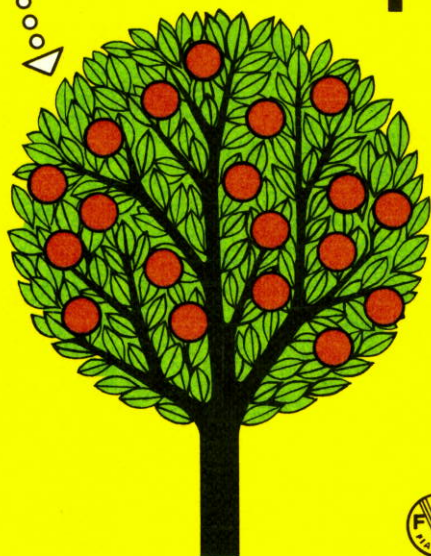


The Sterile-Insect Technique and its Field Applications



PROCEEDINGS OF A PANEL
VIENNA, 13-17 NOVEMBER 1972
ORGANIZED BY THE
JOINT FAO/IAEA DIVISION OF ATOMIC ENERGY
IN FOOD AND AGRICULTURE



INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1974

THE STERILE-INSECT TECHNIQUE
AND ITS FIELD APPLICATIONS

PANEL PROCEEDINGS SERIES

THE STERILE-INSECT TECHNIQUE AND ITS FIELD APPLICATIONS

PROCEEDINGS OF A PANEL ON THE
PRACTICAL USE OF THE STERILE-MALE
TECHNIQUE FOR INSECT CONTROL
ORGANIZED BY THE
JOINT FAO/IAEA DIVISION OF ATOMIC ENERGY
IN FOOD AND AGRICULTURE
AND HELD IN VIENNA, 13-17 NOVEMBER 1972

INTERNATIONAL ATOMIC ENERGY AGENCY
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AND ITS FIELD APPLICATIONS
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FOREWORD

The sterile-insect technique (SIT) is a biological method of insect control that is species-specific, non-polluting and does not destroy beneficial insects. During the past few years SIT has been demonstrated to be effective against a large number of noxious insect species, which continue to compete very successfully with man for the limited food available in the world. Total reliance on insecticides to achieve economical insect control is gradually becoming a practice of the past, and it is anticipated that SIT, in certain instances, will take their place. SIT can be used, under appropriate conditions, to eradicate insects, to control insects and to prevent infestation of non-infested areas from adjacent infested areas (quarantine applications). The technique can be integrated with other methods of insect control, including the limited use of insecticides, parasites, predators, pathogens, cultural practices and resistant varieties of plants.

The control of noxious insects by SIT, once the achievement of technologically advanced countries only, has in the last few years found applications in several developing countries. The approach used in any field program, whether in a developing or a developed country, varies not only with the insect pest concerned, but also with the practical realities within the given country; it reflects not only the professional ability of the entomologists, but very often also their ingenuity.

The present panel, which met in Vienna from 13 to 17 November 1972, dealt with SIT in its entirety. This is the last in a series of such meetings sponsored by FAO/IAEA. Subsequent meetings will be on specialized topics within SIT.

The book is the latest in a series of IAEA publications on the subject. The most recent titles are:

- Panel Proceedings Series: "Control of Livestock Insect Pests by the Sterile-Male Technique" (1968)
- Panel Proceedings Series: "Radiation, Radioisotopes and Rearing Methods in the Control of Insect Pests" (1968)
- Panel Proceedings Series: "Sterile-Male Technique for Eradication or Control of Harmful Insects" (1969)
- Panel Proceedings Series: "Insect Ecology and the Sterile-Male Technique" (1969)
- Panel Proceedings Series: "Sterile-Male Technique for Control of Fruit Flies" (1970)
- Panel Proceedings Series: "Application of Induced Sterility for Control of Lepidopterous Populations" (1971)
- Proceedings Series: "Sterility Principle for Insect Control or Eradication" (1971)
- Panel Proceedings Series: "Computer Models and Application of the Sterile-Male Technique" (1973)

Careful reading of the papers and recommendations published in this present book will be very useful in guiding researchers and administrators in their programs of developing SIT, and in stimulating additional research by entomologists not yet involved in this rapidly advancing method of insect control.

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STATUS OF THE STERILE-INSECT RELEASE METHOD AGAINST THE CHERRY FRUIT FLY (Rhagoletis cerasi L.) IN NORTHWEST SWITZERLAND

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Abstract

STATUS OF THE STERILE-INSECT RELEASE METHOD AGAINST THE CHERRY FRUIT FLY (Rhagoletis cerasi L.)
IN NORTHWEST SWITZERLAND.

After a preparatory phase of 3 years, which provided the necessary background information concerning the distribution and dispersal characteristics of the pest in a 50-ha experimental orchard, a first release program with sterile cherry fruit flies was carried out in 1972. The objective of this release of about 150 000 flies was the study of the logistics and the development of the necessary techniques of marking, handling, releasing and monitoring the flies. The flies were irradiated in the adult stage with 10 krad, marked topically and orally (fluorescent colour and rare earths) and released twice a week for 5 weeks. Extraordinary meteorological conditions and an extremely low cherry crop introduced unexpected problems but increased our experience for future operations.

INTRODUCTION

In 1969 a suitable and completely isolated cherry orchard, covering about 50 ha and containing about 1200 cherry trees, was selected in Northwest Switzerland and prepared for a first release experiment scheduled for summer 1972. Based on the relative density maps of the pest established in 1969, 1970 and 1971 as well as on dispersal studies carried out with marked flies in the same area, a combination of a grid and a strategic release pattern appeared to be the optimum release method [1].

It was decided that field-collected fly material should be used for a series of releases carried out over a period of at least 3 years in order to study the feasibility of the sterile-insect release method against Rhagoletis cerasi in Central Europe [2]. The field experiment described here was considered as first test among a series of similar experiments to be carried out by the members of the OILB working group on genetic control of the cherry fruit fly in their respective countries.

INSECT SUPPLY, STERILIZATION AND MARKING TECHNIQUES

In 1970 a cherry fruit fly collection centre was established in Eastern Austria as a joint project of the Austrian and Swiss fruit fly laboratories in order to have a regular supply of up to 1 million pupae per year, to be used in the planned Swiss and Austrian experiments. A preliminary analysis of a population genetic study of R. cerasi still in progress revealed that the

Austrian and Swiss cherry fruit flies belong to the same geographical race and hence are genetically compatible with each other [3]. Infested cherries were spread on hardware-screening over vermiculite, which provided a cheap and reliable pupation medium for the mature larvae leaving the fruits. The diapausing pupae were stored under optimum conditions and incubated in weekly batches of 40 000 pupae starting in early May 1972. Emerged flies were held at 12-lux light intensity (i.e. high enough for allowing normal feeding activity but too low for mating) on a carbohydrate diet and a 0.1% samarium-chloride solution for later identification by the neutron-activation technique [4]. After mating-frequency tests had shown that the vigour of sterile flies increased with increasing age at the time of irradiation the flies were transferred twice a week to 2°C at the age of 4-6 days, marked a second time by topical application of a fluorescent spray [4], packed into small glass vials with plastic snap-cover in batches of 200 flies, irradiated with 10 krad \pm 10% and transported in a cooler-box to the release site.

RELEASE OF STERILE FLIES

The experimental area, as described earlier [1], was divided into a 30-ha release zone that had shown a chronically low population level and a 20-ha zone that was protected by a mass application of visual traps [5]. In 1971 the wild population in the area had been suppressed by operating 2000 throw-away traps, which had reduced the infestation to marginal levels.

Eighty-eight release stations (one for every 6-7 trees) were operated for five weeks and received twice a week between 200 and 600 sterile flies per station. A total of 150 000 flies were released between 30 May and 27 June 1972. Twenty visual traps operated in both zones were checked twice a week and the ratio between sterile to wild flies was calculated. Although the adjustments of the techniques involved were the prime objective of the experiment, an attempt was made to maintain a ratio of at least 20:1 (sterile : wild flies) as close as possible to harvest time.

EVENTS IN THE FIELD

Three factors influenced the course of events in the field in an unexpected manner: the meteorological conditions shortly before harvest; the extremely low cherry crop (due to a late frost that destroyed up to 90% of the blossoms); and, as a consequence of that, an unexpected change in the dispersal behaviour of the pest.

On the basis of our forecasting system [6] it was calculated that the first flies would appear on 5 June and peak cherry harvest would occur on 10 July 1972. The first forecast was correct as we caught the first flies on 7 June. However, at the end of June, when the cherries were in the optimum stage for oviposition, the temperature dropped for a considerable period of time. This delayed the harvest by 8 days — an occurrence that had not been recorded in the previous 10 years. This long period of favourable conditions for oviposition was overshadowed by a sudden immigration of wild flies from the hotspots of the adjacent trapping zone. Whereas the flies restrict their activities to the closest neighbouring trees under normal crop conditions and therefore do create rather localized hotspots that do not

expand in time, the scarcity of fruits in 1972 changed this usual dispersal behaviour and forced the flies to drastically increase their cruising range in their search for suitable hosts.

Thus the ratio dropped below the 20:1 mark on 23 June and reached very low levels soon afterwards.

At harvest time samples of 50 cherries were examined from 56 and 28 trees of the release zone and trap zone respectively. An average of 14.3% infestation was recorded in the release zone and 16.5% in the trapping zone, which compared quite favourably with about 60-80% infestation in similar areas that had not been treated with insecticides.

CONCLUSIONS

The first release experiment carried out in 1972 showed that the methods developed in the laboratory were practicable in the field and required only minor modifications. Although adverse environmental conditions caused a certain degree of infested fruit, it became apparent that the released flies performed well in the field and that the efforts spent on the development of marking, handling and sterilization methods geared to high-quality flies were justified.

It was evident that the preparatory ecological studies concerning distribution and dispersal patterns were important in the planning phase of the experiment. However, future releases must be based on more flexible schedules in order to cope with unexpected developments of the target population, both in time and space. This is especially true in situations where low host densities change the usual behavioural patterns of the pest populations.

ACKNOWLEDGEMENTS

Warm thanks are extended to Dr. K. Russ, Vienna, for his co-operation and enthusiasm in the establishment and operation of our 'cherry fruit fly factory' in Austria. The contributions of Messrs. B. Katsoyannopoulos, U. Remund and J. Zehnder, which made the experiment possible, are gratefully acknowledged.

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STATUS OF MEDITERRANEAN FRUIT FLY CONTROL BY THE STERILE-MALE TECHNIQUE ON THE ISLAND OF PROCIDA*

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Abstract

STATUS OF MEDITERRANEAN FRUIT FLY CONTROL BY THE STERILE-MALE TECHNIQUE ON THE ISLAND OF PROCIDA.

A further control experiment conducted on the Island of Procida, based principally on the application of the sterile-insect technique, clearly demonstrated that Ceratitis could be eradicated, even in its most favourable environment. Data on the control of fruit infestation, the fertility of the eggs, and the trappings, showed that the very low infestation on the island from August 1972 onwards was solely due to the immigration of already fertilized wild adult flies.

INTRODUCTION

The application of the auto-elimination technique against Ceratitis capitata Wied. began in Italy in 1967 in the Parthenopean Islands with experiments carried out by CNEN in collaboration with the Italian Ministry of Agriculture and Forestry, the IAEA and Euratom. The purpose of the first year of testing was to ascertain whether the sterile-insect technique could be applied practically against this tryptid [1]. In the following years experiments with this technique were carried out methodically, based on the ecological data obtained at the experimental site [2]. However, this latest experiment, which took place on the island of Procida, was not completely positive because the number of sterile insects released was less than foreseen and experimentation had to be interrupted during the month of August. CNEN briefly suspended the control testing. During this time Casaccia brought its large insectary for the mass breeding of the medfly into operation [3] and set up a technique of insect irradiation [4]. In 1971 CNEN initiated again on the Island of Procida a new 4-year control program in collaboration with the Italian Ministry of Agriculture and Forestry and Euratom. The last two years of this program will be dedicated exclusively to ecological studies.

The final objectives of this experiment, which will become part of a vaster program for future research studies, are mainly the following:

- (1) To prove that the sterile-insect technique can be applied in an environment as Procida that is highly favourable to the species, and could be feasibly integrated with other control methods;
- (2) To evaluate in the experimental area the real cost of medfly control based principally on the sterile-insect technique;

* Contribution No. 371 from Laboratorio Applicazioni in Agricoltura del CNEN, Centro Studi Nucleari della Casaccia, S. Maria di Galeria, Rome, Italy.

- (3) To learn more ecological information on Ceratitis in order to improve the technico-scientific aspects involved in the application of the self-eliminating technique - even in the eventuality of expanding this technique to larger areas;
- (4) To stimulate the farmers to control the Ceratitis by forming co-operative groups or committees.

GENERAL INFORMATION

(a) The target species

In the Island of Procida and the surrounding areas Ceratitis is the most harmful insect to the cultivation of fruit and citrus fruits. Apart from being abundantly prevalent in the Gulf of Naples where it is able to accomplish 7 generations a year, the medfly can increase appreciably from one generation to another and destroy up to 100% of the fruit. At present various insecticides with phosphoric ester bases are used in controlling the insect between the months of June and November. These do not, however, eliminate the enormous losses, which for the Island of Procida alone amount up to 60 million lire per year.

(b) The experimental area and the control sites

The island of Procida, which has an area of 3.7 km² and is 2.7 km from the mainland, and the control areas of Mount Procida, Capri and Ischia (Fig.1) present a very favourable habitat for the medfly; the winters are relatively mild and short with a mean temperature of 8°C in the coldest month, and an annual mean temperature of 15 to 17°C. The seasonal rainfall, which is of the autumn-spring type, usually does not exceed 800 mm annually. There is a constant and high degree of atmospheric humidity and an abundance of plant hosts from January to December.

In particular, the Island of Procida and Mount Procida are characterized by family-type agriculture, where fruit and citrus trees are planted together in small plots of land, or sparsely planted among the grapevines.

(c) Prerelease phase

From the ecological data obtained on the Island of Procida in previous years [5-7] it was ascertained that during the autumn-winter period the medfly, besides passing its pupal stage in the soil and its adult stage in this environment, could pass its larval and pupal stage in the fruit of the sour orange tree, which is a troublesome hotspot of infestation. Therefore, to begin the program under the best possible conditions, the following steps were taken 5 to 6 months prior to the distribution of the sterile adult insects:

- (1) Massive and continuous capturing of the male Ceratitis population by means of 5000 'stick' traps using Trimedlure. These were placed throughout the entire island to avoid fertile mating and the subsequent over-wintering of the gravid female (quantitatively very difficult to estimate).
- (2) Collection and destruction of 90% of sour oranges.

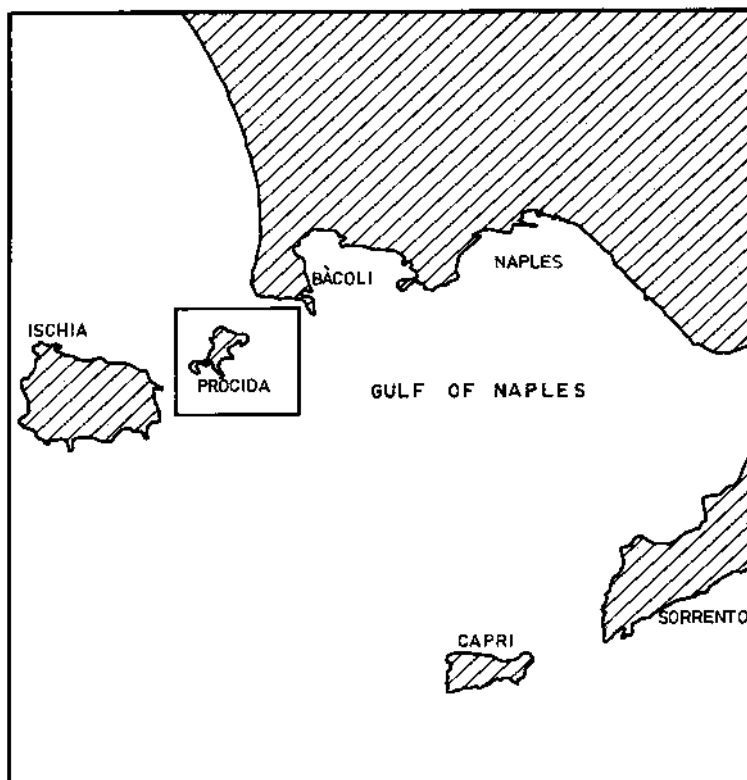


FIG. 1. Experimental area.

(d) Mass rearing and pupal handling

From the early part of 1972 *Ceratitis* breeding in the insectary of Casaccia gradually increased until 4 to 5 million insects were available weekly for the control experiment. The rearing technique was the following: rearing of adult flies in prismatic cloth cages, 125 cm \times 80 cm \times 40 cm, each cage containing 50 000 adults; larval rearing on 'popping' diet; synchronization of the length of the pupal period by means of varying the temperature from 15 to 25°C. Three days before the end of the pupal stage the pupae were first suitably coloured with fluorescent dyes and placed in special paper bags for releasing, in quantities of not more than 10 000 insects per bag. They were kept in air-conditioned cells at 25°C until the time for their irradiation.

(e) Radiation and transport

The paper bags containing emerged adult flies were directly irradiated in the gamma-irradiation plant of Agricultural Applications Laboratory of CNEN's Casaccia Center (Fig.2) [8], the dose varying from 9.2 to

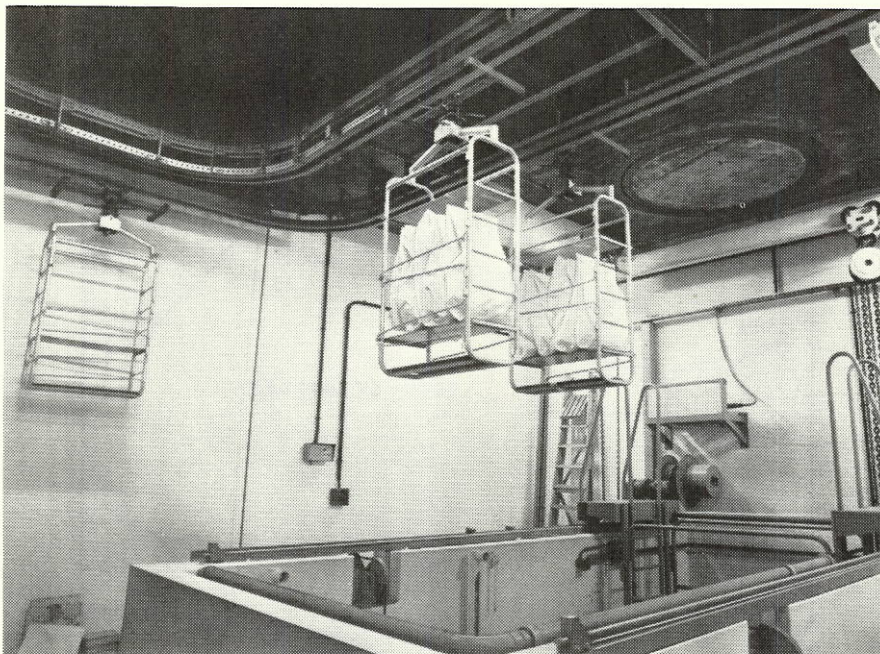


FIG.2. Paper bags containing the emerged adults over the source pool of the gamma-irradiation plant before treatment.

13.0 krad. The insects were transported to Procida by car and ferry. The release of the adult sterile insects was carried out directly by the farmers, who received a certain number of bags in proportion to the extension and importance of their area under fruit cultivation. In areas that were not easily accessible the insects were released by CNEN personnel. Normally there were 2 shipments per week, for a total of approximately 600 bags released; each shipment effecting alternately half of the total surface area of the island (Table I).

(f) Methods of evaluating the effectiveness of the technique

To evaluate the effectiveness of the control method used, the same control techniques were used as in the 1969 experiment at Procida [2]. In each of the 35 sampling areas chosen in the island (Fig.3) the following controls were made weekly; examination of fruit to check for infestation; capturing adult flies with 'Nadel' type traps activated with Trimedlure; and determination of egg hatch taken from insect oviposition on peaches. In the control areas of Mount Procida, Ischia and Capri the same controls were made every 7-15 days with the exception of examining the puncture site, which was done only on Mount Procida.

TABLE I. DATA ON RELEASED AND RECAPTURED MEDFLY ON THE ISLAND OF PROCIDA, 1972

Date of arrival	Weekly shipments	No. of pupae per week (millions)	Percentage of emergence ^a	Adults released (millions)	No. of adult bags	No. of males captured		Ratio Sterile/Wild
						Sterile	Wild	
March 24	1	1,000	91.3	0,981	235			
28	1	1,250	59.5	0,743	250			
April 7	1	1,700	21.7	0,368	350	632	2	316 : 1
11	1	1,500	50.9	0,764	300	2	0	
18-21	2	3,075	75.8	2,330	615	-	-	
26-28	2	3,125	44.9	1,404	625	418	4	104 : 1
May 5	1	1,550	89.2	1,382	310	64	1	64 : 1
9-12	2	3,150	94.1	2,965	630	507	0	
16-19	2	3,400	88.7	3,018	680	403	0	
23-26	2	4,775	37.4	4,173	635	1199	0	
30	1	1,500	82.4	1,236	300	2358	0	
June 6-9	2	5,540	83.8	4,613	615	6762	1	6762 : 1
13-16	2	5,600	70.0	3,923	610	1991	1	1991 : 1
20-23	2	5,600	76.0	4,258	620			
27 and July 1	2	6,200	91.6	5,681	620	2283	0	
4	2	6,100	75.5	4,608	620	3240	0	
11-14	2	4,700	82.9	3,897	597	1007	0	
18-21	2	4,300	74.8	3,345	640	2727	0	
25-28	2	5,200	79.6	4,141	655	1775	0	
August 1-4	2	3,800	66.3	2,522	610	2183	0	
8-11	2	4,400	51.2	2,255	635	1795	0	
17	1	2,700	47.1	1,271	290	306	0	
22-25	2	5,300	47.5	2,520	660	662	0	
29 and Sep. 1	2	4,200	57.1	2,399	660	2452	12	204 : 1
September 6-8	2	3,100	50.7	1,572	620	1823	2	961 : 1
12-15	2	5,400	72.8	3,938	790	1851	0	
19-22	2	6,100	52.9	3,231	800	2985	2	1493 : 1
26-29	2	5,200	48.2	2,509	780	3140	3	1046 : 1
October 3-6	2	3,650	50.1	1,880	620	3070	0	
10-16	2	5,900	60.7	3,582	590	2294	9	254 : 1
18-20	2	5,400	31.2	1,685	686	3359	88	88 : 1
24-28	2	4,100	57.1	2,342	650	650	30	21 : 1
Total	57	128,715	\bar{X} 66.3	85,413	16,398	55,242	105	

^a Taken in the field 72 h after release.

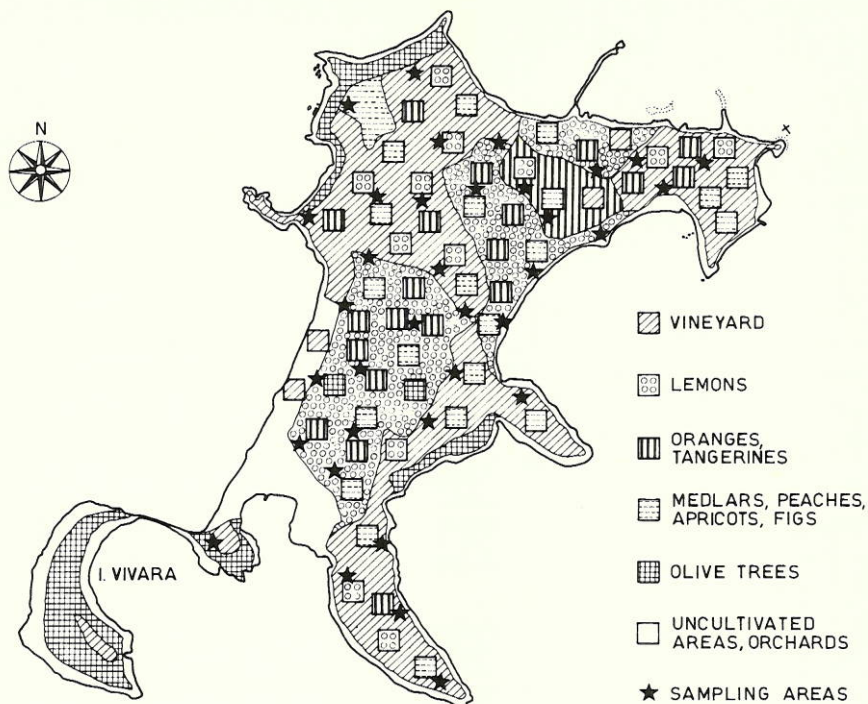


FIG. 3. Map of the distribution of fruit trees on the Island of Procida, together with sampling areas.

RESULTS AND DISCUSSIONS

(a) Fruit infestation

Control of infestation was made on the main plant hosts of the *Ceratitis* present in the various sampling areas. This was done by picking at random an amount of fruit from the trees and placing it in suitable boxes, and by visually examining the fruit hanging on trees and those fallen to the ground. From Table II it can be observed that in the month of March, when the sterile adults were first released, only approximately 4% of the sour oranges were attacked. There was no indication of infestation until the end of August, notwithstanding the fact that thousands of fruit were sampled and that control was extended to zones other than the sampling zone. Vice versa, in the control areas the infestation began in the month of June and continued to spread until practically all the fruit was destroyed by the end of August, in spite of the fact that the farmers had used phosphoric-ester insecticides to limit infestation. Towards the end of August in Procida there was a slight unexpected

infestation of peaches, which could not be subsequently eliminated, notwithstanding the presence of a good number of sterile adults. However, this infestation, which mainly attacked peaches and figs, was slow moving and never reached the disastrous levels observed in the control areas. It has been proven, however, that the Island of Procida has never been completely isolated from the mainland on account of a continuous immigration of wild flies to the island (Fig.4), which previous studies on the movement of the species effectuated in 1968-1969 never clarified [9]. It is likely that this immigration is composed of already fertilized females who would neither be receptive nor mate with the sterile adults present. This immigration begins at the end of August, which coincides with the fruit infestation. The fact that emerged adults from this infested fruit do not behave as laboratory flies in their capacity to deposit eggs in cloth cages could be a confirmation of this theory.

(b) Trapping

In Table I the progress of the trapping that took place at Procida can be observed. 140 traps were exposed weekly for 24 hours in the various sampling areas. Note that wild males of Ceratitis were captured only at the beginning of the experiment and again towards the end of August. These latter captures would coincide with the beginning of the island's August infestation and almost certainly with the initiation of the immigration of the species. Nevertheless, even after the month of August the number of wild flies captured never exceeded more than one fly per day and trap. By contrast, in the control areas the number of flies captured was more than 12 per day and trap (Fig.5).

In the control areas the progress of the trappings was very different, which was probably due to the different environmental conditions in which the species developed. While the population of Ceratitis increased rapidly in Capri, it did so very slowly in Ischia. This phenomenon was observed in the 1968-1969 studies (Cirio, unpublished data). An indirect evaluation of the effectiveness of the control technique was made by comparing the population growth of Ceratitis in Procida during the years 1968, 1969 and 1972 (Fig.6). From the graph we can see that in 1968 the wild adult flies reproduced rapidly from mid-July until mid-August. In 1969 they had reached a great quantity by the month of June, but they remained within the economic injury population level for the entire release period, though they later did reach the same population density as the preceding year.

In 1972 the number of adult flies captured was almost negligible, with an increase only during the month of October, which is directly correlated with the immigration movement of the wild flies. Here, however, from the trappings it seems clear that this number is not so great as to cause enormous hotspots of infestation. From the same figure one can observe the population growth in relation to the density of sterile insects per hectare. In the 1972 experiment it is noted that the high number of insects released at the beginning of the experiment had completely eradicated the local fly population from the month of June until the end of August. In the 1969 experiment, due to the late release and low number of insects released, the population of the island species was not suppressed, even for a short period.

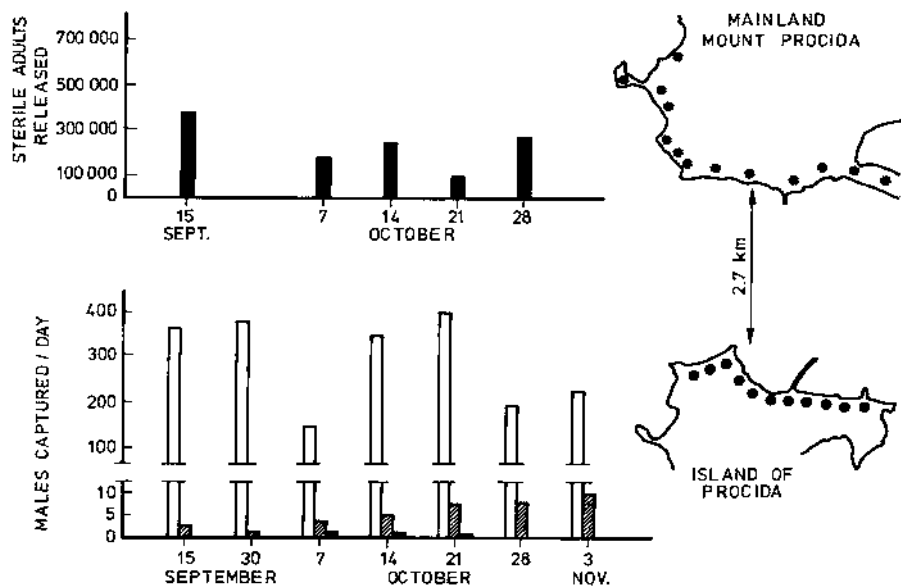


FIG. 4. Number of medfly captured along the north coast of Procida in relation to the number of sterile adults released on Mount Procida. □ Marked flies from Procida; ▨ wild flies; ■ marked flies from Mount Procida; * release points; ● trap position (40 traps controlled daily).

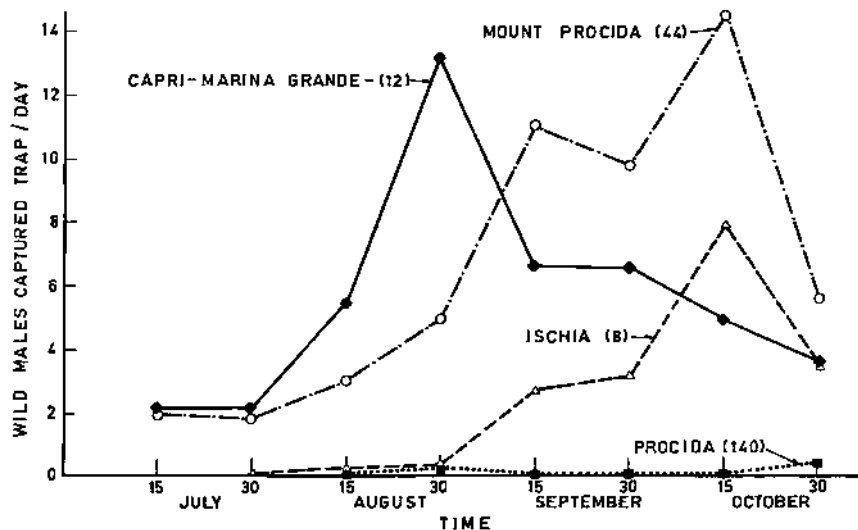


FIG. 5. Number of wild male flies captured on Procida and control areas (1972). Figures in brackets are the number of traps per area. Mount Procida data from Dr. Fimiani, Istituto Entomologia Agraria, Portici, Naples.

