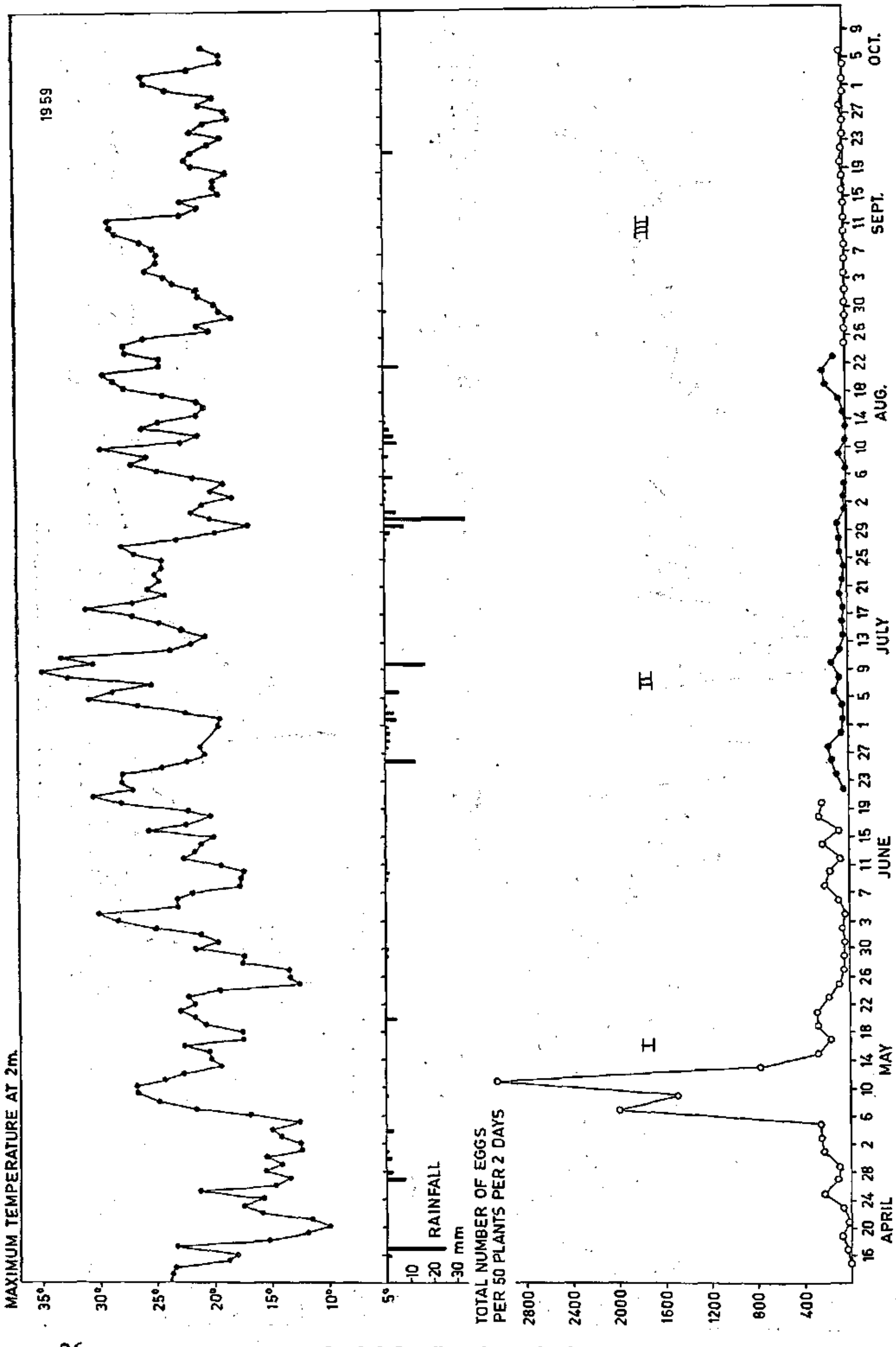



FIG. 18. Explanation see fig. 14.

In 1955, peaks of egg deposition coincided with periods of relatively high temperature. Cool and rainy periods, 7–17 June, 6–12 July, and 9–17 August cut down oviposition rather abruptly.

1956 gave the same results as 1955. Peaks on 8 May and 24 May coincided with peaks in maximum temperature. The cool, very rainy period generally depressed oviposition.

In 1957, an oviposition period between 8–20 May and a peak on 20 June coincided with temperature peaks. Lower temperature and rainfall from 15 August onwards put an abrupt stop to oviposition.

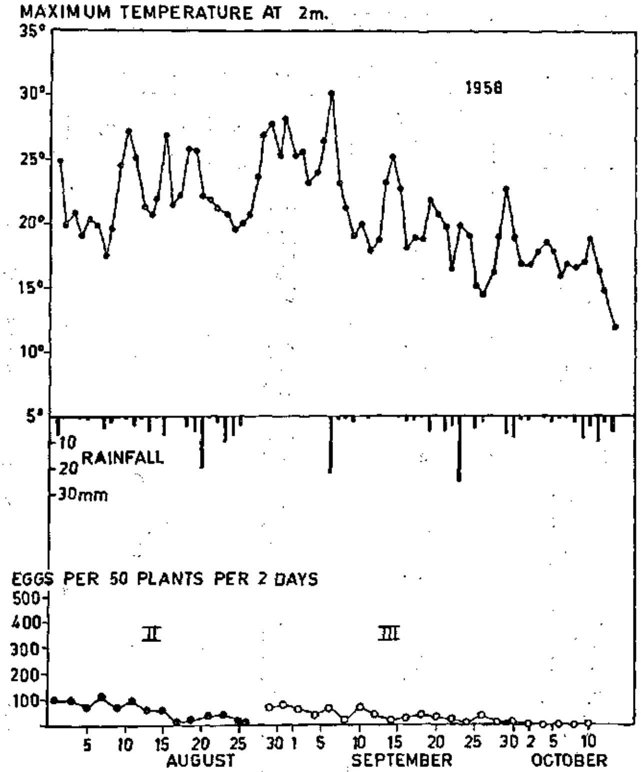


FIG. 17. Explanation see fig. 14.

In 1958, low temperature during 1st generation seems to have inhibited development of this and succeeding generations.

In 1959, insolation and dry soil must have combined, perhaps with other factors, to increase the mortality in the 1st generation to such a degree that the oviposition of succeeding generations was very low.

In conclusion, we may say that relatively cool weather as well as dry and sunny weather promote egg deposition. The former does so by increasing fertility and longevity, as shown in caged populations, the latter by increasing activity of the field population. Oviposition is strongly reduced by rainfall. As a result abundance is greatly influenced by these different seasonal conditions.

## C. Egg fertility

Egg fertility may contribute as a factor of varying importance in the abundance of the generations during the season. We therefore thought it necessary to study this factor in *Erioischia*.

A certain number of eggs deposited on cauliflower plants in the field within two days was collected by the usual washing method, placed in a small petri dish with a small quantity of distilled water and kept in an incubator at 25 °C. This was done several times during the growing season of 1959.

The results obtained are shown in table 10.

TABLE 10. *Egg fertility as observed during the season of 1959.*

| Date | Number of eggs | Empty eggs | Full eggs | Percentage fertility | Notes |
|---|---|---|---|---|---|
| 25/IV | 210 | 205 | 5 | 97.6 | Field Ia |
| 1/V | 138 | 134 | 4 | 97.1 | mean % fertile |
| 3/V | 176 | 171 | 5 | 97.2 | eggs = 95.3 |
| 5/V | 195 | 189 | 6 | 96.9 | $S_x$ = 3.9 |
| 5/V | 300 | 287 | 13 | 95.7 | $S_{\bar{x}}$ = 1.0 |
| 8/V | 100 | 95 | 5 | 95.0 | |
| 13/V | 522 | 507 | 15 | 97.1 | |
| 14/V | 86 | 81 | 5 | 94.2 | |
| 15/V | 131 | 130 | 1 | 99.2 | |
| 19/V | 162 | 146 | 16 | 90.1 | |
| 21/V | 195 | 189 | 6 | 96.9 | |
| 23/V | 146 | 140 | 6 | 95.9 | |
| 31/V | 80 | 74 | 6 | 92.5 | |
| 6/VI | 98 | 82 | 16 | 83.7 | |
| 9/VI | 200 | 190 | 10 | 95.0 | |
| 13/VI | 41 | 39 | 2 | 95.1 | |
| 14/VI | 152 | 134 | 18 | 88.2 | |
| 22/VI | 25 | 24 | 1 | 96.0 | Field IIa |
| 24/VI | 89 | 85 | 4 | 95.5 | mean % fertile |
| 26/VI | 125 | 118 | 7 | 94.4 | eggs = 90.3 |
| 28/VI | 155 | 147 | 8 | 94.8 | $S_x$ = 6.8 |
| 2/VII | 37 | 36 | 1 | 98.1 | $S_{\bar{x}}$ = 1.5 |
| 4/VII | 47 | 45 | 2 | 95.9 | |
| 10/VII | 70 | 59 | 11 | 84.2 | |
| 16/VII | 52 | 47 | 5 | 90.3 | |
| 21/VII | 90 | 83 | 7 | 92.2 | |
| 22/VII | 167 | 139 | 28 | 83.2 | |
| 23/VII | 44 | 38 | 6 | 86.3 | |
| 24/VII | 31 | 28 | 3 | 90.3 | |
| 29/VII | 54 | 48 | 6 | 88.8 | |
| 30/VII | 83 | 76 | 7 | 91.5 | |
| 1/VIII | 24 | 16 | 8 | 66.6 | |
| 3/VIII | 15 | 17 | 2 | 89.4 | |
| 17/VIII | 59 | 53 | 6 | 89.8 | |
| 19/VIII | 140 | 129 | 11 | 92.1 | |
| 21/VIII | 107 | 101 | 6 | 94.3 | |
| 23/VIII | 37 | 34 | 3 | 91.8 | |

The difference between the mean % fertile eggs in field Ia and the same in field IIa is not significant.

If the difference between the means would be significant, it is only a small one; so the decrease in the course of the season is not strong.

## D. EGG AND LARVAL MORTALITY

We have been able to carry out investigations on this problem only in the last two years. In 1958, because of practical difficulties resulting from a very light infestation, the results were insufficient to allow any conclusion. In 1959, only the infestation of the first generation was high enough to satisfy this requirement.

1. *Total mortality (natural enemies included)*

As shown before the highest natural mortality took place between egg and pupal stages. It was felt to be of great importance to study the total mortality within this interval. In addition, it was considered important to establish the part played by natural enemies.

Four replicates of 25 plants, each distributed at random, were taken for egg counts, comprising the total numbers of eggs deposited up to one week before the larva and puparium samplings. About 6 weeks after the first egg deposition took place, 2 replicates of 25 plants each, distributed at random, were taken for larva and pupa counts. Two weeks later, this was repeated with another two replicates.

The methods used for egg, larval and pupal counts have been mentioned before (Chapter III).

The results are shown in table 11.

