THE NATURAL BALANCE OF PESTS AND PARASITES ON CEYLON TEA, ESPECIALLY TEA TORTRIX AND *MACROCENTRUS*

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The evolutionary concept of "a struggle for existence" between organisms of the same species and of different species was introduced by Charles Darwin just over 100 years ago and is now commonly known to the layman. It carries with it the corollary idea of "the balance of nature"—that the numbers of any organism, plant or animal, are controlled by natural enemies and by other factors, *e.g.* as antelopes are controlled by lions and diseases. Perhaps less well-understood is the use of the term 'environment' when used in an ecological sense. When used in this sense, the term implies all of the factors in the surroundings of an organism that affect it directly or indirectly; these may be broadly grouped under four headings: (1) the quantity and quality of food, (2) climatic and other physical factors, (3) other organisms of the same species and of different species, including natural enemies and diseases, and (4) a suitable place in which to live. The study of the distribution and abundance of animals and plants as affected by their total environment is in essence the science of ecology (Greek: *oikos*-house; *logos*-study).

The object of this paper is to consider in a general way certain aspects of the cultivation of tea as they influence the numbers of insect pests and parasites, with special reference to the balance between Tea Tortrix (*Homona coffearia* Nietn.) and the parasite *Macrocentrus homonae* Nixon as affected by the use of the insecticide dieldrin to control Shot-hole Borer (*Xyleborus fornicatus* Eichh.). In order to explain the nature of this balance, I shall have to deal first with general considerations, and in so doing I hope to explain the background to some of our work.

To expand on the definition of the term 'environment' as it applies to any insect or mite pest feeding on tea, let us consider each heading in turn. Each broad category of environmental factors is diverse and complex in character, but I can only deal briefly with each here.

1. <u>Food</u>.—The tea plant, or some part of it, is food to this insect and the abundance or occurrence of the insect is affected by the quantity of suitable food available. Hence, the nutritional and physiological condition of the bush, as well as the genetically determined characters, are of immense importance, especially for the sucking insects and mites. An example of the effect of the genetical characters of the bush is that high-jat tea is more prone to Scarlet Mite (*Brevipalpus californicus* Banks) and low-jat tea more prone to Tea Red Spider (*Oligonychus coffeae* Neitn.). Again there are very great differences in the susceptibility of different clones to Yellow Mite (*Hemitarsonemus latus* Banks) (Cranham, 1960) and possibly to Shot-hole Borer (Judenko, 1960). The development of clones or varieties which are resistant to pests is a large subject which I shall not go further into here. Equally, the effect of the nutritional and physiological condition of the bush on the incidence of pests is very great; on various crops there is work showing the effect of major and minor

nutrients, of water balance, age of foliage, etc., on the development of pests. A few workers have gone so far as to say that a healthy crop, correctly nourished and cultivated, does not suffer appreciable damage from pests and diseases. This is an extreme view of the subject. It is true that plants with a balanced nutrition will often be attacked less or suffer less, and as our knowledge increases we may be able to avoid many pest and disease troubles by suitable adjustment of the manuring and cultivation. These are preventative measures which are inherently sounder than the use of chemical curatives. However, we have a long way to go towards this, but the condition of the plant is manifestly of great importance.

2. CLIMATE affects our tea pests both directly, and indirectly through the effect on the tea bush. The chief climatic factors are temperature, moisture and rainfall, light and sunshine, and wind. By experiments it has been shown that each species of animal has very definite optimum conditions for maximum survival, activity, sometimes for reproductive rates, and population increase. Above and below the optimum there is a falling off in survival, activity, or rate of increase. Beyond certain points inactivity occurs, and beyond that death.

Many instances exist in Ceylon tea of the effect of physical conditions, particularly temperature, as controlled by elevation, on the occurrence of pests. Thus, Shot-hole Borer occurs mainly between 1,000′ and 4,000′ elevation, a distribution that is thought to be due to temperature; *Lygus viridanus* Motsch. (Miridae) is a high elevation pest, usually at 5,000′ to 6,000′ elevation; *Helopeltis theivora* Waterh. (Miridae) is a low-country pest. Thus, tea districts with different climatic conditions have characteristic pests, an effect that is mainly due to climate though not necessarily entirely due to it. Certain pests are present in all districts and at all elevations to some degree.

Seasonal changes in the weather affect the seasonal abundance of pests, and outbreaks of some of our pests appear to be more conditioned by the weather than by natural enemies, *e.g.* Scarlet Mite and Yellow Mite.

3. COMPETITION may occur in various ways between individuals of the same species, *e.g.* in respect of food, shelter or mating. As examples, in a dense nettle-grub outbreak there is not enough food for more than a small proportion to develop; the amount of suitable wood in which female Shot-hole Borers can make galleries and reproduce may be strictly limited, as it is for some time after pruning.

Most species have natural enemies which are important in restricting the numbers of the host species. In the control of insect pests, other (entomophagous) insects are of great importance but there are also predatory vertebrates, spiders and mites, parasitic nematodes, fungi, bacteria, and viruses as agents of natural control.

Apart from direct competition and control, the indirect ways in which animals and plants in an ecological community affect one another are many and diverse.

4. The ecologist's concept of A PLACE IN WHICH TO LIVE implies a 'niche', not taken up by some other species, which provides the right physical conditions and shelter, and fulfills the requirements for mating, reproduction and feeding. With tea pests, we have species that feed on the flush, on mature leaves, on the bark, on mature and new wood, or on the roots. Many of them have to find other suitable places at stages of the life-cycle when they are not feeding on some part of the tea plant. A tea field, although it consists of tea bushes throughout, and is more uniform than any wild habitat, provides diverse local situations of which some are more suitable than others in providing the requirements of each species of tea pest,

and of their parasites and predators. Hence these insects are distributed in an uneven and patchy way over a field or a larger area, sometimes very markedly so.

This consideration leads us to the problem of how insects find the niches in which they are best suited to live, which involves the question of migration and dispersal. This we shall later consider in more detail for Tea Tortrix, and the parasite *Macrocentrus homonae*.

Tea plantations as an environment for insect populations

Tea is a perennial tree crop grown intensively on a very large acreage and this fact in itself is highly important. A long-lived tree crop, unlike an annual crop, exists for long enough on the same ground to build up a balanced community of insects and other organisms. It creates relatively stable and undisturbed conditions year after year and provides an environment for insects which can be compared to that of a forest. In the case of tea, this environment is disturbed by the use of pesticides only a little or very locally, for they are much less used on tea than on many other crops (*e.g.* on most orchard fruits).