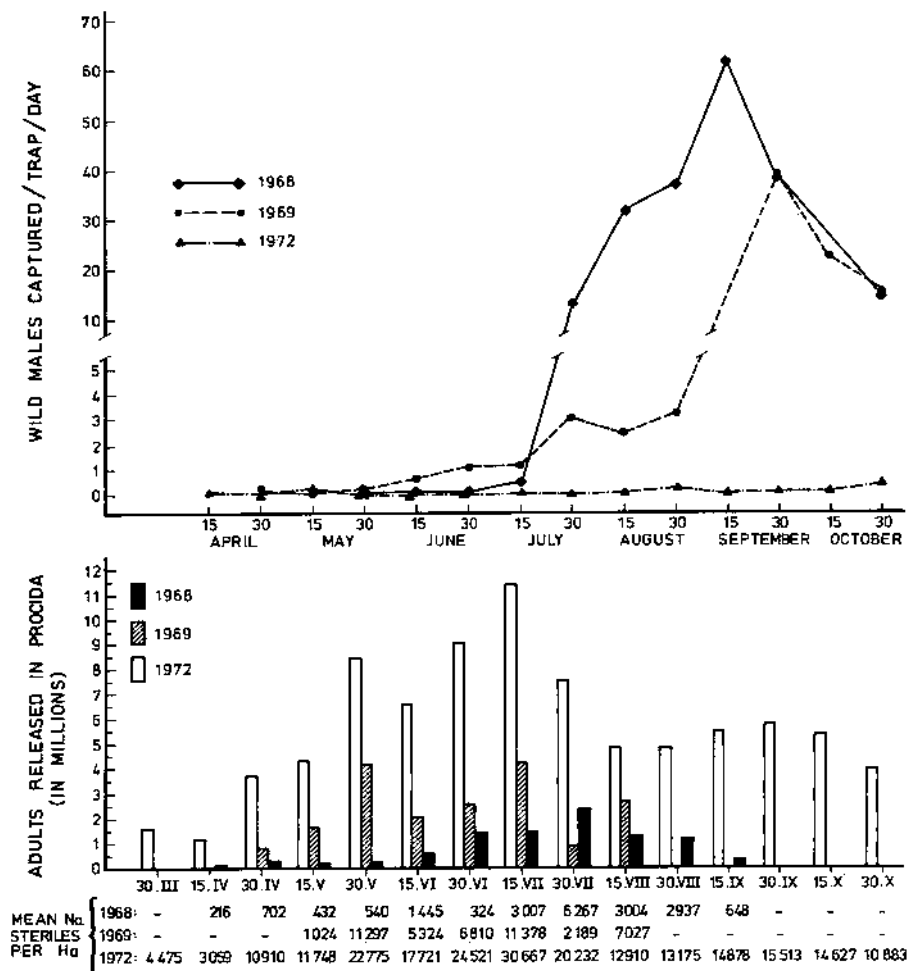


FIG. 6. Relation between number of wild males captured and number of sterile flies released during the experiments in Procida.

It is evident, however, that the trapping system of capturing adult flies is not a suitable method of control. The reasons being the difficulty of recapturing a sufficient number of the adult flies released to enable an accurate estimation of the population, and the different behaviour of the bred and wild flies towards Trimedlure [10].

(c) Examination of the puncture site of oviposition

This control finally demonstrated that on the Island of Procida the infestation present during the month of August and the following months was at a very low level. In fact, checking the puncture sites (Table III)

TABLE III. DATA ON PUNCTURES AND EGG FERTILITY IN PEACHES EXAMINED IN THE RELEASE AND CONTROL AREAS. Punctures selected for study as a non-random sample.

Criteria	Locality				Bacoli ^a
	Procida				
	30/VI	30/VII	30/VIII	30/IX	30/VII
No. of fruit analysed	180	327	402	169	37
Total No. punctures (a+b+c)	117	320	261	220	181
Mean punctures/fruit	0.65	0.98	0.65	1.3	4.9
Punctures without eggs (a)	112	310	246	182	0
Punctures with eggshells (b)	0	0	4	9	137
Punctures with eggs (c)	5	10	11	35	44
Punctures (b+c) (%)	0	0	5.7	20.0	100
Eggs collected	35	119	72	187	168
Eggs hatched (%)	0	0	90.0	15.6	88

^a Data collected by Dr. Fimiani, Istituto Entomologia Agraria, Naples University.

it was found that only 5.7% of the puncture sites in Procida had eggs, in comparison with 100% at Mount Procida. With regard to the egg hatch, collected and placed in Petri dishes, there was no difference between the two areas of control during the month of August. It is possible, therefore, that at Procida the eggs collected were deposited by females that had immigrated and did not mate with sterile adults. In the month of September, while the egg hatch count was high at Mount Procida (data collected by Fimiani on persimmons), in the release area of Procida it was only 15.5%. This difference was probably due to the simultaneous presence of sterile insects, newly emerged insects and insects that had immigrated. The fact remains, however, that the adult sterile insects do have a definite effect on controlling the fertility of adult wild flies.

CONCLUSIONS

The control experiment effectuated this year clearly demonstrated that the sterile-male technique could effectively eradicate *Ceratitis*, even in an environment such as Procida, which is very favourable to the species. In fact, the attack manifested towards the end of August and continued in the following months was due only to the immigration of female insects that had previously mated with male wild flies. Furthermore, to determine the criteria for distribution and to evaluate the possibility of integrating this system with other control methods, the use of the sterile-insect technique has to be based mainly on the characteristics of the working environment. In Procida, for example, the massive trapping of male insects is preferential to the method of setting poisoned bait sprays, which could present hazards to the human population on the island.

With the results obtained in this first year of control we can reach the conclusion that a rational distribution of sterile insects, limited, for example, to only 4 to 5 months with a quantitatively lesser number of flies, could obtain the same results. Finally, the sterile-insect technique, which should be used with great reservation, could and must be considerably simplified in its practical aspects of synchronization of the insect and distribution of adults. The methods for evaluating the effectiveness of the technique must be simplified, as well as obtaining a more efficient collaboration with the farmers.

ACKNOWLEDGEMENTS

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REVIEW OF WORK TO COMBAT THE MEDITERRANEAN FRUIT FLY CARRIED OUT IN CENTRAL AMERICA AND PANAMA

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Abstract

REVIEW OF WORK TO COMBAT THE MEDITERRANEAN FRUIT FLY CARRIED OUT IN CENTRAL AMERICA AND PANAMA.

The work on medfly carried out by the Regional International Organization for Plant Protection and Animal Health (OIRSA), which includes Mexico, the countries of Central America and Panama, is reviewed. Originally, the only OIRSA country infested by medflies was Costa Rica. In that country medflies mass-produced in San José were sterilized and released in the Puntarenas peninsula. Thereafter, large-scale releases were carried out in Nicaragua and Panama. The economics and effects of medfly control by the sterile-male technique are compared with those of other methods of control. Trials with various insecticides carried out in Nicaragua are described.

In April 1955 the Mediterranean fruit fly was discovered in the Republic of Costa Rica and, as a result, a number of expert studies were carried out in the countries of Central America and in Panama at the instigation of OIRSA (whose membership consists of Mexico, the countries of Central America and Panama) to determine the extent to which the Mediterranean fruit fly was present in the OIRSA area. The studies showed that Costa Rica was the only country in the area to be infested.

The presence of medfly in one of the OIRSA countries led to investigations into the habits of the fly, with a view to determining the most effective methods for use in future eradication programs. Supported by the Central American countries, Panama and Mexico, OIRSA started research programs and control campaigns, and as the medfly spread in Costa Rica and towards Nicaragua and Panama this work assumed greater importance and budget allocations for the purpose were steadily increased. Notwithstanding these efforts, the pest had become a real economic danger to hundreds of fruit growers.

Although there was no formal allocation for a study on the sterile-male technique for medfly control, such a project was started in 1962 thanks to the valuable assistance offered by the Department of Nuclear Energy of the Inter-American Institute of Agricultural Sciences and the Costa Rican Ministry of Agriculture and Stockbreeding, and thanks also to the keen support of the staff of the OIRSA laboratory in Costa Rica. A great deal of useful information was obtained from this project.

RELEASE OF STERILE FLIES IN PUNTARENAS, COSTA RICA

After it had been concluded, that the Mediterranean fruit fly could feasibly be controlled by the large-scale release of adults sterilized by gamma rays,

the small peninsula of Puntarenas on the north Pacific coast of Costa Rica was selected for experimental purposes; in the central part of this peninsula there is an area of about 2.5 km² without significant medfly hosts, isolated by the sea to the north, south and west and separated from the mainland by an isthmus 2 km long. After OIRSA had carried out, in the area selected, a series of basic investigations relating both to irradiation and sterile-fly release techniques, with the valuable collaboration of the Inter-American Institute of Agricultural Sciences, the United States Department of Agriculture (USDA), AID and the International Atomic Energy Agency in Vienna, massive releases of sterile flies were effected, for which the Mediterranean Fruit Fly Research Laboratory at San José, Costa Rica, reared more than 2000 000 pupae weekly. The releases carried out in this pilot area in Costa Rica gave quite promising results.

RELEASE OF STERILE FLIES AT CARAZO AND LA CONCEPCIÓN, NICARAGUA

Subsequently, with financial assistance from AID and the IAEA and technical assistance from USDA and IICA, OIRSA carried out further studies with a view to perfecting the various techniques and facilities called for by a large-scale program of this type. This work included the following aspects:

- (a) Preparation of the laboratory
- (b) Training of staff for rearing the fly
- (c) Large-scale rearing of medflies using optimum diet
- (d) Sterilization, determination of the most suitable irradiation dose
- (e) Packaging
- (f) Transport
- (g) Release procedures
- (h) Estimation of the wild fly population in the release area
- (i) Determination of the number of sterile flies to be released and of the release cycle.
- (j) Before starting large-scale releases, it is considered necessary to determine whether the infestation level is suitable or whether it must first be reduced by some other method
- (k) Delimitation of the infested area
- (l) Evaluation of the dispersion of the sterile flies from the release point
- (m) Determination of the sexual competitiveness of the sterile males compared with that of the wild male population.

With the knowledge gained from these studies and with the aid of the organizations mentioned, a start was made with large-scale releases of sterile flies in the region of Carazo and La Concepción in Nicaragua, and of Boquete in Panama. In the course of this work some 50 000 000 sterile flies were released weekly over a period of about 10 months. As a result, the medfly populations were decimated in these areas and no losses of host fruits due to infestation were noted in the field. However, reinfestation occurred in subsequent years, and at the present time an average of about 50% of the production of mandarins (Citrus resnii) is lost.

We at OIRSA, with the courage of our convictions, have continued our work to improve practical sterilization techniques for the control of the Mediterranean fruit fly, though unfortunately not as actively as in previous years because the IAEA and AID have temporarily suspended their technical and financial assistance to OIRSA as from July of this year. This assistance gave highly satisfactory results as regards fruit growing in Central America, Panama and Mexico, and now that the fly is becoming a serious menace to fruit-growing areas in the United States of America we believe that the assistance will be resumed shortly.

I think it is important to mention here that, according to recent estimates, the fruit crops liable to attack and damage by the medfly in Central America and Panama amount to 638 000 tons, valued at US \$53.2 million; of this quantity, 388 000 tons are citrus fruits valued at \$25 million.

It has also been estimated that the following losses are caused directly by the medfly in the infested areas of the OIRSA region:

(a) Mandarin	50% or more
(b) Sweet orange	22% (approx.)
(c) Grapefruit	24% (approx.)
(d) Other fruits	2% (approx.)
(e) Coffee	1% (approx.)

These losses, which have been valued at \$4 million annually, will rise in proportion to any increase in fruit production, i.e. more rapidly than the increase in human population,

In view of the large area infested by medfly in the OIRSA region, any program of eradication will be costly, as can be inferred from the following:

(a) An eradication program using the sterile-fly technique, including the cost of an intensive control program, would involve some \$31 million over a period of six years. Nevertheless, it is considered that the gains accruing from eradication of the medfly in terms of the prevention of fruit loss in the present infested areas would offset the cost of such an eradication campaign by the eighth year. Assuming, moreover, that the medfly would spread to other areas if there were no eradication campaign, the cost of the program could, in fact, be recovered by the sixth year, and thereafter there would be a positive balance of some \$10 million annually.

Experience has been gained in the OIRSA area on the various techniques for handling and mass-rearing the Mediterranean fruit fly in the laboratory, and on the procedures for sterilization, packaging, transport and aerial or ground release of sterile flies. In Costa Rica, Nicaragua and Panama the sterile-fly technique has given excellent results without causing major biological disturbances such as occur with the use of insecticides, which also destroy bees, parasites, birds and other insects, which may be useful to man; with the release of sterile medflies, however, the action is specific and only this species itself is affected;

(b) An eradication program using insecticides plus attractants would involve an approximate cost of \$23.6 million, which is less than the cost of the sterile-fly technique, but other insects would also be affected;

(c) An eradication program using the ULV insecticide method would cost about \$21.8 million, which is much less than the cost of either of the two previously mentioned systems; the effect on other insects, however, would be greater.

Experience has also been gained in the OIRSA region from practical tests, carried out over fairly large areas to assess the efficiency of insecticides for eradicating the medfly, as distinct from their use simply for controlling it.

These tests were carried out at Jinotega and San Rafael del Norte in Matagalpa Department, Nicaragua, over an area of approximately 450 hectares. The following insecticides were employed:

(a) Lebaycid	50%	500 cm ³	in 100 litres of water
(b) Lebaycid	80%	310 cm ³	in 100 litres of water
(c) Malathion	57%	625 cm ³	in 100 litres of water

Appropriate amounts of attractant were added to these insecticides.

The insecticide was applied using motorized pumps and all the medfly host plants present in the area mentioned were treated tree by tree or bush by bush; altogether the insecticide was applied nine times at Jinotega and eight times at San Rafael del Norte, with intervals of about one week between applications. The operation was carried out during April, May and June of this year. The fruit farmers were then advised to collect all fallen fruit, whether affected by medfly or not, and bury it in deep pits.

Trap inspections carried out later showed not a single medfly, although use was made of cardboard traps with a 5% mixture of Stickem and Trimedlure, and McPhail traps (glass) with protein; we can therefore assume that the Medfly has been eradicated from the areas of San Rafael del Norte and Jinotega in Nicaragua.

The possibilities of reinfestation are considerable, and in view of this it has been decided to pay special attention to quarantine control at Tipitapa, 22 km from Managua, Nicaragua; this should greatly reduce the likelihood of medfly being exported. In this connection we have constructed new installations for the application of internal quarantine measures, which will not only make for greater efficiency but will also enable the quarantine inspectors to perform their duties under better conditions.

THE PRACTICAL USE OF THE STERILITY METHOD FOR THE CONTROL OF SOFT TICKS*

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Abstract

THE PRACTICAL USE OF THE STERILITY METHOD FOR THE CONTROL OF SOFT TICKS.

Both male and female soft ticks mate several times. Males irradiated at a dose that induces 99% dominant lethals are fully competitive for 2-3 weeks, after which they become aspermic. Aspermia, due to inhibition of the spermatogenic cycle, occurs also when the irradiation dose is lowered to the level producing only 70% dominant lethals. Thus the irradiated ticks cease to be competitive a few weeks after treatment, even though they survive for several months. Female soft ticks cease to lay eggs after exposure to 3-4 kR. This dose does not reduce their mating capacity.

Flooding a population with abundance of sterile females increases the mating of normal males. Argas persicus males produce more than 50 spermatophores in the presence of 10-fold females, as compared to 12-17 spermatophores produced by males kept at 1:1 male/female ratio. Because of the increased mating activity of the males in the presence of multiple females, the usefulness of sterile females for the control of tick populations is doubtful.

Some years ago the members of our team, who have been working on the control of soft ticks by the sterility method, expressed a very optimistic opinion on the practicability of this approach to soft ticks [1]. Our optimism was based on the fact that irradiated males of the sp. Ornithodoros tholozani competed in the laboratory very effectively with normal males and survived for many months after the irradiation treatment. Since a complete generation of this tick in nature takes 7-12 months, we thought that the release of sterile males once every 6 months into infested caves (which are the habitat of this species) would be enough to control, or even eradicate, this tick.

In preliminary field experiments a cave was flooded with 10-fold sterile males. Examination of population size and structure 4 months after the release of the sterile males indicated no change from the untreated caves (Table I). Furthermore, the population of both treated and control caves contained a larger proportion of tick larvae and nymphs, indicating a lack of effect of the sterile males on the fertility of the natural population.

This observation, together with the fact that treated males survive several months after treatment, led us to test whether the irradiated males maintain their competitiveness for as long as they survive. Most of our work was carried out with males of Argas persicus, but a few comparative observations were repeated also with O. tholozani. These data were recently accepted for publication [2] and will be discussed here only briefly.

Virgin females were flooded with males treated by 12 kR (which produced 99% dominant lethals) at various ratios and kept together for 7 days. The females were then removed and a new group of virgins was introduced. After an additional 7 days the females were replaced with a third group.

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TABLE I. COMPOSITION OF POPULATIONS OF Ornithodoros tholozani TICKS AS AFFECTED BY RELEASE OF STERILE MALES

	Cave I			Cave II			Cave III			Cave IV ^d		
	69-07-09	69-10-16	70-02-17	70-10-22	69-07-09	69-10-16	70-02-17	70-10-22	69-07-09	69-10-16	70-02-17	70-10-22
Adult female	14	3	5	12	6	1	3	2	11	16	10	16
Adult male	14	4	8	4	2	1	4	1	14	21	14	35
3-4th nymph	8	12	8	6	-	1	3	1	34	33	47	20
1-2nd nymph	24	3	22	2	7	1	3	3	40	57	96	40
Larvae			28			1		26			88	18
Estimated population (adults and large nymphs only)	2484			2200	1100			>400	16225			>7100
									1788			1150

Numbers represent ticks collected from 25 litres of soil samples. Total population was calculated by releasing a known number of marked ticks and recapturing some of them.

a 8000 sterile males were introduced into Cave IV on 69-10-29.

TABLE II. COMPETITIVENESS OF Argas Persicus MALES IN SUBSEQUENT MATINGS

Ratio of ♀ : irradiated ♂ : normal ♂	Expected hatching (%)	Percentage of hatching observed		
		1 st round	2 nd round	3 rd round
1 : 0 : 1	100	96	97	97
1 : 1 : 1	50	57.7	87.2	98
1 : 5 : 1	16.7	15.4	91.7	97
1 : 10 : 1	9.1	10.2	67.9	97

TABLE III. EFFECT OF IRRADIATION OF Argas persicus MALES ON SPERMATOPHORE PRODUCTION AND INSEMINATION

Irradiation dose (kR)	Percentage of dominant lethals	Average No. of females inseminated by a single male	Average No. of spermatophores produced by one male
0	0	12.7	17
3	67	4.0	12.9
4	83	4.0	11.6
6	93	3.9	10.8
7.5	97	3.7	5.1
12	99	1.8	3.2

When examining the hatching of the eggs laid by females from the three groups, it was found that, whereas in the first round the irradiated males were fully competitive, the second round showed only a very limited reduction in the fertility of eggs, and in the third round there seemed to be no effect at all (Table II). Over 90% of the females laid fertile eggs in the third round — indicating that the untreated males mated several times.

A careful follow-up of the mating activity of the males revealed that they produce around 2 spermatophores per week during 7 consecutive weeks, and thereafter the rate decreases considerably. On average, each male produces 17 spermatophores throughout its lifespan. Males treated with 12 kR produced only 2.2 spermatophores. Males irradiated with 3 kR (69% dominant lethals) produced 13 spermatophores, whereas intermediate values were found for intermediate doses (Table III). Although the number of spermatophores was dose-dependent, their content was not. At all radiation levels from 7.5 kR and down the number of females that laid eggs after mating with the treated males was around 4. The spermatophores produced afterwards were empty. Thus, although the males were still able to mate, they were aspermic.

The gonads of adult soft tick males contain all types of germ cells starting from spermatogonia up to spermatids [3]. Once all the spermatids are utilized by the irradiated males, no more spermatocytes mature. Examination of the gonads 2-4 months after irradiation showed that the cellular elements in the gonial region disappeared [1].

It seems that in ticks, like in insects, premeiotic stages are much more radiosensitive than the postmeiotic ones.

Since the types of cells present in the testes of soft ticks are the same in all the species studied, it is expected that all species of Argasids will become aspermic after the first few matings and will cease to be competitive, while the natural population will show mating activity over a period of several months.

Since treated males are fully competitive for 2-3 weeks before they become aspermic, one way of keeping the proper ratio between normal males and competitive sterile males is a frequent release of recently sterilized males. This, however, is not a very practical procedure because of the very slow development of the ticks as well as their low dispersion. Since soft ticks are confined to their microhabitat and those that are left a little bit outside usually die within a short time, release of sterile ticks has to be carried out manually by introducing them into the habitat. The frequent visits required for release purposes seem therefore economically prohibitive.

The possibility of producing competitive sterile males by the use of chemosterilants has not been investigated. However, on theoretical grounds, one should not hope for other results than those obtained with irradiation. Differential sensitivity to chemosterilants between spermatids, spermatocytes and spermatogonia was demonstrated in several insects [4].

In view of the limited competitiveness of the males, the possibility of using sterile females for the control of *Argas persicus* was investigated [5].

Mathematical calculations [6] show that when the total number of available matings of the females is higher than that of the males, the rate of extinction of the population increases when the number of sterile females increases. *Argas* females sterilized by 4 kR were found to mate, on average, 14.5 times. Exposure to higher doses decreased the mating capacity of the female.

TABLE IV. EFFECT OF FLOODING OF NORMAL POPULATION OF *Argas persicus* BY 10-FOLD STERILE FEMALES

	Irradiation dose		
	4 kR	8 kR	12 kR
Insemination of normal females (%)	15(3/20)	80(16/20)	60(12/20)
Insemination of irradiated females (%)	90	80	70
Average No. of endospermaphores per female	5.3	2.4	1.4
No. of spermatophores produced by each male	53	24	14

When a population containing normal males and normal females was swamped by 10-fold of females irradiated with 4 kR and kept together for 75 days, only 15% of the normal females were fertilized. When flooding was done with females treated with 8-12 kR, 70-80% of the normal females were fertilized (Table IV). 70-80% of the irradiated females used for swamping were also inseminated. Females exposed to 4 kR seemed to have mated much more than those exposed to higher doses. The number of endospermatothrophes counted in the females indicated that, on average, each male produced more than 54 spermatothrophes during the 75 days of exposure to 10-fold 4 kR-treated females, while about 14 spermatothrophes were produced by males flooded with 12 kR-treated females. Males kept with females at a 1:1 ratio produced 12-17 spermatothrophes during this period (Table IV). Thus the mating activity of the males was greatly increased when they were flooded with females treated with a minimal sterilization dose. An increase in the number of matings per male, when females are more abundant than males, was also observed in the tobacco budworm [7].

Such increase in the male sexual activity in the presence of abundance of females casts a great doubt on the efficiency of sterile females for control purposes.

In our experiment with Argas, in spite of the increased activity of normal males flooded with 4 kR-treated females, only 15% of the normal females were inseminated, as compared to 90% of the treated ones. This may probably be due to the fact that the irradiated females were more attractive than the control ones. Differences in attraction might be attributed to differences in the rate of blood digestion. Only recently fed ticks were used in our experiments. Irradiated females, which do not develop eggs, digest the blood meal much more slowly than do untreated ticks [8]. Fully engorged ticks are much more attractive to males than those that have digested most of the meal. Ticks irradiated with doses higher than 4 kR were not preferred to the control. In nature a population may be composed of ticks at various stages after feeding and, therefore, if flooded with abundance of sterile females, a much higher percentage of the natural population may be inseminated because of the increased mating activity of the males.

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GENETIC CONTROL OF Rhagoletis cerasi L.: PRECONDITIONS, PRESENT SITUATION AND PROSPECTS*

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Abstract

GENETIC CONTROL OF Rhagoletis cerasi L.: PRECONDITIONS, PRESENT SITUATION AND PROSPECTS.

At the present stage of knowledge the technique of controlling the cherry fly genetically by releasing insects carrying dominant lethals seems to be the most promising one. Any hope of a complete eradication, however, might be unrealistic under German conditions. The objective of our research is the suppression of the pest insect to a level of population density that allows an extensive reduction of any chemical control measures for several years. The progress of the rearing experiments and the ecological studies lead to the conclusion that a final decision on the practical usefulness of the technique needs a few more years of study. The experiments in rearing and ecology are described.

METHODS OF GENETIC CONTROL

Today there are several genetic mechanisms known that could possibly form a basis for controlling the European cherry fruit fly. The sterile-insect release method (SIRM) should be mentioned first. Numerous experiments have already been conducted using the SIRM, which involves the production and distribution of dominant lethals. These are the result of chromosomal anomalies. Prevention of DNA synthesis may also play a role, according to observations on the wasp Habrobracon. All these irregularities finally cause the death of the embryo or complete sterility of the F_1 generation, for instance in Lepidoptera. Dominant lethals must be produced afresh at every generation. This treatment causes somatic hazards, lowering the effectiveness of the individual. Possibilities of how to avoid or diminish such undesirable side-effects have already been studied in laboratory experiments. Because of the differences between the ecological influences of the laboratory and the field, however, field research is needed.

Another possible genetic method of insect control is based on the use of translocations. Amongst others, Curtis and Hill [1] and Robinson and Curtis [2] have discussed the different possibilities and problems involved. Without any assurance of future experimental results, these methods demand extensive genetic work. It also seems very probable for theoretical considerations that these control systems are strongly influenced by factors of population dynamics, for instance, immigration rate and density-dependent regulation factors. The latter might be of particular importance in species whose abundance is generally high, as is the case with many fruit flies.

Inversions of chromosome pieces show an effect similar to that of translocations. But their effectiveness depends on additional cytogenetic preconditions, which are frequently absent in the various insect species [3].

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Cytoplasmic incompatibility displays quite a different mode of genetic action. Its practical usefulness has been shown by Laven [4] in eradicating Culex pipiens. The application implies that cytoplasmic-incompatible strains are available and that only one sex is released, otherwise a new strain would be established.

Some other genetic mechanisms may theoretically exist, as, for instance, sex-ratio distortion, as proposed by Milani [5]. All these genetic systems, cytoplasmic incompatibility and the effect of translocations or inversions involve extensive genetic work. So far these techniques are still in the stage of basic investigation. They have the advantage that the mechanism of control is hereditary and does not need a fresh induction at every generation as is the case with SIRM. However, the heritability of the control mechanism does not imply per se the fitness of the insects. The quality of insects carrying genetic control systems is still a problem in all methods of genetic control. The conclusion may be justified that at the present time no genetic control system has any advantage over the SIRM and, therefore, the aim of the efforts to control the European cherry fruit fly is through the application of the SIRM.

A series of large field experiments using the SIRM have already been successfully conducted. Thus the genetic system of the SIRM has proved to be effective; however, it is also known that a complete and large-scale eradication has only been achieved in the case of the screwworm.

USE OF THE SIRM TO CONTROL THE CHERRY FLY

Demecological conditions

The biotops of the cherry fly in Germany are scattered. Due to the environmental conditions this insect does not occur in all regions where cherries are grown. On the other hand, the biotops also cover regions without cherries. In addition, Lonicera, another host plant, is infested by this oligophagous insect. Finally, it should be mentioned that the cherry plantations are normally small. Cherry trees are also frequently found in back yards. Therefore, the preconditions for complete eradication seem to be extremely unfavourable from the aspect of the distribution of the insect alone. The tendency of a population of this species to distribute is very small. For this reason a cherry plantation can be considered as a more or less isolated area. It can be expected that the population of such an orchard can be eradicated but that a certain, even if low, immigration rate will prevent permanent elimination. The gradual build-up of a new population of the cherry fly, which has only one generation per year, takes a period that depends on the capacity of reproduction. There are no exact long-term studies on the innate and mean capacity of reproduction, but in an area of population increase — that is an area with a strong change in fly abundance — the population has been observed since 1965 by catching flies with traps and by estimating the fruit infestation. In the first year the fruits were infested completely. In 1966 and 1967 neither flies nor infested fruits could be established. Then the population reappeared and increased year by year. But not until 1972 had the abundance and the infestation reached a level at which control measures became necessary. In the meantime seven years had passed during which at other sites within

a few kilometres but at a lower sea level complete infestation of the crop had been observed. It is clear that this observation must be verified by other studies that also cover areas with latent and high populations. However, this observation suggests that suppression of the cherry fly in the above-mentioned way is a realistic goal.

The suppression of insect populations by a genetic method of control may be biologically attainable but nevertheless economical considerations may make any application appear impractical. The value of suppressing insects also depends on the expense of producing and releasing the flies.

Artificial breeding

At present the main effort is being directed to breeding the cherry fly under laboratory conditions. This demands an extensive knowledge of the biological requirements. The bottleneck is still raising the larvae to the adult stage. The nutritional, physical and genetical aspects have to be considered.

Nutritional aspects

Keeping the flies and the egg collection technique has already been described [6]. For the feeding studies only neonate larvae were used. Table I shows the composition of the larval diets tested, while Table II shows the results of the diets containing agar. The test diet (No. 78) contained frozen cherries, brewers yeast and a vitamin mixture (Vanderzant's vitamin fortification mixture). The experiments show clearly that neither deep-frozen cherries nor cherries dried at 80°C can provide the basic nutritional requirements. The reason is presumably not the immediate effect of agar-agar or propionic acid because yields of pupae of more than 40% could be attained despite the use of these materials (D 66-67¹, Tables I and III). Probably the method of processing the cherries changed their nutritive quality; for example, no methionin could be found after deep freezing². The addition of casein and casein with vitamins to dried cherries did not improve the conditions for the development of larvae. The growth of larvae, however, was improved if heat-dried cherries were replaced by deep-frozen cherries. But development to the pupal stage could only be observed if vitamins and brewers yeast were added (D 78).

Despite all reservations with regard to the influence of temperature on the cherries, the results (Table I) give reason to question whether even in the field cherries alone provide the basic requirements for the development of larvae or whether endo- or exosymbiotes may play an essential role. The exosymbiotes may be yeast of any species, which are enriched within a cherry during the development of the larvae but the multiplication of which in a diet is prevented by the propionic acid.

The rearing results with diets 59 - 79 show the importance of yeast for the growth of the larvae. Various concentrations of torula yeast were tested in diets 106 - 110 (Table III). The increasing amounts of yeast were compensated by decreasing the water content to maintain constant the relative composition of the other components. The application of Gelgard M should

¹ D = diet number, for composition see Table I.

² The chemical analysis of Dr. Rosopulo is highly appreciated.

TABLE I. COMPOSITION OF THE VARIOUS CHERRY FLY LARVAL DIETS (g or ml)

Ingredients (g or ml)	Diet No.												
	59	60	61	62	63	64	66-71	77	78	79	80-87	95-99	106-110
Paper pulp	-	-	-	-	-	-	-	-	-	-	-	-	10.0
Wheat germ	-	-	-	-	-	-	a	-	-	-	-	4.0	5.0
Sugar	-	-	-	-	-	-	4.0	-	-	-	4.0	4.0	6.0
Brewers yeast	-	-	-	0.6	-	0.6	5.6	-	4.96	-	5.6	-	-
Torula yeast	-	-	-	-	-	-	-	-	-	-	-	5.6	a
Caselin, vitamin free	0.6	-	-	-	0.6	-	-	-	-	2.47	-	-	-
Cherry juice (84% H ₂ O)	-	-	-	-	-	-	-	-	-	-	a	-	-
Cherries, deep frozen and dried (20% H ₂ O)	-	-	-	-	-	-	-	18.0	18.0	18.0	-	-	-
Cherry powder dried at 80°C	15.0	15.0	16.0	15.0	15.0	15.0	-	-	-	-	a	-	-
Vitamin mixture	-	-	1.0	-	1.0	1.0	0.8	1.11	1.04	1.05	-	1.0	0.8
Ascorbic acid (additional)	-	-	-	-	-	-	0.4	-	-	-	0.4	-	0.2
Citric acid	-	-	-	-	-	-	0.8	-	-	-	0.8	-	0.4
Propionic acid	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
4N HCl	-	-	-	-	-	-	-	-	0.02	-	-	0.4	0.4
4N NaOH	-	-	0.08	0.08	-	-	-	0.08	0.52	0.52	3.4	-	0.3
Gaigard M	-	-	-	-	-	-	-	-	-	-	-	-	1.0
Agar-agar	4.0	4.2	4.2	4.2	4.1	4.1	a	3.83	3.60	3.86	a	a	-
Water	80	80.4	79.8	80.2	78.9	78.9	a	76.5	71.5	73.6	a	a	a
pH	4.0	4.0	4.0	4.1	4.0	4.0	4.0	3.95	3.95	4.0	3.9-4	4.1	4-4.1

a For details see text.

TABLE II. DEVELOPMENT OF CHERRY FLY LARVAE ON DIFFERENT AGAR-AGAR DIETS
(3 replications with 60 larvae each)

Main ingredients or stage of development	Diet No.								
	60	62	61	59	64	63	77	78	79
Dried cherries	+	+	+	+	+	+	-	-	-
Deep-frozen cherries	-	-	-	-	-	-	+	+	+
Brewers yeast	-	+	-	-	+	-	-	+	-
Vitamin mixture	-	-	+	-	+	+	+	+	+
Casein (vitamin free)	-	-	-	+	-	+	-	-	+
Eclosion I	-	+	-	+	+	-	+	+	+
Eclosion II	-	+	-	-	+	-	-	+	+
Eclosion III	-	-	-	-	-	-	-	+	+
Pupae	-	-	-	-	-	-	-	+	-

+ = present - = not present

TABLE III. EFFECT OF VARYING CONCENTRATION OF TORTULA YEAST ON CHERRY FLY PUPAL YIELD AND PUPAL WEIGHT

Diet No. (= D)	106	107	108	109	110
Amount of yeast (%)	1.7	3.3	5.0	6.7	8.3
Number of neonate larvae used	1628	1713	1465	1984	890
Yield of pupae (%)	21	36	29	27	35
Mean weight of pupae (mg)	3.0	3.2	3.3	3.3	3.6

avoid an essential change in the consistency of the diet. Increasing the amount of yeast from 1.7 to 3.3% apparently resulted in an increased yield of pupae. Higher amounts apparently did not influence the number of pupae. The variation in yield of pupae with D 107 - 110 may be within the limits of the biological variability, but a relation between the content of torula yeast and the weight of the pupae can be stated.