TABLE 11. *Natural mortality of the 1st generation in 1959.*

| Series | Plants | Eggs counted | L+P counted | % Mortality |
|---|---|---|---|---|
| 1 | 1–25 | (up to 25/5) 5414 | (1/6) 268 | 95.0 |
| 2 | 26–50 | (up to 25/5) 4522 | (1/6) 73 | 98.4 |
| The same two weeks later. | | | | |
| 3 | 1–25 | (up to 10/6) 5821 | (17/6) 79 | 98.6 |
| 4 | 26–50 | (up to 10/6) 4802 | (17/6) 100 | 97.9 |

Mean of the two groups of samples.

| Plants | % mortality | |
|---|---|---|
| 1–25 | 96.8 | mean 97.5 |
| 26–50 | 98.2 | |
| | $S_x = 1.0$ | |
| | $S_{\bar{x}} = 0.7$ | |

Interval (P = 95%) with confidence limits for the mean mortality 89–100%.

2. *Total mortality (natural enemies excluded)*

With the object of detecting the distribution of mortality over the earliest stages, we studied each stage separately in the field. This was done with plants under cages in order to prevent the plants from being infected repeatedly, and, by thus excluding predators, we were able to study their effect by comparison with the total mortality among uncovered plants in the open.

*a.* Egg mortality

Eggs deposited over 2 days were collected. A number of batches of 10 eggs was placed on the soil surface on top of glass tubelets (5 cm long and 0.5 cm in diameter) closed at the lower end with cotton wool and filled with soil. Ten of these tubelets were inserted into the ground around the base of each potted cauliflower plant. Four series of 3 plants each were placed in the field under cylindrical cages to prevent entrance of predators and new oviposition. After an interval of 7 days they were examined for empty and full eggs. Experiments were made in 1958 and 1959, but only in 1959 were sufficient numbers of eggs available. It must be noted that this was an exceptionally dry and warm season.

The results obtained are presented in table 12.

TABLE 12. *Egg mortality under cages as observed in 1959.*

| Date | Series | Eggs placed | Date of examination | Eggs found | Empty eggs | Full eggs |
|---|---|---|---|---|---|---|
| 8/5/'59 | I | 3 × 100 | 15/5/'59 | 233 | 217 | 16 |
| | II | 3 × 100 | | 140 | 120 | 20 |
| | III | 3 × 100 | | 239 | 223 | 16 |
| | IV | 3 × 100 | | 308 | 292 | 16 |
| Total | | 1200 | | 920 | 852 | 68 |

Mean % hatched: $\frac{852}{920} \times 100 = 92.6\% \ (\pm 93)\ \%$

$S_x = 4.1$

$S_{\bar{x}} = 2$

Mortality: 100% – (± 93)% = (± 7)%.

Interval (P = 95%) with confidence limits for the mean mortality: 2–14%.

*b.* Analysis of larval mortality

1) *First instar to third instar larvae.* A known number of newly hatched larvae was placed on the stem at the base of a potted cauliflower plant. After infestation the pots were placed in the field under cages. A series of batches of 5 plants each were examined at several intervals (4, 8, 12, 16, 20 and 24 days) in order to record the mortality in the 3 different larval instars. Two replicates of this experiment were carried out at the same time.

The results are shown in table 13.

The following points emerge:

(α) Mortality from 1st to 2nd instar larvae (3rd instar included).

| Experiment | Larvae placed | Larvae found back | Mortality % |
|---|---|---|---|
| I | 595 | 121 | 79.5 |
| II | 750 | 165 | 78.0 |

Mean % mortality = 78.8. Confidence limits for the mean with (P = 95%) are: 69–88%.

(β) Mortality from 1st to 3rd instar larvae (puparia included). This was calculated in two ways:

(1) Only 3rd instar larvae and puparia were considered. (2nd instar larvae excluded).
Larvae placed 695; recovered 147; mortality ± 79%.

(2) The plants with a number of 2nd instar larvae were excluded:
Larvae placed 555; recovered 108; mortality ± 81%.

If we compare the mortality percentages found in (α) and (β), a striking similarity can be observed. It follows that mortality from the 2nd to the 3rd instar was negligible. The same must have been true between the 3rd instar larvae and pupal stages. Taking into account that egg mortality was 7%, the mortality of first instar larvae in % of the original egg number was 73%.

TABLE 13. *Number of larvae and puparia found back after different intervals. Plants infested with 1st instar larvae in 1959.*

| Date of infestation | Examination after | Series | Plant number | First experiment | | | | Replicated experiment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | larvae placed | L + P found back | | | larvae placed | L + P found back | | |
| | | | | | $L_2$ | $L_3$ | P | | $L_2$ | $L_3$ | P |
| 13/V | 4 d | I | 1 | 20 | 7 | 0 | 0 | 20 | 3 | 0 | 0 |
| | | | 2 | 20 | 0 | 0 | 0 | 20 | 8 | 0 | 0 |
| | | | 3 | 20 | 2 | 0 | 0 | 20 | 5 | 0 | 0 |
| | | | 4 | 20 | 1 | 0 | 0 | 20 | 2 | 0 | 0 |
| | | | 5 | 20 | 6 | 0 | 0 | 20 | 0 | 0 | 0 |
| | | | | 100 | 16 | 0 | 0 | 100 | 18 | 0 | 0 |
| | 8 d | II | 1 | 20 | 6 | 0 | 0 | 25 | 0 | 0 | 0 |
| | | | 2 | 20 | 8 | 0 | 0 | 25 | 0 | 0 | 0 |
| | | | 3 | 20 | 6 | 0 | 0 | 25 | 1 | 0 | 0 |
| | | | 4 | 20 | 14 | 0 | 0 | 25 | 0 | 0 | 0 |
| | | | 5 | 20 | 1 | 0 | 0 | 25 | 2 | 0 | 0 |
| | | | | 100 | 35 | 0 | 0 | 125 | 3 | 0 | 0 |
| | 12 d | III | 1 | 20 | 8 | 0 | 0 | 25 | 0 | 0 | 0 |
| | | | 2 | 20 | 1 | 0 | 0 | 25 | 13 | 0 | 0 |
| | | | 3 | 20 | 2 | 0 | 0 | 25 | 2 | 0 | 0 |
| | | | 4 | 20 | 1 | 0 | 0 | 25 | 14 | 0 | 0 |
| | | | 5 | 20 | 5 | 0 | 0 | 25 | 7 | 0 | 0 |
| | | | | 100 | 17 | 0 | 0 | 125 | 36 | 0 | 0 |
| | 16 d | IV | 1 | 20 | 0 | 0 | 0 | 25 | 3 | 18 | 0 |
| | | | 2 | 20 | 0 | 1 | 0 | 25 | 2 | 0 | 0 |
| | | | 3 | 20 | 0 | 0 | 0 | 25 | 2 | 8 | 0 |
| | | | 4 | 20 | 0 | 15 | 3 | 25 | 4 | 7 | 0 |
| | | | 5 | 20 | 0 | 5 | 0 | 25 | 0 | 3 | 0 |
| | | | | 100 | 0 | 21 | 3 | 125 | 11 | 36 | 0 |
| | 20 d | V | 1 | 20 | 1 | 2 | 0 | 25 | 0 | 0 | 0 |
| | | | 2 | 20 | 0 | 0 | 0 | 25 | 0 | 1 | 0 |
| | | | 3 | 20 | 0 | 11 | 2 | 25 | 0 | 0 | 0 |
| | | | 4 | 20 | 2 | 4 | 0 | 25 | 0 | 2 | 0 |
| | | | 5 | 20 | 0 | 1 | 0 | 25 | 0 | 6 | 0 |
| | | | | 100 | 3 | 18 | 2 | 125 | 0 | 9 | 0 |
| | 24 d | VI | 1 | 20 | 0 | 2 | 0 | 50 | 0 | 6 | 24 |
| | | | 2 | 20 | 0 | 0 | 1 | 25 | 0 | 2 | 11 |
| | | | 3 | 20 | 0 | 0 | 0 | 25 | 0 | 2 | 1 |
| | | | 4 | 20 | 0 | 3 | 0 | 25 | 0 | 3 | 0 |
| | | | 5 | 15 | 0 | 0 | 0 | 25 | 0 | 3 | 0 |
| | | | | 95 | 0 | 5 | 1 | 150 | 0 | 16 | 36 |

d = days, $L_2$ = 2nd instar larva, $L_3$ = 3rd instar larva, P = puparium.

2) *Mortality during host-plant finding.* It was observed by egg-mapping that the female flies deposited their eggs in the soil at 0.0–3.0 cm from the stem of the plant. This means that many young maggots must find their way to the

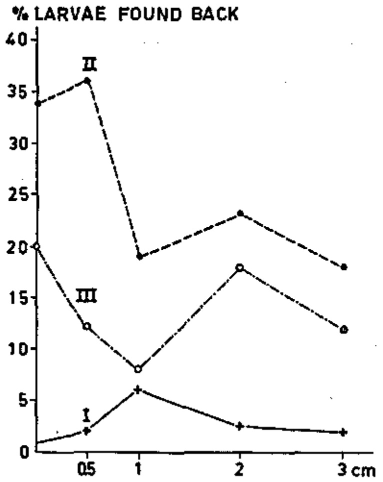



FIG. 19.
Percentage of larvae finding host-plant after emergence from eggs placed at several distances from the stalk.

plant. The efficiency of host-plant finding in the newly-hatched larvae was investigated in relation to the distance at which the eggs were deposited.

A certain number of fresh eggs collected from the field was placed in the soil at several distances from the stalks of cauliflower plants grown in pots under cages outdoors. The pots were then placed in the field under cages. After about ten days the plants were examined in the laboratory for larvae.

The results obtained are presented in fig. 19.

From the results obtained, it is clear that a roughly constant percentage of hatchlings reached their host-plant within the range of 0.5–3 cm from the stalk.

Observation showed that about 92% of the eggs are laid on the stem or within 0.5 cm around it.

We may conclude that in 1959, host-plant finding had no significant influence on the mortality of the newly-hatched larvae.

3) *Larval establishment as a mortality factor.* We have shown that within the limits of distance at which the eggs are normally laid, the newly-hatched larvae can reach their hostplant with little regard to how far from the stalk the

TABLE 14. *Results of experiments on larval establishment in 1959.*

| Date | Series | Plant number | Date of examination | Larvae found | Mortality % |
|---|---|---|---|---|---|
| 9/5/'59 | I | 1 | 19/5/'59 | 7 | 93 |
| | | 2 | | 54 | 46 |
| | | 3 | | 47 | 53 |
| | | 4 | | 8 | 92 |
| | | 5 | | 51 | 49 |
| | | | | 167 | |
| 9/5/'59 | II | 1 | 19/5/'59 | 52 | 48 |
| | | 2 | | 4 | 96 |
| | | 3 | | 44 | 56 |
| | | 4 | | 11 | 89 |
| | | 5 | | 17 | 83 |
| | | | | 128 | |

On every plant 100 eggs were placed. All larvae found were $L_2$.

Mean % mortality = 70.5 %
$S_x$ = 21.6
$S_{\bar{x}}$ = 6.8

Confidence limits (P = 95%): The mean lies in the interval between 55% and 89%.

eggs were deposited. The question now arises as to what percentage the maggots are able to establish themselves on the roots.

To establish themselves, the larvae must make grooves in the roots. These grooves soon become putrified. We found many larvae in moistened and decayed places near the roots. Because of this, larval establishment should be greatly influenced by the cortex texture of the root, the water-condition of the plant and the moisture content of the soil. Under dry conditions these may be important mortality factors.

A hundred fresh eggs were placed on the stalks of cauliflower plants grown in pots. After infestation, the plants were placed in the field under cylindrical cages. Two series of 5 plants each were examined for larvae 10 days after infestation.

The results obtained are presented in table 14.

