

THE PROBLEM OF NEMATODE CONTROL IN TEA PLANTATIONS

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The two major nematode (eelworm) pests of Ceylon tea plantations are *Heterodera marioni* (Coen.) Goodey and *Pratylenchus* (*Anguillulina*) *pratensis* (de Man) Filipjev* *Heterodera marioni*, well known as the cause of root knot diseases of numerous plants, is very destructive to tea seedlings and forms a serious nursery pest. It is also known to tea planters as the cause of large galls or root knots on *Dadap* and *Tephrosia vogelii*, two green manure plants commonly grown among tea. Although the soils of many tea fields are heavily infested by this eelworm, mature tea bushes with few exceptions rarely suffer. This fact will again be referred to later.

The disease caused by *Pratylenchus pratensis* is not so well known, partly because it is not so widespread and partly because it is not easily recognised. Gadd (1938) has published a full account of this pest and the symptoms exhibited by infested bushes. Bushes attacked by *P. pratensis* are usually unthrifty, and have a thin appearance due to deficiency of foliage, but it should be noted that other causes, e.g., scarlet mite attack, often lead to similar symptoms. The only sure way of recognising the disease is by the identification of the eelworms associated with it.

HABITS

The habits of *H. marioni* and *P. pratensis* are alike in so far that both gain entry into the plant through root tips, and both spend part of their life cycle within the roots. In other respects their habits are different. *Heterodera* for instance

extrudes her eggs from the root in a gelatinous mass; so, her young hatch in the soil or in the rotting tissue of old gall, whereas *P. pratensis* lays her eggs within the root where they hatch. *H. marioni* collected from soil consist of larvae and males only whereas a collection of *P. pratensis* from soil usually consists of adult females as well as males and larvae. As *P. pratensis* is born within living roots from which all its food requirements can be obtained, it is perhaps surprising that the species is ever found in any quantity free in the soil. To explain their presence in soil it will be necessary to consider briefly the root system of the tea bush.

Tea, like other plants, absorbs its water and soil nutrients, in solution through the roots. But the greater part of each root is covered by a corky layer which is impermeable to water, and a small region only, immediately behind the root tip, is free of this cork layer and so can absorb water. As the root ages, a cork layer is formed around this region also; but in the meantime the root grows longer and a new water absorbing region is formed, always immediately behind the root tip. This process of continued growth occurs on the tap and main lateral roots which advance into new regions of soil. A tea bush, however, requires a large volume of water daily, and the absorbing areas on the main permanent roots are far too small to obtain a bush's full requirements. A large absorbing area is provided by innumerable fine roots, commonly termed "feeding roots," which can be collected in handfuls from the sites of

* In earlier publications the authors have used the name *Anguillulina pratensis* (de Man) Goffart for this pest. Recent classification of this group of nematodes has resulted in its transfer from the genus *Anguillulina* to *Pratylenchus*; so, in future the name *Pratylenchus pratensis* (de Man) Filipjev, now generally accepted in agricultural literature, will be used for it.

healthy bushes. These feeding roots are of a much less permanent nature; they function for a time, then die and decay, and are later replaced by others. In this way, feeding roots explore the same volume of soil over and over again, whereas the permanent woody roots by continued growth tend to explore new regions. As a source of supply of water and soil nutrients, the feeding roots are of the greatest importance although their life is relatively short.

As the great bulk of water taken up at the roots is later lost from the leaves, the number of leaves a bush can carry must depend to a large extent on the number of feeding roots supplying water. Heavy root pruning results in a wilt and dropping of the leaves. It is also very probable though it is more difficult to prove, that defoliation of a bush results in the premature death of a number of feeding roots. When a bush is pruned a very large number of the feeding roots die, but new ones are formed immediately before the bursting of the buds and development of the new leaves.