Another valuable component of cherry fruit fly diets is wheat germ. Its influence on the development of the larvae should be tested with an agar-agar medium (D 66 - 71, Table IV) because wheat germ influences the texture of the diet more than yeast does. The variation in the wheat germ content was compensated by a change in the amount of agar-agar and water, whereby

TABLE IV. EFFECT OF VARYING CONCENTRATION OF WHEAT GERM ON CHERRY FLY PUPAL YIELD AND PUPAL WEIGHT
Average of three replications with 60 larvae each.

Diet No. (= D)	71	70	69	68	67	66
Wheat germ (%)	0.0	1.0	2.0	3.0	4.0	4.8
Yield of pupae (%)	0	9	23	27	32	33
Mean weight of pupae (mg)	-	2.8	3.2	(3.4) ^a	3.7	3.4

^a Technical failure in weighing is not excluded.

TABLE V. EFFECT OF VARYING CONCENTRATION OF CHERRY JUICE ON CHERRY FLY PUPAL YIELD AND PUPAL WEIGHT
Average of four replications with 60 larvae each.

Diet No. (= D)	80	81	82	83
Concentration of cherry juice (%)	2	4	8	16
Yield of pupae (%)	27	16	27	18
Mean weight of pupae (mg)	3.7	3.8	3.8	3.9

agar-agar was applied by 5 wt/wt (%) of water. A clear relation between the amount of wheat germ and the yield of pupae can be observed, particularly between 0 and 2% wheat germ. The increase flattens at 4 - 5% wheat germ. However, no apparent relation exists between the content of wheat germ and the weight of pupae.

Sugar, yeast and wheat germ apparently do not provide a complete nutritive base for larval development. Therefore, the effects of adding cherries, deep-frozen juice of pressed cherries and the remaining residue were studied. In all cases the kernels of the fruit were removed before processing.

The cherry juice was added in amounts from 2 to 16%, whereby the weight of the components, cherry juice, water and agar-agar (5%), was kept constant at 84.3 g in a total diet of 100 g (D 80 - 83, Table V). The results show no relation between the amount of cherry juice and yield of pupae and, therefore, it was concluded that the water soluble components of a cherry do not, or at least not in sufficient measure, provide the (hypothetical) complement to yeast and wheat germ. A similar result was observed when using the residue of the pressed cherries. It was, therefore, decided not to give the figures here.

TABLE VI. EFFECT OF VARYING CONCENTRATION OF AGAR-AGAR ON CHERRY FLY PUPAL YIELD AND PUPAL WEIGHT
Average of five replications with 60 larvae each.

(Diet No. (= D))	99	98	97	96	95
Agar-agar	1	2	3	4	5
Yield of pupae (%)	0.3	11.0	33.3	40.0	45.7
Mean weight of pupae (mg)	-	3.9	3.4	3.7	3.9

Physical aspects

In all experiments to study the nutritional value of the diets for the development of larvae the physical quality of the diets should be carefully studied. Its importance is shown in the following series of experiments with increasing amounts of agar-agar (D 95 - 99, Table VI). When preparing the diets, water was added such that the weight of the diet was kept at 100 g despite the increased agar-agar content. The relation between content of agar-agar and yield of pupae is obvious. It should be noted that diet 95 resulted in the highest yield of pupae ever observed. The increase in the yield of pupae from 20 to 45% is more than double. No influence on the weight of pupae was found.

Genetic aspects

Amongst others, Da Chuna [7] and Mackauer [8] have discussed the problem of the genetic structure of an insect population, and Bateman [9] has shown that populations of *Dacus tryoni* from different geographic origins have different temperature requirements. It is very probable that other physiological and behavioural properties are more or less marked in different geographic races. Therefore, different geographic origins of pupae of the cherry fly are used for the rearing experiment. It is not expected that a race can be found that tolerates heavy nutritional defects, though perhaps small ones. On the other hand, it is not intended to produce a fly that is well adapted to laboratory conditions but rather to compose a diet that allows the development of insects fully competitive in the field. This demands intensive work in rearing but seems to be a precondition for the later use of any genetic method of control.

The rearing experiments showed that artificial rearing of the cherry fly is possible. Further systematic research pertaining to the three aspects of rearing mentioned will be necessary to provide the basic knowledge for establishing a mass-rearing program. At the same time work-saving techniques must be developed; for instance, egg collection and the processing of eggs and young larvae must be improved. Knowledge of the diapause-regulating mechanism must also be acquired. Previous experiments with photoperiodical and thermal treatment of the larvae have been unsuccessful. However, not all possibilities known to prevent the induction of the pupal diapause have yet been tested.

The aim of suppressing the cherry fly by the SIRM in their economically important biotops implies not only an artificial production of the pest insect but also information on its demecology.

ECOLOGICAL STUDIES

Distributive movement

The field behaviour of the cherry fly was studied by the release-recapture technique. Labelled flies moved from a central release point about 90 m in each direction. Forty-nine yellow sticky traps served for recapture. 5800 Dy-labelled flies were released in the second of the six harvest weeks and 2600 Sm-labelled flies in the third week. As could be expected, the recapture data show a distinct peak at the release point (Fig. 1). But there is a second peak for the flies released later. This accumulation of flies at a distance of 80 m must be explained by the ripening time of all trees at this distance. Three out of four trees were a late ripening variety. It can be concluded from this observation that the cherry fly moves only a very limited distance. However, presumably in search of a suitable breeding place, the cherry fly displays an intense activity in flying short distances. This behaviour offers the highest probability that the species, which is unable to perceive a host plant at any greater distance, finds a breeding site.

Population estimation

The abundance of the cherry fly was estimated by the release-recapture technique in an area where a permanently high infestation occurs and in a second one that must be regarded as an area where the population is

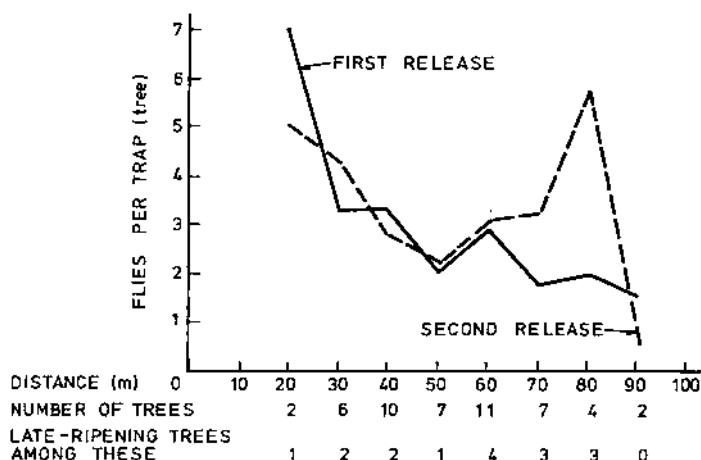


FIG. 1. Distribution of the European cherry fly released from a central point.

increasing. The results can only be outlined very briefly. In the area with the high abundance about 1900 flies per tree were estimated, and in the population-increase area 1000 flies per tree. Even conceding an error of 10 - 20%, such a high abundance demands a tremendous capacity from a future rearing plant. Unless the genetic method is combined with another control measure or a natural decline in the abundance, any success is questionable. Furthermore, the difference between the two population sizes makes a strong effect of abundance-regulating factors very likely. This fact is of importance in the possibility of suppressing a cherry fly population as already mentioned.

These preliminary results show that basic research on the demecology of the cherry fly must be intensified.

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POSSIBILITIES OF USING GENETIC METHODS TO CONTROL THE TSETSE FLY

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Abstract

POSSIBILITIES OF USING GENETIC METHODS TO CONTROL THE TSETSE FLY.

The author reviews briefly the four main genetic methods (hybridization, chemosterilization, radio-sterilization, genetic manipulation) capable of being used to control the tsetse fly. Particular emphasis is placed on the possibilities of radiosterilization, a method which has been the subject of many laboratory studies and which has begun to be used experimentally in the field.

Genetic methods of insect control involve the inhibition or reduction of the reproductive power of individuals through the impairment, modification or replacement of hereditary material. There are four main groups of methods:

- (1) Hybridization
- (2) Chemosterilization
- (3) Radiosterilization
- (4) Genetic manipulation.

1. HYBRIDIZATION

This consists in promoting the mating of insects that belong to closely related species. Such interspecific mating produces infertile hybrids. Thus in the case of tsetse flies (Curtis, 1972), laboratory crossing of Glossina morsitans morsitans males from Rhodesia with G. morsitans centralis females or females of the species G. morsitans submorsitans ugandensis yields a high rate of sterility.

Inverse cross-breeding yields moderate fertility, but the hybrid male progeny is completely sterile owing to the lack of spermatozoid motility. The hybrid female progeny exhibits a higher degree of sterility than the parent females.

Reverse cross-breeds have shown that the sterility of the cross products and of the hybrid females is due to foetal incompatibility between the maternal genes and the genes introduced, and that the sterility of the hybrid male is brought on by heterozygosis at a specific locus.

The males of G. morsitans morsitans could thus act effectively as sterile males in combating one or other sub-species, and would have the advantage over artificially sterilized males of being more vigorous and more competitive. On the other hand, the differences of behaviour between sub-species may be an obstacle to cross-breeding with individuals of the wild species.

2. CHEMOSTERILIZATION

This is the sterilization of individuals by means of chemical agents used in the same way as chemical insecticides. Chemosterilants must cause sterility in both sexes without affecting the longevity of the individuals or modifying their sexual behaviour; they must also be easy to handle and be non-toxic with respect to mammals (especially man). The main chemosterilizing agents currently available fall into the following categories:

- (1) Alkylating agents, which are capable of introducing a hydrocarbon chain into an organic molecule. The most commonly used products are aziridine derivatives such as apholate, tepa, metepa, thiotepa and tetramine;
- (2) Antimetabolites, which interfere with the synthesis of nucleic acids; they are particularly active in female insects when administered to them at the adult stage;
- (3) Phosphoric triamide derivatives such as hempa, a non-alkylating homologue of tepa;
- (4) Insect hormones (of the juvenile hormone type), which are involved in the metabolism of insects.

Only alkylating agents have been tested with tsetse (Chadwick, 1964; Dame and Ford, 1966; Dame, 1968; Dame and Schmidt, 1970). Tepa and metepa cause total and permanent sterility in adult males through tarsal contact. Their longevity remains normal, in the laboratory, of the exposure time does not exceed 60 minutes.

Field trials were carried out in 1967 and 1968 on the islands of Lake Kariba in Rhodesia. During one of the first releases the adult males sterilized through contact with tepa proved to have a shorter lifetime than the wild males and, even though the natural population density had been reduced by about 50% by two applications of insecticides 30 days before the releases, the density of sterile males at the end of the experiment was only 12% of that of the wild males.

In a second campaign, carried out on another island with a small population of G. morsitans, 26 000 sterile adult males were released over 20 months. The natural population of G. morsitans was wiped out, but the other species present on the island (G. pallidipes) persisted.

In a third campaign, carried out in 1968 on the first island, pupae gathered in the field after two aerial applications of insecticide were immersed in a 5% tepa solution and afterwards deposited in containers which protected them against the sun's rays and rain. The insects that emerged during the first three months were completely sterile, but subsequently a number of fertile males and females were released owing to the reduced activity of the chemical sterilizing agent. Even so, the investigators believe that at the end of nine months the wild population had been reduced by about 98%. The sterile males were more competitive than those released during the first two trials.

3. RADIOSTERILIZATION

This method is based on the sterilizing effect of ultra-violet rays, X-rays and — especially — gamma rays. It has been the subject of many studies and therefore we shall devote particular attention to its possibilities.

3.1. Physiological action of ionizing radiation

Ionizing radiations act on the chromosomes of cells (primarily dividing cells), fragmenting them or causing irregular bridges to form between them. The damage caused to somatic cells is of the same nature as that suffered by germ cells. The effect on somatic cells takes the form of lessened longevity and reduced activity, especially sexual activity. It is a function of the radiation dose administered and of the stage at which the insect is when irradiated.

3.2. The use of radiosterilization for genetic control

In the case of many insect species, and especially the tsetse fly, the females usually mate only once — at the beginning of their adult life — and conserve the sperm in seminal receptacles (spermathecae). The spermatozooids are then expelled in small numbers when a mature follicle descends the oviduct. The follicle is fertilized as it enters the uterus.

After the initial mating, the female is either no longer attractive to males or rejects them when they try to inseminate her. When a female mates with a previously irradiated male, the chromosomes of the spermatozooids cannot align themselves with those of the ovule; embryogenesis is arrested prematurely and the female is eliminated as far as reproduction is concerned.

3.3. Choice of appropriate time for irradiating and radiation dose

The purpose of irradiation is to obtain insects that are sterilized but whose behaviour has not been modified; mating, sperm transfer, spermatozoid motility, vigour and longevity must be the same as in the case of the normal males with which the sterile males will have to compete.

Changes in behaviour depend on the stage of development during which the insect is irradiated and on the radiation dose. In the case of tsetse spermatogenesis occurs only during the pupal stage and the adult male emerges with his full complement of spermatozooids (Itard, 1970). Premature irradiation, during the pupal stage, will arrest spermatogenesis and the emerging adult male will have no spermatozooids. Moreover, at this stage the somatic cells undergo very serious changes so that the insect will die before eclosion or will have a very short adult life. Tsetse flies are therefore irradiated at the end of the pupal stage or during the first days of adult life. As sexing of the pupae is not possible, it would seem best to irradiate after eclosion, thereby sterilizing only the males and preserving the females for reproduction purposes.

There is no single standard radiation dose. The dose required depends on the species and has to be determined for each case. In the case of *G. morsitans*, total sterilization is achieved with 19 000 rads; in the case of *G. tachinoides*, with 15 000 rads (Itard, 1968 and 1971); in the case of *G. austeni*, with about 12 000 rads (Curtis, 1968); in the case of *G. fuscipes*, with about 10 000 rads (Itard, unpublished work). With these doses, the longevity of the males is always less than in the case of normal individuals but sufficient to permit several matings. The present trend is to administer lower radiation doses, which do not ensure total sterility but permit greater longevity and better sexual performance.

In the case of *G. tachinoides* (Itard, 1971) and *G. morsitans* (Curtis, 1972), it has been found that, after mating with males that have received low radiation doses, the females produce only a few pupae; most of the adults that emerge from these pupae are sterile or semi-sterile, and there is a sex-ratio shift in favour of males.

3.4. Obtaining sterile males

To ensure that wild females have a better chance of being inseminated by sterile males than by normal males, it is necessary to release into the natural population a high proportion of irradiated males — it is estimated that one needs at least three sterile males to one normal male.

To obtain the necessary sterile individuals one has to rear the *Glossina* species in question on a large scale. The rearing of tsetse flies is a delicate operation owing to their special requirements as regards temperature, humidity and feeding and to their low reproduction rate (Itard, 1971).

It has been estimated that with 50 000 to 70 000 males and females it is possible to obtain an excess of about 10 000 males every ten days.

In this connection, the following study — carried out at the I.E.M.V.T. entomology laboratory — deserves attention. Between the end of January and the end of May 1972 (i.e. over a period of 120 days), with a rearing stock averaging 5100 *G. tachinoides* females, we irradiated 10 300 males, which were sent to Fort-Lamy and, after marking, were released into a natural environment; that is about 860 males every ten days. Taking into account mortalities, 5000 males were kept for reproduction purposes over a period of 120 days — i.e. an average of 1250 males per month. An average rearing stock of 6350 individuals (5100 females plus 1250 males) accordingly produces an excess of 860 males every ten days. To obtain an excess of 10 000 males, the rearing stock would have to be about 73 000 individuals, which is slightly higher than previous estimates. However, the monthly production of pupae during this period increased from 7400 pupae at the end of January to 10 200 pupae at the end of May.

It is therefore reasonable to say that, in mass rearing for the sole purpose of producing sterile males, the rearing stock would have to consist of about 70 000 individuals (one quarter of them being fertile females) in order to obtain 10 000 sterile males every ten days.

3.5. Behaviour of sterile males after release

From the observation of insects in captivity it is not possible to draw firm conclusions about their behaviour in the field, as laboratory rearing conditions favour the elimination of discrimination factors by permitting only a limited range of stimuli. Thus, while sterile males may be capable of copulating under the restrictive conditions of captivity, they may not be able to do so in nature owing to their general weakness.

It is therefore very important to study the behaviour of sterilized males after their release in the field. The first task is the identification of these insects. Various procedures have been used: the application of dyes to the thorax, marking with fluorescent powders (Tibayrenc et al., 1971), labelling with radioisotopes (Cuisance et al., 1971), etc.

By capturing the flies at different time intervals and observing them at rest during the day and the night, it is possible to compare the behaviour of

the irradiated males with that of the wild flies. One study of this type is in progress at Fort-Lamy with *G. tachinoides* males reared at Maisons-Alfort and, after irradiation at 15 000 rads, sent to Chad by air. Mortality during transport is generally low — of the order of 2-13%. The first observations after releases into natural environments within the Kalamaloue reserve, on the banks of the Chari river, showed (Annual Report for 1970) that:

(a) Irradiated males settle in the same trees as wild flies but at slightly greater heights; however, the heights at which they settle reflect the climatic conditions created by each tree;

(b) As regards feeding hosts, irradiated males did not differ in their behaviour from normal flies;

(c) Flies released during the hottest period of the year (April-May) were recovered in the more favourable environments along with non-labelled flies. Like the wild flies, the irradiated males react to unfavourable conditions by seeking and finding environments that suit them;

(d) About 3% of the flies were recovered within one week after release, which corresponds to the recapture rate usually obtained following releases of marked wild flies. The survival time in nature of the irradiated males is therefore at least about eight days;

(e) Lastly, some irradiated males were observed, soon after release, mating with wild females at rest on tree trunks.

From these initial results it would seem therefore that, after release into suitable environments, irradiated males reared in the laboratory behave in the same way as wild flies.

3.6. Pre-release studies

Before releasing sterile insects, it is essential to know everything about the population that one is trying to eliminate: its localization, density, dynamics, adult longevity, sexual behaviour, oviposition sites, flight capacity, dispersal as a function of the seasons, feeding preferences, etc. In short, very precise ecological studies have to be carried out, for it is the results of such studies that enable one to reply to those questions that determine the success of a genetic control operation, namely: at which points should releases be carried out? at what time of the year? how many sterile males should be released?

Such preliminary studies also enable one to delimit the zone to be treated and to isolate it by means of suitable barriers (land cleared of trees, insecticides, etc.) so as to prevent subsequent repopulation by immigrant insects. They are also necessary for determining the type of insect to be reared for subsequent release, for within a particular species there are natural populations that vary ecologically and genetically from one region to another. It is essential that the laboratory-reared individuals should survive within the natural population and fulfil their functions, and hence it is usually necessary to sample as wide a range of individuals as possible from within the population one is seeking to eliminate with a view to rearing and subsequent release after sterilization.

4. GENETIC MANIPULATION

This category includes different methods of selecting individuals that are carriers of certain hereditary abnormalities. When such individuals are

introduced into a natural population, they are not distinguished from normal individuals by the females, so that it is possible to eradicate the natural population within a few generations.

Low-dose irradiation of male tsetse flies causes ruptures of two chromosomes in a large proportion of spermatozooids, and the fragments recombine in new ways (Curtis, 1969). When these spermatozooids fertilize normal eggs they produce partially sterile translocation heterozygotes, which can in fact be identified by their partial sterility.

By selecting individuals with translocation defects in the autosomes and mating them with each other, research workers (Curtis, 1971) have succeeded in obtaining progeny homozygous for the translocation in question — viable and fertile flies which, when mated with normal flies, yield unviable or sterile heterozygotes.

However, the translocation homozygotes are less vigorous than the normal flies and it accordingly seems preferable to rear two different homozygote strains, cross-breed them and release the double heterozygotes thus produced. Simulated computer tests have indicated that this technique would be more effective than sterilization of males with large radiation doses in view of the hereditary transmission of the translocation to subsequent generations (Curtis and Robinson, 1972).

This technique, which is still only in the experimental stage in the laboratory, would have an advantage over the irradiated-male release technique in that only a small number of individuals would have to be introduced into the natural population, and these would be quite vigorous and fully competitive.

CONCLUSIONS

One of the main advantages of genetic control is its specificity; it does not harm other species and it is more rapid in its action than the theoretically less expensive conventional methods.

While the principle of genetic control is simple, its application presents numerous difficulties and thorough studies will still be necessary before the method can be applied widely.

In any case, the methods of genetic control will have to be adapted to each species and cannot be regarded as a miracle remedy. They are simply one of the weapons in the battle against vector insects and do not exclude other methods, such as the use of low-persistence insecticides, modification of the biotope, the use of predators, parasites or pathogens, etc.

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ECOLOGICAL PROBLEMS ASSOCIATED
WITH AN ATTEMPT TO ERADICATE
Dacus dorsalis (Tephritidae: Diptera)
FROM THE SOUTHERN ISLANDS OF JAPAN
WITH A RECOMMENDATION ON THE USE
OF THE STERILE-MALE TECHNIQUE

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Abstract

ECOLOGICAL PROBLEMS ASSOCIATED WITH AN ATTEMPT TO ERADICATE Dacus dorsalis (Tephritidae: Diptera) FROM THE SOUTHERN ISLANDS OF JAPAN WITH A RECOMMENDATION ON THE USE OF THE STERILE-MALE TECHNIQUE.

A population recovery observed after a male annihilation campaign against Dacus dorsalis on Kikai Island prompted an ecological study in conjunction with the possible existence of methyl-eugenol insensitive genotypes. The results of these studies, which included migration, population density, longevity and the effect of trap density, are presented and discussed.

INTRODUCTION

Although there have been many attempts to eradicate injurious fruit flies by distributing male-attractant baits and/or the release of sterile males, few quantitative studies have so far been made on the population density, movement and longevity of these species, apart from intensive studies on the Queensland fruit fly, Dacus tryoni [1-3]. The successful eradication of the oriental fruit fly, Dacus dorsalis, from Rota Island in 1963 by male annihilation with methyl-eugenol-treated baits made it appear that there is little difficulty in the eradication of this fly, at least from small islands. This was the case in Japan when an eradication program was begun on Kikai Island, despite a warning about the possible existence of methyl-eugenol-insensitive genotypes [4].

PROGRESS OF THE ERADICATION EXPERIMENT ON KIKAI ISLAND

The distribution of methyl-eugenol-treated fibre blocks from helicopters at a rate of 150/km² per month began on 6 September 1968 on Kikai Island, southwest of Kyushu. The population of Dacus dorsalis, as measured by the trapping of adults in systematically distributed methyl-eugenol traps

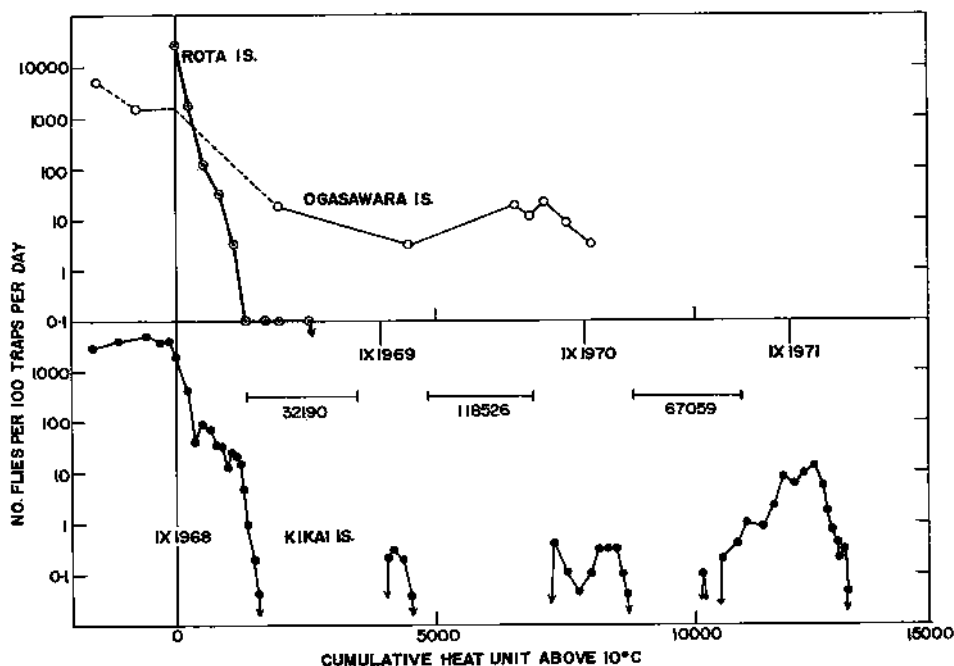


FIG. 1. Fluctuations in the log number of *Dacus dorsalis* adults caught by methyl-eugenol traps after the distribution of methyl-eugenol-treated fibre blocks in Ogasawara [5], Rota [6] and Kikai Island. An index of physiological time is used as the abscissa. Horizontal bars in the bottom figure (Kikai Island) show the periods during which no larvae could be found in dissected fruits (numerals below bars indicate the number of fruits dissected).

(Steiner traps) and by the detection of larvae in fruit, decreased to zero by the end of the sixth month. Thereafter, no adults were captured for a period of 6 months and dissection of more than 32 000 fruits failed to show any trace of larvae. Some adults were, however, caught in the October of 1969 and larvae were also found in guava and some other host fruits. Figure 1 shows a summary of these results. The progress of events on the Ogasawara Islands from 1960 to 1962 [5] and Rota Island from 1962 to 1963 [6] is also shown. The eradication of *D. dorsalis* from the Ogasawara Islands failed after the two years of the distribution of fibre blocks. Cumulative heat units (day-degrees above 10°C) were taken as the abscissa in place of calendar dates to permit comparison of the different localities. The figure shows that the number of adults caught in autumn on Kikai Island increased year by year.

It should be emphasized that the total numbers of flies caught by traps, as shown in Fig. 1, do not accurately reflect the abundance of flies because the traps were competing with different numbers of fibre blocks as the distributions continued. Kojima (personal communication) observed that fibre blocks of the kind used on Kikai Island remain effective for about 6 months under field conditions and then deteriorate rapidly. Initially

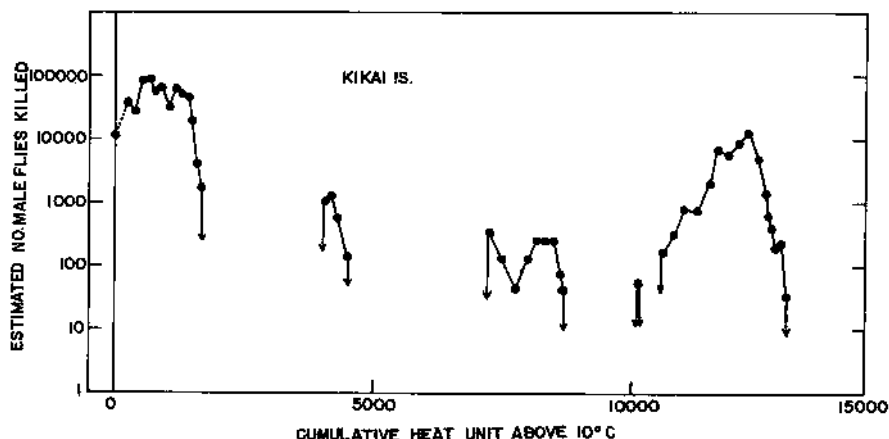


FIG. 2. The estimated numbers of males killed in Kikai Island with fibre blocks and Steiner traps. For explanation see text.

their effectiveness is about equal to that of a Steiner trap (Iwahashi, unpublished). Figure 2 shows the estimated numbers of male flies killed by all the fibre blocks and traps on Kikai Island. This is an approximate estimate only, but the apparent recovery of the population is obvious.

As a result of this situation, which developed on Kikai Island, the Tokyo Metropolitan Government decided to carry out ecological studies before commencing a similar eradication program on the Ogasawara Islands. The following are some of the results of these studies.

MOVEMENT

Long-range movements were studied in a series of mark-recapture experiments between February and September 1970. The results are presented in Fig. 3 [7]. It is clear that the adults frequently moved across the sea, sometimes more than a distance of 50 km. In the case of movement from Haha Jima to Chichi Jima, the adults were considered to be transported not by a typhoon (as there was no typhoon during the period from the date of release to the first recapture) but by ordinary southerly winds. Rates of recapture on other islets were high when the release was made on an islet with poor vegetation. In addition, the rate of recapture of marked flies was high in traps at localities where relatively large numbers of unmarked flies were caught. Thus it was considered that the flies were attracted primarily by the environment around the trap and secondarily by the trap itself. These results suggest that the apparent recovery of the population on Kikai Island, from 1969 to 1971, could have been due to adults moving from Amami Oshima Island some 27 km away. The extent of the recovery, however, seems to be too large to be attributed to this alone.

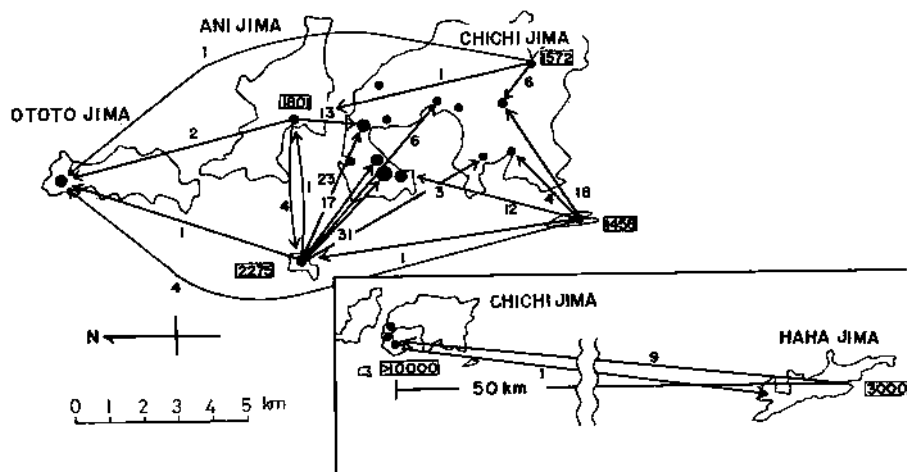


FIG. 3. Inter-islet movements of *Dacus dorsalis* males on the Ogasawara Islands (after Ref. [7]). Blocked numerals show the numbers of flies released and numerals near arrows the number of flies recaptured with Steiner traps. The larger circles indicate that more than one trap was set. Only a part of the results are shown in the figure.

ESTIMATION OF POPULATION DENSITY AND MORTALITY

Figure 4 shows the cumulative curve of recaptures of marked male flies by 10 Steiner traps within a 7-ha area. Releases were made several times between 19 May and 3 June as successive batches of flies emerged. Copulations began on the 13th day after emergence but the flies continued to be caught by the traps even after a month. The last recapture was noted on the 77th day after emergence.

The mathematical models presented so far to estimate the population density based on mark-recapture data are insufficient for the case where recaptured individuals are removed from the population. This is the case for our experiments because Iwahashi (personal communication) remarked that once *Dacus dorsalis* males have been trapped in a methyl-eugenol trap they never come again to traps of the same type. Thus we used a method that is a modified one of Jackson's 'positive method' [8]. Using the recapture data mentioned above, the numbers of male flies caught during each successive 5-day period were combined. Following Jackson, we calculated y_i , the expected number of recaptures when 100 individuals are released at $t = 0$ and 100 individuals are caught at $t = i$, as follows:

$$y_i = \frac{m_i \times 10^4}{M_0 n_i} \quad (1)$$

where M_0 , n_i and m_i are the number of individuals marked and released at $t = 0$, the total number of individuals (marked and unmarked) caught at $t = i$ and the number of marked individuals recaptured at $t = i$. Also, t_0 means a 5-day period from Day 0 to Day 4, t_i means a period from the

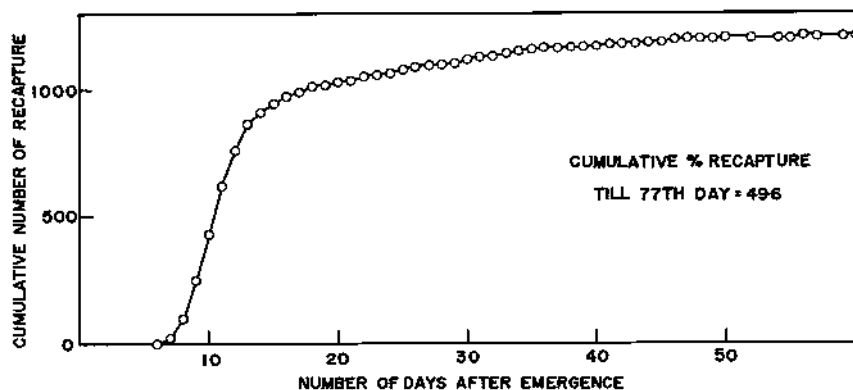


FIG. 4. Cumulative curve of recaptures of marked male flies with 10 Steiner traps distributed in a 7-ha area.