### E. Predation by *Aleochara bilineata* Gyll.

As shown in pages 29-30, an important percentage of the total mortality is probably caused by predators. As it is known that *Aleochara bilineata* is an important enemy of the cabbage root fly, it seemed necessary to give special attention to its role.

Twenty plants grown in pots under cages were placed in the field. Two [1]) specimens of *Aleochara* (a male and a female) were released in each of 10 cages. The second series of 10 cages was used as a control. Eggs were put at the base of each plant inside the cages at successive dates. A week after the last eggs were added, both series were examined separately.

The results obtained were as shown in table 15.

Table 15. *Effect of* Aleochara bilineata *as a predator in cage experiments in 1959.*

| Date examined | Series I | | | | | | Series II | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cage | *Aleo.* released | total number of eggs | L + P found | | | Cage | total number of eggs | L + P found | | |
| | | | | $L_2$ | $L_3$ | P | | | $L_2$ | $L_3$ | P |
| 6/8/'59 | 1 | 2 | 120 | 2 | 7 | 3 | 1 | 100 | – | – | – |
| | 2 | 2 | 120 | – | – | – | 2 | 100 | 2 | – | – |
| | 3 | 2 | 120 | – | – | 5 | 3 | 100 | 1 | 2 | 1 |
| | 4 | 2 | 120 | 1 | 1 | – | 4 | 100 | 3 | – | – |
| | 5 | 2 | 120 | 1 | – | – | 5 | 100 | – | 3 | 4 |
| | 6 | 2 | 120 | 2 | 3 | 3 | 6 | 100 | 1 | – | 1 |
| | 7 | 2 | 120 | – | 1 | 4 | 7 | 100 | 3 | – | 1 |
| | 8 | 2 | 120 | – | – | – | 8 | 100 | 2 | – | 2 |
| | 9 | 2 | 120 | – | 1 | – | 9 | 100 | 2 | – | – |
| | 10 | 2 | 120 | – | – | 1 | 10 | 100 | 2 | – | – |
| Total | 10 | 20 | 1200 | 6 | 13 | 16 | 10 | 1000 | 16 | 5 | 9 |

| Mortality % in: | Series I | Series II |
|---|---|---|
| | 97.1 | 97.0 |

From the above mentioned observations we conclude that the share of *Aleochara* in juvenile mortality was negligible.

[1]) This was the average number of *Aleochara* found per plant in practice.

## F. Role of errant predators

For the sake of convenience, abundance of errant predators is dealt with under Chapter VIII, C.

If we compare mortality data with and without the natural enemies, the following result is obtained.

Natural mortality from egg to 3rd instar larva (pupa included):

1) With natural enemies (P = 95%):

| Lowest value | Mean | Highest value |
|---|---|---|
| 89% | 97% | 100% |

2) Without natural enemies (P = 95%):

| | Lowest value | Mean | Highest value |
|---|---|---|---|
| Eggs | 7% | 7% | 7% |
| L+P | 64% | 73% | 82% |
| | 71% | 80% | 89% |

From this it is clear that the lowest estimation of the contribution of natural enemies is 0%, and the highest estimation is ± 30%. These cases are extremes, and the range has only illustrative value.

Comparing the means, natural enemies caused a mortality of 97%–80% = 17%. The validity of this percentage is uncertain.

## G. Pupal mortality, Parasitism

The two major parasites of the cabbage root fly are *Cothonaspis rapae* Westw. (Fam. *Cynipidae;* Ord. Hymenoptera) and *Aleochara bilineata* Gyll. (Fam. *Staphylinidae;* Ord. Coleoptera). The first-named species parasitizes the larvae, while the second parasitizes the pupae.

De Wilde (1944) found that *C. rapae* destroyed larvae and pupae up to 2-10.4%; *Aleochara* killed pupae up to 37% and other parasites killed 5%.

Pieper (1955) found that up to 15.3% parasitism was caused by *C. rapae* and up to 37.1% is caused by *Aleochara.*

In order to provide information on the percentage of parasitism of the different generations during the season, and on the influence of parasites on pupal mortality, more quantitative data were collected during our investigations.

Puparia of different generations were collected from the fields on several dates by the usual method of larva and pupa sampling. These puparia were buried in moistened sand in glass dishes and kept in an incubator at 25°C. The dishes were daily checked for emerging *C. rapae* and *Aleochara.*

The results obtained are shown in table 16.

Summarizing the total percentages of parasitism by generations during the two years, the following figures can be given.

| Year | Total % of parasitism | | |
|---|---|---|---|
| | 1st generation | 2nd generation | 3rd generation |
| 1957 | 33.9 | 37.4 | 32.4 |
| 1958 | 21.5 | 20.4 | 27.6 |

TABLE 16. *Pupal mortality caused by the parasites* Aleochara spp. *and* Cothonaspis rapae *in successive samples in 1957 and 1958.*

| Year | Date of burial | Puparia | *Aleochara* | | *Cothonaspis* | | Total Parasitism % |
|---|---|---|---|---|---|---|---|
| | | | Total number | % | Total number | % | |
| 1957 | 11/VII | 353 | 102 | 28.9 | 18 | 5.0 | 33.9 |
| | 2/VIII | 360 | 115 | 31.9 | 20 | 5.5 | 37.4 |
| | 27/IX | 85 | 16 | 18.8 | 7 | 8.1 | 26.9 |
| | 28/IX | 100 | 8 | 8.0 | 30 | 30.0 | 38.0 |
| 1958 | 8/VII | 65 | 1 | 1.5 | 13 | 20.0 | 21.5 |
| | 18/VIII | 36 | 0 | 0 | 2 | 5.5 | 5.5 |
| | 27/VIII | 84 | 11 | 13.0 | 7 | 8.4 | 21.4 |
| | 1/IX | 25 | 3 | 12.0 | 1 | 4.0 | 16.0 |
| | 2/IX | 58 | 8 | 13.8 | 3 | 5.1 | 18.9 |
| | 20/IX | 77 | 18 | 23.3 | 4 | 5.2 | 28.5 |
| | 5/XI | 92 | 12 | 13.0 | 2 | 2.1 | 15.1 |
| | 7/XI | 85 | 25 | 29.4 | 3 | 3.4 | 32.8 |
| | 10/XI | 87 | 12 | 13.8 | 12 | 13.8 | 27.6 |
| | 11/XI | 90 | 25 | 26.8 | 5 | 5.5 | 32.3 |
| | 15/XI | 83 | 12 | 14.4 | 13 | 15.6 | 30.0 |

We conclude that in the year 1957 the percentage remained at about the same level in all generations. In 1958, it was about the same in the 1st and 2nd generations, while in the 3rd it was relatively higher.

In view of the large juvenile mortality up to the pupal stage the parasites are of importance, despite their relatively small share in the total mortality.

### H. CONCLUSION

We may conclude that the largest part of the mortality (about 73%) occurs in the 1st instar larva without any influence of natural enemies.

Among the factors responsible larval establishment appears to be of eminent importance.

We wish to draw attention here to the fact that, for technical reasons, egg counts were made every other day. This means that there remains a possibility that part of the eggs were removed by predators during the two-day intervals.

In a recent publication, WRIGHT & HUGHES (1959) mentioned that in their observation plots in England, predators daily took about 50% of the eggs deposited. This means that after two days about 37½% of the total number of eggs deposited will escape predation. If this should prove to be valid under our conditions, our mortality estimation will cover only this fraction.

## CHAPTER VII

## MAGGOT DENSITY AND HOST-PLANT DAMAGE

Practical experience has shown that the damage caused by the cabbage root fly to cruciferous crops varies in the course of one growing season, as well as between seasons. Damage is greatest in early varieties, grown in May and June.

It is also known that the degree of damage is greatly affected by weather influencing the resistance of the plant to maggot attack and its ability to recover. The problem arises as to whether the damage caused depends on weather and soil conditions rather than on maggot density. We therefore compared our data on density with those on plant loss in different years.

The results obtained are shown in table 17.

TABLE 17. *Relation between number of maggots and damage from 1955 to 1959.*

| Year | Field | Date | L+P/50 plants | Plant loss |
|---|---|---|---|---|
| 1955 | I | 8/6 | 844 | — — — |
| | II | 9/8 | 520 | — — — |
| | III | 16/9 | 265 | — — — |
| 1956 | I | 10/6 | 469 | + + |
| | II | 25/8 | 779 | + + |
| | III | 25/9 | 286 | + + + |
| 1957 | I | 7/6 | 2122 | + |
| | II | 2/8 | 820 | + |
| | III | - | - | + |
| 1958 | I | 8/7 | 86 | — — — |
| | II | 25/8 | 305 | — — — |
| | III | 6/10 | 150 | — — — |
| 1959 | I | 1/6 | 348 | + + + |
| | II | 7/8 | 52 | + + + |
| | III | 6/10 | 135 | + + + |

+ + + = severe losses > 40%, + + = moderate losses 20–40%,
\+ = slight losses 10–20%, — = little or no losses 0–10%.

## A. PLANT CONDITION

As appears from the table, the losses in different years do not correlate with maggot density. In 1957 e.g. the number of maggots was extremely high during the 1st generation, while losses were only slight. In the same way the number of maggots was about equal during the years 1955 and 1956, while losses were severe in the latter year and absent in the former. If we compare the weather condition in these two years, we see that the summer of 1955 was relatively warm, while in 1956 it was cool and rainy. If we compare 1958 and 1959 on this bases the expectation lies at hand (number of maggots in 1958 higher than in 1959) that losses in 1958 would be higher than in 1959. However, the inverse is true. Therefore, another factor, "resistance of plant to attack" or "plant condition", must play a role. The plant resists larval attack by forming secondary roots replacing the damaged ones. This reaction provides what we shall call the "recovery power" of the plant, which is to be balanced against the damage caused. In order to maintain a positive balance, the plant must be in a vigorous condition. Both maggot abundance and plant condition are affected by weather factors.

## B. Weather conditions

### 1. *Temperature*

It is shown in chapter VI page 18 that temperature may influence the activity, longevity and egg laying capacity of the flies, as well as the rate of larval growth and accordingly the damage done to the plant. The recovery power of the plant in its turn will be restricted by low temperature. In our opinion, this is the reason why damage in 1956 has been greater than in 1955. Cool weather restricts plant growth. As a result, the plant may suffer even from relatively small maggot populations.

Generally, young plants provide less shade than old ones. As a result, the soil surface temperature under young plants may sometimes reach high values and may affect egg eclosion either directly or indirectly by promoting loss of water. It may thus prevent eclosion, especially when precipitation is low.

### 2. *Precipitation*

It is mentioned in chapter VI page 27 that rainfall severely reduces the activity of the flies. Consequently, fewer eggs will be deposited during rainy periods. On the other hand rain favours egg eclosion and larval establishment on the host-plant (chapter VI page 32).

The recovery power of the plants is greatly enhanced by soil moisture (providing water and salts) and this in its turn is governed by precipitation.

In conclusion, we can say that rainfall generally limits damage and promotes plant recovery. However, in 1959 we saw that absence of rainfall, also, may limit attack (probably through an effect on the adult fly) but at the same time promotes damage (through an adverse effect on the plant).