There are therefore many plant-feeding insects and mites, together with others parasitic and predatory upon them, and scavenging species, which are very widely distributed in tea in relatively small numbers, *i.e.* in numbers sufficiently low for the plant-feeding species not to be regarded as pests. A high proportion of the insect pests of tea have tea as the major host plant; indeed, in the intensive tea districts there is very little else in quantity but tea, except for shade trees and weeds. Many species are almost omnipresent on tea, at least within the areas of their geographic distribution. Those which quite commonly reach damaging levels, we regard as serious pests; others which only occasionally do so are minor or occasional pests. It is important to remember that there are also other plant-feeding species widely distributed in tea, some of which could become numerous and a pest if changes in their environment permitted them to increase.

In the event of an outbreak of a pest, the planter is often inclined to ask: "Where did they come from?" In most cases, the answer is that they were already there on the field, or close by, and changes in the environment have resulted in a large increase in numbers. It is usually a very difficult matter to find what these factors are. Many important factors which have been mentioned above are quite outside the control of the tea planter, *e.g.* climate, the genetical characters of the tea bush (at least on a short term basis), and the numbers of natural enemies. I should like now to consider various routine practices in tea cultivation and their effect on the numbers of insects present, and the balance of populations. I refer to pruning, plucking, manuring, weeding and the use of shade trees. These practices are under the control of the tea planter, or modification of them is, although we cannot necessarily tell you in each case how to modify them to minimise pests. My purpose here is to emphasise the thesis that they do affect insect pests.

Pruning represents to many tea insects a drastic local curtailment of the food supply followed by a marked alteration in microclimate, and then with the growth of young sappy shoots, a change in the food supply. This we might expect would result in an unbalance for different species, for not only the plant-feeding species will be affected; parasitic and predatory species will emigrate from the field or die if there is insufficient host material for them to live on. In fact, a number of pests are more common on tea recovering from pruning, *e.g.* Purple Mite, Yellow Mite, Tea Tortrix, *Lygus*, Thrips and Aphis (*Toxoptera aurantii* Boyer). How far this due to a marked change in food supply, and how far due to a change in the relative numbers of pests and parasites, is open to question. The former is undoubtedly of importance with many pests, but the effect of pruning on the latter has been largely neglected. It is probably fortunate that pruning is a local operation in that a pruned field is usually adjacent to unpruned fields—the migration into the field of insects that may have been wiped out by pruning can more easily take place. Pruning of very large areas simultaneously might in itself have more drastic effects on insect populations, resulting in wider fluctuations from the norm and in pest outbreaks. On the other hand, certain pests are notably few on tea recovering from pruning, *e.g.* Scarlet Mite, which usually becomes abundant in the third and fourth years of a pruning cycle.

Now we might expect that the type of pruning practised (*i.e.* whether it is hard or light, clean or leaving foliage), the season of pruning, and the length of the pruning cycle could all affect directly the numbers of insects and mites after pruning, quite apart from the indirect effect on the condition of the bush. In fact, instances of all these are available. More Scarlet Mites survive the kind of pruning that leaves foliage, and they can then more rapidly develop to damaging numbers. Hard pruning leaves less Shot-hole Borer in the frames than light pruning, a fact whose importance needs further investigations. The season of pruning affects the incidence of Yellow Mite, and of Tea Tortrix (Tubbs, 1934). The length of the pruning cycle affects the numbers of Shot-hole Borer in the bush frames at the time of pruning; there are less after three years than after two years (Gadd, 1949).

Plucking is a routine measure which has an effect on insects that feed on the flush and young shoots, notably Yellow Mite, Thrips, Tortrix and *Lygus*. For Yellow Mite, two close rounds of hard plucking have been recommended as a control measure, but it is not very effective; if we could afford to go in for stripping (*i.e.* removing all growing points even below the table) we might really control Yellow Mite by this method, but this is not a sound practice. If we put bushes out of plucking, and allow shoots to grow up (as for obtaining V.P. material or for resting bushes) we will often notice a marked incidence of Yellow Mite and sometimes of Tortrix. When a Tortrix outbreak occurs, it may be considered that the best thing to do is to rest the bushes; this can be dangerous, for whilst extra foliage will benefit the bushes, the soft young shoots will promote more of an increase of Tortrix. Plucking is in fact a partial control measure, and quite a sound one, for we are removing mostly young caterpillars, which are unparasitized, whilst when we attempt to control by hand-collection of the larger larvae, we are inevitably collecting parasites as well. In the case of *Lygus* bug, which is also a pest of the flush, some of the eggs are laid too low down the shoot to be removed by hard plucking (Calnaido, 1959).

Artificial manuring can have marked effects on the incidence of pests. I have previously mentioned the idea that balanced nutrition of a crop minimises the incidence and damage caused by pests and diseases, but apart from the use of natural manure and compost, it is not easy to determine what is balanced manuring in this context. Generally in agriculture, high nitrogen ratios in the manure create a predisposition to disease and pests, and lack of available phosphate and potash induce a decline in resistance. The classic example for potash is due to Andrews (1923) and concerned tea in India; he showed that the manuring of tea so as to produce a high ratio of available potash to available phosphate in the soil greatly reduced infestation by *Helopeltis theivora* Waterh. With regard to Shot-hole Borer, Gadd (1943) found that increased nitrogeneous manuring increased the crop although it also increased the number of branch breakages resulting from borer galleries; this sort of effect might lead to an initial increase in revenue but a longer-term loss of 'capital' in the bushes, but this has not been conclusively proved.

There is evidence from tree-fruit crops, that high nitrogen levels in the foliage result in an increase in the numbers of Red Spider mites. (Breukel and Post, 1959; Garman and Kennedy, 1949). There has been no investigation of this on tea. However I think it would be indeed surprising if the greatly increased manuring on tea in the last ten years, resulting in the doubling of the crop on many up-country estates, has not had some effect on the incidence of certain pests. We have no proof that it has, but I strongly suspect that the numbers of both Shot-hole Borer and of mites, more particularly Yellow Mite, are higher than they were ten years ago and that the use of more artificial manure has a good deal to do with this. Apart from the effect of the major nutrients, there is work on other crops to indicate the effect of deficiencies and excesses of minor nutrients on the occurrence of pests, but there is as yet no work of this nature on tea.

I can quote only one instance of the effect of weeds on the activities of insect pests on tea, but it is a good example. *Lygus viridanus* is a localised pest at elevations of 5,000 ft. to 6,000 ft. particularly in fields close to jungle areas. The chief hosts are wild plants, and although it can occasionally do severe damage to tea it does not seem to be able to survive on tea alone. Serious attacks have so far often been associated with a cover crop of *Drymaria cordata* and other weeds, and clean weeding resulted in control.

With regard to shade trees, some species are additional hosts for some tea pests. Thus, *Grevillea* and *Albizzia molucanna* are host plants for Scarlet Mite and Tea Red Spider, and tend to increase re-infestation of the tea after pruning (Baptist and Ranaweera, 1955). *Albizzia moluccana* is a common host for Shot-hole Borer of tea (Judenko, 1960a) although the importance of this is not yet clear. Apart from being hosts for tea pests, the degree of shade provided by shade trees influences pests; for example, very poorly shaded fields are more prone to Red Spider Mite attacks, and the drastic removal and pollarding of shade following the introduction of Blister Blight (*Exobasidium vexans* Massee) in South India and Ceylon was one factor in an increase of Red Spider Mite.