Day 5 to Day 9 and so on. Plotting y_i 's against t , we obtain the survival curve of released males and y_0 is an expected number of recaptures, assuming that the released individuals intermingle with the population immediately after release and these are recaptured at that time. y_0 was calculated here with linear regression.

As the recaptured individuals were killed and removed from the population, we use M'_0 in place of M_0 .

$$M'_0(i) = M_0 - \sum_{t=1}^{i-1} m_t \quad (2)$$

This is a corrected value of the number released at $t = 0$ for each date of the recapture. Substituting M'_0 into Eq. (1), we obtain a corrected value, y'_0 , and \hat{N}_0 can be obtained by the following equation

$$\hat{N}_0 = 10^4 / y'_0 \quad (3)$$

The calculated value is presented in Table I. The survival rate, P , was known from the regression coefficient of y_i 's on t . As we released males four times in this season (19, 28, 31 May and 3 June) with different marks, we can calculate the mean of four estimated values and the variance for this season. This procedure is not precise as m_t is not sampled from M_0 but from $P^t(1-p)^{1-t} M_0$ (here p is the rate of capture), even in the case where P and p are constant, but might give an underestimated value of N_0 . The true value might be up to 50% larger than the given value (itô, in preparation). Thus the density of males in the early summer was estimated as about 1500 per hectare. The rate of capture of 1.4 traps per hectare was about 10 to 30%.

The longevity of the adults was remarkably high, despite the existence of many Steiner traps. The survival rates shown in Table I may be overestimated and simulation gave the best value to be 0.7 per 5 days (mean longevity = 13.5 days) for flies released during the course of the experiment

TABLE 1. NUMBER AND SURVIVAL RATE (PER 5 DAYS) OF *Dacus dorsalis* MALES IN A 7-ha AREA WITH A MODIFIED JACKSON'S POSITIVE METHOD
Recapture was made with methyl-eugenol traps. For explanation see text.

Date of release	N_0	\bar{p}
19 May	5 444	0.62
28 May	9 141	0.67
31 May	5 189	0.64
3 June	11 806	0.69
Mean	7 895	0.65
s. d.	3 171	0.08

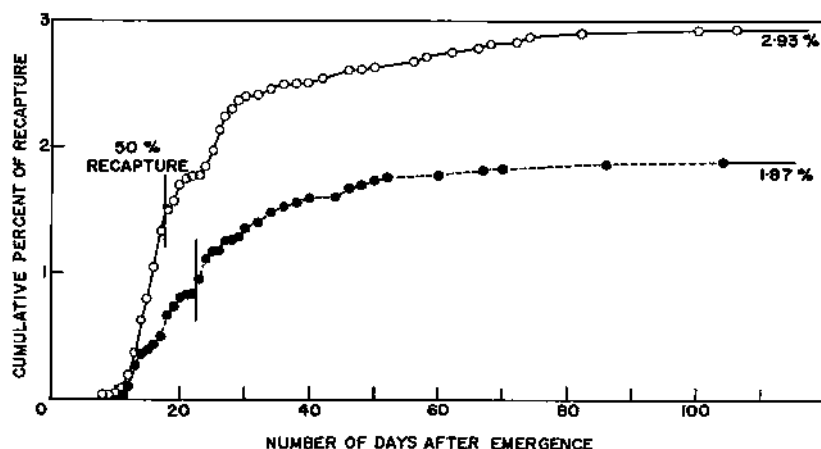


FIG. 5. Cumulative curves for the recapture of marked flies with 10 Steiner traps. Solid circles show data for the strain selected by methyl eugenol through 2 generations and hollow circles the control.

in May and June. In winter some males were caught more than 100 days after release (Fig. 5). The longest record of the duration of life of marked individuals was 217 days for a fly released in December 1970.

DOES A METHYL-EUGENOL-INSENSITIVE STRAIN EXIST?

Figure 5 raises another interesting question. Here the open circles mean data for normal flies (reared on an artificial diet through 2 generations), while the solid circles are data for flies that had been selected for insensitivity to methyl eugenol in the following manner: Fresh male flies were

TABLE II. DIFFERENCE IN RECAPTURE RATES OF SELECTED AND CONTROL FLIES WITH METHYL-EUGENOL TRAPS

S3 refers to a population selected by methyl eugenol through 3 generations and C3 refers to the control

Emergence	17 - 19 Jan. 1972		26 - 27 Jan. 1972		3 - 8 Feb. 1972	
Strain	C3	S3	C3	S3	C3	S3
No. released	922	2628	1240	455	2121	1843
No. recaptured	17	37	122	42	204	126
% recaptured	1.84	1.41	9.84	9.23	9.62	6.84

released into a field cage with methyl-eugenol traps. When about 90% had been caught, the remainder were transferred to a smaller cage and allowed to mate with normal females. Such selection was repeated for two successive generations. Figure 5 shows that the rate of recapture of the selected strain was lower than that of control flies.

A similar experiment was held with flies selected through 3 generations. Flies reared on an artificial diet through 3 generations were used as controls. As shown in Table II, the recapture rates of selected flies were again lower than those of control flies.

We now have data on four more generations and the results show that the selected flies were recaptured in a ratio consistently lower than that for control flies. In addition, experiments in a field cage gave similar results. A detailed description of these experiments will be published (Iwashashi, in preparation).

The fact that the selected flies were trapped at a lower rate than control flies does not necessarily mean the existence of methyl-eugenol-insensitive genes. Another possibility is that we selected flies with less mobility. As the effective range of methyl-eugenol fibre blocks is considered to be not so large, inactive flies may survive longer than active flies when the trap spacing is large. However, the fact that the selected flies were trapped at a lower rate than the control flies, even in a small cage, supports the possibility of insensitive genes.

TRAP SPACING

As a great many flies are attracted to methyl-eugenol-treated fibre blocks [9], one may conclude that methyl eugenol can attract flies at a long distance. The fact that some flies released in an area with many traps were recaptured in the same area several months after the release does not support this idea. An experiment carried out by Miyashita and Sekiguchi (personal communication) showed that the diameter of the effective range of a methyl-eugenol fibre block is less than 150 m for *Dacus dorsalis*. Thus there is a possibility that some flies entering a natural 'pocket' of habitat can survive for long periods. An experiment on the relationship

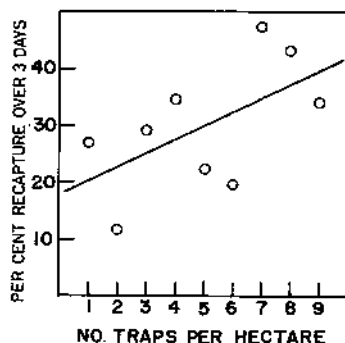


FIG. 6. Relationship between the trap density and the percentage of marked flies recaptured.

between trap density and the percentage of flies recaptured was made in March 1972 over a 4-ha area. The trap density was increased on every third day, progressively from 1 to 8/ha. Fifteen-day-old flies with different marks were released every third day and the per-cent recapture for each 3-day period was recorded. Although there were fluctuations due to climatic conditions, the per-cent recapture clearly increased with the trap density (see Fig. 6). The density of fibre blocks on Kikai Island was 150 per km² per month. Distribution of many more baits is suggested.

We have indicated that there are many problems to be solved in the eradication of *Dacus dorsalis* by the male annihilation technique. Our results show that the rate of capture with methyl-eugenol baits is not so high as has been believed in the past. The possibility of the existence of lure-insensitive gene(s) must be especially noted and studies must be done on this point in the near future. It should be noted that methyl eugenol is the strongest fruit-fly lure. The effect of the cue lure, for example, against *Strumeta cucurbitae* and *Dacus tryoni* is believed to be far lower than that of methyl eugenol against *Dacus dorsalis*. Thus we recommended to the government that the release of sterile males should be accompanied with the initial treatment of attractant baits and/or protein hydrolysates, not only for *Strumeta cucurbitae* but also for *Dacus dorsalis*. The Japanese Ministry of Agriculture and the Okinawa Prefectural Government decided to establish a ⁶⁰Co-irradiation apparatus in Okinawa Island this year to eradicate *S. cucurbitae* from Kume Island, which is some 200 km away from other islands inhabited by *Strumeta*. In addition, the Tokyo Metropolitan Government is now attempting to establish a ⁶⁰Co-irradiation apparatus in Ogasawara Island to eradicate *Dacus dorsalis* from the Ogasawara Islands.

Finally, we would like to suggest in conclusion that many more ecological studies on the population density, longevity, movement and genetic heterogeneity of fruit flies must be made in the near future.

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STATUS OF THE STERILE-INSECT RELEASE METHOD IN THE WORLD

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Abstract

STATUS OF THE STERILE-INSECT RELEASE METHOD IN THE WORLD.

The suppression of insect pests in the field by the sterile-insect release method (SIRM) is summarized. Some of the obstacles to the application of this method are reviewed. A number of misconceptions about the SIRM are analysed and refuted. The screwworm program in the Southwestern United States of America and Mexico is examined.

When I learned a few days ago that I had been assigned this ambitious title for discussion at this Panel, I was somewhat dismayed. It is difficult to keep up with research and field trials on the sterile-insect release method in my country and certainly impossible to know all that is going on in the rest of the world. I cannot hope to do justice to this topic, but I will endeavour to present a status report that summarizes my observations and personal opinions in this area. I sincerely hope that you will forgive me for any sins of omission.

I believe there is one thing upon which we all agree: As entomologists we have reached the crossroads in our endeavours in controlling insects that affect human and animal health and agricultural production. Our former reliance on pesticides is gradually being curtailed, not only by those sincerely concerned about adverse effects on the environment, but just as much by the problem of resistance. It is unlikely that this trend will be reversed in the future. In fact, a more realistic view would be to accept the idea that our reliance on pesticides will become even more restricted. Therefore, we find ourselves, to an increasing degree, seeking alternative methods of pest control. The sterile-insect release method (SIRM) has for some years been regarded as a promising alternative.

Critics of this technique can justifiably chastise us by pointing out that the only successful large-scale application of the sterile-male technique has been restricted to a single species of insect, the screwworm fly. Seventeen years have elapsed since eradication of this species from the island of Curaçao and 13 years since the species was eradicated from the Southeastern United States of America. The species was reported eradicated from the USA and British Virgin Islands in 1972 as a result of a program conducted by the Animal and Health Inspection Service (APHIS), USDA, in co-operation with the US Air Force, Special Operations Force. These agencies are at present conducting a similar screwworm program in Puerto Rico. The screwworm program in the Southwestern United States and Mexico, initiated in 1962, has been extremely successful. How much longer will it be before

TABLE I. DEMONSTRATION OF INSECT POPULATION SUPPRESSION FOLLOWING RELEASE OF STERILE INSECTS

Species	Test sites
<u>Ceratitis capitata</u> (Wiedemann) (Mediterranean fruit fly)	Hawaii, USA Capri, Italy Procida, Italy Tenerife, Spain Murcia, Spain Grenada, Spain Puntarenas, Costa Rica Carazo, Nicaragua Tacna, Peru
<u>Dacus dorsalis</u> Hendel (Oriental fruit fly)	Guam, Southern Marianas Saipan, Tinian and Agiguan, Southern Marianas
<u>Dacus curcubitae</u> Coquillett (Melon fly)	Rota and Guam, Southern Marianas
<u>Anastrepha ludens</u> (Loew) (Mexican fruit fly)	Tijuana, Mexico
<u>Dacus tryoni</u> (Froggatt) (Queensland fruit fly)	Warren, Australia
<u>Glossina morsitans</u> Westwood (Tsetse fly)	Lake Kariba, Rhodesia
<u>Hylemyia antiqua</u> (Meigen) (Onion maggot)	Wageningen, The Netherlands
<u>Culex fatigans</u> Wiedemann	New Delhi, India
<u>Anopheles albimanus</u> Wiedemann	Lake Apastepeque, San Salvador
<u>Haematobia irritans</u> (L.) (Horn fly)	Kerrville, Texas, USA
<u>Stomoxys calcitrans</u> (L.) (Stable fly)	Hague, Florida, USA
<u>Musca domestica</u> (L.) (House fly)	Latium, Italy Grand Turk, Bahama Islands
<u>Anthonomus grandis</u> Boheman (Boll weevil)	South-east USA
<u>Meiolontha vulgaris</u> F. (Cockchafer)	Vendlincourt, Switzerland
<u>Laspeyresia pomonella</u> (L.) (Codling moth)	Summerland, B.C., Canada Yakima, Washington, USA
<u>Heliothis virescens</u> (F.) (Tobacco budworm)	St. Croix, US Virgin Islands

TABLE I. (cont.)

Species	Test sites
<u>Heliothis zea</u> (Boddie) (Corn earworm)	St. Croix, US Virgin Islands
<u>Manduca sexta</u> (L.) (Tobacco hornworm)	St. Croix, US Virgin Islands
<u>Pectinophora gossypiella</u> (Saunders) (Pink bollworm)	San Joaquin, California, USA ^a

^a Sterile insects used to prevent establishment of species in area but not to suppress an established population.

similar success on another species is available? I will not endeavour to review all research contributions and field tests demonstrating the efficiency of the SIRM. All of us are familiar with these programs and most of them have been adequately documented in former panels and symposia published by the IAEA.

Table I briefly summarizes these field programs. The list is impressive and demonstrates that the release of sterilized insects has been repeatedly shown to be effective in suppressing insect populations in small and medium-sized field tests. Now we must determine whether the SIRM will be applicable for the suppression and possible eradication over larger areas, for what species it will be most useful, and when we can realistically begin its application.

Until a few years ago the major obstacle to the successful application of the SIRM to most insect species was the problem of mass-rearing. When the book, *Insect Colonization and Mass Production* [1], appeared, only three species of insects could be reared "by the millions". At present there are at least six laboratories capable of producing over 10 million medflies, Ceratitis capitata (Wiedemann), per week and the majority of these are in developing countries. Even previously difficult-to-rear species are being produced in large numbers. In laboratories of the US Department of Agriculture the production of boll weevils, Anthonomus grandis Boheman, is at present 1 million per week in a plant with a 15-million per week capacity. Production of pink bollworm, Pectinophora gossypiella (Saunders), exceeds 1.3 million per day, codling moths, Laspeyresia pomonella (L.), are produced at a rate of 3 million per year, and the production of the tobacco budworm, Heliothis virescens (F.) is 70 000 per day. The "Screwworm Plant", located at Mission, Texas, has a 200 million per week capability. The Canada Department of Agriculture laboratories can produce 2 million codling moths per month, and WHO laboratories in New Delhi are at present producing nearly 5 million Culex fatigans per week. Even the tsetse fly, Glossina morsitans Westwood, is being produced today in numbers that were undreamed of only a few years ago [2]. As the mass-rearing techniques have improved, rearing costs have decreased. For many species the inability to mass-rear per se is no longer the major obstacle to launching autocidal programs.

In spite of these advances, there is a great need to improve the quality of the insects produced, to make sure they are free of disease and fully competitive once released in nature. The fitness of the released insects should approach that of the native insects with which they will compete for mates. This may be very difficult to accomplish. In the process of colonization of an insect species certain characteristics important for survival in the wild are either selected against or at least lose their selective advantage under laboratory conditions. In either case deterioration of the laboratory colony over an extended period of time is expected.

Actually, we know very little about the components of fitness in nature. The relative importance of longevity, sexual vigour, ability to disperse, response to stimuli, or ability to locate food is difficult to assess. We do know that the genotypes present in nature are the most fit since they are the result of continued selection for all fitness components. Therefore, it appears reasonable that we should endeavour to release insects that genetically resemble the wild ones.

Loss of competitiveness can also be attributed to the irradiation treatment used to sterilize the insects. Except for a few well-documented problems, for example, the boll weevil cannot be sterilized with ionizing irradiation without drastic effects on longevity, much progress has been made in minimizing the detrimental effects of the sterilizing treatment [3-6].

One of the greatest achievements in recent years has been progress in dispelling some of the misconceptions about the SIRM. Perhaps, taken individually, these are not particularly impressive, but collectively they present some real progress in theory and planning for insect control. A few of these are enumerated below:

1. That the released insects must be completely sterile

It was formerly thought that the released insects must be completely sterile. This is not necessarily true. If the fully sterilizing treatment severely lowers the competitiveness of the released insects, serious consideration should be given to the possibility of utilizing substerilizing doses in order to increase competitiveness and to maximize the impact of the released insects. For certain species a slight residual fertility would be desirable in control programs (as opposed to eradication programs) if it significantly increased the competitiveness of the released males. The residual fertility in the males cannot have any adverse effect on the size of the next generation, provided that the females released simultaneously are sterile. Released insects can only increase the size of the next generation if the females are capable of producing viable eggs. When the adult stage is not damaging to crops, the release of males that are only semisterile but whose progeny are fully sterile may be more advantageous than the release of fully sterile males. Applications of this principle to Lepidoptera have been previously discussed [4, 7].

2. That the SIRM is applicable only on islands or in special ecological situations

Eradication of the screwworm fly from the Southeastern United States of America should disprove this idea. However, we are just beginning to appreciate that in many areas a species is often relatively or completely

isolated by ecological factors. For example, many agricultural pests are one-host species whose distribution is limited to areas where the crop is grown. Other species that cause damage over vast areas during some seasons are restricted to much smaller areas during other seasons. Many other examples of ecological isolation are known.

3. That the SIRM is feasible only in large-scale programs where total eradication is the objective

It is probable that long-term suppression of a species below economically important levels will be the goal in many future programs. Actually, many agricultural situations exist in which the SIRM could achieve extremely economical control by preventing build-up of the insect population to damaging levels without the use of pesticides. The overall impact of continued effective control over several years may provide a level of control that becomes increasingly more economical.

4. That the SIRM will be effective as the sole control technique

In most situations integration of the sterility approach with other chemical and biological methods would be preferable to any method used alone. Numerous possibilities for integration exist: Use of pesticides to lower the insect population before release of sterile insects; programs in which the sterile males produce the usual suppressive effects on the populations and the females produce inviable eggs that can support the growth of beneficial parasites; use of cultural methods to reduce density to relatively few per acre; use of attractants (male annihilation), pheromones, hormones, light traps, sound and many other suppressive measures. These diverse approaches could all be integrated into a pest-management system utilizing the best features of each method at the proper time.

THE SCREWORM PROGRAM IN THE SOUTHWESTERN UNITED STATES AND MEXICO

The campaign to suppress the screwworm fly in Southwestern United States of America and Northern Mexico was inaugurated in 1962. This campaign represents the major application of the SIRM in the world in scope and duration. A brief examination of the program may provide us with useful guidelines for our future programs.

Table II shows the incidence of screwworm cases reported in the Southwest during the past 10 years. During the period 1963-71 there was little doubt that an immensely successful operation was underway. Ten years of success in the control and near eradication of a major pest certainly constitutes ample proof that the sterile-male technique does work on an area-wide basis. From 1964-1971 it was generally agreed that self-sustaining populations of screwworm flies had been eradicated from the Southwestern United States and that most of the cases each year were attributable to immigrating flies from Northern Mexico. This year (1972) there has been the worst epidemic of screwworm cases since records have

TABLE II. INCIDENCE OF SCREWORM CASES REPORTED IN THE US SOUTHWEST^a

Year	Texas	Oklahoma	New Mexico	Arizona	California	Arkansas
1962	49484	444	1133	231	-	-
1963	4916	20	1447	728	-	-
1964	223	0	14	158	-	0
1965	446	0	122	465	7	0
1966	1203	0	93	509	70	0
1967	835	0	0	23	14	0
1968	9268	0	70	405	135	0
1969	161	0	18	32	8	0
1970	92	0	33	23	5	0
1971	444	0	0	4	0	25
1972	90980	1035	1254	2317	27	6

1972: Kansas 3; Florida 2; Louisiana 1.

^a These data are based on larvae identified and records compiled at Mission, Texas, by the Field Operations Section, Screwworm Eradication Program, Veterinary Sciences, Animal and Plant Health Inspection Service, US Dept. of Agriculture.

been kept. No one knows the exact reasons for this sudden reversal in a successful program. Several explanations are possible, and these are currently being investigated:

(1) Weather: The winter of 1971-72 was perhaps one of the mildest ever in the Southwestern USA. Conditions for continuous screwworm breeding were favourable much farther north than could be expected during average winter seasons; therefore, screwworm populations were much higher in Northern Mexico than during average years. Areas in Northern Mexico and Southern Texas that are normally semi-arid had unusually heavy rainfall and therefore supported abnormally high screwworm populations. Simultaneously, the number of flies released per unit area had to be reduced because of budgetary limitations.

(2) Changes in competitiveness of the released flies: Although there have been several attempts to maintain genetic variability and vigour in the release strain, it is possible that there was a significant deterioration of the laboratory colony.

(3) Genetic changes in the native population: Since the native population on the USA-Mexico border has been subjected to the pressure of sterilized flies for the past 10 years, there is, of course, the possibility that the native population could have evolved differences that would place the released flies at a serious disadvantage. If, for example, there was selection for earlier mating, changes in mating behaviour, location of mating, or other behavioural changes, the released insects could be isolated from the random mating pool to some degree.

I hasten to point out that despite a rather disappointing record during the past year the program is not doomed. There is no apparent reason why the success achieved in the years 1964-71 cannot again be attained. Loss of competitiveness of released flies because of laboratory adaptations can, of course, be reversed by substituting field-collected strains into the laboratory mass-rearing facility. If any genetic changes in the native population have taken place, the flies collected for the new laboratory colony would possess the same genotypes as the wild population and, therefore, would possess similar behavioural patterns. Loss of vigour because of changes in larval diet introduced several times during the course of the program can be resolved by reverting to the original successful production methods that originally produced effective, competitive flies. All these possibilities are currently being studied. However, it is premature to consider further changes or modifications in the program until recently inaugurated field and laboratory studies have produced additional data. Recently an agreement was signed between the Governments of Mexico and the United States of America for an extended program in Mexico to begin during the next year and on 7 February 1973 the joint Mexico-US Commission for Eradication of Screwworms was organized.

In closing, I am very optimistic that the SIRM will play a central role in the control, suppression and possible eradication of other species of insects. It appears that for the near future dipteran species may be the best candidates, although it should not be too long before Lepidoptera can be effectively controlled by this technique. Relatively clear-cut and easy successes similar to those achieved in early screwworm programs may be difficult to repeat. Further developments, particularly in the areas of insect colonization, field ecology, population dynamics and sterilization techniques, are required. The obstacles that must be surmounted in the application of this approach to the control of insect populations are certainly no greater than the obstacles present in other alternative methods of insect control.

ACKNOWLEDGEMENTS

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CONTROL OF *Ceratitis capitata* Wied. BY THE STERILE-MALE TECHNIQUE IN SPAIN*

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Abstract

CONTROL OF *Ceratitis capitata* Wied. BY THE STERILE-MALE TECHNIQUE IN SPAIN.

Since 1965 INIA has been carrying out a program for the biological control of *Ceratitis capitata* (Wied.) by the sterile-male technique. Preliminary experiments on the island of Tenerife and on the Spanish mainland (Province of Murcia) have shown that the method is effective when applied to small isolated areas. In 1972 a more extensive field experiment was carried out in the Province of Granada, in southern Spain. The main objective was to protect a semi-isolated area of about 100 ha (including 25 ha of regular peach orchards) exclusively by means of sterile-insect releases. The area is situated approximately 80 km from the coast at 950 m above sea level. Prior to the start of the experiment a study was made of the successive appearances of the pest from the south (on the coast), to the experimental area.

Between June and October a total of 40 million pupae were irradiated in Madrid 24 to 48 hours before emergence and transported to the experimental area by train. An estimated total of 25 million adults were released. From June to September the release cages were hung outside the plantations, around the periphery. When the earlier varieties had been harvested, releases were continued both outside and inside the plantation. No chemical treatment was applied.

Examination of the fruit during harvesting showed the following results: (1) in the earlier varieties not a single peach was found to be infested with *C. capitata*, (2) in adjacent reference areas (treated with chemicals) attacks by *C. capitata* on the same varieties and during the same period affected between 5 and 14%; (3) the late variety (Campiel) in the experimental area suffered infestation ranging from 0.5 to 1.6%. The results indicated that the application of the sterile-male technique was effective, and that it is possible to protect a relatively isolated area by releasing sterile insects around the periphery.

INTRODUCTION

1. Background

In 1965 INIA started a program for the biological control of *Ceratitis capitata* Wied., using the sterile-male technique. The ultimate objective is to develop a technique which, when suitably combined with conventional systems, would allow control of the pest while at the same time eliminating a number of the undesirable side effects (contamination of the environment, disruption of biological equilibrium) that result from the exclusive application of chemical insecticides.

From 1966 to 1969 a series of basic investigations were carried out with a view to improving mass rearing and sterilization methods [1-4]. At the same time small-scale field experiments were undertaken in order to study release methods and the effectiveness of the technique [3-7]. 1969 saw the first experimental attempt in Spain, in the province of Murcia, at controlling the pest in a small ordinary plantation of citrus and stone fruits by the exclusive use of the sterile-male technique. The results were

* This project has been assisted by the IAEA under Research Contract No. 848.

very satisfactory, showing that the technique is completely effective when applied to small isolated areas [4, 8]. During 1970 and 1971 the laboratory investigations [9] and field tests [10] were continued on a small scale for the purpose of studying some problems that have to be resolved before the method can be applied economically on a large scale: irradiation of adults; survival and dispersion of the sterile insects in the field; release methods; the occurrence of 'sterile punctures' in stone fruits; and ecological studies.

2. Present situation

In the light of the work described, the present situation can be summarized as follows:

(a) The tests carried out in 1969 showed that in sufficiently isolated areas the sterile-male technique can be applied on its own with complete effectiveness for the control of C. capitata, even when the native population is very large. As a single positive test is not sufficiently significant, however, it was decided to carry out a further field experiment in 1972, which is described in this paper.

(b) A problem encountered during the 1969 test was the occurrence of 'sterile punctures' in stone fruits caused by the irradiated females. The punctures do not affect either the quality or the wholesomeness of the fruit, but can spoil its external appearance to a certain extent. The 1970 and 1971 tests showed that except in some varieties of peach the sterile punctures are not visible to the naked eye and do not therefore constitute such a serious problem as was initially thought [11].

(c) The application of this method as the sole means of control is too costly at the present time. Improved techniques and mechanization of the operations involved in a large-scale program would obviously result in a substantial cost reduction. The use of the method as part of an integrated program for the control of low-density populations could be viable even in present circumstances.

1972 PROGRAM

1. Objectives

- (a) To confirm the effectiveness of the sterile-male technique for the control of C. capitata over a larger area than that treated in 1969 (and with different characteristics), using improved methods.
- (b) To study the times of occurrence of adult C. capitata over a very large area (approximately 200 000 ha) with a view to enlarging the experiments year by year.
- (c) To study the possibility of establishing a cordon sanitaire around a plantation exclusively by making peripheral releases of sterile insects.
- (d) To attempt to reduce the occurrence of sterile punctures by reducing the density of released insects inside the plantations.

2. Description of the area

On the coast of the province of Granada C. capitata is an endemic pest and, in view of the climatic conditions, is present in adult form all through

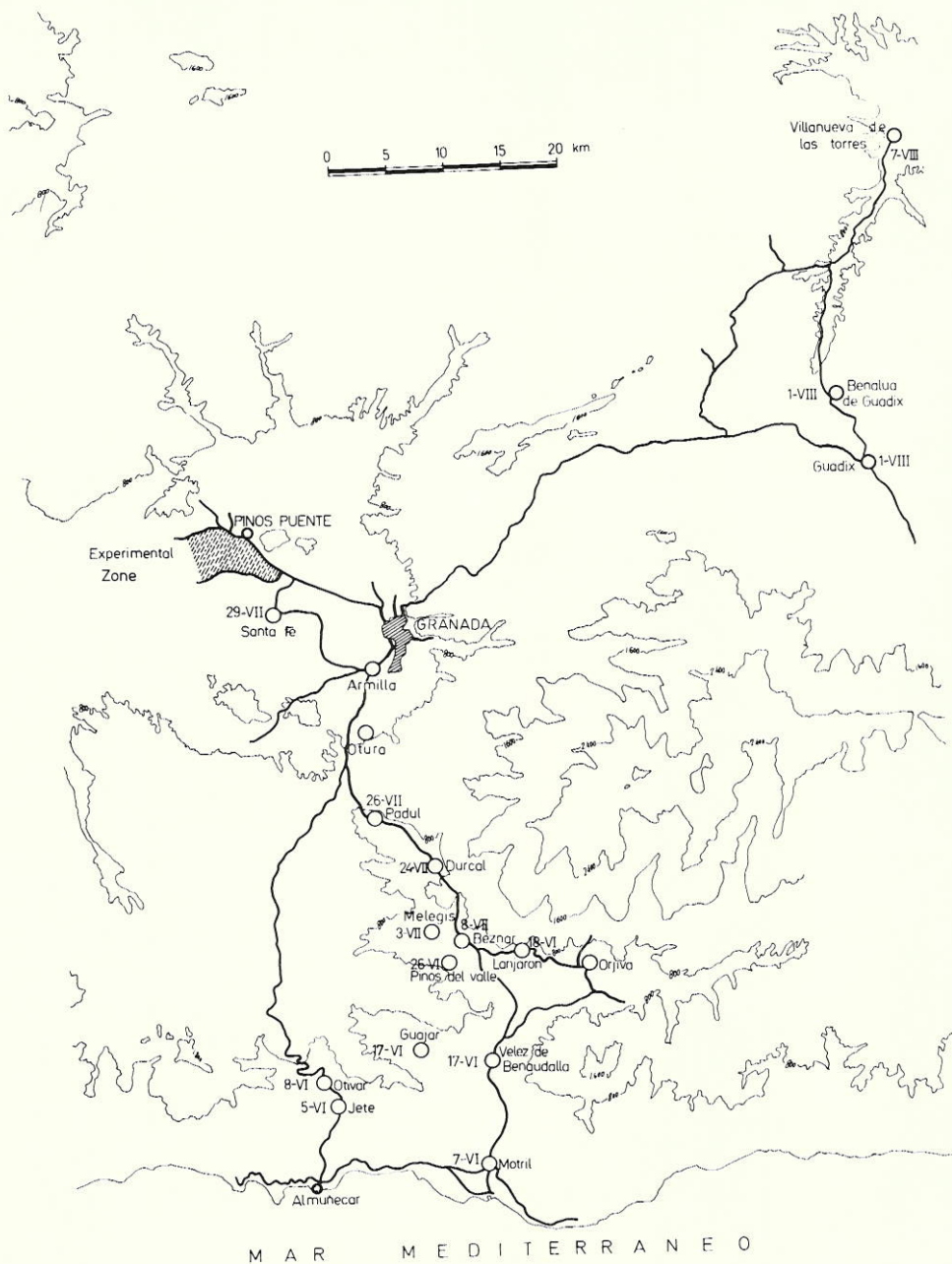


FIG. 1. General map of the survey area and situation of the 1972 experimental area. The dates indicate the first appearance of adult *C. capitata* at each place.