With this brief sketch in mind we may consider what is likely to happen to female *P. pratensis* that enter (1) a young tap and (2) a feeding root. Entry is always obtained near the root tip in the water-absorbing area; and experiments to induce the eelworms to enter through the corky layer of the root have invariably failed. A female entering a taproot bores her way through the cells until the whole of the body is within the root where she feeds. In due course, eggs are laid and the young hatch, become adult and in turn have young. Meanwhile, the root continues growth, penetrating further into the soil; but the eelworm and her family remain relatively in the same position. As time goes on, the eelworm colony becomes larger, the region of the cortex in which they have fed dies, and a lesion is formed. These eelworms apparently do not leave the root; they merely move a little further in the

cortex so that their heads always lie within living cells. Such lesions contain large numbers of eelworms but the damage they do to the bush is probably very small.

The female that enters a feeding root has no such assured future. She enters near the tip, feeds, and raises her family. But in the course of time the root begins to die and then decay. Conditions are then no longer favourable for the eelworm as there are no living cells on which to feed. Consequently the eelworms must leave that root and travel through the soil in search of others in which to live and feed. Heavy infestations of feeding roots also result in their premature death. The presence of numbers of *P. pratensis* free in soil is probably due more to the death and decay of infested feeding roots than to other causes

The number of eelworms of the species *P. pratensis* found free in soil is usually relatively small compared with the number in susceptible roots growing in that soil. This fact is well demonstrated by the following experiment: A tea seedling was established in a six-inch pot, and 200 specimens of *P. pratensis* from a tea root were added to the soil. Five months later only 190 eelworms were recovered from the soil but over 6,000 were obtained from the roots. The eelworms were collected from the roots by immersing them in water for seven days, but by no means all the eelworms (probably not more than half) were recovered by that method. Had the count been made after pruning the plant and after the premature death of feeding roots, the ratio of eelworms in roots to the number free in the soil would probably have been much narrower.

Soil in which plants infested by *H. marioni* are growing, usually contains a large number of larvae due to the fact that the eggs are extruded in masses from the roots. Entry into the roots is made by

larvae; the females after taking up a feeding position do not move from that position; they die after extruding their egg masses.

Neither *P. pratensis* nor *H. marioni* can obtain proper nutrition while living free in the soil; yet they can survive long periods of starvation (Gadd, 1942). Specimens of *A. pratensis* have survived for 8 months in damp soil from which all living plants, from which food might be obtained, have been rigidly excluded.

CONTROL MEASURES

Control measures, to be rational, must be based on known facts regarding the life-history of the pest and host. From what has already been said, it will be evident that in any infested planted area, the eelworms will be located in the roots of growing plants and free in the soil. For obvious reasons it would seem easier to kill the pest in the soil than to free living plants without damaging them.

Disinfection and Sterilisation.—Plant-parasitic nematodes living entirely within roots or other plant parts, are well protected against their natural enemies, and are difficult to bring into contact with poisons. In order that a poison should reach them it would have to be absorbed by the plant without injury, and then conveyed to the site of the parasites in sufficient quantity to be toxic. Eelworms, however, appear to be highly resistant to most known poisons, and there seems little probability at present that one will be found harmless both to the plant and the consumers of the crop, yet deadly to the pests within the plant tissues.

The one sure way of destroying parasitic nematodes within plant tissues is by killing, preferably by fire, the plant itself and with it the harboured pest. Plant pathologists have as a goal the cure of plants, particularly perennials like tea to which such radical killing methods cannot easily be applied; yet little is known of

plant therapeutics though considerable advance in disease control has been made in the recent years by nutritional means. At present, however, no curative treatment is known by which a *growing* plant can be freed of nematode pests, nor have general observations suggested favourable lines for investigation.

Plant parasitic eelworms cannot survive exposure to high temperatures, and use has been made of this fact for ridding dormant planting material. *e.g.*, bulbs (Goodey, 1933) and chrysanthemum stools prior to taking cuttings (Hodson, 1933), of nematode pests hidden within their tissues. Considerable care is necessary for efficient treatment because too high a temperature will kill the plants, whereas too low a temperature or too short an exposure to the correct temperature (110°F) will allow the eelworms to survive. The margin between the too high and too low temperatures is never very large. This method of control is of particular value when suspect material has to be planted on clean ground, but if the soil is heavily infested the treatment of the planting material can have but limited value.