Biological control of insects on tea

I use the term biological control here in the sense of natural balances already existing as well as in the sense of artificial introductions of parasites or predators by man for the purpose of controlling a pest. It is clear that we have on tea a natural balance of many pests, and potential pests, with their natural enemies, a condition largely undisturbed by the use of pesticides.

The only chemicals used widely and routinely are copper fungicides for the control of Blister Blight (*Exobasidium vexans* Massee); this use does not affect most insect pests appreciably, as far as we know. However, it is fair to comment that the use of copper was adopted urgently to control an epidemic disease; the possible side-effects were not known by experiment beforehand; and in the following years when successful control of the disease was obtained, the possible side-effects have not been fully investigated. One such possible effect, on the increase of mites, is at present under investigation.

Clearly, it is in the interests of the tea industry to avoid the use of pesticides wherever possible; when we use them to control serious pests, that use should be well-informed. In the case of Shot-hole Borer in the mid-country, we have a most serious pest, and attempts over many years to minimise its attacks by cultural means have met with very little success. If we can use insecticides in such a way as not to disturb the general balance on tea we are justified in doing so. So far, in the use

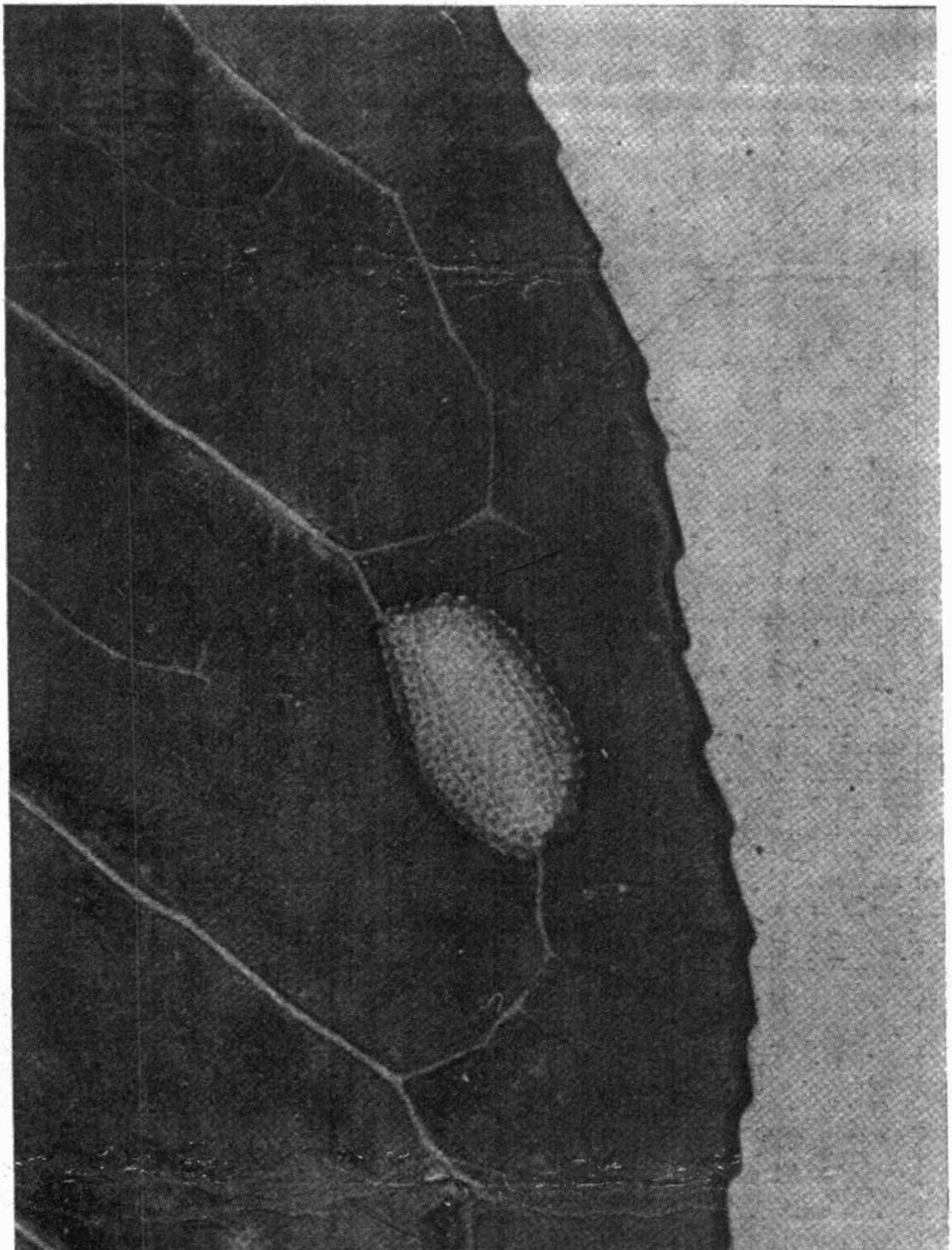

Figure 1. Egg-mass of Tea Tortrix, containing about 140 eggs. The egg-mass measures 0.4 inches on its longest axis.