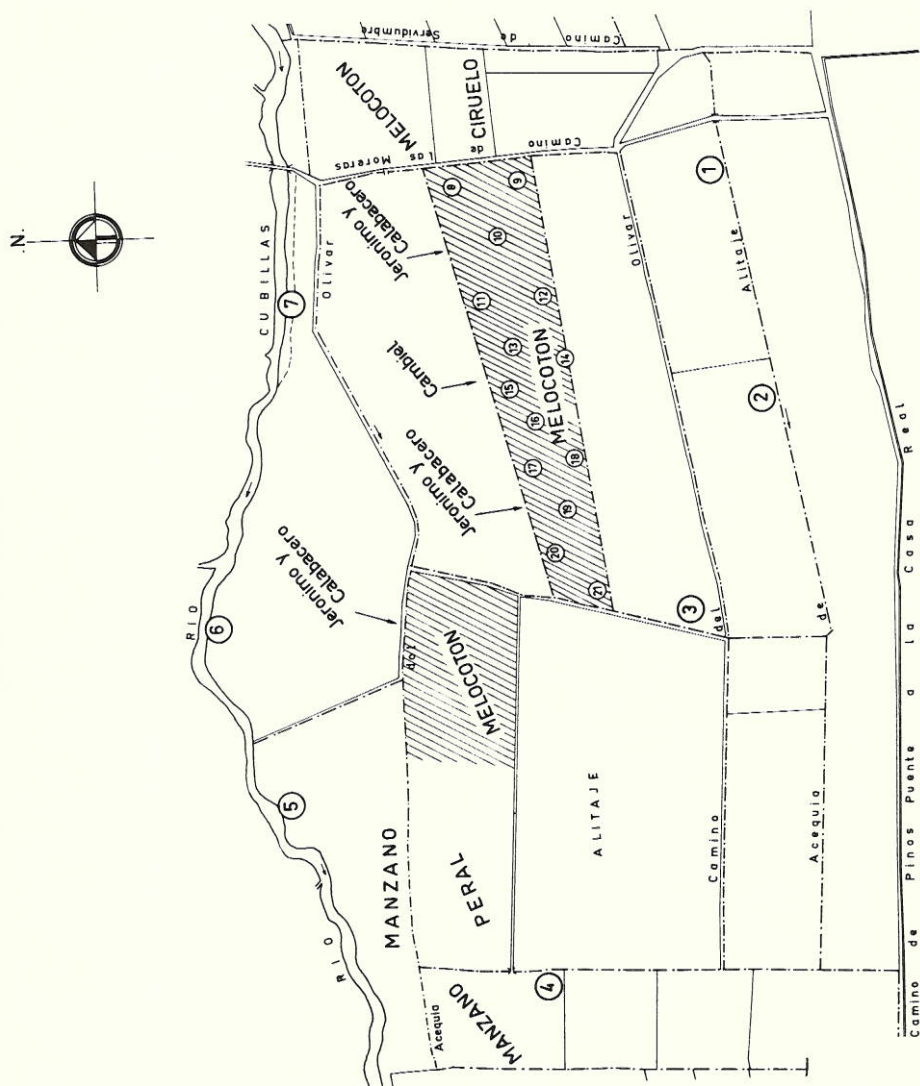


FIG. 2. Map of the experimental area. The shaded areas are those protected solely by the use of sterile males. The numbers indicate the location of the release points (three release cages at each point).

the year. In this area the important host plants are peach, apricot, orange and fig. Other fruit species characteristic of the area (and which are not found in the rest of the peninsula) are cherimoya, guava, mango and avocado. A wild host of great importance is Opuntia ficus indica [5].

Away from the coast the host plants are limited mainly to stone fruits in regular orchards. The early fruits normally escape attack by C. capitata. Attacks occur later in the season; it is assumed that this is due to the migration of the insect from the warmer coastal areas.

One of the objectives of the 1972 tests was to study the successive appearances of adults throughout the area between the coast and the interior (Fig. 1). This study was made easier by the geographical characteristics of the area. Although in effect we are concerned with a migration of insects from the coast, the only natural routes would be up the Lecrín and Almuñecar valleys. The latter is less likely because of its topographical characteristics, but it has nonetheless been included in the study.

The area for application of the sterile-male technique is situated at Pinos Puente in the Granada plain (850 m above sea level). Its total area is approximately 100 ha, including a regular peach plantation of 25 ha having approximately 10 000 trees in all spaced at 5 m intervals (Fig. 2). This area had already been subjected to a preliminary test in 1971, when a study was made of the cultivation and plant-health practices followed, and data were obtained on the field and normal losses due to the pest. In 1971, too, experimental sterile-insect releases were made in order to study insect dispersion and longevity [10]. New, more practical and economic release techniques were developed, and logistic preparations were made for the more extensive experiments of 1972.

The peach plantation in question contains the Jerónimo, Calabacero and Campiel varieties. The Campiel variety (approximately 600 trees) matures very late and is thus the most susceptible to attack by C. capitata¹.

The average total harvest obtained from these varieties is 220 000 kg, including approximately 25 000 kg of the Campiel variety.

Normally, attacks by C. capitata, like those of other parasites, can be controlled quite effectively by chemical means. A point to bear in mind, however, is that attacks by C. capitata occur at the beginning of the harvest; hence, in order to produce healthy fruit the treatments have to be almost continuous, with the result that the fruit may be contaminated by the time it reaches the market — depending on the type of insecticide used.

In a normal year, despite insecticide treatments, attack by C. capitata affects at least 5% of the early crop and between 13% and 17% of the Campiel variety.

The plantation offers very favourable conditions for biological control tests with sterile males. Although not topographically isolated, it is surrounded by herbaceous crops; there are no known host plants within a radius of approximately 5 km, apart from a few small isolated patches.

Plantations at Armilla and Santa Fe were chosen as the reference areas. In altitude, climate, topography and ecological conditions they are just like the Pinos Puente zone.

¹ The time difference between ripening of the Campiel and Jerónimo varieties is approximately 30 days. A complete new cycle of C. capitata can therefore occur, starting from the generation that had punctured the earlier varieties.

The main characteristics of the experimental and reference areas and the insecticide treatments carried out in them in 1972 are as follows:

- (1) PINOS PUENTE (experimental area)
Area of peach plantation: 25 ha
Age of trees: 5 and 8 years
Varieties: Jerónimo, Calabacero and Campiel
Treatments: No insecticide treatment applied since the beginning of the experiment.
- (2) ARMILLA (reference area)
Area of peach plantation: 4 ha
Age of trees: 3 years
Varieties: Jerónimo and Calabacero
Treatments: Two treatments (28 July and 12 August) with Labaycid and Buminal in patches, 0.5% and 0.5%.
- (3) SANTA FE (reference area)
Area of peach plantation: 8 ha
Age of trees: 6 years
Varieties: Jerónimo and Calabacero
Treatments: 1 treatment (3 August) with Labaycid.

3. MATERIALS AND METHODS

3.1. Capture of wild insects

Plastic fly traps containing an attractant (Trimedlure) and an insecticide (DDVP) were mounted at Jete, Motril, Otívar, Velez de Benaudalla, Guajar, Faragút, Lanjarón, Pinos del Valle, Melegís, Beznar, Durcal, Padul, Santa Fe, Benalua, Guadix and Villanueva de las Torres (Fig. 1). These locations were chosen on the basis of their geographical situation in the Lecrín valley and its side valleys in order to detect the possible insect penetration referred to above. Four fly traps were mounted at each of the places mentioned, in regular peach plantations. At some of the places there were other crops in addition: orange, medlar and apricot. All the fly traps were inspected twice a week and inspections were continued until the presence of the insect was established.

3.2. Release of sterile insects

In the experimental area of Pinos Puente sterile-insect releases were commenced at the beginning of June. All the insects were obtained from the Madrid mass rearing laboratory (El Encín), where they had been sterilized by radiation from the cobalt-60 source. The method used was the same as in 1971 [10]. The radiation dose applied was 8 krad ($\pm 12\%$). Irradiation was carried out 48 to 24 hours before eclosion. Transport was by rail (at night).

The insects were released from cages suspended from trees and made of a fabric mesh sleeve 50 cm in diameter and 1 m high with a plastic tray fitted at the bottom and a removable lid at the top. The irradiated pupae

were introduced into the bottom tray (approximately 50 000 pupae each time) and crinkled paper or the remains of local vegetation were added in order to avoid any heaping up of newly emerged flies.

Experience acquired in 1971 showed that these cages are easier to handle than the paper bags that had previously been used [5, 8, 10]. When cages are used, the adults make their way out of them as and when their turn for eclosion comes, so that the yield is maximum and the insects are released under better conditions. Moreover, savings on labour are made, and the whole distribution process is better controlled.

In the 1972 tests the release cages were located as shown in Fig. 2. From the beginning of the experiment in June until 1 September all releases were made exclusively from the 21 cages situated at points 1-7, i.e. those located on the periphery of the plantation.

From 1 September onwards releases were also made from points 8-12 and 17-25, which are situated in the sections containing the Jerónimo and Calabacero varieties (harvesting of which had already been completed by that time) and from points 13-16, which are situated in the sections containing the Campiel variety.

Except for some of the first consignments, none of the released insects were labelled or coloured as previous observations appear to indicate that these operations adversely affect the vitality and longevity of the flies in the field. Nor were the insects given food of any kind in the cages, in view of the results obtained in the 1971 tests [10].

The schedule of releases and the numbers of insects released are shown in Table I.

3.3. Checks on the fruit

In the experimental area and the reference areas samples were taken of the fruit as it was harvested (including fruit lying on the ground). The sampling was carried out by taking fruit from boxes at random and on various days during the harvest. Details of the number of peaches examined for each sample and the total harvest in each case are given in Table II.

4. RESULTS

Figure 1 shows the dates on which adult C. capitata made their first appearance at each of the places mentioned.

Table II shows data on attacks on peaches by C. capitata in the reference areas (Armillá and Santa Fe) and in the experimental area (Pinos Puente).

5. CONCLUSIONS

(1) Attacks by C. capitata on the earlier varieties of peach (Jerónimo and Calabacero) were zero in the experimental zone protected exclusively by sterile insect releases. (In previous years 5% of the fruit of these varieties was found to be affected despite conventional chemical treatments.)

(2) In the adjacent reference areas, attacks by C. capitata on the same varieties and during the same period varied from 5 to 14%, despite conventional chemical treatments.

TABLE I. RELEASE OF STERILE INSECTS

Date	No. of pupae	Percentage eclosion	Corresponding actual number of useful adults released	Remarks
June 6	300 000	89.4	208 200	-
9	300 000	72.3	216 900	-
14	300 000	65.7	197 100	-
18	100 000	32.1	32 100	Sharp temperature drop
24	200 000	28.3	56 600	Rain and wind storm
28	250 000	31.4	78 500	Low temperatures
July 1	300 000	45.7	137 100	Low temperatures
5	300 000	52.3	156 900	Low temperatures
7	375 000	64.1	240 375	-
12	300 000	60.3	180 900	-
20	300 000	62.3	186 900	-
22	300 000	0.0	0	Delay in transport
27	700 000	65.1	455 700	-
Aug. 1	1500 000	45.3	679 500	Low eclosion due to wrong
5	1800 000	56.2	1011 600	timing of irradiation in
9	1850 000	56.8	1050 800	relation to the cycle
12	1000 000	76.4	764 000	-
17	1250 000	75.9	948 750	-
19	1700 000	72.3	1229 100	-
22	1500 000	78.0	1140 000	-
24	1300 000	75.4	980 200	-
26	2200 000	68.3	1502 600	-
29	1600 000	71.4	1142 400	-
31	2100 000	69.3	1455 300	-
Sep. 2	1600 000	25.0	400 000	Gale (temperature drop and rain)
5	1600 000	45.0	720 000	-
7	900 000	64.3	578 700	Improved temperature
9	900 000	78.3	704 700	-
12	900 000	73.4	660 600	Good weather

TABLE I. (cont.)

Date	No. of pupae	Percentage eclosion	Corresponding actual number of useful adults released	Remarks
Sep. 14	600 000	76.3	457 800	-
16	900 000	68.7	618 300	-
19	900 000	79.6	716 400	-
21	900 000	59.2	532 800	Rain
23	2200 000	69.7	1533 400	-
26	1500 000	71.3	1069 500	-
28	1500 000	65.7	985 500	-
30	1500 000	53.4	801 000	Gale
Oct. 3	1000 000	25.3	253 000	Heavy rain
5	1000 000	32.5	325 000	Rain
7	1000 000	57.1	571 000	-
TOTALS	40 725 000	61.3	24 979 225	

(3) The two above conclusions would appear to confirm the hypothesis that it is possible to protect a relatively isolated area by creating a cordon sanitaire around the periphery, applying exclusively the sterile-male technique.

(4) The data in Fig. 1 clearly show the progress of the pest from the south (on the coast) to the north. It has still to be established conclusively whether these progressive appearances are due to migration of the insect, to eclosion in situ or to a combination of the two. Nevertheless, the three conclusions set out above would appear to indicate that the first hypothesis (migration) is the most probable.

(5) Medfly attack on the late variety of peach (Campiel) in the experimental zone varied between 0.5 and 1.6%. (In previous years the fraction of fruit affected had been of the order of 15%.) A direct comparison is not possible as there is no other plantation containing this variety in the vicinity of the experimental area. In these circumstances it is logical to suppose that there occurs an intense migration of adults from nearby plantations to this area, as it provides the main host during the period concerned. In view of this, we believe that the low percentages of fruit affected can be considered quite satisfactory.

(6) In the Jerónimo and Calabacero varieties no 'sterile punctures' visible to the naked eye were found. In the Campiel variety numerous punctures were observed, although they were not such as to create a serious problem. This would appear to confirm the hypothesis that the problem can be resolved if the times and places of release are suitably combined.

TABLE II. CHECKS ON FRUIT (PEACHES)

Place	Date	Harvest ^a (kg)	No. of peaches examined ^a	Condition of the fruit		
				Healthy	Attacks by <i>Ceratitis</i> <i>capitata</i>	Attacks due to other causes (insects, fungus, birds, etc.)
				%	%	%
<u>ARMILLA</u>	21-8	11430	1350	1202 (89.0)	67 (4.9)	81 (6.0)
Total harvest		11430				
<u>SANTA FE</u>	22-8	12700	1500	1211 (80.7)	151 (10.1)	138 (9.2)
	23-8	10260	1500	1326 (88.4)	72 (4.8)	102 (6.8)
	25-8	12080	1500	1141 (76.0)	219 (14.6)	140 (9.3)
	23-8	11660	1500	1286 (86.7)	122 (8.1)	92 (6.1)
Final harvest		86458				
<u>PINOS PUENTE</u>	21-8	14380	1500	1428 (95.2)	0	72 (4.8)
Jerónimo and	26-8	15720	1500	1409 (93.9)	0	91 (6.0)
Calabacero varieties	28-8	13860	1500	1394 (92.9)	0	106 (7.0)
	29-8	18700	1500	1419 (94.6)	0	81 (5.4)
Total harvest		220000				
Campel variety	25-9	640	899	271 (30.1)	15 (1.6)	613 (68.1)
(fruit from the ground	28-9	4150	2850	2586 (90.7)	15 (0.52)	249 (8.7)
before harvesting)	30-9	3560	2425	2189 (90.2)	21 (0.86)	215 (8.8)
(Harvest)	4-10	6200	4540	3897 (89.7)	45 (1.0)	398 (8.1)
	7-10	5800	3950	3584 (90.7)	54 (1.3)	312 (7.8)
Total harvest		28000				

^a Average: 1 kg = 7 peaches.

ACKNOWLEDGEMENTS

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THE POSSIBILITY OF APPLYING THE STERILE-MALE TECHNIQUE TO THE CONTROL OF TSETSE FLIES IN NIGERIA AND THE PROBLEMS TO BE FACED

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Abstract

THE POSSIBILITY OF APPLYING THE STERILE-MALE TECHNIQUE TO THE CONTROL OF TSETSE FLIES IN NIGERIA AND THE PROBLEMS TO BE FACED.

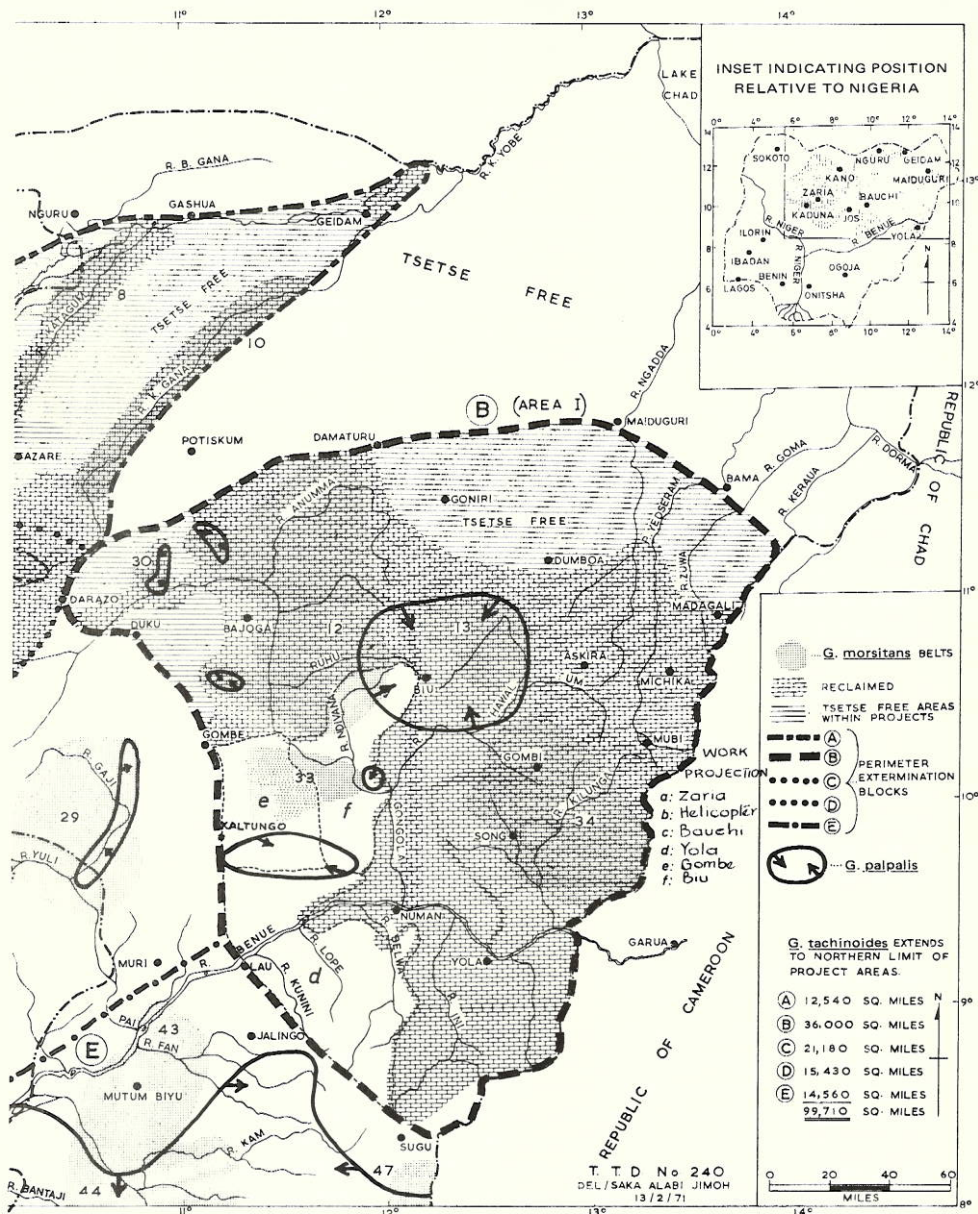
Previous methods and those still being used to control or eradicate the tsetse fly in Nigeria are briefly mentioned. The situations under which and the possible sites where the SIRM could be applied in Nigeria and the tsetse species that can be considered are also mentioned. It is concluded that the SIRM technique should continue to be investigated and tested to perfection, not only because this would silence the outcry against environmental pollution but also because it is not known when tsetse flies will develop resistance to insecticides.

INTRODUCTION

Tsetse control and eradication in Nigeria have in the past been effected by the modification of the habitat of the flies by clearing significant elements of the woody vegetation that afforded essential tsetse microclimates. This work was directed primarily against the riverine tsetse flies, *Glossina palpalis* (Robineau-Desvoidy) and *G. tachinoides* (Westwood). The most successful refinement was the method described as partial clearing [1]. In the early 1950s, however, the use of modern synthetic insecticides as a means of control and eradication came into being [2]. Since then insecticides (mainly DDT and Dieldrin) have been the main weapons used against the flies and, although their use in Nigeria is limited to a single application to the dry-season resting sites of the flies, nevertheless the outcry against environmental pollution being waged in the advanced countries makes it necessary for all workers in this field to try and find an alternative means of control and eradication. The sterile-male (biological control) technique could be this alternative means once the difficulties involved in making it effective are overcome.

POSSIBLE CASES UNDER WHICH THE METHOD CAN BE APPLIED

Under Nigerian conditions there are two possible cases where the method can be applied. First, it has been agreed that one case where this technique could be of use would be to exterminate the remnants of a fly population, the main portion of which had been initially exterminated by insecticide; for example, if a focus is suddenly discovered in the centre of an area already reclaimed from tsetse flies by means of insecticides. Secondly, the method could be of use in cases where isolated, circumscribed tsetse belts exist.



SPECIES AND POSSIBLE SITES

1. G. morsitans

At present there are really no naturally isolated belts of appropriate size remaining in the country. Experience of the re-invaded Anchau forest reserve following helicopter spraying shows how careful one has to be. Sub-belts of Belt 27 (Fig. 1) seem to be the only possibilities remaining, other than the larger Belt 29. The sub-belts could possibly be made more secure in their isolation by ground or helicopter spraying, though this has to be done at the cost of diverting resources from our planned extermination program. The extermination of Belt 29 by the SIRM would be a major and very valuable achievement, avoiding the outcry, which is certain if insecticides are used (Belt 29 is a game reserve), even though we believe little actual permanent damage would be done.

2. G. tachinoides

Two isolated but dense pockets just south of the Bauchi-Darazo motor-road existed. These have, however, recently been eliminated by spraying. More pockets can however be found on the upper reaches of the River Gongola (Fig. 1), particularly near Fedare. There is certainly also one and possibly more on the northern edge of Wase grazing reserves and one isolated pocket exists on the source of the River Karaduwa, which may, however, also be eliminated during the coming dry season.

3. G. palpalis

The only completely isolated G. palpalis pocket remaining is in the Yankari complex (Belt 29). The Tula-Dadiya focus will be sprayed this dry season. There are some much smaller possibilities on the rivers running northeast from Toro and probably also on the rivers running off the Plateau to the north and northwest. It may also be possible to find suitable areas on the southeast edge of the Plateau above Kwa/Kwang.

PROBLEMS TO OVERCOME

Problems that have to be overcome to make the sterile-male technique effective are quite numerous, both technically in the laboratory and out in the field. We have to be able to rear the flies in large enough numbers to get sufficient males to sterilize. A means of actually determining the size of the tsetse population in a given area has to be found so as to gauge accurately the number of males to be released. Additional difficulties in an operation of this kind (provided of course that the many technical laboratory and other procedural difficulties have been overcome) would be to obtain a population of flies that would survive in the locality in which they are released. For example, suppose G. morsitans was discovered in the middle of a reclaimed area in a Sudan vegetational zone in the north, would a population of males collected or reared from flies that came from the Guinea Zone further south be able to survive in a Sudan zone environment, even if they had not been

damaged in the process of sterilization? These are some of the difficulties envisaged that may crop up during the initial stage of using the SIRM before the whole technique is perfected.

CONCLUSION

In concluding, it is quite obvious that there is a great need to continue with the investigations being carried out towards perfecting the SIRM for the control of tsetse flies and other insects, not only because its effective use will silence once and for all the outcry against environmental pollution (with insecticides) but also because it is not known when resistance to insecticides will be developed by tsetse flies. Genetically it has been shown that tsetse flies have the ability to develop resistance to insecticides. At the moment the consensus of opinion is that no insecticidal resistance has been developed by tsetse flies and that the appearance of flies in an area otherwise believed to have been reclaimed from tsetse could be due to re-invasion from another focus or could be due to a focus that has been overlooked during the reclamation exercise. It is, however, agreed that even if the above is the case, it is only a matter of time before tsetse flies develop resistance to insecticides and therefore it is necessary to look for and perfect an alternative means of control and extermination.

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CODLING MOTH CONTROL BY THE STERILITY PRINCIPLE IN BRITISH COLUMBIA: ESTIMATED COST AND SOME BIOLOGICAL OBSERVATIONS RELATED TO COST*

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Abstract

CODLING MOTH CONTROL BY THE STERILITY PRINCIPLE IN BRITISH COLUMBIA: ESTIMATED COST AND SOME BIOLOGICAL OBSERVATIONS RELATED TO COST

The estimated annual cost of controlling the codling moth, *Laspeyresia pomonella* (L.), in a relatively large area (2220 hectares) by release of sterile moths is approximately \$153 per hectare, which is about twice the cost of chemical control. The most expensive single item is the release of the sterile insects from helicopter. This is about 39% of the total costs. Because rearing costs are high, particular attention is given to the relationship of the prerelease infestation to the numbers of sterile insects required for control. Four years' experience in a 40 ha apple and pear orchard indicates the replacement of codling moth sprays with the sterility principle may decrease the cost of controlling other pests; probably fewer mite and aphid sprays will be needed and the status of minor pests will likely remain unchanged.

Despite exceptionally promising results, British Columbia growers probably will not adopt the sterility principle of control for codling moth until costs are brought closer to those of chemical control. Costs may be appreciably reduced by releasing the sterile insects from the ground, by using less expensive ingredients in the larval diet (e.g. replacement of casein by soybean flour), and by fully mechanizing the rearing procedures.

INTRODUCTION

Limited experiments in British Columbia apple orchards during the mid 1960s indicated that the codling moth, *Laspeyresia pomonella* (L.), could be controlled by the release of radiosterilized moths [1-3]. Starting in 1969 the work was expanded to a 40-hectare pome fruit orchard to determine the feasibility and economics of commercial control. The present paper is devoted primarily to an analysis of the cost of control with observations on host plant preferences, moth dispersal and distribution and other factors that influence the numbers of sterile insects required for control. Details of the experimental procedures and results of the sterility program will be published elsewhere. It is sufficient to state here that codling moth suppression was excellent, for the percentage of apples injured by this pest at harvest was 0.1 in 1968 when three chemical sprays were used for control, and 0.05, 0.02, 0.007 and 0.0005 from 1969 to 1972, respectively, when codling moth sprays were replaced by sterile-insect release.

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RELATIONSHIP OF PRERELEASE INFESTATION TO NUMBERS OF STERILE MOTHS REQUIRED FOR CONTROL

Field work in the mid 1960s indicated that maintenance of a ratio of 10 sterile to 1 wild (fertile) male codling moth, as determined by traps baited with virgin females, was too low to prevent the wild population from increasing when conditions were favourable for reproduction. The overflooding ratio had to be increased to about 20:1. Although it has not been shown experimentally, it seems likely that if the control area is small and subject to immigration, the minimum ratio would have to be increased to 30 or 40:1. This increased ratio would counterbalance the effect of those wild female migrants already inseminated by wild males.

In the 40-hectare experimental orchard, for the years 1970 to 1972, the average ratio of sterile to wild moths caught in traps in any one trapping period (usually one night) never fell below 43:1, and under these conditions codling moth injury was reduced at least 50% each year, despite some reinfestation from outside areas. If sterile moths were released in a sufficiently large area (say about 2000 hectares in the narrow fruit growing valleys of British Columbia), the detrimental effect of inseminated females flying into the control area would be largely avoided or reduced to the point of insignificance. In such circumstances it seems reasonable to believe that a ratio of 40:1 would be more than adequate to induce a rapid downward trend in the wild population.

Maintenance of a specific ratio (40:1 in this instance) will depend primarily on the numbers of codling moths that overwinter successfully and on the numbers of sterile moths that are released at the peak of eclosion of the overwintered insects. With the persistent and very effective insecticides that are currently available against codling moth, it is relatively easy to reduce the wild population to extremely low levels within one year. The infestation, in terms of injured fruit at harvest, should be reduced to at least 0.05% in preparation for sterile-moth release the following spring. Most commercially operated apple and pear orchards will require two or three sprays and neglected host trees four or five sprays. Also, to achieve this level of infestation particular attention must be paid to trees near buildings, in gullies, and in other areas where an extra effort is needed to obtain good spray coverage. Wherever possible, neglected trees should be destroyed to avoid the expense of having to treat these potential sources of infestation with sprays or sterile moths in subsequent years. It may also be necessary to fumigate props that are used to support heavily bearing branches, for props are a preferred overwintering site for diapausing larvae.

Fruit examination over several years in British Columbia has shown that not more than 50% of the codling moth injury observed at harvest is caused by mature larvae that have left the fruit to overwinter. These larval exit holes are made by diapausing second generation larvae, and also by late-maturing first generation larvae, some of which also enter diapause and consequently are capable of overwintering. Apples attacked by early-maturing first generation larvae usually fall to the ground in June and July and consequently are not included in the harvest records. However, so few of these early-maturing larvae enter diapause that their contribution to the overwintering population is negligible.

There are other food sources that could theoretically contribute to the overwintering population. Immature apple and pear fruit that are removed

from the trees, to ensure satisfactory fruit size at harvest, are dropped to the ground where they often remain in good condition throughout summer. However, the codling moth does not seem to lay eggs on the fallen fruit. English walnuts do not appear to be used, as they are in California, as larval food for this insect. Peaches, apricots and cherries are sometimes attacked by this pest in British Columbia but only where they are adjacent to apple or pear trees that are severely infested. No other wild or cultivated host species of the codling moth has been found in the southern fruit growing areas of British Columbia. However, it has been reported that the codling moth is capable of completing development on the vegetative parts of apple and pear trees [4, 5]. Recent attempts to rear the insect on such food in the laboratory have been unsuccessful, indicating that if some larvae do mature on this diet in the field, their numbers are likely to be very small.

It may be concluded that in British Columbia the size of the overwintering codling moth population can be estimated reasonably accurately from the percentage of the harvested apple and pear fruits injured by this pest. Since not more than one-half of this injury is caused by fully grown larvae, 0.05% injury at harvest (the suggested maximum level of injury prior to initiation of a sterile-moth release program) means that a maximum of 0.025% of the harvested fruit has produced larvae that are potentially capable of overwintering.

Now, the annual yield of pome fruits (based on the years 1968, 1970 and 1971) in the interior of British Columbia is 653 million apples from 9700 hectares and 114 million pears from 1400 hectares. Taken collectively, this is an average of approximately 69 000 pome fruits per hectare. If 0.025% of this number yields mature codling moth larvae, this means that the potential overwintering population is about 17 larvae per hectare.

It is not known how much overwintering mortality occurs in these very low codling moth populations, but biotic and abiotic agents would likely kill at least 20% of the insects. This would leave a spring population of approximately 14 larvae per hectare.

In 1969 49 400 sterile moths (male:female=1:1) per hectare were released over a period of 22 to 23 weeks. The resulting fruit injury at harvest was 0.05% compared with 0.1% the previous year. The release period was unnecessarily long and maximum releases were not made at peak eclosion of the wild adults. If a release program was initiated when fruit injury was 0.05% (rather than 0.1% as in 1969) and if the release period was reduced to 20 weeks and releases were roughly synchronized with eclosion rate, then it should be possible to attain control with about one-fourth of the moths used in 1969, i.e. 12 350 sterile adults per hectare.

Trap records indicate that a maximum of 48% of an overwintered codling moth population could emerge as adults within a period of one week. (The average maximum emergence in a one-week period in three orchards in three years was 36%.) Consequently, if 14 larvae per hectare overwintered successfully, we could expect a maximum of $48/100 \times 14$ or 7 adult moths to emerge during a one-week period. At a constant release rate of 618 sterile moths per hectare per week (i.e. 12 350 moths per hectare in a 20-week period), the resulting theoretical minimum ratio of sterile to wild moths would be 618:7 or 88:1. However, it should be possible to double the ratio to 176:1 (even when allowances are made for losses of sterile insects because of the method of release, predators and so on) if the weekly release rate is approximately synchronized with the eclosion rate of the wild insect.

It must be remembered that when a codling moth infestation is low, the surviving insects are often limited to a very restricted area. In the present example, for instance, the seven wild moths that emerge in a one-week period may originate from only one or two trees. Since the sterile moths are released at a uniform rate per unit area (at least until the points of infestation are located) the effective ratio of sterile to wild moths will be appreciably lower than the average per acre ratio of 176:1. More information is needed on the dispersal of sterile males when they are released together with sterile females, but results with female-baited traps suggest that many of the sterile males move 33 metres or further within a few days [6]. Consequently, a realistic minimum ratio of sterile to wild males in the immediate area of the wild females may be about 40:1 rather than the theoretical 176:1 overall ratio.

To recapitulate, if fruit injury at harvest is 0.05%, the judicious release of 12 350 sterile moths per hectare the following year may be expected to yield a minimum ratio of about 40 sterile moths to 1 wild moth, which should induce a downward trend in the wild population. However, 12 350 sterile moths per hectare will be inadequate for control unless prerelease treatment (destruction of neglected host trees, chemical sprays and fumigation) is sufficiently thorough to eliminate hot spots of infestation. Also, the area under control must be large enough to virtually eliminate the problem of moth fly-in from outside.