## C. Seasonal trends in damage and maggot density

During four successive years of experimentation (1956–1959), we have found that the number of eggs deposited per 50 plants sampled is less in summer than in spring. The same was found by Gibson & Treherne (1916) in Canada, de Wilde (1947) in Holland, and Miles (1953) in England. According to Slingerland (1894), the summer decrease is due to migration of the flies to wild crucifers. De Wilde, however, could not confirm this under Dutch conditions. It is clear that this decrease may be due to the reduced longevity of summer flies, resulting in the decrease of the number of eggs laid per female (chapter VI page 18). The same was found by Gibson & Treherne (1916), and by Miles (1953). The latter ascribed it to shortage of food, as the adult fly feeds on pollen and nectar, and flowers are most abundant in spring time. De Wilde pointed out the importance of parasites, predators and weather conditions. Hille Ris Lambers (1933) observed that the beet fly (*Pegomyia hyoscyami*) lays a varying percentage of fertile eggs in the course of season.

### 1. *Seasonal course of predation*

It is mentioned in chapter VI that counts of settling predators by the "auger" method and those of errants by the "soil-trap" method showed that both categories are comparatively more numerous during the first generation of *Erioischia* than during the second and third generation. The total number of eggs eaten will therefore be higher during the spring. Accordingly, we have found that the number of eggs developing to fullgrown larvae is smaller in summer than in spring. Finally the predators will play a role in reducing maggot populations, which will also result in less damage, other conditions being equal.

### 2. *Seasonal course of parasitism*

It is evident that the percentage of parasitism is greatest at the end of the season (chapter VI page 34). We may conclude that the parasites have a beneficial effect in reducing the risk of summer damage by reducing maggot populations.

### 3. *Seasonal course of egg fertility*

It is shown in chapter VI page 28 that the percentage of eggs hatching varies during the course of the season. The number of maggots developing from a given number of eggs will therefore vary, and so will the damage.

## D. Conclusions

It is evident that maggot density is not the only factor affecting plant damage. Plant condition also plays a role, by determining the susceptibility of the plant to maggot attack.

Weather factors influence both maggot populations (increase in egglaying capacity of the flies at relatively low temperature and decrease of activity in rainy weather) and plant condition (promotion of the recovery of the plant by rainfall and relatively high temperatures).

Damage is, generally, less in summer than in spring. The factors involved in this phenomenon may be summarized as follows:

1) Reduced longevity of the female flies resulting in less oviposition at high temperatures.
2) Increase in number of parasites and predators in the course of the season.
3) Unfavourable summer weather conditions for eggs and newly-hatched larvae.
4) Low spring temperature reducing the recovery power of the plant.

CHAPTER VIII

# EFFECT OF CHEMICALS ON THE ABUNDANCE OF *ERIOISCHIA* AND ITS PREDATORS

In the foregoing chapters it has been shown that the natural mortality of the cabbage root fly was highest in the juvenile stages (90–92%, pupae excluded).

We have shown by analysis of the natural mortality that natural enemies can be of some importance. However, they are not capable of preventing considerable economic crop losses. Chemical treatment of the remaining population of the pest is very necessary, as the survivors (8–10%) are, as a rule, sufficient to cause considerable crop losses. In view of the high natural mortality, we are inclined to think that chemical treatment may disturb one or more factors responsible for this mortality. Chemicals killing 90% of the larva population and at the same time reducing natural mortality to a low level might be without any effect. Moreover in killing natural enemies we probably remove important regulating factors, thus enabling very high levels of infestation to occur. To obtain the highest percentage kill by an insecticide, its application must be synchronized with the most susceptible stage in the life cycle of the insect. Investigations showed that both the eggs and the newly-hatched larvae of *Erioschia* are highly vulnerable stages for some new soil insecticides. Since the oviposition of each generation lasts for more than one month, the insecticides to be used must persist over this period of time. The two modern insecticides Aldrin and Chlordane, are the most recommended.

It is generally accepted that an overall chemical treatment of the soil may result in the reduction of natural enemies of soil pests. We were interested to find out whether the same is true when local applications of high concentrations of insecticides are made around the plant. These might give control of the pest and at the same time might not seriously affect the natural enemy populations.

For these reasons, attention was concentrated upon Aldrin and Chlordane, on the local method of their application, and on the most closely associated natural enemies (*Aleochara* spp.).

We also took notice of errant predators sampled by means of soil traps.

## A. REVIEW OF LITERATURE

### 1. *Natural enemies*

The cabbage root fly, like other insect pests, is exposed to the attack of many natural enemies through its life cycle.

WASHBURN (1908) mentioned that *Cothonaspis rapae* parasitized up to 46 % of the autumn generation.

SCHOENE (1916) in the U.S.A. and GIBSON & TREHERNE (1916) in Canada mentioned that *C. rapae* was the most important parasite in both countries.

TREHERNE (1916) in Canada distinguished three important groups of predators:

*a.* Red mites of the genus *Thrombidium* which feeds upon the eggs of *Erioischia.*
*b.* Many species of the fam. *Staphylinidae.*
*c.* Many species of the fam. *Carabidae.*

SMITH (1927) in England found that *C. rapae* was the most important parasite.

JAMES (1928) in England found that *C. rapae* caused 25 % parasitism.

LUNDBLAD (1933) observed *C. rapae* in Sweden.

DE WILDE (1947) in Holland observed that the adult flies were attacked by a fungus disease resembling *Empusa muscae.* He also mentioned the two Staphylinids *Aleochara bilineata* GYLL. and *A. bipustulata* L., as the most important predators and parasites; the red mite *Thrombidium* sp. as predator of the eggs; and the predatory carabid beetle, *Harpalus aeneus* F.

WRIGHT & HUGHES (1959) in England mentioned the Carabid beetles, especially *Bembidion lampros,* as eating about half the eggs present around the plant in a warm and sunny day. They also mentioned *Aleochara* spp. and the Cynipid *Idiomorpha* (*Cothonaspis*) *rapae.*

Thus *Aleochara* sp. and *Cothonaspis rapae* are generally associated with cabbage root fly populations. It will be necessary therefore, to give a short summary of the life cycle of both.

a. *Aleochara bilineata* GYLL. Its life history was studied by WADSWORTH (1916), KEMNER (1926) and DE WILDE (1947). The adult beetles which live in galleries in the ground near the roots of the cabbage plants lay their eggs in the ground. Only the first larval stage is free-living. It penetrates into the puparium of the cabbage root fly and some other Diptera. After this, it lives as an ectoparasite between the pupal cuticle and the puparium wall. The second and third larval stages show parasitic degeneration. Pupation takes place within the host puparium.

Development from egg to adult takes 40–45 days. There are 2–3 generations per year corresponding with those of the host insect.

b. *Cothonaspis rapae* WESTW. The biology of *Cothonaspis* was studied by JAMES (1928) and MOLTSCHANOWA (1930). The eggs are laid in the 2nd and 3rd instar larvae of the cabbage root fly. The larva of *Cothonaspis* has three instars, and pupates inside the cabbage root fly puparium. The adults appear later than those of *Erioischia* as can be expected from a larva parasite.

2. *Chemicals*

During the past decades several succesful methods of chemical control of the cabbage root fly have been developed.

DE WILDE (1947) discussed the control methods up till 1947. Methods developed since that time are mentioned below.

DILLS & ODLAND (1948) found that out of 23 different compounds tested for the control of the cabbage root fly, chlordane was the most toxic and was found to have no deleterious effect on cabbage.

STITT & EIDE (1948) stated that chlordane dusted at a delayed date on the plants (three weeks after transplanting) gave poor maggot control. In none of the tests did it cause any injury to the plants when applied in contact with the roots.

EIDE *et al.* (1950) mentioned that both chlordane and aldrin gave good control of *Erioischia* in broccoli, cauliflower and seed cabbage plantings. Both materials were entirely safe when used as dusts.

STITT (1951) mentioned that both aldrin 2.5% and chlordane 5% when applied by broadcasting, banding and furrowing for the control of *Erioischia* in radishes gave significant reduction of the maggots when compared with the untreated check.

GÜNTHART (1953) recommended, in the case of cauliflower, that the soil should be watered with chlordane emulsion at 4.5 lb. against the cabbage root fly.

STITT (1953) mentioned that aldrin applied in the furrow with the seed at 0.03–0.1 lb. active ingredient per 100 linea feet of row gave satisfactory control of the maggots injuring turnips, while chlordane gave inferior control.

WRIGHT (1954) pointed out that application with a "spoon" appeared to be a much more satisfactory method of treating the base of the plant for the control of *Erioischia* than application with a handduster and broadcasting was inferior to both. He observed that chlordane did not act by deterring adults from ovipositing round treated plants.

WAGN (1954) stated that the best control of *Erioischia* in swedes was achieved by aldrin when the dust was applied along the rows in June.

WRIGHT (1955) found that treating plants raised in pots with 0.2% chlordane emulsion at the usual rate resulted in uniform and vigorous growth, with a significant increase in the number and weight of marketable heads and no plants killed by *Erioischia*, whereas over 12% of the untreated ones were killed and many others stunted. An emulsion containing 0.05% aldrin, applied at the usual rate to plants in pots also gave very good protection.

DANIS, SWENSON & PATTERSON (1955) in the U.S.A. mentioned that aldrin was effective at dosages of 8 lb. toxicant per acre. In tests of the persistence of such treatment in the following year, aldrin reduced the amount of damage to subsequent crops of both cabbages and swedes. In radish seed-beds, when measured amounts of wettable powder were sprayed over the soil surface and raked into the top 3–4 inches before sowing, aldrin at 4–8 lb. gave satisfactory protection, whereas chlordane at 4–8 lb. did not.

KING & FORBES (1955) in Canada mentioned that aldrin was the most effective insecticide when applied to rows of *Rutabagas* three feet apart by the hand, furrow and spray methods at 5, 2.5 and 5 lb. per acre. Chlordane, even at high rates, did not give adequate commercial control.

FORBES & KING (1956) in Canada mentioned that when the rates for the hand, spray and furrow methods were 5.5 or 2.5 lb. of aldrin per acre, spray treatment at 200 gal. per acre prevented any material damage; the furrow method gave 90% reduction of damage; the band method gave good commercial control. Field-scale methods of treatment afford as high a degree of effectiveness, as the more precise, small plot, band methods (in Rutabaga fields).

FORBES & KING (1957) in Canada observed that excellent control of *Erioischia* was possible with aldrin in mineral soil, while the same did not hold for muck and peat soil. This is due to the adsorption of the insecticides by organic matter in the soil while the oviposition habits of the fly in loose soils contribute to the poor control. It seems likely that breakdown of insecticides is involved.

In mineral soils band treatments with granulated or emulsifiable formulations give highly satisfactory control. With spray treatments at least two applications are needed, 1.5 lb. of toxicant/200 gal. water per acre, resulted in 99% control.

The Plant Protection Service (P.D.) in Holland has carried out research on control methods for *Erioischia* over five years (1953–1957) and obtained important results which can be summarized in the following points.

1. Soil treatment: A preventive soil treatment of pot-plants with aldrin or dieldrin gave satisfactory control of the cabbage fly in the following spring.

2. Dust treatment: The results can be improved by mixing the amounts recommended (3 grams) with diluents at 1 : 10. Therefore, 30 grams should be spread at the base of the plants. The supposition that 15 grams of the mixture would also have a sufficient effect appeared not to be justified.

As to the comparison of the materials the following can be said:

*a*. The chlorinated hydrocarbons showed a constant effect. The differences among chemicals belonging to this group are very small. Although heptachlor dust is perhaps a little more effective than chlordane, this cannot be stated with aldrin.

*b*. The organic phosphorus compounds had a less constant effect. Parathion appeared more unreliable than diazinon.