Heat can more easily be applied to kill eelworms in soil from which living plants have been removed, as higher temperatures can be used. Steam is commonly used for the purpose. Steam sterilisation is of particular value for green house soils where one can ensure that the temperature of all the soil to be used is raised to the required degree, and so eradicate the pest. But equal success cannot be achieved with field soils. Eelworm populations of field soils can be materially reduced by steam sterilisation but complete eradication cannot be achieved. A reduction of the population may be sufficient to allow of a profitable temporary crop being taken, but when the crop plant is perennial, like tea, nothing short of

complete eradication of the pest is likely to prove of permanent value. A small population would soon increase to gigantic proportions on the roots of the susceptible perennial plants, and the soil would become as heavily infested as before treatment.

Much that has been said of steam sterilisation applies equally to the use of poisons for sterilising soils. It has proved impossible to obtain complete eradications of plant-parasitic nematodes from field soils by their use. Eelworms are peculiarly resistant to many poisons, so the choice for control purposes is restricted. Silver salts have proved deadly to both *H. marioni* and *P. pratensis* *in vitro* (Gadd, 1941) but the result when the same salts are applied to soils has been very disappointing. It will be obvious that if a poison used for soil sterilisation is also toxic to plants, the soil must be freed of the poison before plants can be grown in it. For that reason volatile substances are to be preferred. The best known and most successful are formaldehyde and chloropicrin (Taylor, 1943).

The fact that *H. marioni* and *P. pratensis* cannot long survive desiccation has a practical value in that it affords a method of freeing small volumes of soil of these eelworms without the use of chemicals. Sun-drying of soil, previously sieved to remove all roots, has proved of value where seedlings are to be raised in baskets (Gadd, 1941). The soil must be spread thinly to ensure thorough drying; consequently a large drying area is required for a relatively small volume of soil. This, together with the labour involved, reduces the value of soil desiccation as a means of control on an appreciable scale.

A method of control which has the greatest value is by rotation of annual crops. A susceptible crop is grown on

infested soil only at long intervals. Immune or resistant crops are grown in the intervals during which time the eelworms, owing to the absence of susceptible roots, are starved and their number reduced. Again, this method does not result in eradication of the pests though it reduces the parasitic nematode population sufficiently to enable one susceptible crop to be grown successfully. The method is, of course, impossible with a permanent crop like tea, nor does it suggest the possibility of starving the nematodes completely from infested areas from which tea has been removed. Mention has already been made of the lengthy period that *P. pratensis* can survive starvation. *H. marioni* is probably even more difficult to starve out of soil because it has so many more host plants on which it may survive. During the starvation period the soil must be kept free of all plant growth as the presence of susceptible plants among the weeds would undo any beneficial effect achieved by starvation.

Natural Enemies.—Due largely to the medium in which they live, relatively little is known of the natural enemies of soil eelworms. So far as is at present known their chief enemies are predatory nematodes belonging to the genera *Dorylaimus*, *Mononchus* and *Diplogaster*, certain fungi, and disease causing organisms like Sporozoa.

Every fertile soil contains numerous species of nematodes in large numbers, none of which may be harmful to plants. The number of known plant-parasitic species is relatively small though they receive most attention in agricultural literature. Many species feed on bacteria and decaying vegetable and animal matter, and these, as might be expected, are most numerous. There are, however, other species which prey on their own kind. Their food may be described generally as living animal matter, or more specifically, as nematodes, rotifers and other microscopic soil organisms. So far as can

be ascertained such predacious nematodes do not chase their prey, but take what happens to pass within reach, and they do not seem to have any great preference for particular species. One cannot, for instance, induce a *Mononchus* to feed only on *H. marioni* or *A. pratensis* when other species are available and easily obtained. Under natural conditions the bulk of the predators' food is obtained from non-parasitic species which spend their whole life cycle free in the soil. No species of predator is known to the writer to enter infested roots to feed on the parasites there. Nevertheless, when such parasites pass through the soil they are likely to become prey to the predator. The activities of some predatory nematodes have been watched under laboratory conditions, and the junior author has in his collection specimens of *Mononchus* in the act of swallowing *A. pratensis* worms.