ESTIMATED COST OF CONTROL

The annual operational cost of control in a small isolated area, at a release rate of 12 350 sterile moths per hectare, is currently about \$133 per hectare (Table I). This does not, however, include the salaries of an entomologist to manage the program and of a highly trained technician to supervise insect rearing. Upkeep and repair of buildings and equipment are also omitted.

There are approximately 11 100 hectares of apple and pear trees in the main fruit-growing area of British Columbia. Capital costs for rearing facilities and also annual operational costs would be too great to permit the whole area to be treated at one time with sterile moths. A more realistic approach would be to treat 2220 hectares at a time. It is estimated that after two years of release the wild codling moth population would be virtually eliminated. Release then would be discontinued in the first 2220 hectares and started in the next adjoining block of 2220 hectares. (Moth release would have to overlap adjacent blocks if they were not sufficiently separated to prevent wild moths from reinvading the first block.) Following this schedule it would take 10 years to treat the entire pome fruit area. Pockets of reinfestation would likely occur, but these could be eliminated by reintroducing sterile moth-release in these small areas.

The estimated annual operational cost of control in 2220 hectares (Table II) would be about \$139 per hectare, including the salaries of a permanent maintenance man, a specialist for insect rearing and a project manager. The repair and upkeep of buildings and equipment are also included, but not amortization of the capital costs of the moth production and sterilization facilities.

Now, the current yearly cost of codling moth control by chemicals in British Columbia, on the basis of a survey of 23 growers in 1971 and 39 in

TABLE I. CURRENT OPERATIONAL COSTS PER HECTARE PER SEASON (6 MONTHS) FOR CODLING MOTH CONTROL IN 40 HECTARES AT A RELEASE RATE OF 12 350 STERILE MOTH PER HECTARE^a

	\$
Helicopter rental at \$120/h (60 moth releases/season, 25 min/release)	75.00
Larval food with calco oil red to mark the moths (12 350 moths for release and 2200 to maintain the colony)	20.28
Paraffin wax to spray surface of larval food	0.12
Chemicals for cleaning and disinfecting	0.15
Replacement of larval food trays	2.47
Wax paper for oviposition cages	0.40
Power, light and water	1.85
Pheromone-baited traps (1 per 1.6 ha)	0.74
Automobile (estimate)	1.48
Labour: 5 semi-skilled men for insect rearing at \$3.63/h	15.24
3 technicians to irradiate, release and trap moths, and to conduct quality control work (estimate)	14.82
	<u>\$132.55</u>

^a Not included are salaries for a highly trained technician to supervise the insect rearing and for an entomologist to supervise the entire program. Upkeep and repair of buildings and equipment are also omitted.

TABLE II. PROJECTED OPERATIONAL COSTS PER YEAR IN 2220 HECTARES AT A RELEASE RATE OF 12 350 STERILE CODLING MOTHS PER HECTARE

	\$
Helicopter rental at \$96/h	133 200
Materials and supplies	52 600
Power, light and water	5 400
Repair and upkeep of buildings and equipment	15 000
Labour: 1 entomologist to supervise the program	15 000
1 highly trained technician to supervise insect rearing	9 000
1 maintenance man to service and repair equipment	9 000
3 semi-skilled men for insect rearing (6 months) at \$4000 each	12 000
7 unskilled men for insect rearing (6 months) at \$3500 each	24 500
5 high school students to trap and identify moths (18 weeks) at \$2000 each	10 000
3 technicians to irradiate and release the moths, to conduct quality control work for 6 summer months, and to rear insects and repair equipment for 6 winter months at \$7800 each	23 400
	<u>\$309 100</u>
	Cost per hectare = \$139.23

1972, is \$78.65 per hectare on apples and \$60.50 on pears (average of 2.6 sprays on apples and 2.0 on pears; cost per spray was \$12.05 for insecticide and \$18.20 for applying the spray). Considered collectively, the average cost of chemical control on pome fruits (9700 hectares of apples and 1400 of pears) works out to \$76.36 per hectare. However, this figure should be reduced about 10% (to \$68.72) because non-bearing trees are not sprayed for codling moth. This 10% saving cannot be realized with the sterility method of control if the moths are released from aircraft. It is too difficult, with the typically small orchards of British Columbia, to determine when the insect metering equipment should be stopped and restarted so as to avoid releasing moths over non-bearing blocks of trees. The annual operational cost of the sterility method of control, with the current aerial procedure of moth release, therefore remains at \$139 per hectare which is about 2.0 times that of chemical sprays.

Implementation of the sterility method for codling moth control may result in some reduction in the numbers of sprays required for other pests, though the saving would be less now than about five years ago. In recent years some species of predacious mites have developed a tolerance to the organic phosphate insecticides that are used for codling moth control. If these insecticides are used at the minimum dosage required for control, the predacious mites usually survive in sufficient numbers to prevent the phytophagous species from reaching injurious levels. The advantage of this tolerance will be lost, however, if the codling moth becomes resistant to organic phosphates, for then a new chemical group of insecticides would have to be introduced for moth control. The predacious mites probably would be decimated by the new insecticides with a resulting flare-up of injurious phytophagous mites, which would then have to be suppressed by special additional sprays.

During the four years of sterile-insect release in the 40-hectare orchard the numbers of sprays needed for pest control on the apple trees were generally fewer than the numbers required — excluding those for codling moth — in neighbouring orchards. Each year the apples in the experimental orchard received dormant oil, alone or with ethion, at the green tip stage of bud development for Quadraspidiotus perniciosus (Comstock). Also, every other year diazinon or azinphosmethyl was required at the pink bud stage for Archips argyrospilus (Walker), and during the fourth year of release (1972) a summer spray of endosulfan was applied for Typhlocyba pomaria McAtee which was particularly troublesome throughout British Columbia in 1972. No other sprays were needed for pest control on the apples. In neighbouring apple orchards the spray program for Q. perniciosus, A. argyrospilus and T. pomaria was essentially the same as in the experimental orchard. However, many of these orchards also required an annual summer spray for aphids or mites. With the exception of the codling moth sprays, the spray program in the experimental pear trees was fairly similar to that in neighbouring pear orchards. Some saving was realized in a reduction in the numbers of mite sprays in two years, and in the total absence of aphid sprays, but one spray was needed annually for control of one or more species of sawflies. However, the experimental block of pear trees has had a long history of annual sawfly infestation and no sawfly problem has arisen in other pear orchards under programs of sterile codling moth release.

It seems reasonably safe to conclude that in the absence of codling moth sprays most growers would save an average of at least one mite or aphid

spray every two years. If one-half the cost of this spray is added to that of the codling moth sprays, the total annual cost would be \$83.72 per hectare. However, where codling moth sprays are omitted, a special spray may be needed every four or five years for Grapholitha prunivora (Walsh) or for some other potential pest. Consequently, it would seem reasonable to reduce the \$83.72 per hectare to about \$76. This would make the operational cost of the sterility program about 1.8 times that of a chemical spray program.

The capital cost of a suitable rearing facility is not known accurately at this time. However, on the basis of the money spent on the present facility and from the experience gained in operating this complex, it is estimated that a building of about 700 square metres would be needed to produce the sterile insects required for annual control in 2220 hectares and that such a fully equipped structure (including the irradiator) would cost approximately \$300 000. If the building was used for 10 years, this capital expenditure would add \$13.51 per hectare to the annual cost of the program. Thus the estimated total cost of control per year by sterile-moth release would be \$152.74 per hectare, which is 2.0 times that of chemical sprays.

Introduction of a sterility program of control would result in a number of fringe benefits. The absence of such things as environmental pollution by persistent codling moth insecticides, insecticide hazards to orchard workers, birds and other animals, and problems associated with residue tolerances at harvest, would be given some consideration in the final analysis but it is impossible to put a specific dollar value on such benefits.

POSSIBLE METHODS OF REDUCING COSTS

There are a number of ways in which it should be possible to reduce costs of control by the sterility principle. Under current operating conditions in the 40-hectare orchard the cost of helicopter rental (at \$120 per hour) represents 57% of the operational expenses (Table I). To treat 2220 hectares the projected cost for a helicopter (at \$96 per hour) is still very high — 39% of the total cost of the entire control program (Table II). Results of codling moth release with fixed-wing aircraft have not been encouraging in the USA [7], but more recent work in British Columbia suggests that this less expensive method of release should be re-examined. Even greater savings may be possible by ground release from inexpensive all-terrain vehicles fitted with low-pressure tyres. These vehicles can be driven over irrigation pipes and on relatively rough terrain and are low enough to permit easy passage between tree rows.

The flight lanes currently used during release are 30 metres apart. However, results with female-baited traps [6] suggest that sterile males, particularly when released without sterile females, disperse sufficiently rapidly to allow the lanes to be moved farther apart.

Recent experiments indicate that the cost of the larval food may be reduced 35% by replacing most of the casein in the present dietary medium [8] with a mixture of soyflour and gluten, by substituting acetic acid for citric acid, and by replacing Wesson's salts with a simplified mineral mixture.

Further mechanization of the rearing procedures, particularly an improved system for adult moth collection and better methods for transporting trays of larval food from one area to another, would affect considerable savings in labour.

Until these and other methods are introduced to bring the operational costs of the sterility procedure more in line with those for chemical control, it seems unlikely that release of sterile codling moths will be accepted and adopted by fruit growers in British Columbia for commercial control of this pest.

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CURRENT VIEWS REGARDING THE APPLICATION OF THE STERILE-MALE TECHNIQUE FOR THE CONTROL OF CODLING MOTH IN AUSTRIA

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Abstract

CURRENT VIEWS REGARDING THE APPLICATION OF THE STERILE-MALE TECHNIQUE FOR THE CONTROL OF CODLING MOTH IN AUSTRIA.

Investigations were carried out on the number of codling moth generations in various climatic regions of Austria. In these investigations it was possible to prove the presence of codling moth in altitudes of 1200 m (above sealevel) and also the occurrence of a second generation at an altitude of 900 m (above sealevel). The latter was surprising, as one would expect that at these altitudes the occurrence of a second generation would be prevented by the low temperatures. However, it seems that a second generation at these high altitudes cannot be explained by the effective temperature and the photoperiodicity only. Therefore investigations were carried out to use total radiation as a parameter for the occurrence of a second generation at high altitudes.

Investigations were also carried out on the practice of genetic control in Austria. In Kirchberg a. Walde, Styria, an apple orchard proved to be very well suited for such a program, because of its topography and the low population density of the target species.

1. INTRODUCTION

The control of codling moth is very important in nearly all fruit-growing areas in Austria. In many orchards the control of this pest, in addition to apple scab, is regarded as the key factor for successful fruit growing.

Depending on the topography and ecological situation in Austria, however, the intensity of the infestation and the population density of the pest are very variable. This is shown mainly by the differing number of generations, which varies from year to year [1].

Before practical tests for the application of genetic control can be started, it seems necessary to get a general view of the yearly change in generations. Therefore we commenced investigation on this topic in various climatic regions of Austria.

2. NUMBER OF CODLING MOTH GENERATIONS IN VARIOUS CLIMATIC REGIONS OF AUSTRIA

The beginning of diapause in the codling moth is governed by photoperiodic inductions [2-6]. A second generation of codling moth in Austria (48° N) therefore commences not later than 1 August (16½ hours daylight). In view of this, we investigated to what extent one or two generations will develop since this seemed to be very important for the use of the genetic control of codling moth in different areas of Austria.

TABLE I. IMPROVED SCHEDULE OF STRIP EXAMINATION

Corrugated cardboard strip No.	Date of fixing	Date of removal	Strips remained on the tree until
1	71-05-20	71-07-01	71-10-15
2	71-07-01	71-07-20	71-10-15
3	71-07-20	71-08-15	71-10-15
4	71-08-15	71-10-15	71-10-15

2.1. Methods of investigation

In different altitudes of the Austrian apple-growing area corrugated cardboard strips were fixed to the trunks of the apple trees at the beginning of June and removed in the middle of October of the same year. These strips were then searched for pupae or the remains of pupae. The presence of a pupa integument or the remains of a pupa integument on a control strip was taken as proof that at least larvae were able to develop into a second generation.

In 1971 this method was improved in some places by fixing and removing the strips repeatedly during the season in the following way. Four corrugated cardboard strips were used successively and were fixed and removed as shown in Table I. After the strips (except No. 4) had been removed from the trunks, they were put into plastic boxes, which were hung in the shady parts of the tree tops for further observation of the generation dynamics.

This repeated collection of the 4 cardboard strips improved the chance of obtaining pupae integuments and moths of the second generation for identification. The more precise data would be useful as a parameter for the occurrence of a second generation.

2.2. Results of the investigations

In 1970 the investigations were carried out in 133 and in 1971 in 75 places at various altitudes and climatic regions of the Austrian apple-growing area.

It was found that the codling moth may occur in Austria up to an altitude of 1200 m (above sealevel) (e.g. St. Ulrich am Pillersee, Tyrol). It was also found that in altitudes up to 500 m a partial second generation is almost a certainty. This second generation can be extremely extensive in local areas.

In addition, it was observed that in 1970 as in 1971 a second generation developed locally at altitudes up to 900 m (above sealevel) (Fig. 1).

This result was surprising, as one would expect that at these altitudes in Austria the occurrence of a second generation would be prevented by the prevailing low temperature in connection with the photoperiodism.

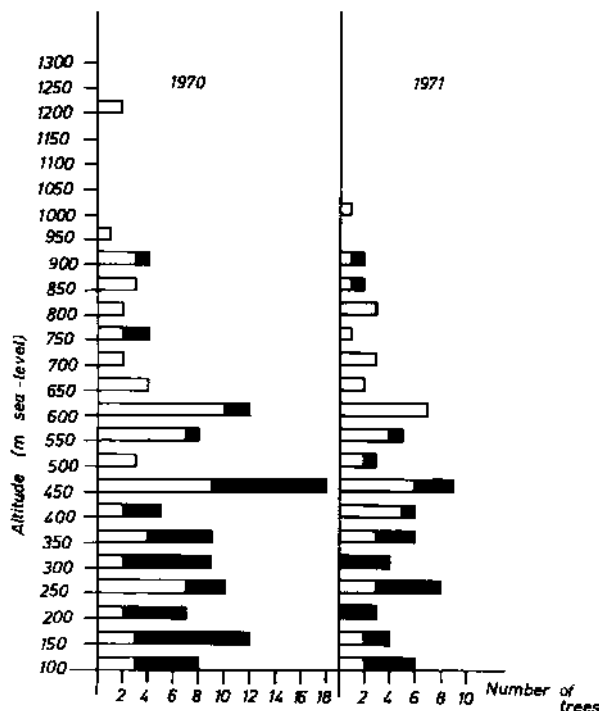


FIG. 1. Occurrence of a second generation at various altitudes in Austria. □ only one generation found; ■ two generations found.

Because in such extreme altitudes the occurrence of a second generation — even if it is very poor — could not be explained by the temperature situation only, we tried to use the 'global radiation' as a parameter for the occurrence of a second generation.

Because of the photoperiodic limitation, codling moth larvae in Austria do not finish their metamorphosis after 1 August nor develop a second generation under natural conditions. This statement is identical with the fact that the critical day length is in this case approximately 16.5 hours (civil twilight plus possible duration of sunshine). If the day length is less, and this is the case from approximately 1 August on in Austria, the larvae are forced into diapause.

To enable the larvae to finish their metamorphosis before this critical day, proper temperature conditions must prevail to ensure the complete development of the larvae to the prepupal stage.

According to our research, 525 degree-days ($^{\circ}\text{C}$) — counted from the beginning of the year (sum of the mean temperatures above $+10^{\circ}\text{C}$) — are required for the full development of the larvae of the first (hibernating) generation in the field.

If these 525 degree-days are not reached by 1 August, one can assume that the codling moth will not be able to develop a second generation, because all larvae hibernate in diapause.

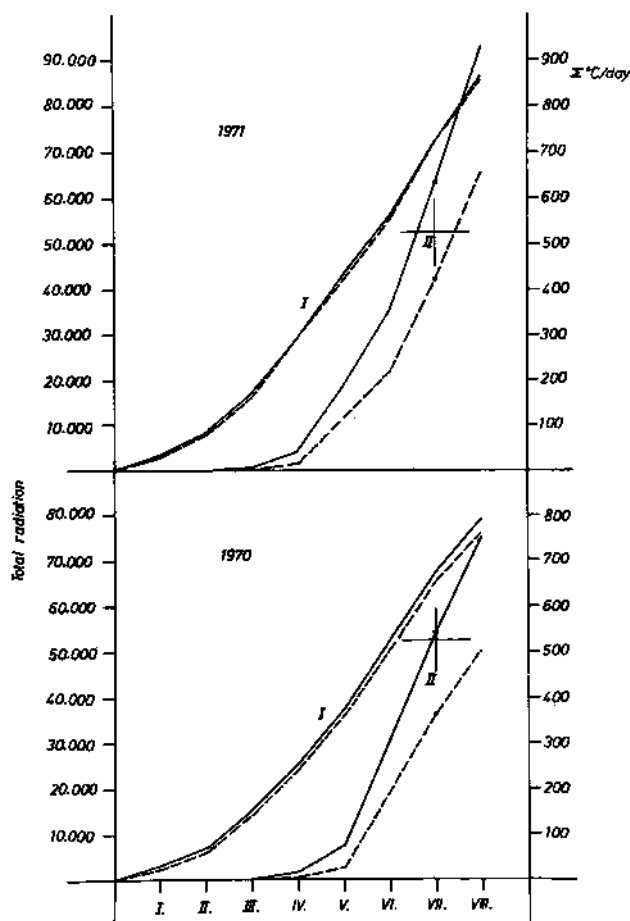


FIG. 2. Total radiation (I) and effective temperature (II) from Innsbruck (570 m) and Rinn (900 m) in 1970 and 1971.

This prerequisite — the critical effective temperature sum of 525 degree-days — will undoubtedly be reached nearly every year in altitudes up to approximately 500 m (above sealevel), but this is not the case in higher altitudes. In such habitats it seems to be more difficult for the codling moth to develop a second or further generation. But both in 1970 and 1971 the occurrence of a second generation of the codling moth could be observed, e. g. in Zams, Tyrol (550 m above sealevel) and in Tulfes, Tyrol (900 m above sealevel). As it could be assumed that at least in Tulfes (900 m) neither in 1970 nor in 1971 were the temperature conditions sufficient for the development of a second generation, both places were compared with regard to the effective temperature sum and the 'total radiation'.

The following results could be observed: In both 1970 and 1971 the effective temperature sum, e. g. of Rinn (900 m) (being the closest station to Tulfes), was far lower than the critical effective temperature sum of 525 degree-days necessary for the development of the second generation before 1 August and, on the other hand, in 1970 the corresponding effective temperature of Innsbruck (570 m) (being the closest station to Zams, 550 m) was only just above the critical temperature, but in 1971 it was far above this value. According to this observation, a second generation could be expected nearly every year in Innsbruck (570 m) and in Zams (550 m) (Fig. 2). Our own investigations showed this to be the case in 1970 and 1971.

2.3. The influence of the 'total radiation' on generation dynamics

As already mentioned, a partial second generation was found in Tulfes (900 m) (3 km from Rinn, 900 m, the nearest meteorological station to Tulfes). The observed area at Tulfes, where we found a second generation in 1970 and 1971, represents an extremely high-altitude apple-growing area and is situated in a very sunny high site in the Inn Valley. The temperature situation is favourably influenced by the well-known warm 'Föhn' winds. Nevertheless, this favoured climatic situation did not seem to be a sufficient explanation for the occurrence of a second generation and when we compared the total radiation (Fig. 2) of Innsbruck and Rinn it could be shown that these values were nearly identical.

This similarity of the 'total radiation' is certainly not a reliable criterion for the possible existence of a second generation in all these places, even at altitudes of 900 m (Tulfes). However, it does seem to suggest that by using the 'total radiation' as parameter in future a better explanation can be given for the occurrence of a second generation than by comparison of the total effective temperature alone. It also seems certain that radiation is not as important at lower altitudes than at higher altitudes. At very high altitudes the intensive total radiation affects the ecosystem immensely.

Therefore it can probably be stated that the codling moth in Austria is able to exist up to very high altitudes, probably up to the upper limits of the apple-growing area. By making use of the high 'total radiation', this species is able to develop a second generation at particularly favourable places, even at high altitudes.

The existence of local strains that are able to produce a second generation by being adapted to high altitudes and lower temperatures, remains for future investigation.

3. RESEARCH ON MAKING USE THE GENETIC CONTROL METHOD IN AUSTRIA

Genetic control is planned as soon as possible in connection with an integrated control program in an apple orchard in Kirchberg a. W., Styria (500 m above sealevel).

An ecological investigation of the special conditions was first started there in the 1972 season. It was shown that the chosen area is especially well suited for the genetic control of the codling moth because it is completely isolated and surrounded by forests, which exclude codling moths not belonging to this biotope.

Investigations of the population density revealed a very low codling moth population in this orchard. The average infestation in 1972 was not more than 8.8% in completely untreated lots.

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PRESENT STATUS OF THE PERUVIAN PROJECT ON MEDITERRANEAN FRUIT FLY CONTROL BY THE STERILE-MALE TECHNIQUE

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Abstract

PRESENT STATUS OF THE PERUVIAN PROJECT ON MEDITERRANEAN FRUIT FLY CONTROL BY THE STERILE-MALE TECHNIQUE

A brief review of the attempts for controlling or eradicating the Mediterranean fruit fly, *Ceratitidis capitata* (Wied.), by the sterile-male technique in the isolated valleys of southern Peru from 1969 to 1972 is made. In addition, information is provided about the efforts for adequate installations, various transportation systems and for building up a new factory for rearing medflies.

1. INTRODUCTION

At the panel meeting on Application of the Sterile-Male Technique to the Eradication or Control of Harmful Species of Insects held in 1968 [1] the author presented a brief survey describing the work carried out — from the start of the project in 1965 until the beginning of 1968 — not only on the Mediterranean fruit fly, *Ceratitidis capitata* Wied., but also on the South American fruit fly, *Anastrepha fraterculus* Wied., and the cotton stainer, *Dysdercus peruvianus* G. Since then the project on the last-mentioned pest has been discontinued, while those on *A. fraterculus* Wied. and *C. capitata* Wied. have grown considerably larger and are now accordingly being treated as separate projects. For this reason, I shall here deal briefly with the work performed by the team of professional officers, technicians and workmen charged with the Mediterranean fruit fly project.

2. BASIC LABORATORY WORK

2.1. Development of a larval diet for Peru

The OIRSA larval diet still contained imported constituents such as Nipagin, torula type B yeast and wheat germ. In our earlier report we referred to the replacement of wheat germ first by torula yeast and then by unicellular fodder yeast [1]. More recently, during 1969 and 1970 Ramos and Vargas [2] succeeded in replacing Nipagin by sodium benzoate and in regulating the quantities of water, yeast, bagasse, HCl and sugar so as to obtain a very cheap Peruvian diet such that a million pupae would cost only US \$10.90 (allowing 15% recovery of pupae from eggs). It would thus have been possible to reduce the cost of the diet needed for a million pupae by more than 95%. Unfortunately, in practice there have been some setbacks in the production of this diet, especially for lack of adequate air-conditioning, which resulted in infestation by *Drosophila* and in fungus infections.

2.2. Determination of irradiation dose and competitiveness

In the tests carried out by Ramos, Vargas and Alcola [2] during 1968, 1969 and 1970 it was found that 8 kR could give 99.04% sterility and 10 kR 99.08%. However, mating ability was inversely proportional to the dose used. For this reason, we introduced the competitiveness factor and found that with a 50:1 ratio sterility was inversely proportional to irradiation dose. Considering these results and those obtained elsewhere in the world [3-5; Lindquist, personal communication], we decided, after Dr. Fried's visit to Peru, to reduce the irradiation dose from 10 to 9 kR and we are now planning to reduce it further to 8 kR if the field tests to be carried out in the summer of 1973 yield positive results.

2.3. Determination of the colour of dyes for marking irradiated pupae

Vargas in 1968 and Picho in 1969 carried out tests in which pupae were marked with fluorescent dyes of various colours and found that with 4 g of dye per litre of pupae the toxicity was 57% for green, 47.5% for red, 42.0% for yellow, 24.5% for blue and 23.0% for pink.

Blue was rejected since it did not permit rapid identification of the flies and pink because flies dyed with this colour produced eggs of very low viability. Yellow (arc yellow) was chosen as the regular dye for marking irradiated flies since it enables one to differentiate the flies easily without special training.

3. BASIC FIELD WORK

3.1. Curves of annual fluctuations in population

After the first annual curve had been obtained for Tacna in 1968, a few experimental releases were performed between January and April 1969.

The annual curve for Tacna was based on 450 Steiner traps, which were in position until May 1969 and were rebaited for one month in July; from November 1969 their number was reduced to 275. The curves for native flies reflecting the effects of sterile insect releases and/or the application of insecticides indicate August to December as the period of lowest population while those plotted without such interference indicate the lowest population in the December-March period. The population rose in April and May, when the harvesting of the host fruits was completed. These results cast doubt on the effectiveness of the trap used as an index of normal population in the field.

In Moquegua 446 traps were used in the release area of 2304 ha (9 square miles) during 1969-1971. Towards the end of 1971 the number was reduced to only 104 Steiner traps in the release area and 64 in the rest of the valley (measuring 1464 ha or 5.72 square miles): altogether 168 Steiner traps, which figure has remained unchanged.

The lowest population was observed in the period between June and October in the release area, where all fruit trees had been subjected to intensive treatments with insecticide baits, and the highest in November and December 1969. When, on the other hand, sterile insects were used, the lowest population was observed in November and December 1970 and from

August to December 1971. It must also be pointed out that 1972 is evidently an exceptional year during which wild flies are reproducing at such an alarming rate that they cannot be kept in check by the sterile flies. This has occurred not only in Tacna and Moquegua — the areas covered by our project — but also in the United States of America in the case of the screw-worm, *Cochlyomyia hominivora*.

To get round this difficulty we have reduced the irradiation dose to 9 kR and started large-scale rearing under natural conditions at La Molina (as was done in San José Costa Rica in 1968-1969). Lastly, we have carried out four treatments with insecticide baits containing 0.4% Malathion and 0.4% hydrolysed protein. After two months, however, we cannot claim to have achieved satisfactory results.

3.2. Longevity and dispersion of irradiated flies

Both in Tacna and at Moquegua we carried out tests during which we released medflies irradiated with 10 kR and dyed with a fluorescent powder. Flies were recaptured to a distance of 400 m for 36 days in 1968 and 1970. In 1971 in a similar test carried out in the Ilo area, where the principal crop is olive, flies were recaptured up to a distance of 1 km for eight weeks.

3.3. Medfly damage potential

By introducing 10 pairs of wild flies at a time into 64 m³ (4 × 4 × 4 m) cages around fruiting apple, peach or mango trees in Moquegua, we determined that each female could damage 0.5-3 fruits on average and that the males lived from 2 to 15 days and the females from 2 to 18 days. The females performed 1-3 ovipositions.

3.4. Medfly hosts

By direct observation in the field or by recovery of adults from damaged fruits in glass flasks in the laboratory, we have determined 22 hosts in Tacna and Moquegua [2]:

Duraznero (<i>Prunus persica</i>)	Peach
Manzana (<i>Malus pumila</i>)	Apple
Chirimoyo (<i>Annona cherimola</i>)	Chirimoya
Naranjo agrio (<i>Citrus aurantium</i>)	Sour orange
Naranjo dulce (<i>Citrus sinensis</i>)	Sweet orange
Higuera (<i>Ficus carica</i>)	Fig
Peral (<i>Pyrus communis</i>)	Pear
Membrillero (<i>Cydonia vulgaris</i>)	Quince
Mango (<i>Mangifera indica</i>)	Mango
Pacae (<i>Inga feuillei</i>)	Inga tree
Lima (<i>Citrus aurantifolia</i>)	Sour lime
Olivo (<i>Olea europea</i>)	Olive
Damasco (<i>Prunus domestica</i>)	Apricot
Níspero (<i>Mespilus germanica</i>)	
Cirdero (<i>Prunus domesticus</i>)	Plum
Guayabo (<i>Psidium guajava</i>)	Guava
Tuna (<i>Opuntia ficus indica</i>)	Cactus fruit

Aji (<i>Capsicum frutescens</i>)	Chilli, pepper
Pomorrosa (<i>Eugenia jambos</i>)	Rose apple
Cafe (<i>Coffea arabica</i>)	Coffee
Nogal (<i>Juglans regia</i>)	Walnut
Lucuma (<i>Lucuma biferia</i>)	

3.5. Efficiency of traps

By releasing marked insects we found that the Steiner trap gave a re-capture of 0.1%, while the 'Pegotrampa' -- gum trap or sticky trap -- baited with 0.6 ml Trimedlure and 30 g adhesive material per 25 cm² captured five times more flies.

4. RESULTS OF MEDFLY RELEASES IN TACNA AND MOQUEGUA

In 1969 one million flies were released each week for 20 weeks in Tacna after two aerial applications of insecticides. The numbers of released flies were found insufficient, however, and the populations increased from 1 to 40 flies per trap per week. In 1970 it was decided to operate only in the upper part of the valley with an area of 767.05 ha (approximately 3 square miles), where the population was 30.7 flies per trap per month in May, 23.7 in June, 6.2 in July and then until July 1971 between 0.8 and 5.7. 95% of the fruit was healthy with slightly more than 170 million sterile flies in 14 months. Since the same amount of healthy fruit was found in the lower area, where insecticides had been applied constantly, it was decided to release flies in the whole valley from October 1971 to June 1972. Again the number of flies turned out to be insufficient and the native population reached uncontrollable limits, as a result of which a large part of the harvest and much of the farmers' confidence in the technique were lost. The release of flies in Tacna was accordingly suspended until the new facilities, of which we shall speak later, could be made available.

In Moquegua from 1969 until 10 July 1970 266 771 applications of toxic bait were used in the area that had been prepared for release and the populations declined from 0.11 to 0.06 flies per trap per day. After the releases started the population rose to 0.08 flies per trap per day in August but fell successively in September, October, November and December, reaching a minimum of 0.0003 flies per trap per day. Thereafter, it grew to 0.009 flies per trap per day in January, to 0.017 in February, to 0.02 in March, to 0.27 in April, to 0.38 in May, and then fell slightly to 0.24 in June. Nevertheless, the farmers were satisfied with their harvests, which they considered the healthiest since the medfly had been introduced in the valley, and only 28 000 applications of poisoned bait had been carried out in the worst infestation foci, as against 266 000 in the preceding year. The rise in fly population appeared to be due to migration from Ilo, 25 km downstream, judging by captures in the gorge separating the zones and by the fact that the migrations were inversely proportional to the fly population in Ilo.

In August 1971 we resumed the release of flies, following Steiner's formula for calculating birth rate [6]; the density of 0.36 flies per trap per month thus found could not be reduced at any time, and the population

in fact reached a maximum of 28.94 flies per trap per month in April. In 14 months we released 574 740 000 flies over an area of 2304 ha (9 square miles). A point to be noted is that during this last experiment the climate was exceptional in the coastal area of Peru, creating ideal conditions for the breeding of medfly in the field, for the growth of the native population could not be stopped (the figures were 0.36, 0.38, 0.57, 1.11, 0.88 and 1.17 flies per trap per month) in spite of the fact that more flies were released than were necessary during the first six months (August to January). From February to May 1972 we released fewer than the necessary number because of the increase in the native populations and short supply of the materials used for preparing the diet, as a result of which the production declined, especially during February and March.

All these imponderable factors, together with a shortage of equipment in the airline transporting the flies and reorganization in the Ministry of Agriculture, were responsible for our failure to achieve complete success; it was possible to obtain more than 80% healthy fruit with only 54 000 insecticide treatments, 25% of which were carried out between February and May in order to control the hot spots.

5. PRODUCTION AND EXPANSION OF THE REARING PLANT

Table I shows monthly fluctuations in the production of pupae and the percentage of recovery during the January 1969-October 1972 period. It will be seen that, whereas the average figures for these two quantities have increased every year, the cost of diet for producing a million pupae fell by half in 1970, in comparison with 1969, in spite of a small rise in the price of a kilogram of Levafor from 5.80 to 7.00 soles. In 1971 and 1972 the price of Levafor almost doubled (10 soles) but the increased cost was offset by the greater efficiency of the plant.