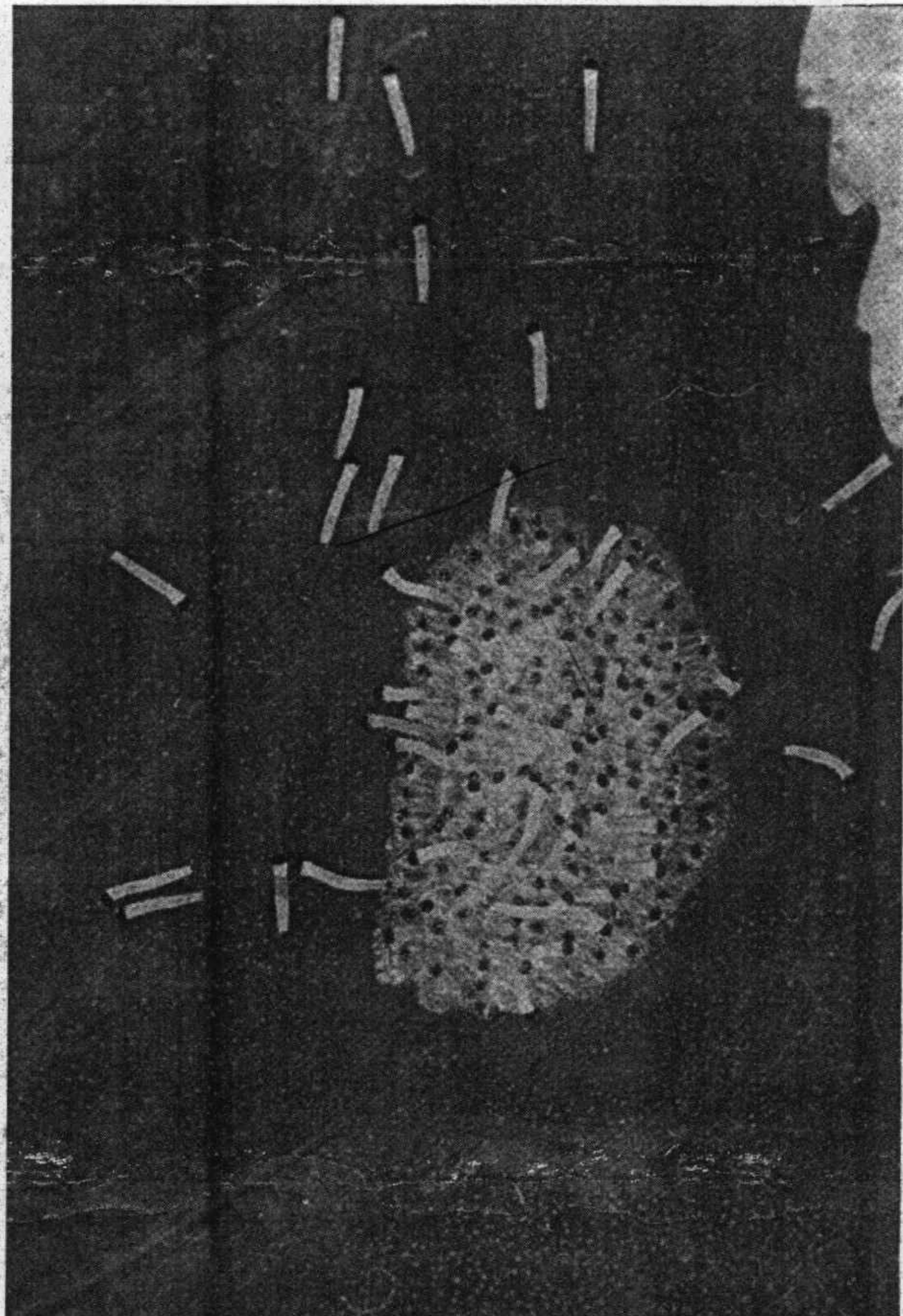

Figure 2. Newly-hatched Tortrix larvae emerging from an egg-mass. Each larva is about one-sixteenth of an inch long.

Figure 3. Tortrix larvae of the final growth stage on a leaf; they are about one inch long.

Figure 4. Tea shoots with leaves rolled over and webbed together by Tortrix larvae to form 'nests', inside each of which one larva feeds and is protected.

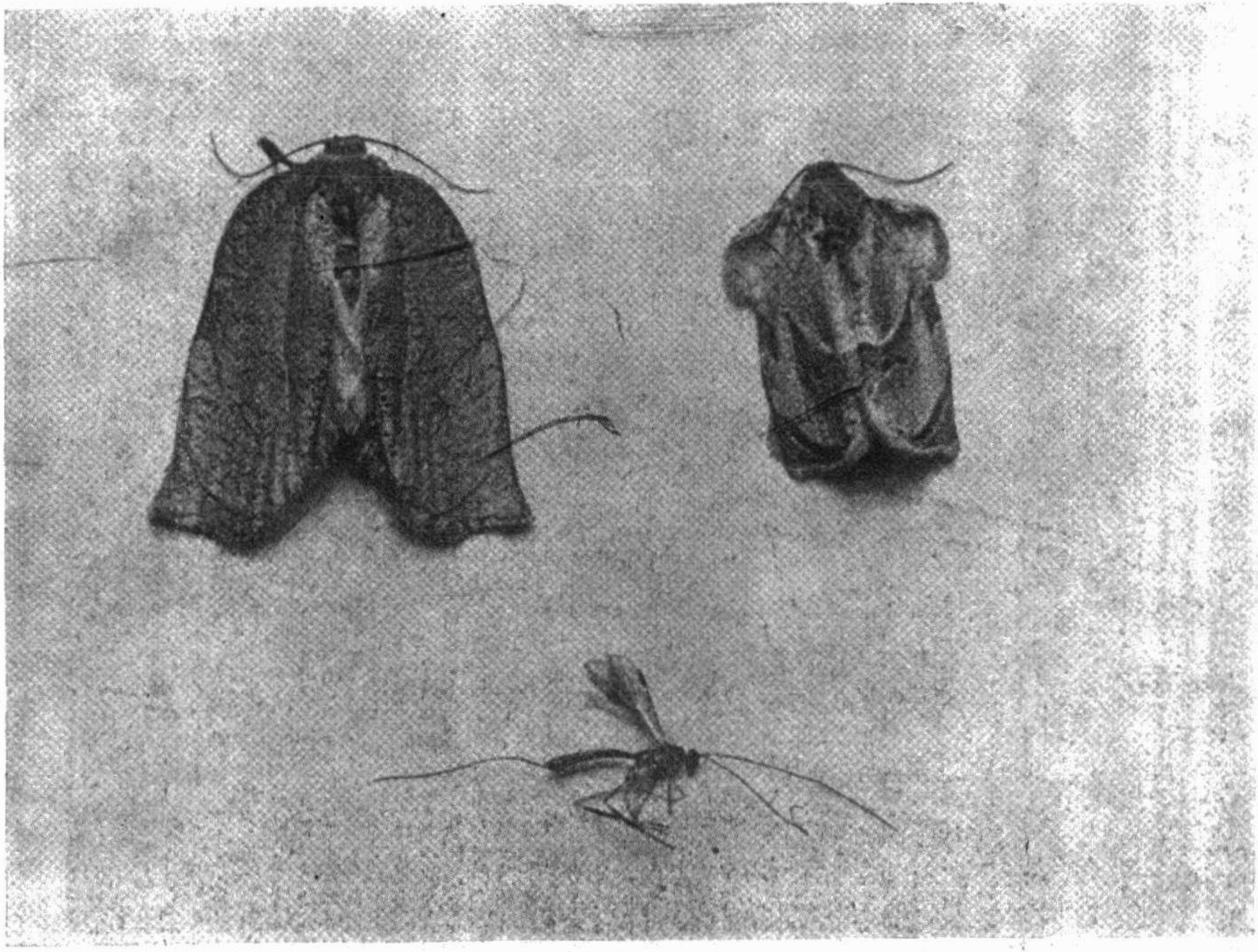

Figure 5. Tortrix female moth (left) and male moth (right). A female adult *Macrocentrus* is shown below. The female moth is half an inch long.