Little is known concerning the value of predatory nematodes in the control of plant parasitic species. Thorne (1927) in a study of the economic importance of species of *Mononchus* estimated their numbers, in the sugar-beet growing sections of Utah and Southern Idaho infested with *Heterodera schachtii*, to vary from a few specimens only to nearly 300,000,000 per acre. To be of much economic importance their number must be great. Species of *Mononchus*, *Dorylaimus* and *Diplogaster* are found in Ceylon tea soils but in no instance have they occurred in such numbers as to constitute a menace to other nematode populations.

Among soil fungi are a number of species highly specialised for catching nematodes by means of traps of various sorts. A trapped eelworm rarely escapes and its body is used by the fungus as food. A parasitic eelworm moving freely through the soil is as likely to be caught in a trap as is a non-parasitic species, but it is only when moving through soil that the parasitic species runs that risk. The longer a

parasite remains free in the soil, the greater the total risk. Of *H. marioni*, only larvae and the occasional male can be caught, but adult *P. pratensis* of both sexes as well as larvae may be trapped when they leave dying or dead feeding roots and move towards living roots.

The number of eelworm-consuming fungi in a soil will depend to a large extent upon the size of the eelworm population; the greater the number of nematodes the greater the number of fungi which can live on them. The simplest way of increasing the non-parasitic eelworm population of a soil is by the addition of decaying organic matter. It has long been known that the addition of organic matter to soil often gives beneficial results in nematode control, and Lindford *et al* (1938) have indicated how that control operates. Decomposition of organic matter results in a greatly increased population of total nematodes in the soil, and this in turn supports the building up of large populations of plant and animal forms destructive to nematodes, including nema-capturing fungi, predacious nematodes, and predacious mites. These collectively attacking various types of nematodes, destroy larvae of the root-knot nematodes and other parasitic species as well as the free-living forms which comprise the greater part of the total nematode population in the soil during early weeks of decomposition. Consistently in five experiments decomposition of large amounts of organic matter in soil was associated with reduction in numbers of *Heterodera marioni* galls on roots of indicator cowpeas.

Lindford *et al* pointed out quite clearly that their experiments afford no prospect of eradication of the root knot nematode or other parasitic eelworm and that nothing less than eradication is sufficient for some purposes, as in nurseries and propagating beds. However, with the present unsatisfactory position of eelworm control for permanent crops any method offering pros-

pects of amelioration is worthy of consideration, and this one is worthy of attention. Heavy green manuring at any time is likely to prove of value against *H. marioni* because the larvae are always present in infested soil, but more apparent benefit can be obtained when planting susceptible plants, e.g., dadaps, by using large quantities of decaying vegetable matter in the supply holes. As regards its value against *P. pratensis* little is known from experiment, but from what has been said earlier regarding the effect of pruning on feeding roots and the escape of the nematodes from dying roots, it would appear that the best time for applying heavy doses of green manure to tea infested by this pest would be shortly after pruning.

During his investigations of the economic importance of some *Mononchs*, Thorne (1927) noted that their populations varied greatly from year to year. Two species were found to be attacked by sporozoan parasites that sterilise them and so reduce their numbers. Other undetermined causes also greatly reduced the numbers of other species, and in one field practically exterminated a species. In a later paper, he (Thorne 1940) reported the discovery of another species of sporozoan which attacked *Pratylenchus pratensis*. At the time of collection the nematodes were living free in the soil, having left maturing cotton roots, and 66 per cent of the individuals were parasitised.

A similar sporozoan parasite of *A. pratensis* has been observed once only in Ceylon, and then a few worms only were seen to be infested. A careful search is made for these and other parasites whenever *A. pratensis* infested soil is examined, and from general observations it would appear that the species is particularly free from attack by disease-causing organisms. Nevertheless the discovery that one of our most serious plant-infesting nematodes can

be severely attacked by a parasite is most encouraging and gives rise to the hope that at some time such parasites may be utilised in developing a natural control of the pest.