Table I is self-explanatory as regards the progress made in adapting facilities that had not been constructed specially for producing flies. The 15% recovery of pupae from eggs is not the highest figure attainable nor does it represent an average because, in our opinion, a very important part is played by moisture and aseptic conditions; for this reason, we are very hopeful that in the new facilities designed especially for rearing medfly we shall achieve a recovery above 20% and keep this figure constant through the year so as to obtain 100-250 million flies every week. We can then carry out the final experiment, which should establish the sterile-male technique for many years as one of the most efficient and reliable methods of insect control.

CONCLUSIONS

The sterile-male technique has been shown to be efficient in medfly control when the minimum requirements for its application are satisfied.

Although the 10 kR dose produces competitive males, it can be reduced to 9 and even 8 kR to increase the competitiveness further without affecting the sterility of the females.

TABLE I. PRODUCTION OF *C. capitata* Wied. AND PERCENTAGE OF PUPAE RECOVERED FROM EGGS BETWEEN JANUARY 1969 AND OCTOBER 1972 IN THE FACILITIES OF THE LA MOLINA AGRICULTURAL RESEARCH STATION

Month	1969			1970			1971			1972		
	Pupae produced (thousands)	Per cent recovered	Pupae produced (thousands)	Per cent recovered	Pupae produced (thousands)	Per cent recovered	Pupae produced (thousands)	Per cent recovered	Pupae produced (thousands)	Per cent recovered	Pupae produced (thousands)	Per cent recovered
January	5344	-	10260	8.90	35820	9.67	131250	18.56				
February	4780	-	8607	8.50	75035	14.72	99600	14.17				
March	4635	-	20120	18.61	63520	13.64	94560	18.69				
April	8340	7.72	24560	20.22	72875	14.12	116210	17.63				
May	7805	8.62	32520	21.57	99850	15.30	160380	23.02				
June	15365	8.63	35255	21.70	87750	16.29	129886	17.00				
July	8150	7.79	44835	16.16	126280	15.97	121034	11.83				
August	7822	9.62	45370	10.07	65900	9.65	43840	9.29				
September	4169	6.42	64925	13.70	77850	11.78	34830	11.39				
October	1942	2.60	65345	12.10	138378	19.84	11920	13.61				
November	2947	4.88	44355	10.81	102970	23.87	-	-				
December	4273	5.07	36970	9.27	101550	15.57	-	-				
Yearly total	76372		433132		11049778		942510					
Monthly average	6364	6.82	36094	14.09	87482	15.04	94251	15.12				
Cost per million	\$985.55	US\$22.72	\$513.54	US\$11.84	\$566.58	US\$13.06	\$563.59	US\$12.99				

The Peruvian larval diet can give more than 20% recovery of pupae from eggs and possibly above 30% in large-scale rearing when air-conditioning and asepsis are ideal.

The isolated valleys in the Peruvian coastal area are ideally suited for applying the sterile-male technique for insect control.

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FIELD EXPERIMENTS WITH THE RELEASE OF STERILIZED ONION FLIES, Hylemya antiqua (MEIG.)

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Abstract

FIELD EXPERIMENTS WITH THE RELEASE OF STERILIZED ONION FLIES, Hylemya antiqua (MEIG.).

After extensive laboratory research radiosterilized onion flies were released in a semi-isolated wild onion fly population on a 1-ha plot during 1971 and 1972. Although all the available data have not yet been analysed and the experiment is intended to continue for another two years, data are presented that indicate the reduction of the fertility of the wild population. Preliminary conclusions of the experiment and their implications for the future are discussed.

INTRODUCTION

The authors reported previously on the problems encountered in the control of the onion fly, Hylemya antiqua (Meig.) [1]. The list of insecticides to which the fly is resistant has been extended in 1968 by dichlofenthion, 4-5 years after the beginning of application. Laboratory studies have shown that irradiation of the pupae 1 day prior to hatching with 3 kR of X-rays [2, 3] results in effective sterilization. Cage experiments did not reveal any reduction in the competitiveness of the sterilized males [2]. Histological studies of irradiated insects did not show any damage to the organs other than the gonads [4]. A satisfactory rearing method has been developed [3] and is being steadily improved by Noorlander. Dispersal, population size and population dynamics are being studied by Loosjes. For 1970 we intended to have release experiments in large-size field cages, followed by field releases in 1971. The cage experiments, however, failed because the onion fly did not establish itself in them. Lack of knowledge of the habitat requirements of the onion fly must be the reason for this failure. We proceeded with the study of the field cage experiment but decided, to avoid undue delay in the program, to stick to the schedule and carry out field releases in 1971, for which experiment the preparations had already been started at the same time as the field cage experiment.

METHODS

In 1970 we chose a site at Lienden where we planted a 1-ha plot with onions. In the area no commercial onion growing occurs and therefore a low natural population could be expected. In spring fertile onion flies were released. By the end of 1970 the plot contained an estimated population of 17 000 onion fly pupae. This population size is similar to the size of the population that still develops in a field treated in Spring with an insecticide.

For the following years adjacent 1-ha plots were sown with onions. The pupae used in the experiment were in 1971 and in 1972 the third generation offspring of field-collected pupae. Most of them had been stored as 3-day-old pupae for various periods at 3°C and were then placed for 9 days at $21 \pm 0.5^\circ\text{C}$ prior to their irradiation with 3 kR X-rays delivered by an electron generator (energy 1.5 MeV). From the beginning of the emergence of the first generation — determined from depots — weekly releases of sterilized pupae were carried out. The pupae were dug into the soil at different spots scattered over the field. The emergence of these pupae was checked from a depot containing $\frac{1}{2}\%$ of the number of pupae dug in. In the field a number of flight-interception traps, developed by Loosjes, were installed. Daily the catches of these traps were taken alive to the laboratory and separated into males and females. The males were checked for the presence of a label — dye or radioisotope. The females were put into cages and allowed to lay eggs for one week. The eggs were collected every second day and checked on hatchability. After this week the females were analysed on the presence of a label and their ovaries were checked for development. This allows sterile and fertile females to be distinguished. The first have completely undeveloped ovaries, whereas the latter have normal, developed ovaries.

In 1971 only small groups of sterile flies were labelled in order to study the dispersal in and around the field. The ratio sterile/fertile flies in the catch could be deduced from the dissection of the ovaries of the females. In 1972 all sterile flies were labelled with a dye and hence the ratio sterile/fertile could be studied both from the label and from the ovarian development.

Weekly observations were carried out on the number of infested plants on 50 randomly chosen control rows, 10 m long, representing 1.7% of the area. Each infested plant was marked. The infested plants on half the length of the control rows were removed one week later and a soil sample was taken and checked for the presence of pupae and larvae. The other half of the rows were similarly treated at harvest time. From these data the population of diapausing onion fly pupae can be estimated.

RELEASE SCHEDULE

For 1971 a release schedule (see Fig. 1, bottom) was developed for the first generation. Phenological data on the emergence of the first generation were available for a number of years and for various localities. Starting from the 1% emergence point — which is situated between 20 April and 15 May — we constructed a curve, of which each point represents the maximum emergence that had occurred during the period of observation. A number of diapausing pupae collected in the field previously were put in a depot. From this depot the 1% emergence was determined. For security's sake we started the release of some thousands of sterile pupae as from 20 April. The emergence of the second generation was deduced from a sample of pupae collected in the field. As insufficient first generation pupae were collected, we missed the actual beginning of the second generation, with the consequence that during that generation insufficient sterile pupae were brought into the field.

In 1972 (see Fig. 2, bottom) we followed the same procedure for the first generation as in 1971. The emergence curve, however, showed a very different picture. Emergence started on 29 April, but proceeded very slowly

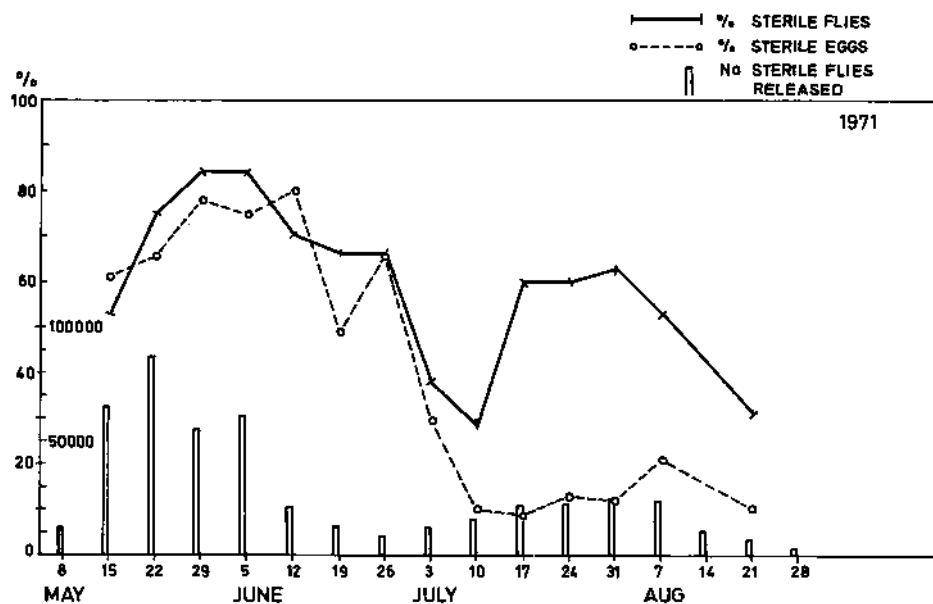


FIG. 1. 1971 release experiment with sterilized onion flies (see text).

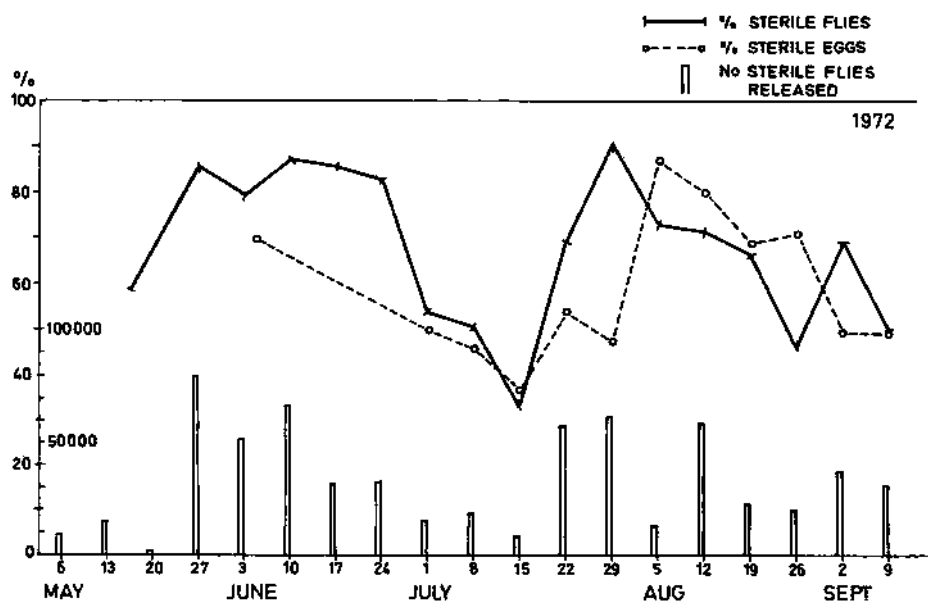


FIG. 2. 1972 release experiment with sterilized onion flies (see text).

due to cold weather during May, resuming the normal fast rate during the first half of June. By that time we had spent most of the sterile pupae. Still another complication arose. The 1971 onion field was now sown with winter wheat. Under this crop the soil — with the hibernating onion fly pupae — warmed up much more slowly than the bare soil where the depots were installed. Although detailed observations are available, we have indications that the fertile flies emerged in the second half of June only. For the second generations we tried a continuous coverage with a weekly release of about 60 000 pupae.

RESULTS

As the aim of the release of sterile males into a population is the reduction of the fertility of the fertile females, data on these two aspects are presented here¹. In 1971 the composition of the fly population, consisting of sterile and fertile flies, could be established for the females only. The 1972 data show that the ratio sterile/fertile males follows the same pattern as the ratio for the females.

As the ovarian development is inhibited by the irradiation, the eggs collected in the laboratory from the field-collected females must have been laid by fertile females. The hatchability of these eggs reflects, therefore, the mating by either sterile or fertile males.

In Figs 1 and 2 curves on the percentage of sterile flies in the catches are compared with curves on the percentage of the eggs that failed to hatch. For May and June 1971 the sterility of the eggs follows closely the sterility of the fly population. This indicates that the sterile flies have been efficiently reducing the fertility according to their relative numbers. In July and August, the period of the second generation, this correlation disappears and the egg sterility falls short of the sterility of the fly population. In this period infection of the flies by the fungus *Entomophthora* sp. was rapidly expanding. We assumed a preferential infection of the sterile flies by the fungus, as the sterilized pupae were dug in week after week on the same five release sites. The emerging sterile flies — more susceptible due to their still soft chitin — would have a higher chance of being infected than the emerging wild flies scattered over the field. The fact that an infested fly is still able to fly when its reproductive organs are already completely destroyed by mycelium growth could explain the inefficiency of the sterile flies present to inseminate the fertile females.

In 1972 the correlation between the sterility of the fly population and the egg sterility persisted throughout the year. It should be noted that during May and June only 16 egg batches could be collected with an average sterility of 69%. One cannot, therefore, attribute too much value to this part of the egg sterility curve. During the second generation the release sites were changed weekly to a different site in the field. We could no longer find a preferential fungus infection of the sterile flies, although the infection level was high. There is no discrepancy between the two curves.

¹ Further analysis of the data from the experiments will be published at a later date.

REMAINING FLY POPULATION

Sampling of pupae just prior to harvest permitted an estimation of the fly population at 13 000/ha by the end of 1971 and at 9000/ha by the end of 1972. The damage to the crop was negligible. Attempts to hold a satisfactory comparison with a plot without sterile flies have failed so far. A check plot of sufficient size will be available in 1973.

DISCUSSION

The two experiments described form part of a four-year program. During the first two years the effect of the release of sterile flies has been clearly established. The general level of sterility, however, is not sufficient for effective control. Comparing the release curve with the sterility curves, it appears that the release was not optimally carried out. The gap between the two generations was over-estimated and the numbers released at that time of the year were too small. For the following year this has to be compensated by a higher release rate around 1 July.

ACKNOWLEDGEMENTS

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CURRENT STATUS AND PROSPECTS OF APPLYING THE STERILE-INSECT RELEASE METHOD AGAINST Dacus oleae

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Abstract

CURRENT STATUS AND PROSPECTS OF APPLYING THE STERILE-INSECT RELEASE METHOD AGAINST
Dacus oleae.

Results of research of the last three years of relevance to the sterile-insect release method against Dacus oleae (Gmelin) are briefly reviewed and their possible effect on the success of the method, when applied, is discussed. It is concluded that the outlook is still promising and that, besides the other phases of the work, small-scale releases of sterilized flies must continue to determine some problems to be faced in the field.

The FAO/IAEA Panel on Sterile-Male Technique for Control of Fruit Flies, held in Vienna in September 1969, summarized in its proceedings [1] the situation pertaining to the olive fruit fly, Dacus oleae (Gmelin), as follows:

"Considerable data are available at present; however, more are required before implementing large-scale control and/or eradication programs. Thorough laboratory evaluation followed by small-scale field tests (of several square kilometres) of the sterile-insect release method should be conducted immediately to determine the areas of research that require further investigation. However, on the basis of present knowledge it is recommended that much of the information listed in Annex B should be derived as soon as possible, especially the diet improvement and nutritional studies and the chemical and physical attractants".

The information listed in Annex B to those proceedings included mass rearing, irradiation, marking, quality control, release methods, survey, sampling and evaluation techniques, biology and ecology, adverse effects, economic aspects and genetic studies.

Most work of some relevance to the sterile-insect release method until 1969 involved the determination of proper doses of gamma-rays or chemicals for sterilizing this insect, the release of sterilized and normal males in caged olive trees to determine the sterile/normal insects ratios needed for control, the use of a chemosterilant in the field, determining the distance of dispersal of released flies or of wild flies labelled in the grove, the development of artificial diets for larvae and adults and of methods of continuous rearing in the laboratory, and aspects of the adult ecology, reproductive behaviour and physiology. Much of this work has been reviewed by Silva [2], Mourikis and Fytizas [3], and Orphanidis and Kalmoukos [4].

Some work from the last 2-3 years relevant to the subject is given below to somewhat update the picture of the feasibility of the method against D. oleae, and help in the evaluation that closes this paper.

LABORATORY STUDIES

Mating frequency of females

Cavalloro and Delrio [5] reported that the females are mostly monogamous. At 28°C and 16-h photoperiod roughly 44% of their olive-reared females mated once, 25% twice, 15% three times and only 8% more than four times. This confirms earlier work of other colleagues. Yet, in another of their experiments at 26°C over 50% of their females had their second mating 5.8-9.6 days after the first, on average.

Economopoulos [6] found that during the first 35 days at 25°C following their first mating olive-reared females mated again every 6-10 days, and artificial-diet-reared females every 12-18 days, on average. Intermating periods were considerably longer, often twice as long, during the second 35 days of the experiment. His conclusion is that the females of this species may mate several times during their lifetime.

Sequence of sperm utilization in females mated more than once

Economopoulos and colleagues (unpublished data) [6] reported that when females mated with normal and then with radiation-sterilized males egg hatch soon dropped in more than 50% of the females and remained low for the rest of their lives. They concluded that a "successful" (large sperm transfer) second mating replaces sperm already stored in the spermathecae. However, various other cases were also observed. Their work substantiates previous work carried out at the same institute and indicates that it is the sperm of the second mating that fertilize the eggs of most bimated females.

Cavalloro and Delrio [6] also found that when a non-irradiated female is subject to more than one mating, the last male (sterile or non-sterile) to mate with her is the one that chiefly determines the degree of fertility of the eggs laid. These results show that released sterile males should, within a few days, reduce the viable progeny of most mated but receptive wild females.

Laboratory data have shown that the mating frequency of a female may be influenced by a number of factors. Therefore, the percentage of wild females receptive to mating at any given time cannot be known.

Sterilizing doses of gamma rays

For the time being, 8 krad administered to advanced pupae seems a satisfactory dose and has been used by most investigators. Six and 7 krad have also been found promising and may be worth further testing.

Sexual competitiveness of radiation-sterilized males

Economopoulos [7] measured the competitiveness of males, irradiated with 8 krad of gamma rays as advanced pupae or as young adults, at 25°C, 13-h photoperiod with reduced light intensity in the last 3 hours, and an initial ratio of 4 irradiated artificial-diet males per wild couple. He found that irradiation at the pupal stage reduced the mating competitiveness considerably, 3 to 4 times or even more, and that egg hatch of the wild females was markedly reduced only during the first 4 weeks of his experiment. Conversely, irradiation at an early adult stage did not reduce the males' mating competitiveness and the egg hatch remained at the expected low levels throughout the 10 weeks

of the experiment. It should be pointed out that the observed reduction of competitiveness was due to a reduction of the frequency of mating of irradiated males as compared with normal males. Sperm of irradiated males were not less competitive than those of normal males. Work by Cavalloro and Delrio [6] confirms this.

The pupal stage being the most convenient to irradiate and transport, we must take into consideration the probability of reduced male competitiveness in calculating the numbers to be released. Further work in the laboratory is also needed with a variety of irradiated/normal fly ratios, population densities and conditions of maintaining the flies to substantiate the reduction in competitiveness, especially after the results of Ahmed and Ouye with Ceratitis capitata (Wiedemann) [6].

Rearing

In contrast to some other Tephritidae, the olive fruit fly has not been easy or cheap to rear. Although continuous production of a few thousand flies per day has been achieved, satisfactory continuous mass rearing has not yet been reached. Several improvements have been made, tested or suggested concerning the adult diet and the way it is offered, the cages, the maintenance and eggng of adults, the handling of eggs, the composition of artificial larval diets, the handling of pupae and the isolation and control of a pathogenic microorganism. Most of these recent improvements are summarized in the FAO/IAEA Information Circulars Nos. 12-14, and in laboratory reports.

The largest present colony of D. oleae, that of the Democritus N.R. Centre in Greece, is still reared on the same expensive larval diet developed several years ago and in much the same cages and time-consuming eggng method used by Hagen et al. [8]. This shows that considerable work is needed before simpler rearing methods can be adopted.

Marking

Covering the pupae with a fluorescent dye (powder) marks the flies satisfactorily. Marked flies can be detected for at least two months (Economopoulos, unpublished data).

Flight studies

Boller and Remund (unpublished data), using a flight mill at Wädenswil, developed a satisfactory method for flight ability comparisons in D. oleae. It is hoped that they will soon use their set-up to detect possible adverse effects of such factors as sterilizing gamma-ray doses, marking, chilling and artificial diet on the ability to fly of adults intended for release.

FIELD STUDIES

Sterile/normal insects ratio needed for control

Cavalloro and Delrio [6] found in laboratory experiments and confirmed in pilot tests in the field that the best ratio of wholly sterile males per normal

(fertile) couple is 8:1. They also expressed the view that a lower ratio and a substerilizing dose of 7 krad might be of practical use and would, likewise, be suitable. This ratio is the same as reported satisfactory by Manikas and Baldwin [9] for caged olive trees and twice that reported by Melis and Bacetti [10], who were the first to irradiate male olive fruit flies and release them in caged small trees together with normal couples. Only the abstract of the paper by Cavalloro and Delrio, which contains no details of their method, was available to me.

The 4:1 and 8:1 sterile (S) to normal (N) insect ratios reported by the three above groups are not explainable on the basis of laboratory data on egg hatch, unless we assume that S males are much more competitive than N males. Such an assumption should rather not be sustained. Using the formula suggested by Fried [11] and some laboratory data, we see (Table I) that to reduce the hatch of eggs of wild females to 5% we need an S/N ratio

TABLE I. REQUIRED STERILE (S) TO NORMAL (N) INSECT RATIOS TO REDUCE THE EGG HATCH OF WILD FEMALES TO DESIRED LEVELS
Calculated with the method of Fried [11].

Desired % hatch of eggs of wild females	Expected % hatch with sperm of		Required S/N insects ratio
	Sterilized males	Normal males	
10	2 ^a	85 ^b	9.4/1
5	2	85	26.7/1
3	2	85	82.0/1
10	1 ^b	85 ^b	8.3/1
5	1	85	20.0/1
3	1	85	41.0/1
Desired % developing to pupae	Expected % eggs developing to pupae		
10	0.3 ^b	41 ^b	3.2/1
5	0.3	41	7.7/1
3	0.3	41	14.1/1

^a See Ref. [13].

^b See Ref. [12].

of at least 20/1. However, if it is a general rule that roughly only 1/3 of the eggs fertilized with irradiated sperm give viable larvae [12], we must need a ratio of only 8/1. Yet, considering that artificial diet flies, irradiated as pupae, showed reduced sexual competitiveness [7], we come to the conclusion that S/N ratios exceeding 25/1 should be planned for field releases.

Field performance of released flies

Economopoulos and colleagues of the Democritus N. R. Centre have been releasing laboratory-reared olive fruit flies in N. Greece since June 1971 in order to obtain some information of the field performance of irradiated flies and of the condition and population density of wild flies. The flies were reared on an artificial diet, irradiated as advanced pupae and released as 2-day-old adults every 1-2 months. In some cases unirradiated flies were also released for comparison. Released and wild flies were captured in McPhail traps baited with a protein hydrolysate solution. The information available at this time is summarized as follows (Economopoulos, unpublished data): (1) laboratory flies were usually recaptured, within the first 3 weeks from release; (2) most flies were recaptured very close to the point of release and very few at the farthest traps (3 km away); (3) there were indications that most wild flies tended to concentrate in the area where laboratory flies were released; (4) many recaptured flies mated in the field; and (5) many wild flies were caught during the winter months, especially when sunny warm days preceded the trap examination. Most of these winter-caught wild females had undeveloped oocytes and no sperm in their spermathecae.

Chemical control

Protein hydrolysate bait sprays, under low or ultralow volume, can reduce rapidly the adult population of *D. oleae* [4]. Also, cover sprays with 0.1% parathion caused, within only one hour, approximately 50% of the olive fruit flies to drop dead on sheets spread under the trees. The remaining 50% of the total killed was killed in the next 2 days [14]. Therefore, the rapid reduction of undesirable wild populations before or during the release period seems possible. To my knowledge, no attempt to develop a satisfactory method of this type using an insecticide of short residual action has been reported. Such a method would also be useful in determining, at a given time, the density of the released population and test the validity of the data from traps. Unfortunately, no strong attractants are known for *D. oleae* and the efficiency of such traps is considerably influenced by the prevailing relative humidity [14].

DISCUSSION

The results of recent work suggest that pupae should be irradiated as late as possible and field releases made at rather short intervals and start well ahead of the fruiting season, preferably in late winter. A reduction of the overwintering wild population with a fast-acting insecticide may be advisable. The flies should be released at many points in the grove, preferably

not more than 200 m apart, and their numbers be sufficient to cope with large wild populations likely to be produced on the local crop or move in from other areas.

The available information does not allow a discussion of how practical the method is likely to be against *D. oleae*. In years of a good olive crop huge number of flies can be produced in groves where no control measures are taken. A good crop of 40 kg/tree of a medium-size fruit variety provides sufficient food for the production of at least 16 000 flies, i.e. 1.6 million flies/ha. Such high populations should rarely be expected, but their possible occurrence must not be overlooked. The importance of wild olives (*Olea europea* var. *sylvestris* Bouy.) as sources of infestation of neighbouring olive groves is not known. Even more important, we know practically nothing of the magnitude of dispersive and possible migratory movements of adults during the year and a reliable method of mass production at a reasonable cost has not yet been developed.

Pilot release tests in groves of a sufficient size are needed to obtain experience and determine the cost. At the same time, the dispersal pattern of the species must be studied over a number of years in carefully selected areas. Then, if a satisfactory method of mass production is also available, a consideration of the practicality of the method for eradication, or control, in combination or not with other control methods, will be possible.

The outlook continues to be promising. The results of recent work are not discouraging and, if the research groups engaged in some phases of the method against the olive fruit fly intensify their work, we must expect to have in a few years much of the information needed for field releases aimed at control. It is encouraging that one group has at least started releasing artificially reared and sterilized flies in an area selected for future mass releases. This work will disclose the difficulties involved and suggest the direction of future work.

If what was noticed in the laboratory holds in the field, we must expect released sterile males to be sufficiently competitive during their first 2 weeks in the field. Radiation-sterilized males are known to make their female partners as unreceptive to another mating as normal males do. Therefore, I feel that, if irradiated flies are released every 2-3 weeks, the result of the possible reduction of competitiveness of the released males after their first week will not be such as to endanger the feasibility of the method. The positive results of all three applications of the method on small caged trees give a further hope that the method will work.

In view of the high cost of the available rearing methods and lack of knowledge on the magnitude and pattern of possible mass dispersal flights of this species, the application of the method must rather be limited to small and sufficiently isolated olive groves, preferably in areas unfavourable to the build-up of large wild populations.

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RESEARCH ON RICE INSECTS IN THAILAND

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Abstract

RESEARCH ON RICE INSECTS IN THAILAND.

At least 27 species of rice insect pests are considered to be either of major or potential major importance in Thailand. To date, however, only rice leafhoppers, rice gall midge and rice stem borers have been intensively studied. Most of these species are widespread; however, the rice gall midge (Pachydictyophora oryzae Wood-Mason) is confined primarily to the Northern, Northeastern and Southeastern areas. A brief discussion of the major insect pests is given.

INTRODUCTION

Rice insect pests in Thailand are just as numerous as in other countries of Southeast Asia. The importance of each species varies, depending on climatic conditions, biological factors, cultivation methods and topography of the area. As no detailed survey has yet been made, it is difficult to state precisely which species are the most important. However, helpful information can be obtained from records containing the number of requests for assistance in insect control, the frequency of occurrence and the area of infestation of each species.

Wongsiri and Kovitvadhi (1967) presented a general discussion, including a list of rice insects, at the symposium on rice insects held at the International Rice Research Institute in 1964. At least 27 species were considered to be either of major or potential importance in Thailand but to date only rice leafhoppers, rice gall midge and rice stem borers have been intensively studied. Most of these species are widespread; however, the rice gall midge (Pachydictyophora oryzae Wood-Mason) is confined primarily to the Northern, Northeastern and Southeastern areas. A brief discussion of the major insect pests follows.

RICE LEAFHOPPERS AND PLANTHOPPERS

Five species of leafhoppers and planthoppers are of special interest. In order of importance, they are:

- Rice green leafhopper, Nephotettix virescens (Distant)
- Rice green leafhopper, Nephotettix nigropictus (Stål)
- Zigzag wing leafhopper, Recilia dorsalis (Motschulsky)
- Brown planthopper, Nilaparvata lugens (Stål)
- White-back planthopper, Sogatella furcifera (Horváth)

Studies on the varietal reaction of rice to brown planthoppers, Nilaparvata lugens, are being carried out in the laboratory. Eight lines of varieties, all of which contained Mudgo as one parent, were found to be resistant to attack by this planthopper. Six varieties were resistant to the white-back planthopper and included TKM-6, Pankari, IR5, C4-63, EK 1259 and EK 1263. Tests for resistance to rice green leafhoppers are being studied both in the laboratory and field. Results of the tests are still being evaluated.

Wongsiri and Katunyukul (1967) reported that egg parasites of leafhoppers are common in Thailand. Two common egg parasites are Angylus flaviolus Waterhouse and Japania adei Ishii. In addition, several unidentified species have been collected. Parasitism was high in egg samples collected in various localities, with some samples being 100% parasitized. Adult leafhoppers parasitized by dryinid wasps were found in the Bangkok area and pipunculid flies were collected in the Chiangmai area. Pipunculid parasites do not attack the nymphs of Nephotettix spp. in the first and second instars, but attack the third to fifth instars, depositing eggs singly underneath the abdomen near the metathorax. The egg and larval stage lasts 12 to 15 days and then the parasites pupate outside the body of the host. The pupal stage lasts 11 to 13 days and adults live for 3 to 7 days after emerging. Pipunculid parasites were found in 48% of specimens collected near Ratchaburi. Predators of leafhoppers in Thailand include ladybird beetles, dragon flies, lacewings and spiders. A green myrid (possibly Cyrtorbinus) eats leafhopper eggs.

Study of the effects of some granular and liquid insecticides on rice green leafhoppers, Nephotettix spp., in the field has shown that when insecticides were applied 14 and 21 days after transplanting Mipcin 4% granule gave the best control of both nymphs and adults. Sevein W.P. 85% Kilval E.C. 50% and Furadan W.P. 50% were also effective against these insects. New and promising insecticides are being tested continuously for their effectiveness.

Studies on ecological factors and the biology of rice green leafhoppers are continuing as a long-term project. So far it has been found that temperatures of 25-30°C and a relative humidity ranging from 70-90% are the most favourable conditions for leafhopper growth and development. Seasonal fluctuations of rice green leafhopper population, including their habits and migration, are being studied to help provide information on their control.

Data from nightly light-trap catches at 18 different Rice Experiment Stations, which represent the major rice-producing areas of Thailand, showed that for Nephotettix spp. 12 generations are commonly observed each year. Large increases in population were observed in June and July at Rangsit, Klong Luang and Sanpatong Rice Experiment Stations. This seems to be closely related to epidemics of the yellow-orange leaf virus infection in the same areas. Populations of Nephotettix spp. have continued to increase each year in the above 3 stations but have decreased at the Pan and Sakonakorn Rice Experiment Stations, located in the North and Northeast regions respectively. This project is continuing and it is anticipated that it will provide some basic information for the control of yellow-orange leaf virus disease in the future.

RICE GALL MIDGE

Studies on varietal reaction to the rice gall midge, Pachytiplosis oryzae Wood-Mason, in the field and the laboratory have shown that EK lines from

India, when crossed with the newly developed dwarf varieties and experimental lines in co-operation with the Breeding Division of the Rice Department, possess the desired grain and plant type characteristics along with the high degree of gall midge resistance of the Indian parents. Five lines have been selected for planting in farmers' fields in large-scale tests in the Northern, Northeastern and Southeastern areas to ascertain resistance to the gall midge and acceptance by farmers.

Studies of effects of some granular and liquid insecticides to rice gall midge both in the field and the laboratory have shown that when applied 15 and 30 days after transplanting at the rate of 1 kg active ingredient per hectare, Thimet 10% G, Terracur-P 5% G, Imidan-dyfonate 10% G and Cytrolane 10% G gave excellent control of gall midge. Bayrusil 25% E.C. also gave promising results.

A preliminary study on the integrated control of the rice gall midge under severely infested conditions in the Northeast in 1971 showed that when 1 and 2 kg active ingredient of Diazinon granules were applied to both resistant and susceptible varieties, the following results were obtained:

(1) Two kilograms of Diazinon drastically reduced the infestation of the gall midge on resistant varieties from about 10 to 2%. On RD1, a susceptible variety, infestation was also reduced but still remained higher than 10%.