Figure 6. A mass of *Macrocentrus* cocoons on a leaf. Each cocoon is about one-fifth of an inch long.

of dieldrin applied to the bush frames after pruning, the only important side-effect observed has been an increase in the numbers of the Tea Tortrix caterpillars through local destruction of the parasite *Macrocentrus homonae*. In a survey, carried out in early 1960, it was clear that dieldrin had caused an increase of Tea Tortrix to a damaging level on about half the number of fields on which it had been used. In a few instances, damage by Tortrix was very severe.

Tortrix was a most serious pest of tea until the late 1930's, more particularly in all up-country districts in the South-West monsoon zone, although it occurred to some extent in all districts. It is now something of a rarity to see Tortrix in any numbers and many planters do not know the insect. The life cycle of Tortrix is that of a typical moth. Egg masses are laid by the female moths on the upper surfaces of mature leaves (Figure 1). The tiny newly-hatched larvae (Figure 2) tend to move upwards to the growing points of the bush and begin feeding. From the second instar to the fifth (final) instar, they make nests by webbing two or more leaves together, or sometimes of one leaf rolled over so that the sides are spun together (Figure 4). The larvae, or caterpillars, are dark green in colour with a shiny black head and about one inch in length when full grown (Figure 3). They do not devour the leaves completely and even in the most severe attacks Tortrix does not completely defoliate a field as can the Fringed Nettle Grub (*Macroplectra nararia* Moore)—some very ragged foliage is left. Several nests are usually constructed by one larva in the course of its development, and the mature larva pupates inside the final nest. The adult moth emerges about ten days later. The adult female is a small pale-brown tortrix moth, bell-shaped in outline when at rest and about 12—13 mm. in length; the male is more grey in colour and about 8 mm. long (Figure 5). The egg lasts about 6-11 days, the larval stage five to six weeks, and the pupal period is about seven-ten days. Thus, one generation takes about seven to eight weeks up-country, although evidence suggests it is only five to six weeks or less at lower elevations.

Various entomologists were concerned with the control of Tortrix for more than thirty years, including Green, Jardine, Hutson, Light, and Redman King. King spent several years studying possibilities for biological control. The indigenous parasites of Tea Tortrix which occurred at this time were well known and studied; they were numerous but none provided an effective control. It was not until 1935 that various parasites of Tea Tortrix present in Java were imported from that country. Amongst these was *Macrocentrus homonae* which was released at St Coombs in 1935 and again in 1936. By February, 1937, it was clear that the parasite had established itself on about 50 acres at St Coombs and that about 50% of the Tortrix host material examined was parasitized. Subsequent examinations on neighbouring estates showed that the parasite was migrating quite fast. Only two further liberations were made—one at Maskeliya in October, 1937, and the other at Madulsima in August, 1938. By 1939 it was known that the parasite had established itself in Dimbula, Maskeliya, Pussellawa, Dolosbage, Punduloya, Kotmale, and in Morawak Korale in the same year. It is interesting to note the remarkable migration of the parasite to the last named district, as this district is widely separated from others by extensive areas of jungle and other crops. These facts speak highly of the powers of migration of *Macrocentrus*.

Since 1940, Tortrix has been a minor pest of tea, and it is generally kept at a very low population density by *Macrocentrus*. The percentage parasitism is normally well over 80%. It is important to stress that Tortrix is not wiped out by *Macrocentrus*; if this happened, *Macrocentrus* would itself be destroyed, for as far as we know, Tortrix is the only suitable host insect for this parasite in Ceylon. Tortrix and *Macrocentrus* have been present on every field that we have examined for this purpose, although usually in extremely low numbers. As with any balance between a host insect and its parasite, the numbers of both are fluctuating reciprocally, *i.e.* peak numbers of Tortrix are coincident with a trough in the numbers of *Macrocentrus* and *vice versa*. Tortrix is generally more numerous from December to April; occasionally and locally a peak in Tortrix numbers is sufficient to cause local damage and to be called an outbreak; environmental factors, most likely climatic, have caused a temporary unbalance, but the balance is usually restored within a few weeks.

Macrocentrus homonae is a small Braconid parasite described by Nixon (1940) and the life history has been described by Gadd (1946). In brief, the adult female parasite (Figure 5), by means of her long ovipositor, lays a single egg in each young Tortrix caterpillar that she parasitizes. Development of the parasite inside the Tortrix caterpillar is polyembryonic, that is, the single egg gives rise by division to several *Macrocentrus* larvae, sometimes as many as 40. These larvae feed at first on the body fluids of the Tortrix host, finally emerging from the skin of the Tortrix caterpillar when the latter is mature, and turning back to consume the whole host body except for the head capsule and part of the cuticle. Each larva then spins a silken cocoon inside which it pupates; all the cocoons from a single host are matted together to form a mass of brown cigar-shaped cocoons (Figure 6). The duration of development is about ten days for the egg stage, two weeks for the larvae, and two weeks for the pupae. Adult females live for 6–38 days in captivity. The life cycle thus coincides well with the generations of Tea Tortrix.

The introduction of *Macrocentrus* therefore resulted in an extremely successful biological control of Tortrix which had been a serious pest of tea for over 25 years, reducing it to the status of a very minor pest. It is interesting to note that a distinguished worker in the field of biological control, D. C. Lloyd (1960), has recently emphasised that most instances of successful biological control have been achieved on perennial crops, rather than on annual crops. Lloyd quotes instances on coconuts, citrus, coffee and various deciduous fruits, forest and shade trees, sugar cane, and alfalfa. To quote Lloyd in this connection—"the effective environment of an organism has been defined as that containing everything of direct importance to the particular organism. It is probable that tree and other perennial crops provide better approximations to this environment than do field crops because of their fortunate combination of extension, continuity, and fixity". Lloyd goes on to say "Really effective natural enemies have been shown to disperse rapidly and have good host-searching capacities. These faculties involve many sense organs, and prevailing opinion is that the adult is attracted first to the type of environment or host area, and then to the host insect".

It will be clear from these arguments that tea as a perennial crop relatively undisturbed by the use of pesticides is a most suitable crop for the preservation of existing natural controls and for work on the introduction of parasites where likely material is available. It is also clear that the question of migration or dispersal of the host (pest) insect and of the parasite is fundamental to our understanding of biological control.

The effects of spraying dieldrin

From the survey of estate trials with dieldrin that was made in 1960, we know that dieldrin had caused an increase in Tortrix population to a damaging level on about half the number of fields on which it had been used; on the others it had not. When a Tortrix outbreak did occur, it was in nearly all instances apparent about two or three months after spraying. This observation is very significant. We may be able to avoid Tortrix outbreaks if we know the factors conducive to them, and the detailed sequence of events resulting in them. At present the picture is not complete, but let us consider some of the facts we have. Data in support of these statements will be reported elsewhere.

1. Dieldrin is not an effective control for Tortrix and, even when used at the rate of 1.5 lb. in 70 gallons of water per acre and applied as a thorough foliage spray, it gave a very low percentage kill.