Host Immunity.—Plant parasitic nematodes have great ability to find and select their proper host plant. Some species, like *H. marioni* are known to attack a large number of different plant species, which are called their hosts, whereas others have only one known host plant. The chief species of plant-infesting nemas, including *A. pratensis* have many hosts. Steiner (1925) has described their habits as follows: "If a number of different host plants are growing on a given soil area, the nemas in the soil will always find out and attack the one they like best, leaving the others unharmed, even though they too are favoured host plants of that species of nemas." This phenomenon has suggested an apparent method of control, by trapping the nematodes in a most favoured host.

For instance, many Ceylon tea fields are infested with *H. marioni* which cause disease of *Tephrosia vogelii* and *Dadaps* intergrown for green manure. *H. marioni* in a few fields is known also as pest of old tea, but from general experience *T. vogelii* is the more favoured host. When *T. vogelii* is planted in infested soil, the larvae of *H. marioni* by preference go into their roots and settle down to a sedentary life. If at this stage, before the larvae have become mature and begun to lay eggs, the *T. vogelii* plants are uprooted and destroyed a large number of parasites would be trapped and destroyed, and the soil population would be reduced accordingly. *Tephrosia*, however, is not intergrown with tea as a trap-crop, but as a green manure. Consequently the plants are not removed at the right time. By the time they are removed, several generations have been reared on their roots and the nema-population in the

soil has been considerably increased. If instead of *H. marioni* the soil is infested with *A. pratensis*, and *T. vogelii* is interplanted with tea, the nemas would go to the tea in preference to the Tephrosia. In such circumstances Tephrosia would be useless as a trap crop.

The trap crop idea is simply to plant a highly susceptible crop in the soil and to catch as many nematodes as possible in the root system. Then comes the most important step. Before the stage of development is attained at which a new generation of nemas will develop, the plants must be killed to cause the death of the contained parasites. The time of destruction of the host plant therefore is very important. If destruction is delayed more harm than good is likely to result. *H. marioni* breeds at different rates in different hosts (Gadd, 1939) so the optimum time for lifting the trap crop has to be accurately determined.

Godfrey and Hoskins (1934) who carried out experiments with sprouted cowpea and tomato plants as trap crops to catch *Heterodera marioni* in containers showed that the largest catch was made at the first planting and that subsequent planting of trap crops recovered only low additional proportions. The third successive planting of the trap crop did not entirely eradicate the nematodes, nor did the fourth do so with absolute certainty, though remaining infestation was decidedly low. The trap crops were lifted after 30 days. The conditions of these experiments in which the root systems were limited within containers undoubtedly made for a more complete catch than would occur in open fields.

It will be evident that the correct use of a trap crop under certain circumstances may give beneficial results, but it fails to give the complete extermination necessary when a permanent crop is to be planted.

Another curious and important fact concerning the relationship between para-

sitic nematodes and the host plant is that if the ancestors of a population have lived for a number of generations on a single species or even variety of host plant, their descendants may not attack any other plant known to be a host; or if they do so, it will be only with difficulty and then only in small number. For instance, *Heterodera schachtii* is known to infect peas and oats as well as many other hosts. But when they live on peas alone for years they become highly specialised on that crop and will then fail to attack oats severely. As Steiner (1925) has pointed out, this fact is of great importance when studying resistance and immunity of host plants.

In an experiment to test whether certain green manures and weeds were susceptible or resistant to *A. pratensis*, the plants were established in 6-inch pots and to each were added 200 worms from tea-root cortex. The population of nematodes had passed many generations in tea and in consequence was highly specialised to that host. After six months the plant roots and soils were examined. Only in those pots in which tea seedlings had grown was there a marked increase in the parasitic nematode population and a severe infestation of the roots. Over 4,000 parasites were recovered from tea roots, whereas no other species gave more than 100, using similar methods of recovery. Obviously tea plants proved more suitable for this specialized strain of *A. pratensis* than did *T. vogelii* to mention only one of the less susceptible plants. The question arises whether the eelworms which maintained themselves on the Tephrosia roots would in the course of time, if given nothing but Tephrosia roots to live in, give rise to a strain which would prefer Tephrosia to tea. From what is known of other plant-parasitic nematodes the answer is most probably 'Yes.' For this reason Steiner recommends that perennial plants, even though they are not yet known as hosts, should rather be excluded from crop rotation in nema-infested fields, as any

nema population having the same plant at its disposal for generations may adapt itself to it.