In the control advice for 1956, therefore, stress is laid upon the application of the chlorinated hydro-carbons aldrin, heptachlor or chlordane. Parathion and other phosphor-esters are less reliable and not recommended.

The Institute of Phytopathological Research (I.P.O.) at Wageningen studied chemical control methods for *Erioischia* over 7 years (1951–1957). As a result both chlordane and aldrin gave the best control. Therefore, their use was highly recommended.

LIGHT & MORTON (1959) in England found that aldrin dust applied before sowing in seed-beds gave better results than dieldrin and dipterex, when applied at a rate of 2.8 and 5.6 lb. per acre, or to the drills as a 1.25% dust at 0.5 or 1 oz. toxicant per 10 yd. of row.

After this review of literature on chemicals it is clear that the two mostly recommended insecticides for the control of *Erioischia* are chlordane and aldrin, and the best method of application is the "spoon" method.

### B. Effect of chemicals on *Erioischia* and subterranian *Aleochara*

In studying the effect of chemicals on the control of a pest and their influence on its natural enemies, the abundance of these enemies in relation to their host in untreated fields (under natural conditions) must be known. For this reason, in the experimental fields designed for our natural mortality investigations, counts of larvae and puparia of *Erioischia* as well as those of *Aleochara* sp. were made. The methods of sampling and counting (auger method) have been described previously (chapter III). These counts were made on five plants at weekly intervals during the growing seasons of two successive years (1958 and 1959).

In order to study the effect of chlordane and aldrin on the populations of *Erioischia* and *Aleochara*, two types of experimental fields were designed, synchronizing with each generation during the seasons of 1957, 1958 and 1959. Each field consisted of fifteen plots of twenty-five plants each, separated by broad bean plants. Five plots were treated with aldrin, another five with chlordane, and the last group was left untreated as a control. These plots were distributed at random (fig. 20).

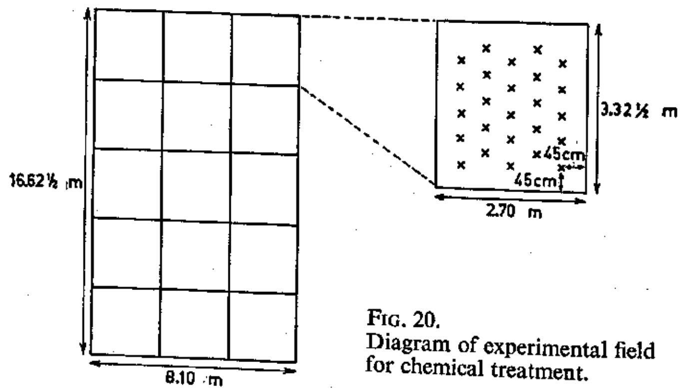



Fig. 20.
Diagram of experimental field for chemical treatment.

The first type of field was treated directly after transplanting, as normally practiced, the second was treated about two weeks before transplanting in order to test if pretreatment will result in serious maggot infestation by killing the natural ennemies of the pest.

The "spoon" method was used for applying the 2.5% aldrin and 10% chlordane dusts at the rate of three grams of each, separately, per plant.

Error of *Aleochara* counting. To judge whether the same method used for larvae and puparia counts gives reliable results about *Aleochara*, 10 beetles were released inside a cylindrical cage open on both sides and placed vertically in the experimental field and were watched till they had disappeared in the soil. Then the soil was examinded by the "auger" method. This was repeated 10 times with other *Aleocharas*. The mean percentage recovery was 98. We therefore have not applied any correction factor.

Presence of *Aleochara* near or between the plants. The question whether *Aleochara* is present in the soil between the plants, or burrows only near them, was studied by examining 50 samples taken from soil between the plants and another 50 taken from plants with roots. The samples, in both cases, were taken at random from an untreated experimental field. The "auger" method was used for the counts. The number of *Aleochara* found were 2 (between plants) and 52 (near plants). All the 50 plants examined were found infested with maggots. Thus the number of *Aleochara* in the soil between the plants can be neglected, and we assume that in sampling our plants we can gain a reliable impression of the total population of *Aleochara* present.

The results obtained in untreated fields during the years 1958 and 1959 are shown in table 18. Those from directly treated fields during the years 1957, 1958 and 1959 are shown in table 19, while fields treated two weeks before transplanting in 1958 and 1959 are dealt with in table 20.

TABLE 18. *Counts of* Erioischia *(larvae = L, puparia = P) and* Aleochara spp. *per five plants in untreated fields in 1958 and 1959.*

| 1958 | | | | 1959 | | | |
|---|---|---|---|---|---|---|---|
| Field | Date | L+P | *Aleochara* | Field | Date | L+P | *Aleochara* |
| I | 21/V | 5 | 1 | I | 29/IV | 3 | 0 |
| | 28/V | 3 | 12 | | 6/V | 10 | 0 |
| | 5/VI | 16 | 2 | | 13/V | 15 | 0 |
| | 12/VI | 11 | 6 | | 20/V | 15 | 2 |
| | 19/VI | 31 | 3 | | 27/V | 48 | 5 |
| | 26/VI | 10 | 1 | | 3/VI | 47 | 4 |
| | 3/VII | 15 | 6 | | 10/VI | 26 | 2 |
| | | | | | 17/VI | 29 | 2 |
| II | 7/VII | 4 | 0 | II | 24/VI | 0 | 0 |
| | 14/VII | 5 | 0 | | 1/VII | 3 | 0 |
| | 21/VII | 8 | 0 | | 8/VII | 12 | 3 |
| | 28/VII | 7 | 1 | | 15/VII | 2 | 1 |
| | 4/VIII | 39 | 0 | | 22/VII | 6 | 0 |
| | 11/VIII | 59 | 4 | | 29/VII | 9 | 0 |
| | 18/VIII | 32 | 3 | | 5/VIII | 7 | 0 |
| | 25/VIII | 28 | 0 | | 12/VIII | 5 | 1 |
| | 1/IX | 42 | 6 | | 19/VIII | 10 | 3 |
| III | 1/IX | 1 | 0 | III | 26/VIII | 0 | 0 |
| | 8/IX | 0 | 0 | | 2/IX | 0 | 0 |
| | 15/IX | 10 | 1 | | 9/IX | 3 | 0 |
| | 22/IX | 14 | 0 | | 16/IX | 4 | 1 |
| | 29/IX | 15 | 0 | | 23/IX | 4 | 1 |
| | 6/X | 14 | 0 | | 30/IX | 6 | 1 |
| | 13/X | 7 | 0 | | 7/IX | 3 | 0 |
| | 20/X | 10 | 0 | | | | |

If we examine the results obtained in table 18 for the relation between the number of L + P of *Erioschia* and *Aleochara* in 1958 and 1959 we find that no correlation can be seen in any of the observations.

In studying the data obtained with individual plants, which we do not give in detail, we find that of the 235 plants sampled, 153 plants were infested and

82 plants uninfested with the maggots. In 39 cases *Aleochara* was found near infested plants and in 4 cases near uninfested plants. In 114 cases of infested and 78 cases of uninfested plants, no *Aleochara* were found.

Evidently, although there is no significant correlation between the number of maggots and the number of *Aleochara,* the latter is found only near infested plants. We conclude that for the settling of *Aleochara* near the roots, the presence of *Erioischia* larvae is essential.

TABLE 19. *Counts of* Erioischia *(L + P) and* Aleochara *in fields treated with aldrin and chlordane.*

| Year | Field | Examined on | Aldrin | | Chlordane | | Control | |
|---|---|---|---|---|---|---|---|---|
| | | | L+P | Aleochara | L+P | Aleochara | L+P | Aleochara |
| 1957 | I | 5/VII | 3 | 0 | 7 | 1 (†) | 268 | 11 |
| | | 24/VII | 7 | 0 | 8 | 0 | 180 | 10 |
| | II | 24/VIII | 8 | 0 | 5 | 0 | 32 | 0 |
| | | 10/IX | 21 | 0 | 15 | 0 | 119 | 0 |
| 1958 | I | 10/VI | 1 | 1 (al.) | 1 | 1 (al.) | 23 | 7 |
| | | 30/VI | 2 | 5 (al.) | 1 | 1 (al.) | 28 | 14 |
| | II | 12/VIII | 1 | 2 (al.) | 2 | 0 | 60 | 10 |
| | | 27/VIII | 1 | 0 | 1 | 0 | 52 | 7 |
| | III | 4/X | 1 | 0 | 1 | 0 | 18 | 0 |
| | | 18/X | 2 | 0 | 2 | 0 | 26 | 0 |
| 1959 | I | 2/VI | 3 | 0 | 5 | 0 | 66 | 6 |
| | | 18/VI | 4 | 0 | 2 | 0 | 22 | 0 |
| | II | 7/VIII | 0 | 0 | 0 | 0 | 14 | 1 |
| | | 21/VIII | 0 | 0 | 0 | 0 | 30 | 2 |
| | III | | 0 | 0 | 0 | 0 | 24 | 0 |

1. On every date 10 plants per kind of treatment were examined.
2. † = dead; al. = alive.

The number of larvae and pupae per plant in the different fields of the year 1957 was greatly reduced by the treatment with aldrin and chlordane. This is summarized in table 19.

The differences between the results obtained with aldrin and chlordane are not significant. The influence of the two insecticides on the number of *Aleochara* could not be analysed as the numbers of predators in the control, aldrin, and chlordane plots were too low.

As regards the years 1958 and 1959, it is clear without statistical analysis, that the number of L + P was negligible after treatment with aldrin and chlordane. The differences between the effects of aldrin and chlordane are not significant. The correlation between *Aleochara* and L + P numbers is not significant. Statistical analysis of the *Aleochara* data is not possible as the numbers are either very small or zero.

From table 20 in which the results of the pre-treatments are plotted we see that in field IV (1958) the application of aldrin and chlordane prevented development of any larvae and pupae. The same was true in 1959. As to the effect of aldrin and chlordane on *Aleochara*, the numbers found were very small and the beetles may possibly have been affected. There are no significant differences between the effects of the two chemicals.

TABLE 20. *Counts of* Erioischia *(L+P) and* Aleochara *in pre-treated fields in 1958 and 1959*

| Year | Field | Date of examination | Kind of treatment | L+P | Aleochara |
|---|---|---|---|---|---|
| 1958 | IV | 1st Exam. 30/IX | A | 0 | 0 |
| | | | B | 0 | 0 |
| | | | C | 37 | 3 |
| | | 2nd Exam. 15/X | A | 0 | 0 |
| | | | B | 0 | 0 |
| | | | C | 27 | 0 |
| 1959 | I | 1st Exam. 2/VI | A | 1 | 0 |
| | | | B | 1 | 1 (alive) |
| | | | C | 38 | 1 |
| | | 2nd Exam. 19/VI | A | 1 | 0 |
| | | | B | 0 | 0 |
| | | | C | 22 | 1 |
| | II | 1st Exam. 10/VIII | A | 1 | 0 |
| | | | B | 0 | 0 |
| | | | C | 10 | 0 |
| | | 2nd Exam. 21/VIII | A | 0 | 0 |
| | | | B | 1 | 0 |
| | | | C | 15 | 1 |

In all cases 10 plants per treatment were examined.
A = Aldrin, B = Chlordane, C = no treatment (control)

In the control plots there was no significant correlation between the number of maggots and that of *Aleochara*.