(2) One kilogram of Diazinon was not sufficient to show any marked reduction of infestation.

(3) Resistant varieties showed a higher increase in yield due to the 2-kg application than did the RD1 variety.

Studies on the ecological factors and the biology of the rice gall midge are continuing as a long-term project. So far it has been found that temperatures of 25-30°C and a relative humidity ranging from 80-100% are the most favourable conditions for gall midge growth and development. Collections of suspected biological strains of gall midge from three different regions are being tested for varietal reaction and taxonomic investigation. Studies on the development of gall midge on resistant varieties showed that growth was retarded and most larvae failed to survive the third instar stage. This strongly suggests that antibiosis is the major contributing factor to resistance.

Studies on environmental factors affecting seasonal fluctuations in the gall midge population have shown that climatic factors, including temperature, rainfall, and daily amount of sunshine, have a pronounced effect on population density. Temperatures of 25-27°C are usually the most favourable for gall midge outbreaks, while temperatures lower than 21°C completely halt development. Rainfall of about 120 mm per month and relative humidities of approximately 50% appear to be optimum for growth and reproduction.

Vungsilabutr and Hidaka (1968) conducted experiments on the rice gall midge in the Northern part of Thailand. The results of their studies with special reference to mechanisms of natural control can be summarized as follows:

(A) Fluctuation pattern of the rice gall midge

A typical fluctuation of population densities of the rice gall midge during planting season is given in Fig. 1. In northern Thailand the rice gall midge usually appears in July and disappears in the middle of November. The

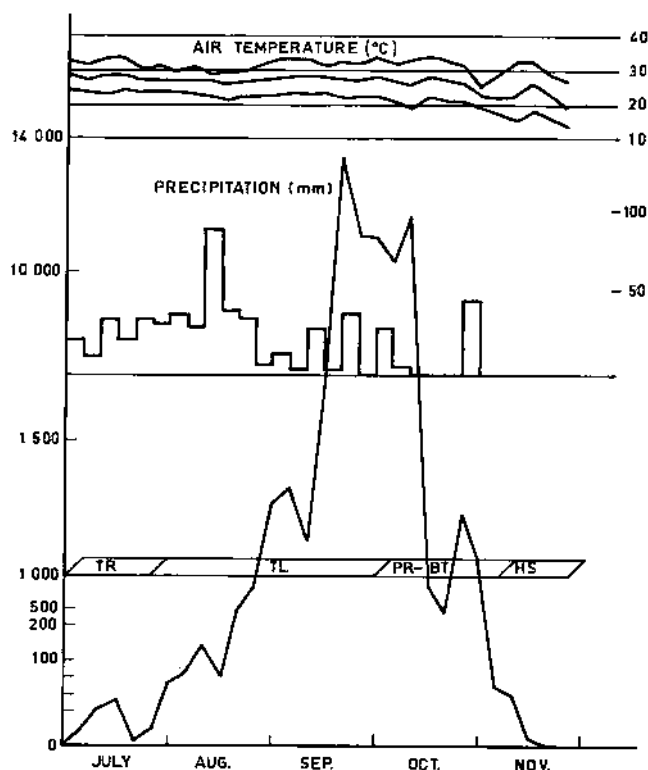


FIG. 1. Monthly fluctuation in population density of the rice gall midge at Pan Rice Experiment Station, 1969.

numerical peak of gall occurrence is at the end of September or early October. The rice gall midge has 7 overlapping generations. According to Fig. 1, the insect begins to increase in number from July to September, and declines from October to November. This shows that the population densities clearly increase from the 1st to the 4th generations and decrease from the 5th to the 7th generations. These types of monthly fluctuation have been observed in Northern Thailand every year.

(B) Population increase of the rice gall midge

(a) One of the important factors affecting population increase is growing stages of rice plants, as shown in Fig. 2. It is shown that the rice gall midge distinctly increases in number during the period of vegetative growth of rice plants. According to Fig. 2, which has been obtained from studies on the effect of the growing stages of rice plants on larval development and gall occurrence, the survival rate of the larvae was significantly higher in 28 and 42-day-old plants, and the galls were abundant in 28 and 46-day-old plants. This means that the larvae increase only in the tillering stage.

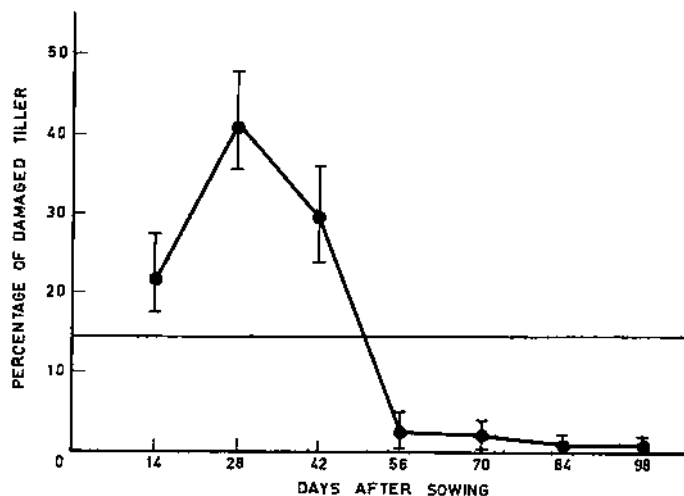


FIG. 2. Relation between damaged tiller and growing stages of rice plants at Pan, Chiengrai, 1968.

To investigate in detail the relations between the growth stage of rice plants and gall occurrence, the rice plants were sampled at random every week and carefully dissected under the binocular microscope in the laboratory. The results are given in Fig. 3. During the tillering stage the growth points continue to increase in number until the primordium formation. It is clearly understood that the larvae increase in number in proportion to the number of growing points on which the larvae feed. The growing points greatly affect the population increase of the rice gall midge. It is suggested that the insect can establish a higher population density if the rice variety has longer tillering stages.

(b) Rainfall is positively related to the population increase of the rice gall midge during the planting season. In particular, rainfall during July and August is most important for adult activity in relation to egg laying and higher percentage of hatching, as shown in Figs 1 and 4. The rainfall provides high humidity around the paddy field for the whole day. In other words, a high percentage of cloud and fewer hours of sunshine are also related positively to building a high population density of the rice gall midge.

(c) Usually the natural enemies of the insect are very few during July and August, which also permits the rice gall midge to increase in number easily, as shown in Fig. 3.

(C) Population decrease of the rice gall midge

(a) It is interesting to note that the growing stages of rice plants are also concerned in the reduction of the population density of the rice gall midge, which is especially reduced by onset of the primordium, as shown in Fig. 2. The insect larvae cannot grow in the primordium, which causes

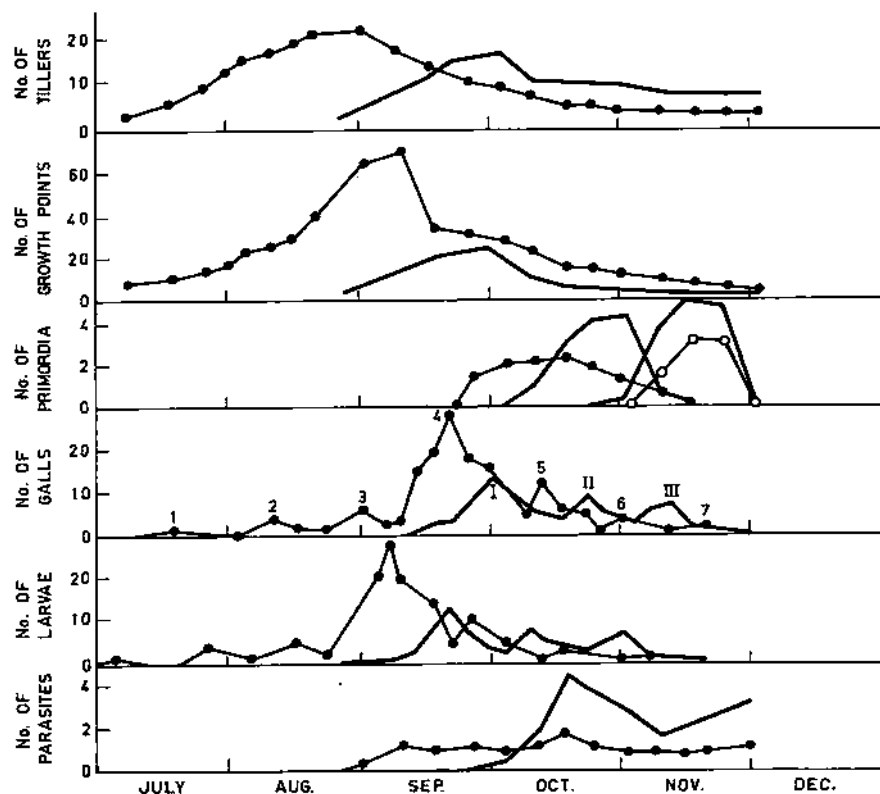


FIG. 3. Effect of planting date of rice plants on gall occurrence and parasites of the rice gall midge at Pan Rice Experiment Station, 1969.

high mortality of the larvae. As shown in Fig. 1, the population density of the insect gradually decreases from October to November. There is evidence that the generative growth period of rice plants greatly affects the insect population, as shown in Fig. 3.

(b) In relation to the growing stage of rice plants, it is considered that severe damage caused by the rice gall midge to rice plants could be avoided if a shorter period of vegetative growth were established in the paddy field. A change in the transplanting date would shorten the period of the vegetative growth, as given in Fig. 3. It is concluded that the insect population occurring with late transplanting was positively lower than with early transplanting. It has been proven that the rice gall midge has 2 to 3 generations during the period of vegetative growth when late transplanting is carried out. The insect cannot increase in number when the rice plants have a short period of vegetative growth.

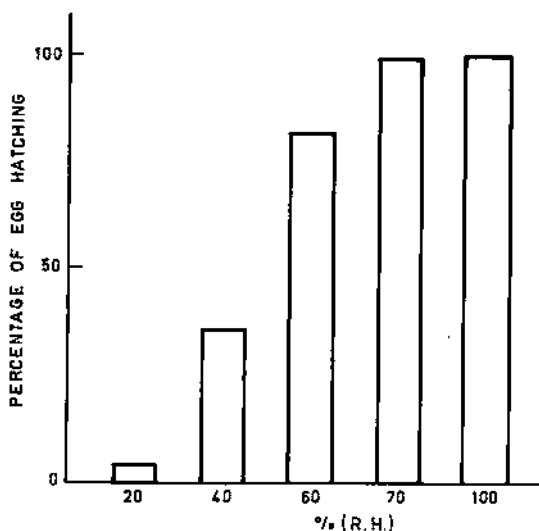


FIG. 4. Relation between relative humidity and egg hatch of the rice gall midge at Pan Rice Experiment Station, 1970.

(c) One of the interesting factors that reduce the population density of the rice gall midge is the presence of resistant varieties. It has been proven that the adult insects cannot distinguish between resistant and susceptible varieties. The number of eggs deposited and the number of the newly hatched larvae penetrating the growing points show no significant difference between resistant and susceptible varieties. It was clear that the larvae that had penetrated into the resistant variety could not develop because of either a nutrient deficiency or a substance that inhibited larval development, as shown in Fig. 5.

(d) Natural enemies effectively control the population density of the insect, especially after the onset of the primordium. Figure 6 shows the correlation between the decrease in the insect population density and the activities of natural enemies. A platygasterid parasite is one of the most important natural enemies, as shown in Fig. 7, parasitism reaching more than 65% in October and November.

(e) As far as the author has observed, the population density of the rice gall midge in the 2nd crop of rice during the dry season is much lower than in the rainy season. It is considered that the main factors affecting the insect population decrease are: (1) the adults removed from the alternate host plants to rice plants are comparatively less in number; (2) the effects of lower humidity based upon longer hours of sunshine without rainfall. The mortality of adults and eggs deposited on rice plants is extremely high under conditions of low humidity during dry seasons.

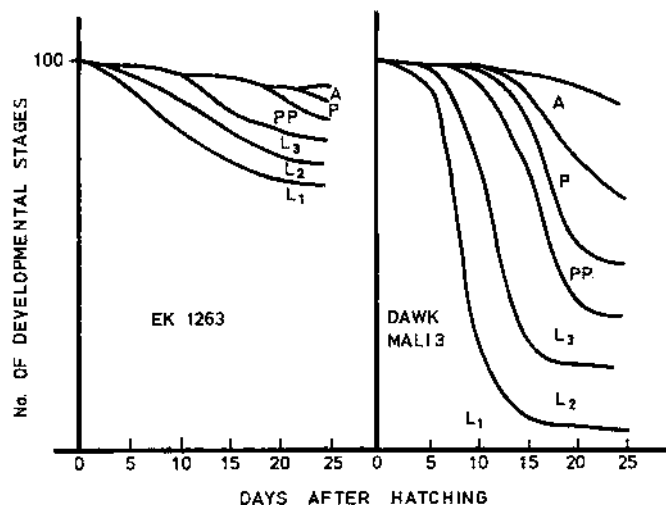


FIG. 5. Differences in the larval development between resistant (EK1263) and susceptible (Dawk Mali-3) varieties at Pan Rice Experiment Station, 1970. A = adult; P = pupa; PP = prepupa; L₁ - L₃ = first to third instar larvae.

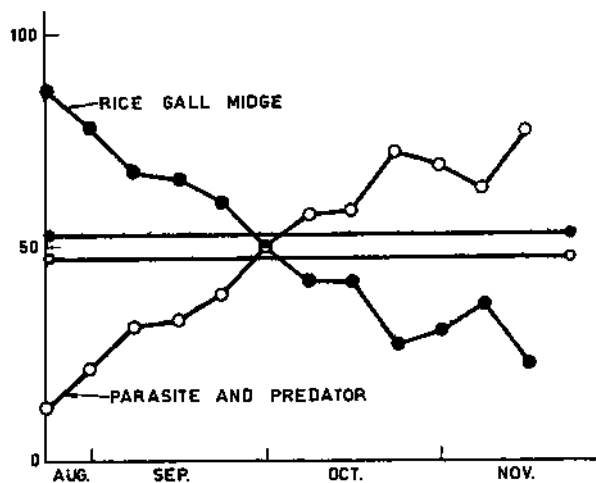


FIG. 6. Interaction between parasites and the rice gall midge at Ngao, Lampang, 1970.

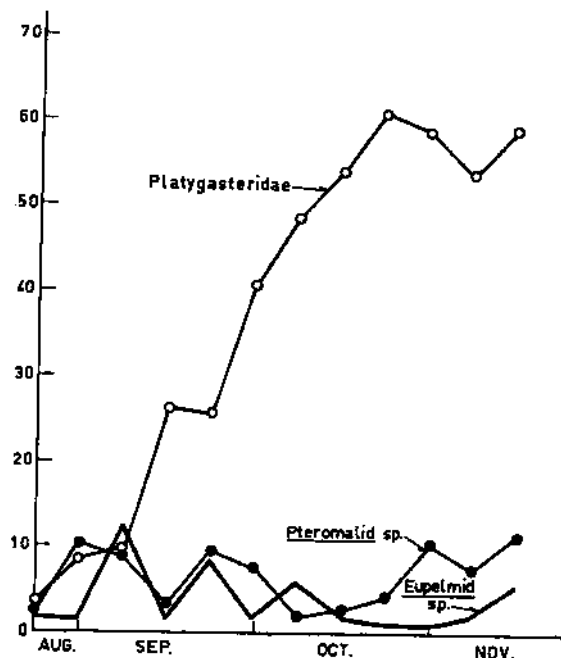


FIG. 7. Population fluctuation of rice gall midge parasites at Ngao, Lampang, 1970.

General discussion

Factors concerning the increase and decrease in the insect population densities are divided into two categories, i. e. biological and physical factors. The biological factors greatly affect the monthly fluctuation in population density.

With regard to the increase in numbers of the insect, the growing points during the period of vegetative growth of rice plants are positively related to a build-up in population density of the rice gall midge, which continue to increase in numbers in proportion to the number of growing points. It is observed that the insect population really increases only during the period of vegetative growth. The susceptible stage of rice plants attacked by the rice gall midge is at 28 to 42 days. This suggests that the susceptible stage is the time to control the insects by insecticide or other methods in the paddy field.

It is also interesting that the number of rice gall midges increases more during longer periods of vegetative growth than during shorter ones. This is proved by the fact that rice plants transplanted early are more severely damaged by the insect than those transplanted later.

On the other hand, it is interesting to note that the insect is successfully controlled by the onset of primordium and by natural enemies. The phenomenon of the reduction in population density has been observed annually after

the beginning of October. The larvae cannot develop in the primordium because they cannot form the larval chamber in the primordium, on which they also cannot feed. The larval mortality is higher after the onset of the primordium than during the tillering stage.

Natural enemies are also important in reducing the population density of the rice gall midge after the onset of primordium. The percentage of parasitization increases from the end of September to November, the hymenopterous parasites having an especially important role in reducing the number of insects. It is also noteworthy that parasitism is much higher in late transplanting than in early transplanting. This indicates that late transplanting has the advantages of:

- (1) High parasitism of the rice gall midge
- (2) Few insect generations
- (3) Less damage to rice plants compared with early transplanting.

It is considered that when we carry out integrated control of the rice gall midge we should find technical methods of reducing the population density to below the economically injurious level during the vegetative growth stage. These would include:

- (1) Choosing a planting date to ensure a short period of vegetative growth;
- (2) Utilizing resistant varieties. These kill the insect larvae that have penetrated into the growth points, but it is very unfortunate that the rice gall midge should not be eradicated by using highly resistant varieties. From the ecological viewpoint the insect population should be maintained lower than the economically injurious level in the paddy field so that moderately resistant varieties should be recommended to the farmers rather than highly resistant ones. The utilization of highly resistant varieties only for the rice gall midge would create new problems: (1) the other insect pests may severely attack the resistant varieties; (2) what are at present minor insect pests may become major rice pests; (3) the insect fauna in the paddy field may be changed; and (4) the dominant relationship among the insects in the agro-ecosystem may be broken. The other method is to transfer promising parasites from their original habitat to other places during the period of vegetative growth, the timing of this to be 14 to 28 days after transplanting.

The insect population density in the paddy field should be stabilized below the economically injurious level. It is considered that the method of population stabilization will be clarified through a knowledge of the mechanisms of increase and decrease of the insect population density.

RICE STEM BORERS

Four species of rice stem borers are of special interest since they are usually responsible for most of the damage caused by this insect. In order of importance, they are as follows:

- Dark-headed rice borer, Chilo polychrysus Meyr.
- Pink borer, Sesamia inferens (Walk.)
- Yellow rice borer, Tryporyza incertulas (Walk.)
- Striped rice borer, Chilo suppressalis (Walk.)

Varietal reactions to stem borers are being examined under field conditions. So far, the Indian variety TKM-6, lines of PTB18 and PTB21, IR8 X TKM-6 and a selection from crosses of EK parents from India with Thai varieties and experimental lines were found to be highly resistant in tests conducted during the 1971 Dry Season. These tests are continuing.

Tests on the effectiveness of granular and liquid insecticides on rice stem borers under field conditions have shown that when insecticides were applied in the Dry Season at 20, 40 and 60-day intervals after transplanting at the rate of 1 kg active ingredient per hectare, Terracur-P 5% G, Furadan 5% G, B.H.C. 6% G and Birlane 10% G gave excellent control for all species present. Sumithion 50% E.C., EI2967 (thio-methyl) 46% E.C. and EI2960 40% E.C. have also shown promise.

Procedures for mass rearing Sesamia inferens and Chilo polychrysus in the laboratory using rice stems, rice seedlings and artificial diets have been developed. Mung beans have been successfully used in artificial diets for rearing Sesamia inferens, Chilo polychrysus and Chilo suppressalis.

Field surveys of parasites on rice stem borer eggs are being carried out in the Central and Northeastern regions. It has been found that up to 90% parasitization of Tryporyza incertulas by Telenomus spp. commonly occurs but eggs of Chilo polychrysus and Chilo suppressalis were not parasitized to a large extent. However, Trichogramma spp. successfully parasitize C. polychrysus and C. suppressalis. Mass rearing of Trichogramma spp. parasites by using rice moth (Corcyra cephalonica) eggs is being studied as a possible biological control of stem borers. So far, the application of granular insecticides to paddy water has not significantly reduced parasite populations when compared with untreated control plots.

Nightly light-trap catches have been carried out for 5 years at 18 different Rice Experiment Stations, which represent the major rice-producing areas in Thailand, in an attempt to develop a forecasting system. The results have shown that there were 9 generations of the Tryporyza incertulas moth per year in the Central Plain, Northeast and South but only 8 generations in the Northern region. On the basis of seasonal abundance of T. incertulas, the country was divided into three separate regions, namely, an eastern, central and western region. No large year to year changes in population have been observed within each of these zones.

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STATEMENTS AND RECOMMENDATIONS

I. GENERAL STATEMENTS AND RECOMMENDATIONS

Having considered the development and present status of various field programs of insect control by the sterile-insect method¹, the Panel recognizes three phases of progress towards the application of this method:

PHASE 1. Small-scale field and laboratory research to gather basic information, such as behavioural and ecological data, rearing methods and sterilizing doses and procedures, etc.

PHASE 2. Large-scale field studies to evaluate the feasibility of the technique for eradication and/or population suppression. This should be of sufficient scope for economic evaluation and provide a blueprint for conversion to an operational program.

PHASE 3. Operational program use.

Once the SIM is applied commercially for the suppression of regional pests, in the Panel's opinion the Joint FAO/IAEA Division should encourage and actively support setting up regional laboratories. This should be done preferably in developing countries, taking into account the presence, importance and distribution of the particular insect. The regional laboratory would function also as a training ground for both laboratory and field aspects of the sterile-insect technique.

The Panel's review of the Joint Division's programs concerned with the practical use of the SIM for insect control indicates that this Division's contributions have been numerous, significant and laudable. The Agency has established and maintained a central role as the co-ordination centre for the application of the SIM. In a relatively short time the Joint Division has successfully helped to develop the required biotechnology for applying the SIM to a number of pests. This expertise and information immediately has been transferred to field applications in several developing countries (see IV; phases 1 and 3).

As the number of countries utilizing the SIM continues to increase, it is envisaged that the Agency's role will continue to expand. In order to draw on all the expertise in the SIM existing, the Panel recommends:

THAT the Joint Division establish a Technical Advisory Group of approximately six members actively engaged in this area. The chief function of this Advisory Group would be to assist the Joint Division in maintaining efficiency in the development and implementation of the SIM. To achieve this, members of the Advisory Group would serve without remuneration for a period of one to two years and keep in very close contact with the technical staff. In this connection, the Panel recommends setting up a small review committee to determine periodically the Joint Division's entomology program so that species are included if they require study, or dropped, if not.

¹ SIM, previously known by the equivalent, more restrictive term 'sterile male technique'.

II. THE ROLE OF THE STERILE-INSECT METHOD IN ERADICATION, CONTROL AND INTEGRATED CONTROL PROGRAMS

As a result of the well-publicized eradication of the screwworm from Curaçao and the efforts of the past ten years to eradicate this pest from the southern USA, the sterile-insect technique became associated in most entomologists' minds with eradication. This approach led to a narrow conception of the technique, restricting it to situations of complete isolation, single-pest targets and immense investments in personnel and finance. The Panel recognizes that the SIM has applications in the control of several pests and performs an important function in integrated control programs.

With the advent of integrated control, in which the harmonious use of all means of pest control is brought to bear on the target pest, the role of sterile insects needs reassessing to fit this broadened concept. This modern attitude leads to the consideration of possibilities of using the SIM to which insufficient attention had been given in the past, i.e. various degrees of control from suppression to eradication on the one hand, and preventive quarantine on the other. Just as confining the SIM to eradication is a dangerous misconception, so is considering it a panacea to solve all pest-control problems. The role of the sterile insect varies with its use for eradication, suppression or quarantine (caretaker-population). Whereas in eradication the sterile insect is a powerful tool for pushing low populations to extinction, in suppression it is one of several mortality factors put into operation. Given the necessity to initiate control measures, the following are some of the requirements to be met prior to including the SIM in an integrated control program:

- (1) The target insect must be a key pest with substantial economic or public health impact
- (2) Sterilization of the pest species must be possible, leaving it reasonably competitive with its wild counterpart
- (3) Techniques for economic mass rearing, handling and releasing that do not lower the quality of the insect produced must be developed
- (4) Quality-control procedures must be available for counteracting in the laboratory any divergence in crucial characteristics of the sterile insects from their natural counterparts. Likewise, procedures for detecting such divergences in the field are essential.

The complexity of any type of sterile-insect control measure thus puts it beyond the endeavour of the individual farmer and requires an organized area-wide approach.

III. THE ROLE OF THE JOINT FAO/IAEA ENTOMOLOGY PROGRAM IN IMPLEMENTING THE STERILE-INSECT TECHNIQUE IN DEVELOPING COUNTRIES

Laboratory

Considering the amount of money, manpower and space available for research at Seibersdorf, the Panel is impressed with the progress that this laboratory has made in recent years in the mass rearing of several insect pests.

In all its contacts with country SIM programs the Agency staff should continuously stress that mechanization and economy of the rearing system should not be at the expense of the fitness of the insects produced. The competition of the released insects with wild insects being central to the success of the SIM, efforts to prevent genetic and physiological deterioration of the mass-reared insects must be emphasized. The Agency should assume leadership in developing criteria for meaningful quality control activities so that high-quality sterile insects are used in programs. This will include criteria to guard against genetic changes in rearing cultures modifying behavioural patterns, in addition to routine monitoring of such things as longevity, radiation dose, etc. Therefore, the Panel recommends the following as main objectives for the Seibersdorf laboratory:

- (a) Development of economic methods of mass rearing applicable in developing countries
- (b) Improvement of irradiation methods
- (c) Development of quality-control procedures
- (d) Training personnel.

Consideration should be given to the number of insects that can be conveniently investigated at Seibersdorf at any one time with due regard to the objectives outlined above and quarantine regulations. Therefore, the Panel recommends

that the laboratory continue developing various aspects of the sterile-insect technique relative to a species of economic importance until:
(i) it has been shown not to be practical or economic in the foreseeable future; or (ii) the particular species is being suppressed by the sterile-insect technique commercially.

The Panel noted that very limited artificial rearing of Lepidoptera is carried out in Seibersdorf and that this is done mainly for training purposes. As recognized by a previous Panel (FAO/IAEA, Vienna, 1971) "mass rearing of lepidopterous insects . . . represents one of the most difficult obstacles to the immediate field testing of the sterility principle for a great many of these pests." Therefore, the Panel recommends

That the Agency attempt to find funds for constructing a model Lepidoptera rearing facility in Seibersdorf.

Field programs

The Panel recognizes the assistance the Joint Division has continuously rendered the implementation of field programs involving the sterile-male technique. However, experience shows that programs tend to bog down once mass rearing has been achieved and actual field experiments start. The availability on short notice of experts in field techniques able to help solve urgent programs in field programs is crucial.

Therefore, the Panel strongly recommends that the Joint Division intensify its support of work on marking, logistics of release, release-recapture and field assessment.

Meetings

Regarding the co-ordinated research programs, review meetings should be held where laboratory and field programs are in operation. This, we feel, would encourage and increase participation by local persons including those in the chemical and other industries related to pest control.

While Symposia cover the general aspects of the sterile-insect approach, panels should address the more specific problem areas, i. e. those concerned primarily with operations in Phases II and III of SIM development. Thus, meetings on specific insects should be encouraged (e. g. the Panel on the "Application of the Sterility Principle for Tsetse Fly Suppression", convened in Paris, 7-11 June 1971, by the Joint Division in liaison with the Office International des Epizooties and the Institut d'Elevage et de Médecine Vétérinaire des Pays Tropicaux). Likewise, the Panel agreed that when such meetings focus on a single subject the Agency should publish a composite Panel report prepared by the experts themselves rather than their individual papers.

The theme of the next panel should be problems and methods in population assessment. This should be followed by a panel on the execution of large-scale feasibility studies.

The Agency should take the steps necessary to ensure free and complete exchange of information relative to the various programs by sponsoring meetings of the personnel executing SIM programs.

In view of this, the Panel recommends
that the Agency persevere in convening Panel meetings.

Training and fellowships

The Panel feels that the training activities of the Division are very useful not only for training people to carry out activities in the field, but also for promoting interest in the sterile-insect technique. Likewise, fellowships are fulfilling a useful purpose and should be continued.

Films and publicity

Films on the sterile-insect technique are very useful, as shown by the high demand for them. The Agency should consider filming the problems in the field and actually make the films available free of charge to member countries. Also, copies of these films should be made in different languages and they should be easily accessible to those requiring them either for demonstration purposes or for publicity. The Panel recommends

that the use of films for training and publicity be updated and expanded.

Co-ordinated research programs and agreements

Individual contracts have been a major tool for advancing the development of the sterile-insect technique: these should be continued. In addition, individual research contract programs should be connected with regional/national programs wherever possible.

The Panel recognizes that the Agency has limited resources for developing its co-ordinated programs, the primary objective of which is to promote the practical application of the SIM to major pests in developing countries.

Therefore, the Panel recommends

- (a) Reappraising projects of limited application to developing countries
- (b) Continuing and/or expanding those that are highly relevant, e. g. medfly, olive fly, tsetse; as regards the latter, the Panel recommends expanding the co-ordinated research program to include more laboratories and/or institutes, e. g. :
 - (i) institutes in African countries which, in addition to laboratory studies, should emphasize SIM field work: NITR, EATRO, TTD (Nigeria);
 - (ii) the Israel Institute for Biological Research (nutrition);
 - (iii) Maisons-Alfort (Glossina tachinoides)
- (c) Supporting some exploratory research for the control by the SIM of noxious insects on which little or no data exist.

IV. STATE OF DEVELOPMENT OF THE STERILE-MALE TECHNIQUE IN THE CONTROL OF VARIOUS PESTS FROM LABORATORY STUDIES TO ACTUAL FIELD PROGRAMS

In connection with the three general phases of development of the SIM previously defined (see I), pests can be grouped as follows (list not all inclusive):

- PHASE I: 1. All species under investigation except those listed in Phases II and III.
- PHASE II: 1. Medfly - Spain, Italy, Israel, Tunisia, Cyprus, USA; Costa Rica, Nicaragua, Peru, Argentina
- 2. Codling moth - Canada, USA
- 3. Queensland fruit fly - Australia
- 4. Boll weevil - USA
- 5. Heliothis zea - USA (Virgin Islands)
- 6. Heliothis virescens - USA (Virgin Islands)
- 7. Tobacco hornworm - USA (Virgin Islands)
- 8. Caribbean fruit fly - USA
- 9. Oriental fruit fly - USA
- 10. Mosquitoes - India, USA, El Salvador
- 11. Housefly - Italy, USA
- 12. European cockchafer - Switzerland.
- PHASE III. A. Eradication
 - 1. Screwworm fly - Curaçao, S.E. USA
 - 2. Melon fly - Rota
- B. Population suppression
 - 1. Pink bollworm - USA
 - 2. Mexican fruit fly - Mexico, USA
 - 3. Screwworm fly - Mexico, S.W. USA.

When setting up a research program for the suppression of a Phase I insect by the sterile-insect technique, essential elements of its ecology,

such as dispersal, need for sterile males only, population density, multiplication potential and mating behaviour should be known besides modes of sterilization and rearing. The research personnel necessary for such a program should be allocated if such a program is to be successful. After the research phase of a sterile-insect program has been successfully concluded with small-scale field trials, the authorities concerned should decide whether to carry the sterile-insect program one step further and evaluate the feasibility on a practical scale.

The Panel recommends

that such a step be taken only in situations where the concept is feasible and lasting benefits may reasonably be expected.

Scaling up to Phase II involves setting up a mass-rearing facility, carrying out releases on a relatively large area, developing techniques for dispersing sterile insects, measuring the results as well as evaluating the economics of the operation. In this connection, the Panel recommends

that the Agency assume leadership in the exchange of information on methods of sterile-insect dispersal and recapture as well as maintain a directory of personnel developing such systems for the use of all co-operators.

Based on the results obtained after Phase II, a Phase III regional application for control or eradication can next be considered. So far the only insects on which sufficient information is available for embarking upon regional programs of control are the medfly and the screwworm. Once work on other species reaches the same level of development, a regional approach to their control should be considered. Specifically, the Panel recommends

considering such an approach for:

- (a) Co-ordinated control of the medfly in the Mediterranean basin
- (b) Co-ordinated control in areas where several species of fruit flies attack the same host complex, e. g. medfly and Anastrepha in South America.

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