2. On the other hand, it proved highly lethal to *Macrocentrus*, even when applied only to the basal parts of bushes in plucking. When a Tortrix outbreak develops after spraying with dieldrin, we find that the percentage of Tortrix parasitised by *Macrocentrus* is very low or nil, and the percentage gradually increases until the parasite has regained control and brought the Tortrix down to low numbers. In the instances observed so far, this has taken between two and six months.

3. Within a large field, it takes longer for *Macrocentrus* to regain control at the centre of the field than at the edges. The 'time lag' will presumably depend on the migratory powers of *Macrocentrus* and on the persistent effects of dieldrin.

Hence, it could be that Tortrix outbreaks develop from (*a*) individuals that survive on the field after pruning and spraying, or (*b*) individuals migrating in from neighbouring fields, or, of course, (*c*) both sources. We noted earlier that Tortrix is almost omnipresent in small numbers. Further it is quite likely that it is attracted to 'young' fields after pruning by the presence of many succulent young shoots, though we do not know this. Insufficient is known about the flight habits of Tortrix to know if it could migrate at such a rate as to result in outbreaks within two or three months, which is the duration of only one or two generations of Tortrix.

We can surmise that certain factors will influence the numbers of Tortrix present on a field after pruning and the rate of increase of Tortrix, *e.g.*:

(1) The type of pruning employed—we would expect clean pruning virtually to destroy the local Tortrix population because of shortage of food, and hence the *Macrocentrus* population as well; pruning that leaves foliage (as is usual in the mid-country) should allow some Tortrix to survive.

(2) The season of pruning—if pruning and spraying are carried out when the numbers of Tortrix are naturally somewhat higher or are rising, an outbreak is more likely. Numbers are normally rising in the latter months of the year, highest in December to April and falling off with the onset of the S.W. monsoon. They may also be reduced by the N.E. monsoon, particularly in Uva. It has in fact been observed that certain outbreaks were cut short by the onset of the monsoons.

(3) The time of spraying after pruning—if we defer spraying until the new foliage is growing, we are generally more likely to induce a Tortrix outbreak, probably because the persistent effects to *Macrocentrus* of dieldrin on the foliage are more marked than when dieldrin is on the bark only. Reference should be made here to the work of Baptist (1956) who found that if dieldrin was sprayed within two or three weeks after pruning and not later, Tortrix outbreaks did not occur. More recently, however, outbreaks occurred on two estates where spraying was done within a few days of pruning. Pruning in these instances left foliage, so that Baptist's conclusions may still be correct for clean pruning. However, the type of pruning employed in mid-country is usually necessitated by the condition of the bushes.

It is now clear that the disturbance to the balance between Tortrix and *Macrocentrus* occurs because dieldrin does kill *Macrocentrus* and does not kill Tortrix. Thus, it may be that (1) there are Tortrix present on the field at the time of spraying which survive, but the *Macrocentrus* are virtually destroyed, so that the Tortrix population increases to an outbreak level in about three months, afterwards being brought under control by *Macrocentrus* migrating into the field; or (2) Tortrix is not present on the field but can migrate into it after spraying and multiply, but immigrating *Macrocentrus* are killed until the residual effects of dieldrin have gone. Both of these circumstances might apply in different cases, or both may act together; we do not yet know, but it is important that we find out in order to determine the best timing for control measures for Tortrix.

The disturbance to the balance between Tortrix and *Macrocentrus* might be prevented by using a chemical for shot-hole-borer control that does not have much effect on the parasite. This is not thought to be an attribute of any general insecticide that might control Shot-hole Borer, although some might be effective but much less persistent than dieldrin. Alternatively, if it is the survival of Tortrix on the field that matters, we may be able to use a chemical for shot-hole-borer control which also gives a high kill of Tortrix, or we may continue to use dieldrin and add DDT to it to control Tortrix.

It has been found that DDT will give an effective control of Tortrix. A single spraying round of 6 pints of a 25% DDT emulsion formulation in 50-60 gallons of water per acre has given effective control; the cost of the insecticide is only 10-12 rupees. The problem of when we might best use DDT depends on whether outbreaks develop chiefly from Tortrix which survive on the field or from Tortrix which immigrate.

If the former applies, we might use the DDT with the dieldrin, but here we must remember that the type of spraying cover required for spraying DDT against Tortrix and for spraying dieldrin against Shot-hole Borer are different. DDT for Tortrix must be applied as a thorough foliage spray and the dieldrin for Shot-hole Borer must be applied to the bark of the bush frame. Where cut-across pruning is practised, we should be able to use the dieldrin and the DDT effectively together to cover the whole of the bush frame and the foliage left; this would cut out the cost of labour for an extra spraying round of DDT. If pre-pruning or lung pruning are employed, separate applications of dieldrin and DDT will be necessary.

If, on the other hand, it is immigrating Tortrix that matter most, the use of DDT before bud-break will be ineffective and we shall need a separate application to the young foliage at, say, about tipping time. In any event, at this time it should prove effective in preventing an outbreak whether it develops from Tortrix which have survived *or* those which have immigrated.

It may be thought that there is some objection to increasing the use of insecticides in this way, by using DDT to control a side-effect created by dieldrin. We are correct to ask if DDT may not itself create further side-effects such as an increase in mites. With regard to *Macrocentrus* in this instance, we have already destroyed them with dieldrin, and we do not aggravate this with DDT; we are in effect keeping the Tortrix down artificially only until the *Macrocentrus* can return to carry on its activities. Evidence suggests that one spraying round of DDT is sufficient to do this. So long as DDT does not produce unwanted side-effects, which have not so far been observed, we can safely use it. It will be better to use it at about tipping time to prevent an outbreak than at a later stage to cure one, for damage from Tortrix is usually widespread before it is noticed, and by that time *Macrocentrus* may be starting to work into the field.

So far we have considered the factors upsetting the pest-parasite balance. Thought must also be given to the restoration of the balance. Here we are concerned with the persistent effect of insecticides to *Macrocentrus* and the migratory powers of the parasite. These aspects will receive study; certainly it appears that about three months after spraying if not sooner, *Macrocentrus* can migrate into the field, and that from then on it depends on the rate of migration and the size of the area treated. Normally we treat single fields of a maximum of 40-50 acres in extent and on this scale if does not take *Macrocentrus* more than a matter of weeks to reach the centre of the field once it is active at the edges. Evidence of its great ability for dispersal was quoted earlier. Moreover, the capacity of the parasite to find the host, and its rate of increase (being polyembryonic) are excellent. There is some evidence from instances when outbreaks lasted six months, which is longer than most, that this was because of difficult conditions for the parasite, such as excessive drought (the adult parasite must drink water) or excessively wet weather. Experience from the few estates that are progessively spraying all fields with dieldrin as they become due for pruning, does not suggest that the re-establishment of the parasite under this type of programme will be more of a problem than on single fields. Artificial introduction of *Macrocentrus* cocoons to the centre of a large field, once it is apparent that the parasite can enter the edges of the field, may be useful and could be easily done by labourers trained for it.