The following conclusions may be drawn:

1. Settling *Aleochara* were found almost exclusively near the roots of infested plants.
2. Aldrin and chlordane when applied at the normal rates by the spoon method, directly or about two weeks before transplanting, gave a sufficient maggot control and had an equal effect.
3. Since *Aleochara* seems to be attracted only to maggot-infested plants, both chemicals probably have no deleterous effect on the beetle under practical conditions.

### C. EFFECT OF CHEMICALS ON ERRANT PREDATORS

For errant predators, not covered by the "auger" method, the "soil-trap" (fig. 21), method was used. Twenty traps with some alcohol in the bottom of each for attraction, were placed at random at several dates in the untreated, treated and pre-treated fields. This was repeated in another series of fields.

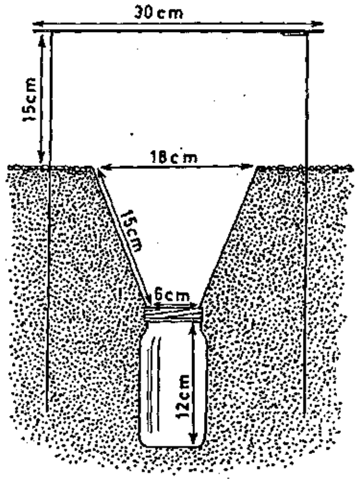



FIG. 21.
Soil-trap for sampling errant predators.

The results obtained are shown in table 21 and table 22.

TABLE 21. *Counts of* Aleochara *by soil-traps in untreated, directly treated, and about two weeks pre-treated fields in 1959*

| | Untreated | | | | Directly treated | | | | 2 weeks pre-treated | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | | | | b | | | | c | | |
| Field | Date | Soil-traps | *Aleocharas* | Field | Date | Soil-traps | *Aleocharas* | Field | Date | Soil-traps | *Aleocharas* |
| I | 16–19/6 | 20 | 245 | I | 25–28/6 | 10 | 7 | I | 25–28/6 | 10 | 9 |
| | 19–22/6 | 20 | 83 | | 28/6–1/7 | 10 | 2 | | 28/6–1/7 | 10 | 4 |
| | 22–25/6 | 20 | 88 | | 1–4/7 | 10 | 10 | | 1–4/7 | 10 | 17 |
| | Total | | 416 | | | | 19 | | | | 30 |
| | Mean/trap | | 20.8 | | | | 1.9 | | | | 3.0 |
| II | 8–11/8 | 20 | 5 | II | 14–17/8 | 10 | 51 | II | 14–17/8 | 10 | 51 |
| | 12–15/8 | 20 | 114 | | 18–21/8 | 10 | 32 | | 18–21/8 | 10 | 28 |
| | 15–18/8 | 20 | 163 | | 21–24/8 | 10 | 90 | | 21–24/8 | 10 | 69 |
| | Total | | 282 | | | | 173 | | | | 148 |
| | Mean/trap | | 14.1 | | | | 17.3 | | | | 14.8 |
| III | 28/9–1/10 | 20 | 55 | III | 28/9–1/10 | 20 | 29 | | | | |
| | 1–3/10 | 20 | 71 | | 1–3/10 | 20 | 36 | | | | |
| | 5–7/10 | 20 | 24 | | 5–7/10 | 20 | 26 | | | | |
| | Total | | 150 | | | | 91 | | | | |
| | Mean/trap | | 7.5 | | | | 4.6 | | | | |

In table 21 two things merit further discussion. In the first place it is clear that *Aleochara* catches were about equal in the treated and pre-treated plots. In the second place, the effect of these treatments was considerable in June, but small or absent in August and October.

The only explanation we can give is, that *Aleochara* seems to be more settling at the beginning of the growing season than during full summer.

This would be in accord with table 18, showing that the number of *Aleochara* found near the roots was greatest during the first generation.

If we combine these data with our findings mentioned on page 44, that the presence of *Erioischia* larvae seems essential for *Aleochara* settling near the roots, it follows that under field conditions, local treatment diminishes the number of *Aleochara* merely by removing its main host or prey.

As is shown in table 22, a total of 21 genera and 38 species of errant predators were found in the untreated field, while in the treated field there were 14 genera and 20 species. The total number of specimens was 585 in the untreated and 193 in the treated field.[1]) From this we conclude that errant predators other than *Aleochara* are found in untreated fields in much greater number than in treated fields in terms of genera, species, and specimens. The same considerations seem to be valid here as have been given in our discussion of the effect on *Aleochara*. In this respect, we may again ask ourselves whether the predators, generally, are more attracted to infested than to uninfested plants.

[1]) The author feels greatly indebted to Mr. P. VAN DER WIEL for determining the specimens collected.

TABLE 22. *Counts of errant predators during the 1st generation in 1959*

| Family | Species | Total no. |
|---|---|---|
| | Field I. Untreated, sampled 16–25/6/1959 | |
| *Carabidae* | *Pseudophonus pubescens* MÜLL. | 157 |
| ,, | *Poecilus lepidus* LESKE | 43 |
| ,, | *Broscus cephalotes* L. | 2 |
| ,, | *Pterostichus vulgaris* L. | 1 |
| ,, | *Harpalus aeneus* F. | 16 |
| ,, | *Harpalus latus* L. | 1 |
| ,, | *Calathus melanocephalus* L. | 9 |
| ,, | *Calathus erratus* SHLB. | 4 |
| ,, | *Amara fulva* DE G. | 10 |
| ,, | *Amara spreta* DEJ. | 9 |
| ,, | *Amara similata* GYLL. | 1 |
| ,, | *Amara consularis* DFTS. | 2 |
| ,, | *Amara bifrons* GYLL. | 2 |
| ,, | *Platynus dorsalis* PONTOPP | 1 |
| ,, | *Bembidion lampros* HRBST. | 32 |
| ,, | *Bembidion femoratum* STRM. | 51 |
| ,, | *Bembidion ustulatum* L. | 2 |
| ,, | *Bembidion quadrimaculatum* L. | 1 |
| ,, | *Clivina collaris* HRBST. | 1 |
| ,, | *Acupalpus meridianus* L. | 1 |
| *Staphylinidae* | *Quedius tristis* GRAV. | 1 |
| ,, | *Quedius cinctus* PAYK. | 1 |
| ,, | *Tachyporus obtusum* L. | 1 |
| ,, | *Oxytelus rugosus* F. | 6 |
| ,, | *Oxytelus inustus*GRAV. | 2 |
| ,, | *Oxytelus complanatus* ER. | 3 |
| ,, | *Oxytelus nitidulus* GRAV. | 3 |
| ,, | *Oxytelus tetracarinatus* BLOCK. | 13 |
| ,, | *Oxytelus sculpturatus* GRAV. | 2 |
| ,, | *Platystethus arenarius* FOURCR. | 2 |
| ,, | *Xantholinus angustatus* STEPL. | 10 |
| ,, | *Philonthus debilis* GRAV. | 2 |
| ,, | *Philonthus Gabrius nigritulus* GRAV. | 3 |
| ,, | *Aleochara bilineata* GYLL. | 87 |
| ,, | *Aleochara bipustulata* L. | 58 |
| ,, | *Haploderus caelatus* GRAV. | 2 |
| ,, | *Lathrobium fulvipenne* GRAV. | 1 |
| *Forficulidae* | *Forficula auricularia* L. | 42 |
| | Field II. Treated, sampled 25/6–4/7/1959 | |
| *Carabidae* | *Pseudophonus pubescens* MÜLL. | 49 |
| ,, | *Pseudophonus griseus* PANZ | 1 |
| ,, | *Harpalus aeneus* F. | 31 |
| ,, | *Amara fulva* DE G. | 7 |
| ,, | *Amara spreta* DEJ. | 6 |
| ,, | *Amara bifrons* GYLL. | 2 |
| ,, | *Calathus erratus* SAHLB. | 10 |
| ,, | *Calathus melanocephala* L. | 6 |
| ,, | *Clivina fossor* L. | 1 |
| ,, | *Acupalpus meridianus* L. | 4 |
| ,, | *Bembidion lampros* HRBST. | 17 |
| ,, | *Bembidion femoratum* STRM. | 37 |
| ,, | *Platynus dorsalis* PONTOPP | 1 |
| ,, | *Broscus cephalotes* L. | 1 |
| *Coccinellidae* | *Coccinella 11-punctata* L. | 7 |
| *Staphylinidae* | *Xantholinus angustatus* STEPH. | 3 |
| ,, | *Lathrobium fulvipenne* GRAV. | 1 |
| ,, | *Aleochara bilineata* L. GYLL. | 9 |
| ,, | *Aleochara bipustulata* L. | 3 |
| *Forficulidae* | *Forficula auricularia* L. | 7 |

# SUMMARY

## I. Introduction

The abundance of the cabbage root fly, *Erioischia brassicae* Bouché, affecting crucifers in the Netherlands, was studied under field conditions at Wageningen, during the growing seasons of five successive years (1955–1959).

The factors influencing the natural abundance were studied experimentally.

The relation between maggot density and the damage caused to the host-plant (cauliflower) was investigated. The damage was, in general, most severe in spring. Attention was paid to climatic conditions influencing both maggots and plants.

Chemical control methods being considered the most effective catastrophic mortality factor, the effect of 2.5% aldrin and 10% chlordane dusts on *Erioischia* populations and on the abundance of its natural enemies was studied.

## II. General remarks on the cabbage root fly and its damage

The geographical distribution of the cabbage fly is restricted to the temperate zone of the holarctic region (35–60° N.L.). The number of generations varies from one to five per year in different countries. The behaviour during the active stages, together with the under- and above-ground symptoms of the damaged plant, are summarized.

## III. Materials and methods

### A. *Materials*

Cauliflower transplants (cultivars Alpha and Lecerf) were used. All cultural treatments were practised in the normal local way. The soil of the experimental plot was blackisch-brown gravel sand.

The humus content was low (3–4), the water table very deep (20 metres), and the pH (KCL) 4.7–5.0.

### B. *Arrangement of the experimental field*

Several fields succeeding each other and synchronizing with the cabbage root fly generations were utilized during the growing season. Each field was divided into nine plots of 60 plants each, separated by rows of Vicia faba (fig. 1).

### C. *Counting methods*

A census method was used for estimation of *Erioischia* populations over the whole field. The abundance of all stages was calculated per 50 plants. The following methods were used for counting the different stages:

1. for eggs, the "washing method" (plate IIa, b).
2. for larvae and puparia, the "auger method" (figs. 3, 4 and plate IIIa, b).
3. for adults, the "catching-cage" (fig. 5a, b).

A detailed description of each of these methods is given. The number of specimens missed by these sampling methods were proved to be negligible.

## IV. Distribution of *Erioischia* populations

The types of insect distribution according to their biological significance are summarized. With Erioischia, we checked our method of sampling in relation to the distribution of the eggs deposited per plant in the field. For this purpose,

central and peripheral plants were compared, as well as eastern to western and northern to southern plots (fig. 1 and table 1). No significant differences were found. Attractional distribution is dealt with in chapter VI.

## V. Abundance of different stages in course of the season

For assessment of the mortality in the different stages of *Erioischia* under natural conditions, the most useful method was sampling the population density at successive intervals and determining how many individuals of a certain stage has grown from a preceeding one.

It is clear from the results obtained, presented in figs 6–10 and table 2 and 4, that a very high natural mortality occurs in the earliest stages (juvenile mortality). Survival of to the pupal stage was 8–10% of the eggs. Remarkably, this fraction remained more or less constant through five climatically different years (1955–1959).