That perhaps is counsel of perfection but it is very disheartening to a tea planter whose crop is perennial. Must then tea in nema-infested fields ultimately fail? Our knowledge of the many factors affecting the problem of host immunity, as Steiner clearly shows, is far too incomplete to afford any dogmatic answer to that question. Much more has to be learned of the immunity problem involving as it does the whole behaviour of the plant under influence of attacking nemas.

Very large areas under tea in Ceylon are infested by *Heterodera marioni* as is shown whenever *T. vogelii* is intergrown with the tea, yet with small exceptions, the tea to all appearances is unharmed. The same parasitic nematode, however, is a serious and destructive pest in tea nurseries. The evidence points to the fact that although tea in the seedling stage is susceptible to, and suffers severely from, attacks by *H. marioni* yet older tea as a rule is either less attractive or is able in some unknown way to neutralise the effect of the eelworm attack, and so escape serious damage. Evidence has been obtained that some *H. marioni* larvæ do enter the roots of tea bushes, but normally they fail to cause giant cells and to complete their development. Nevertheless, in certain areas, *H. marioni* is known to cause severe damage to the roots of mature tea bushes, but such areas are extremely small when compared with the large area of *H. marioni* infested tea soils. Why then should old bushes in certain areas be susceptible while in larger areas the bushes are resistant? Is it that in certain areas a specialised race, capable of breaking down the bushes' resistance, has evolved, or is it due to a loss of the bushes' resistance due to climatic, soil or other conditions? These questions cannot be answered at present, but the facts

disclose problems of considerable importance. If a specialised race has been evolved there is grave risk of its spread to other tea bushes, and there is also the probability that similar evolution is occurring in other fields. Observations over a number of years give no indication of marked spread nor have new infested areas been located. If, for unknown reasons, the natural resistance of the bushes has been broken down, the need for investigations regarding the nature of that resistance becomes obvious. At present we do not know why tea seedlings are more susceptible to attack by *H. marioni* than are the roots of older plants.

The problem with *A. pratensis* is somewhat different, as this nematode attacks seedlings and older plants alike; in fact it is better known on bushes than on seedlings. But in heavily infested fields, where the majority of the bushes are sickly, there are others apparently healthy and vigorous, giving a normal yield. Fluiter (1937) reports similar observations concerning coffee growing in soils infested by the same nematode. He states that many of the plants are killed but a good percentage seem to remain healthy, even though their roots are invaded by the parasite. By selecting these apparently resistant plants and growing them on, even in infested soil, they retain their resistance.

Experiments with tea seedlings have shown clearly that some are more resistant to and, in consequence, suffer less from attack by *A. pratensis* than others, though none has been found to be completely immune. There is no reason for belief, therefore, that any of the apparently healthy bushes growing in infested fields are entirely immune from attack either, but there is clear evidence that they are probably highly resistant.

The promising results reported with coffee give rise to the view that something

M. marioni
at *H. marioni*

similar may be obtained with tea by the use of resistant material. At present, tea bushes are raised almost entirely from seed, and, as previously stated, tea seedlings grown from any sample of seed vary considerably in their resistance to *A. pratensis*. The continued use of seedlings can therefore lead only to the further planting of a large proportion of susceptible plants in infested areas. The alternative is to propagate vegetatively the most resistant bushes, selected in heavily infested fields.

Whether the use of resistant material will give the desired control in infested tea areas yet remains to be determined. Work has been directed towards the selection and propagation of resistant bushes preliminary to the planting of selected material in an infested area, but considerable time must elapse before the results can be known.

SUMMARY

The problem of nematode control in tea areas is discussed in relation to the two pests *Pratylenchus (Anguillulina) pratensis* and *Heterodera marioni* and is shown to be one of great difficulty. Methods which have considerable value where annual crops are concerned have relatively small value for permanent crops like tea, mainly because none has yet been found which will completely eradicate the pests from growing plants or from field soils. Many methods of plant and soil disinfection are discussed, the value of natural enemies in biologic control is indicated, and the need for research into the host-parasite relationship is shown.

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