It is sometimes asked if the Tea Research Institute can supply the parasite for liberation in fields with Tortrix outbreaks following dieldrin. There is no need for us to do this. In all instances so far, the parasite was available nearby, and moved into the field from tea or jungle boundaries as soon as the persistence of dieldrin permitted it. Introduction before this time would fail. Once it is apparent that the parasite can enter the edges of the field, it may be useful to liberate it in the middle, but it does not take long for it to get there of its own accord.

The use of DDT mentioned here is still experimental, but several large-scale field trials have shown that it is promising. Pending the completion of trial work, there is so far no reason to think that Tortrix outbreaks will be a serious bar to the use of dieldrin, or that we need fear any permanent damage whatever to *Macrocentrus*, that precious ally that costs us nothing to maintain.

But we are not leaving the matter there, and large-scale trials are being carried out under our supervision on twelve estates. These trials must be large-scale and in various districts in order to assess the matter fairly. We have to have more evidence that unwanted side-effects will not occur. The work involved is too great for us to do alone, so we have had to ask for your help. This has been most generously given, and we are very grateful to the Superintendents and companies concerned.

We are hopeful that by the end of this year we will be able to give you an effective method of shot-hole-borer control by which Tea Tortrix can be prevented from causing trouble as well.

Summary

A description is given of the meaning of the term 'environment' in relation to pests and their natural enemies in Ceylon tea. The effects of certain routine measures in tea cultivation—namely, pruning, plucking, manuring, weeding, and the use of shade trees—on the incidence of pests and parasites are discussed. The value of natural enemies of tea pests is stressed; the fact that tea is a perennial bush crop

largely undisturbed by the use of pesticides creates conditions that minimise the upset to natural balances between pests and parasites.

A brief resume is given of the successful introduction to Ceylon of the parasite *Macrocentrus homonae* Nixon in 1935–6 for the control of Tea Tortrix (*Homona coffearia* Nietn.), formerly a major pest, and since 1939 a minor pest of Ceylon tea due to the activities of *M. homonae*.

The effects of the experimental use of dieldrin sprays after pruning for the control of Shot-hole Borer (*Xyleborus fornicatus* Eichh.) are described; *Macrocentrus* is virtually eliminated temporarily from the area sprayed. The probable factors influencing Tortrix outbreaks after spraying dieldrin are discussed; these include the survival of Tortrix after pruning and dieldrin spraying, the relative migration rates of Tortrix and *Macrocentrus*, and the persistent effects of dieldrin.

A single spray of a DDT emulsion (2 lb. actual DDT per acre) has proved an effective control for Tortrix, and the optimum timing for this additional treatment is considered.

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Question No. 14.—Mr G. C. Du Pre Moore, Supdt., Deltotte Group, Galaha.

Clone TRI 2026 has been found very prone to shot-hole attack in my district (Galaha). What information is there on the susceptibility of this clone to Shot-hole Borer and the advisability of using this clone for replanting?

Director: Dr Judenko's work on clonal resistance is so far in a preliminary stage. I believe there was no clear-cut indication for clone TRI 2026, and much more experience is necessary in different districts. A clone may still yield well although badly attacked, (*e.g.* TRI 2024). There is a preliminary indication that TRI. 2023 may be resistant. In respect of clones and Shot-hole Borer at present, superintendents will have to rely a good deal on their own local experience. (Judenko, 1960).

Question No. 15.—Mr R. J. Barlow, Stonycliff Group, Kotagala.

Do Shot-hole Borer and Tortrix live in shade trees?

Dr Judenko: Yes, Shot-hole Borer affects *Albizzia moluccana* and in a lesser degree Dadap and *Gliricidia.* Secondly, I was able to find that Shot-hole Borer from *Albizzia moluccana* is able to infest tea.

Mr Cranham: Tortrix has quite a large host-plant range; certainly it can be found occasionally in *Albizzia* and Dadap in small numbers. There are quite a few wild plants and jungle trees that also harbour Tortrix, and consequently also harbour *Macrocentrus* so that you can expect, and we have found, that *Macrocentrus* can come from jungle boundaries, as well as from tea boundaries, in to the sprayed field.

Question No. 16.—Mr J. G. Riminton, Supdt., Forres Estate, Maskeliya.

Is there any evidence of Shot-hole Borer developing resistance to dieldrin?

Question No. 17.—Mr W. A. Aiyadurai, Supdt., Madulkelle Estate.

Is there a possibility of the beetles developing a resistance to the dieldrin subsequently?

Director: There is certainly no evidence so far. Induced resistance is a difficulty which most commonly occurs with fast-breeding insects and mites, *e.g.* house flies, mosquitoes and red spider mites. It has occurred with relatively few agricultural pests. If it does happen, we shall have to face it when it comes, but there is no reason to concern ourselves about it at this stage.

Question No. 18.—Dr T. Visser, T.R.I.

Would it be practical to leave strips of unsprayed tea in a sprayed area in order to sustain *Macrocentrus* population and to assist in their re-establishment in the sprayed tea?

Mr Cranham: This thought has occurred to us and at least one planter has done it. It is very doubtful if it would help to maintain *Macrocentrus* which is a very active insect and would move across the dieldrin-sprayed strips. It would certainly reduce the duration of control of Shot-hole Borer because reinfestation of the sprayed strips from the unsprayed strips would be more rapid than when whole fields are treated.

Question No. 19.—Mr A. V. E. Felsinger, Uva Ketawella, Hali Ela.

Is *Macrocentrus* the only known parasite to attack Tortrix? Are there others which may be less affected by dieldrin?

Mr Cranham: There are many parasites of Tortrix. I think about twenty were recorded before the introduction of *Macrocentrus* in 1935–36. None of these, however, was a really effective parasite, and they have since been virtually squeezed out by *Macrocentrus*. Recently we have noticed that one of them, *Bethylus montanus*, has been present in dieldrin-sprayed areas before *Macrocentrus* could get back. It would seem to be, therefore, less affected by dieldrin, but it is not likely to help very much in controlling Tortrix—it may help a little.

Question No. 20.—Mr G. D. Austin, Houpe Bungalow, Houpe S.P.O.

Are any experiments being laid out anywhere to ascertain the loss of crop caused by Shot-hole Borer?

Dr Judenko: Experiments are being carried out as given in my paper—three replicated trials and three large-scale experiments with duplicate plots only.

Question No. 21.—Mr S. Ananda Rau, U.P.A.S.I.
Mr P. de Jong, Tata-Fison, India.

Is any work in progress to find alternative insecticides to dieldrin for shot-hole control: and also alternatives to DDT for Tortrix control, to find a dual control agent?

Director: Some other insecticides have been tried. For instance, Dr Judenko earlier gave some attention to chlordane but he found dieldrin much superior on an equal cost basis. The trial work involved is very considerable and we have at present to concentrate our available resources on the promise shown by dieldrin if we are to achieve results. This is not to say that in the future we may not be able to improve on the method worked out.