## VI. Factors influencing abundance

A. *Adult condition* (fig. 11a, b, c and table 6)

The effect of temperature on the rate of oviposition and longevity of the flies of different generations was studied under partly controlled conditions. The method used is described. At the same temperature, the females of the over-wintering generation have a greater fertility, and longevity than subsequent generations. At higher temperature (24°C) the longevity is less within the same generation. Females usually live longer than males.

B. *Oviposition*

The factors affecting oviposition, upon which the abundance of other stages depends, were:

*a*. Plant size (figs. 12a, b, c and table 7 and 8).

There is a positive correlation between plant diameter and the number of eggs deposited. The correlation coefficient is higher when calculations are based only on the plants with the lowest numbers of eggs. No significant correlation was found between the height of the plant and the number of eggs.

*b*. Plant age (table 9).

There were no sginificant differences between the mean number of eggs deposited near young and old plants, although large plants were favoured for oviposition over small ones of the same age.

*c*. Seasonal conditions (figs. 14–18).

The number of eggs deposited per fifty plants every two days was compared with the daily temperature and rainfall during the growing seasons of the five different years. Relatively cold weather promotes egg deposition by increasing fertility and longevity. Dry and sunny weather promotes also egg deposition, by increasing the activity of the field population. Oviposition is reduced by rainfall.

C. *Egg fertility* (table 10)

Laboratory experiments in 1959 showed that the difference between the mean % fertile eggs in the first generation and in the second one was not significant. But due to the varying percentage of fertile eggs, egg fertility may contribute as a factor of varying importance in the abundance of generations during the season.

D–F. *Egg and larval mortality* (tables 11, 12, 13, 14, 15 and fig. 19).

In the two years of investigations on this problem (1958 and 1959), the infestation was high enough for our purpose only during the first generation of 1959.

The total mortality up to the 3rd larval and pupal stage, with and without natural enemies, was studied in the field. Predators were found to cause an estimated juvenile mortality of only about 17%. *Aleochara bilineata* GYLL. proved to be of very little importance as a predator.

In order to detect which stage has the highest mortality, each stage was studied separately under cages in the field. The methods used are described. The highest mortality found was in the first instar larva (±79%, = ±73,5% of corresponding egg number), while egg mortality was very low (±7%).

The efficiency of host-plant finding by the hatchlings was investigated in relation to the distance of the eggs from the plant (fig. 19). Within the natural range of 0–3 cm it had no significant influence on the mortality of the newly-hatched larva.

The larval establishment on the host-plant involved an estimated mortality of about 63 % during the first instar larvae (table 14). It is greatly influenced by plant condition (old, young, tender, hard).

G. *Parasitism* (table 16)

The parasites attacking larvae and puparia of *Erioischia* proved to be of importance in the natural control of the latter. The most important parasites reared from the host puparia were:

1. *Aleochara bilineata* GYLL. and *A. bipustulata* L., parasites of the pupa.
2. *Cothonaspis rapae* WESTW., parasite of the larva.

These major parasites gave a total pupal mortality of 5.5–38%.

## VII. MAGGOT DENSITY AND HOST PLANT DAMAGE

From the literature reviewed, it appears that the damage caused by the cabbage root fly in the crucifer growing areas in the Netherlands is considerable, between 10 and 80%. The factors influencing the extent of damage were investigated.

Maggot density, when studied in relation to plant loss (table 17), proved not to be the only factor which affects damage. The "plant condition" factor also plays a role by determining susceptibility of the plant to maggot attack.

Weather factors influence both the maggot population (increase in egg laying capacity of the female flies at low temperature, and decrease of activity in rainy weather) and the plant condition (promoting the recovery of the plant in rainy weather).

Practical experience showed that damage in spring is generally greater than in summer. The factors affecting this phenomenon were studied and may be summarized as follows:

1. Greater longevity and fertility of the female flies of the over-wintering generation.
2. The increase in number of parasites in the course of the season.
3. Unfavourable weather conditions for eggs and newly-hatched larvae during summer as compared with spring.
4. Low spring temperature reducing the recovery power of the plants.

VIII. EFFECT OF CHEMICALS ON THE ABUNDANCE OF ERIOISCHIA AND ITS PREDATORS

Following a discussion on the natural mortality, the possibilities of biological control are examined. Although natural enemies can be of importance in natural control, they are not capable of preventing economic crop losses. Therefore, chemical treatment of the remaining population of the pest is indespensible.

The important chemical control methods are reviewed and the most promising insecticides *aldrin* and *chlordane* discussed.

The biology of the most closely associated natural enemies of *Erioischia, Aleochara* and *Cothonaspis* is summarized.

The correlation between the number of maggots and *Aleochara* was studied in weakly intervals in untreated fields during the growing seasons of two years (1958 and 1959). No significant correlation was found (table 18). Strikingly, *Aleocharas* are found exclusively near infested plants.

The effects of aldrin and chlordane, when applied at the normal rates by the spoon method to the base of the plants, directly or about two weeks before transplanting, on the maggots and on the settled predators (*Aleochara*) on the one hand (table 19, 20 and 21), and on errant predators on the other hand (table 22), were compared. Aldrin and chlordane gave a sufficient control of the maggots and no significant differences could be found between their effects.

As regards their influence on *Aleochara*, this beetle was found to be absent in treated plots. This may be due, however, to the absence of *Erioischia* in these plots.

The errant predators were found in untreated fields in much greater numbers of species and specimens than in treated fields (table 22). This might be due to a direct effect of the treatment, but is more probably due to a reduction of the maggot population upon which the predators live.

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## SAMENVATTING

### I. Inleiding

Gedurende het groeiseizoen van vijf achtereenvolgende jaren 1955–1959, werd onder veldomstandigheden het verloop van de populatiedichtheid van de koolvlieg *Erioischia brassicae* Bouché, die in Nederland Cruciferen aantast, bestudeerd.

De factoren die de talrijkheid beïnvloeden werden experimenteel onderzocht.

Voorts werd het verband nagegaan tussen het aantal maden en de schade, toegebracht aan de waardplant (bloemkool).

De schade was in 't algemeen het sterkst in het voorjaar.

Ook werd de invloed van het klimaat bestudeerd met betrekking tot het insect en de waardplanten.

Waar verondersteld werd, dat de chemische middelen de meest ingrijpende mortaliteitsfactor zijn, werd de invloed van 2,5% Aldrin en 10% Chloordaan stuifpoeders op *Erioischia* populaties en de talrijkheid van zijn natuurlijke vijanden bestudeerd.

### II. Algemene opmerkingen over de koolvlieg en de door haar veroorzaakte schade

De geografische verspreiding van de koolvlieg is beperkt tot de gematigde zone van het holarctische gebied (35–60° N.Br.). In de verschillende landen varieert het aantal generaties per jaar van 1–5.

Een samenvatting werd gegeven van het gedrag van de actieve stadia en van de onder- en bovengrondse schadesymptomen aan de plant.

### III. Materiaal en methoden

A. *Materiaal*

Planten van de bloemkoolrassen Lecerf en Alpha werden gebruikt als proefgewas. Alle cultuurmaatregelen werden genomen, zoals dat in de praktijk plaatselijk gebruikelijk is. De grond van het proefveld bestond uit zwart-bruin grintzand. Het humusgehalte was laag (3–4%), de grondwaterstand diep (± 20 m) en de pH (KCL) 4,7–5,0.

B. *Opzet van de proeven*

Verscheidene elkaar in groei opvolgende velden, waarvan de ontwikkeling samenviel met het optreden van koolvlieg-generaties, werden voor het onderzoek gebruikt. Ieder perceel werd in 9 veldjes van 60 planten verdeeld. De veldjes waren gescheiden door rijen tuinbonen (*Vicia faba*) (fig. 1).

C. *Het tellen*

Een monstermethode werd toegepast om de populatiedichtheid van *Erioischia* op het hele veld te bepalen. De talrijkheid van alle stadia werd omgerekend op 50 planten.

Voor het tellen van de diverse stadia werden de volgende methoden toegepast:

1. voor de eieren, de spoelmethode (Plaat IIa, b).
2. voor de larven en poppen, de kokermethode (fig. 3, 4 en Plaat III a, b).
3. voor de imago's, de vangkooien (fig. 5a, b).

Van elk dezer methoden wordt een beschrijving gegeven. Aangetoond werd dat de telfouten, die bij deze methoden werden gemaakt, te verwaarlozen zijn.

## IV. Verspreiding van de Erioischia populaties

Een samenvattende beschrijving werd gegeven van de typen van insectenverspreiding naar hun biologische betekenis. Bij *Erioischia* controleerden we onze methode van monstername door bestudering van de verspreiding der eieren, die per plant werden gelegd. Daartoe werden planten uit het midden en uit de randrijen met elkaar vergeleken; eveneens werden oostelijk en westelijk en noordelijk en zuidelijk gelegen veldjes met elkaar vergeleken (fig. 1 en tabel 1). Er werden geen significante verschillen gevonden. De preferentie voor bepaalde typen planten wordt behandeld in hoofdstuk VI.

## V. Populatieverloop van diverse stadia gedurende het seizoen

Voor het bepalen van de sterfte in de verschillende stadia van *Erioischia* onder natuurlijke omstandigheden is de doeltreffendste methode het nemen van monsters uit de populatie op opeenvolgende tijdstippen en te berekenen hoeveel individuen van een bepaald stadium uit een voorgaand stadium zijn voortgekomen.

Uit de verkregen resultaten, welke in fig. 6–10 en tabel 2, 4 zijn samengevat, valt af te leiden dat een zeer hoge natuurlijke sterfte voorkomt in de eerste stadia (jeugdsterfte). Tot aan het popstadium bedroeg het aantal overlevenden 8–10% van het totale aantal eieren, dat verzameld was. Het was merkwaardig, dat dit percentage gedurende de 5 klimatologisch zo verschillende jaren (1955–1959) min of meer constant bleef.

## VI. Factoren die de populatiedichtheid beïnvloeden

### A. *Toestand van de imago* (fig. 11a, b, c en tabel 6)

Het effect van de temperatuur op de ovipositie en de levensduur van de vliegen uit verschillende generaties werd bestudeerd onder tendele gecontroleerde omstandigheden. De methode die daarbij werd toegepast, werd beschreven. Bij dezelfde temperatuur hebben de vrouwelijke dieren van de overwinterende generatie een grotere fertiliteit en langere levensduur. Bij hogere temperaturen (24 °C) is de levensduur binnen eenzelfde generatie korter. In de meeste gevallen leven de vrouwelijke dieren langer dan de mannelijke.

### B. *Ovipositie*

De factoren die van invloed zijn op de eiafzetting, waarvan de talrijkheid van de andere stadia afhangt, waren:

*a.* Grootte van de plant (fig. 12a, b, c en tabel 7 en 8).
Er is een positieve correlatie tussen de diameter van de plant en het aantal afgezette eieren. De correlatie-coëfficient is hoger wanneer de berekeningen alleen zijn gebaseerd op de planten met weinig eieren. Er werd geen positieve correlatie gevonden tussen de hoogte der planten en het aantal eieren.

*b.* Ouderdom van de plant (tabel 9).
Er werden geen significante verschillen gevonden tussen het gemiddelde aantal eieren dat werd afgezet bij jonge en bij oude planten, ofschoon bij dezelfde leeftijd aan grote planten de voorkeur werd gegeven boven kleine bij het afzetten van eieren.

*c.* Seizoen (fig. 14–18)
Het aantal eieren dat per 50 planten om de andere dag werd afgezet, werd vergeleken met de dagelijkse temperatuur en neerslag tijdens het groeiseizoen in

5 verschillende jaren. Betrekkelijk koud weer bevordert de ovipositie doordat de fertiliteit en de levensduur van het insect toeneemt. Droog en zonnig weer begunstigt eveneens de ovipositie doordat dan de activiteit van de veld-populatie toeneemt. Eiafzetting wordt verminderd door regen.

C. *Ei-fertiliteit* (tabel 10)

Laboratoriumproeven toonden in 1959 aan dat het verschil tussen het gemiddelde percentage levensvatbare eieren in de eerste generatie en in de tweede niet betrouwbaar is. Evenwel kan wegens het variërend percentage fertiele eieren, de eifertiliteit als factor van wisselende betekenis het populatieverloop van de generaties gedurende het seizoen beïnvloeden.

D–F. *Ei- en larvesterfte* (tabel 11, 12, 13, 14, 15 en fig. 19)

In de twee jaren onderzoek (1958 en 1959) was alleen de talrijkheid van de eerste generatie in 1959 hoog genoeg voor ons doel. De totale sterfte tot aan het larve- en popstadium werd te velde bestudeerd, met en zonder natuurlijke vijanden. Gevonden werd dat de natuurlijke vijanden naar schatting omstreeks 17% jeugd-sterfte bewerkstelligen. *Aleochara bilineata* GYLL. bleek als predator van weinig betekenis te zijn.

Om vast te stellen in welk stadium het hoogste percentage sterfte voorkomt, werd ieder stadium afzonderlijk bestudeerd in kooien in het veld. De daarbij gebruikte methoden werden beschreven. Het hoogste percentage sterfte werd gevonden bij de larven van het eerste stadium (± 79%), terwijl de mortaliteit in het ei-stadium laag was (± 7%).

De doeltreffendheid waarmee de waardplant werd gevonden door de juist uitgekomen larven werd onderzocht met betrekking tot de afstand, waarop de eieren werden afgezet (fig. 19). Binnen een normale afstand van 0–3 cm had de afstand geen significante invloed op de sterfte van de pas uitgekomen larven.

De vestiging van de larven op de voedselplant brengt een geschatte mortaliteit van ongeveer 63% gedurende het eerste stadium met zich mee (tabel 14). Dit wordt ten zeerste beïnvloed door de toestand van de planten (oud, jong, teer, sterk).

G. *Parasitisme* (tabel 16)

De parasieten die larven en poppen van *Erioischia* aantasten bleken van belang te zijn bij de biologische bestrijding. De belangrijkste parasieten die voortkwamen uit de poppen waren:

1. *Aleochara bilineata* GYLL. en *A. bipustulata* L., parasieten van de pop.
2. *Cothonaspis rapae* WESTW., parasieten van de larve.

Deze belangrijke parasieten veroorzaakten samen een parasiteringspercentage van 5.5–38% van het aantal pupariën.

## VII. AANTAL MADEN EN SCHADE AAN DE WAARDPLANT

In de literatuur werd gevonden dat de schade veroorzaakt door de koolvlieg in de gebieden waar kool wordt geteeld aanzienlijk is. Deze schade bedraagt tussen 10 en 80%. De factoren die de omvang van deze schade bepalen werden onderzocht.

De grootte van de madenpopulatie, bezien ten opzichte van de schade aan de plant (tabel 17), bleek niet de enige factor te zijn die deze schade beïnvloedt. De toestand waarin de plant verkeert speelt ook een rol doordat deze de gevoeligheid van de plant voor een aantasting bepaalt.

Het weer beïnvloedt zowel de omvang der madenpopulatie (toename van de leg-capaciteit van de vrouwelijke dieren bij lage temperatuur en afname van de activiteit bij regenachtig weer) en de gevoeligheid van de plant (het herstelvermogen van de plant verbetert bij regenachtig weer).

De ervaring was dat de schade in 't voorjaar in het algemeen groter is dan in de zomer. De factoren die hierop van invloed zijn werden bestudeerd en kunnen als volgt worden samengevat:

1. Langere levensduur en grotere vruchtbaarheid van de vrouwelijke dieren uit de overwinterende generatie.
2. Toeneming van het aantal parasieten in de loop van het seizoen.
3. Ongunstig weer voor de eieren en pas uitgekomen larven in de zomer ten opzichte van het voorjaar.
4. Lagere temperatuur in het voorjaar, die het herstelvermogen van de plant vermindert.

## VIII. Het effect van chemische middelen op de talrijkheid van Erioischia en zijn predatoren

In aansluiting op een discussie over de natuurlijke sterfte werden de mogelijkheden voor een biologische bestrijding onderzocht. Ofschoon natuurlijke vijanden van belang kunnen zijn bij de natuurlijke regulatie zijn ze niet in staat economische verliezen te voorkomen. Daarom is de bestrijding met chemische middelen noodzakelijk.

Een overzicht wordt gegeven van de belangrijkste chemische bestrijdingsmiddelen en de meest belovende insecticiden Aldrin en Chloordaan worden besproken.

Een kort overzicht wordt gegeven van de levenswijze van de belangrijkste vijanden van *Erioischia, Aleochara* en *Cothonaspis*.

Het verband tussen het aantal maden en *Aleochara* werd in het groeiseizoen van twee jaren (1955 en 1959) in onbehandelde velden wekelijks onderzocht. Er werd geen significant verband gevonden (tabel 18). Het was opvallend dat *Aleochara* uitsluitend nabij aangetaste planten werd gevonden.

De invloed van Aldrin en Chloordaan, bij toepassing van normale hoeveelheden met een lepel aan de plantvoet, terstond na het overplanten of ongeveer twee weken later op de gevestigde predatoren (*Aleochara*) (tabel 19, 20 en 21) enerzijds en op toevallige predatoren (tabel 22) anderzijds, werd vergeleken.

Beide middelen gaven voldoende resultaat; er kon echter geen betrouwbaar verschil worden gevonden tussen de werking van de beide middelen als ze onderling werden vergeleken.

*Aleochara* werd in behandelde velden niet gevonden. Dit kan natuurlijk ook het gevolg zijn van de afwezigheid van *Erioischia* in deze velden.

De toevallige predatoren werden in onbehandelde velden in veel groter aantallen soorten en exemplaren gevonden dan in behandelde velden (tabel 22). Dit is mogelijk een gevolg van directe behandeling, maar zeer waarschijnlijk evenzeer van een achteruitgang van de madenpopulatie waarop de predatoren leven.

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PLATE I

(a)


(b)

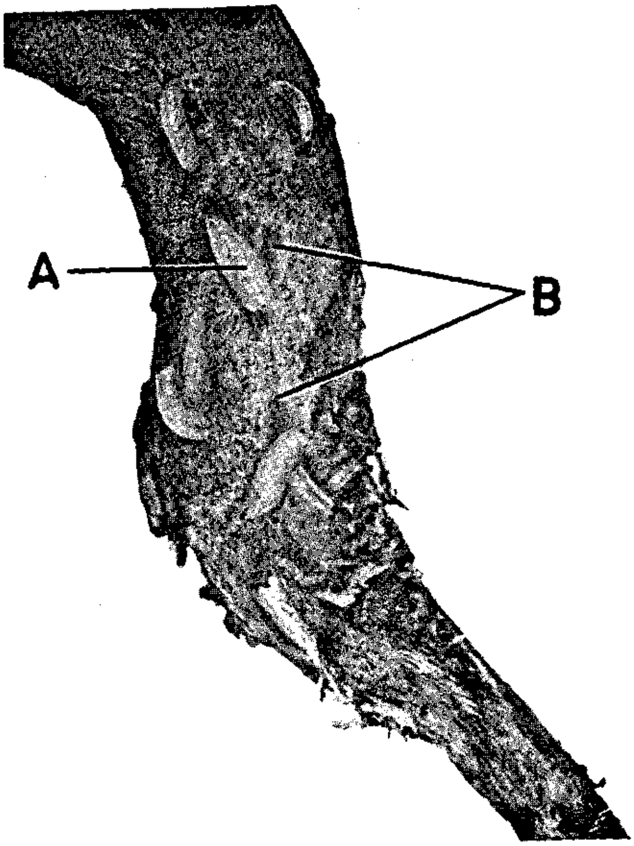


PLATE I (a) Cauliflower plants in the beginning of flowerformation showing various symptoms of attack. (A) healthy plant, (B) plant stunted and beginning to wilt, and (C) Total loss.
(b) Third instar larvae of *Erioschia brassicae* BOUCHÉ in decaying root system of heavily attacked plant. A. Larvae, B. Tunnels.

PLATE II

(a)

(b)

PLATE II (a) Collecting of eggs in the field.
(b) Counting of eggs in the laboratory.

PLATE III

(a)

(b)

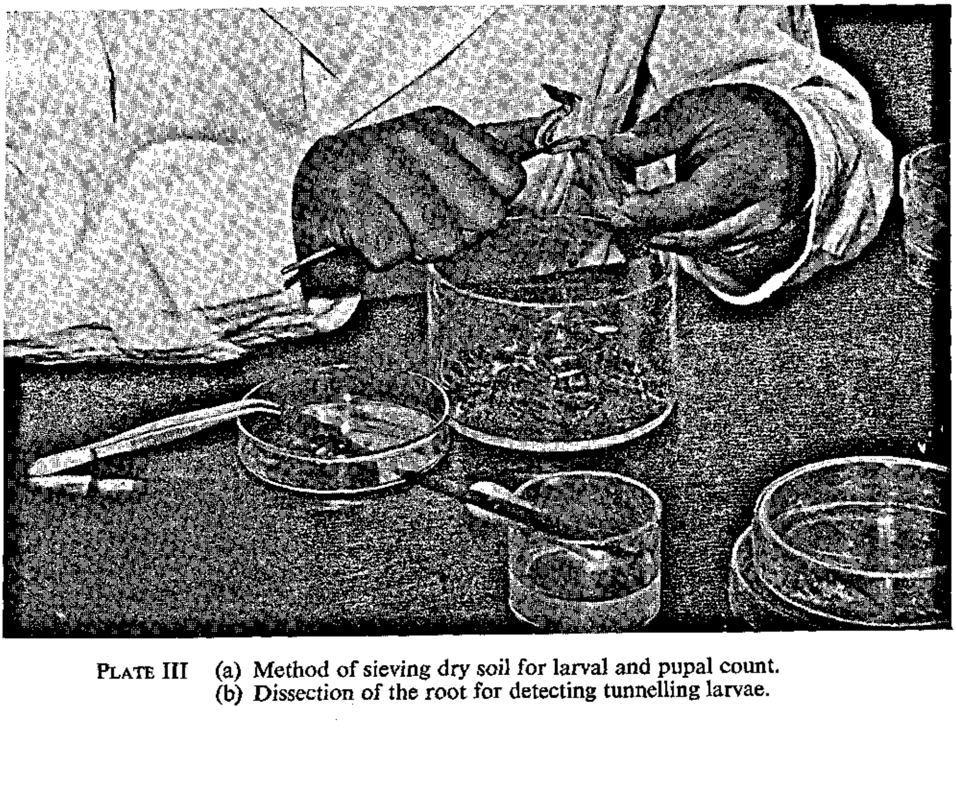

PLATE III (a) Method of sieving dry soil for larval and pupal count.
(b) Dissection of the root for detecting tunnelling larvae.