Question No. 22.—Anon

How long has dieldrin been known to be effective against Shot-hole Borer? Could Mr Newton of Sanquhar say anything on this?

Mr Newton: Control of Shot-hole Borer was carried out on Sanquhar by Dr Baptist in 1955. He did three experiments. Unfortunately in the beginning no plucking trials were started; so we got no results on actual yields until later. It wasn't until a year and a half after the actual spraying took place that I decided to do some plucking trials in fields running on to three years. The results were not very good. Yet I managed to get my V.A. and the Company to agree to further trials. I did 9,000 bushes and against that I counted a 9,000-bush control. Our sprayed area was so good in comparison to the control that accordingly we decided to spray the entire pruned area. I have records of the monthly results, especially on young tea. Some of the healthy tea has responded very well indeed, other fields not so well; but I can only say that practically all the fields which have been sprayed have shown an increase in crop over their pruning cycles. Whether this is entirely due to Shot-hole Borer or more manure and better cultivation, it is hard to say; but recent counts taken by Mr Cranham of Shot-hole Borer in standard units of wood show that dieldrin spraying has had a very marked beneficial effect upon the destruction of the borer beetle. In one instance, another insecticide has been used; comparing results with dieldrin after 18 months, although the actual attacks are approximately the same, there are no live larvae or live beetles in the dieldrin-sprayed area, whereas in the areas sprayed with the other insecticide there are considerable numbers of live larvae and beetles. I have written an article for the *Tea Quarterly* and you will be able to read in that exactly what we have been doing.

Question No. 23.—Mr V. Ratnayake, Deniyaya.

Have you observed any effect on prevalence of mite or red spider by the spraying of dieldrin for Shot-hole Borer?

Question No. 24.—Mr A. Passingham, Galbode Estate, Ratnapura.

It may be of interest that under the experiments carried out by Dr Baptist and Mr Austin at Galbode Estate in 1955, spraying with DDT in the control of Tortrix, following dieldrin spraying, in all instances resulted in intense yellow-mite infestation with seriously retarded growth of the young foliage.

Mr Cranham: In reply to these two questions, we have not yet seen any convincing evidence that dieldrin or DDT spraying will generally increase mite numbers. This may be so, and we are watching our trials carefully to find out. It must be remembered that Yellow Mite is very common on fields recovering from pruning and there must exist a big difference in mite attack between a sprayed area and a comparable unsprayed area in order to indicate anything. This we have not so far seen at all for Yellow Mite, but there is one trial where there is more Red Spider mite on the sprayed area.

Question No. 25.—K. D. Seelanatha, Matale West.

Isn't the widespread application of dieldrin over a period of years likely to eliminate *Macrocentrus homonae* or reduce it greatly so that, as prior to its introduction from Java, Tea Tortrix will once again appear as a serious pest, more serious than the incidence of Shot-hole Borer at present? What work has been done to approach the problem from a biological angle? Is there a possibility of approaching it, judging from the sex life of the *Xyleborus fornicatus*, in the manner the problem of the Screw Worm was solved by irradiation?

Director: This has got six or seven questions in it actually, and the first point is that before *Macrocentrus* was introduced from Java it was not present in the island at all, and the second is, as Mr Cranham has pointed out, once it got going here it spread extraordinarily rapidly and over wide gaps; if all tea in Ceylon or in the shot-hole-borer country were pruned in the same week or in the same month, there might be a danger of serious interference with *Macrocentrus* if all that tea were sprayed with dieldrin. But in fact the situation is not at all like that. In a large part of the shot-hole-borer country, pruning cycles are 3 or 4 years, that is to say, in at least a third of your tea the *Macrocentrus* on it has had ample opportunity to recover, and it can then invade the neighbouring fields which have recently been sprayed. I don't think there is the slightest danger of eliminating *Macrocentrus* by this dieldrin spraying. Nor do I think that it will seriously affect the population.

The second part of the question: first of all there might be a misconception about the name of this species—*fornicatus*. This was named by Eichhoff in Germany, nearly 100 years ago, from a specimen from Ceylon; the name *fornicatus* means arched or vaulted in this context. There are, however, many ways in which we might approach the problem of control, but the use of gamma-rays or X-rays—irradiation—to sterilise the males—a method used with Screw Worm—seems to be one of the least likely to succeed for Shot-hole Borer. This method proved practicable for the Screw Worm, but is probably applicable to only a very few pest problems.

Question No. 26.—Mr R. M. Winter, Manager, Pillagoda Valley Estate.

What are the views on pruning deeper into wood affected by borer until galleries are eradicated—does this control borer effectively?

Director: People have tried hard pruning, and various other things, but have abandoned those lines now. We have, in the low country, frequent pruning—18-month pruning cycle—which is a quite useful thing. We are trying to deal with the insect on its own merits, and to allow pruning of the bush in the way that is best for it.

Question No. 27.—T. Moreton, Lethenty Group, Hatton.

Referring to tea not attacked by Shot-hole Borer, can Tortrix be controlled by spraying 'Arkotine'. Also does a ground cover such as *Drymaria* harbour *Macrocentrus* and thereby prevent it from infiltrating into tea?

Mr Cranham: 'Arkotine' is a DDT emulsion and can therefore be used for Tortrix control in the way described. We know of no connection between weeds or cover crops and the activities of *Macrocentrus*.

Question No. 28.—Mr Ananda Rau, U.P.A.S.I.

Is there any explanation for the failure of dieldrin to control Tortrix, which is stated to be readily controlled by DDT, considering that both are chlorinated hydrocarbons?

Director: That is the sort of question that I think many people in other parts of the world are trying to answer, and our set-up is not an appropriate one to tackle that sort of question. There is a great deal of variation in the activity of different chlorinated hydrocarbon insecticides.

Question No. 30.—Mr Frank de Silva, Epalawa Estate, Kegalle.

China tea appears to be more resistant to Shot-hole Borer than the Assam jat. Would it not be possible to produce a hybrid of these two which would be fully resistant to this pest?

Director: Mr Cranham says that he has seen China jat badly attacked. That is to say, in his view, the first assumption is not correct. Secondly, there are in the Island enormous numbers of varied hybrids of China and Assam jats. We have tried to get planters to discover a single bush which is uninfested in an infested field and so far we have not got anywhere with it, and it is for that sort of reason that we are going on now with this insecticide work which does look as if it is very close to success. Any breeding programme is likely to be extremely protracted, and there is no guarantee of success. We may find individual seedlings which appear to be resistant and of course Dr Judenko is studying the existing clones. Preferably we want to choose our clones for yield, quality, vigour and all that sort of thing; and rather than reduce the value of these qualities by breeding into it Shot-hole Borer resistance, we feel that it is more profitable to get the best bushes we can for yield, and so on, and use our insecticide.