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CONTENTS

† SOME EXPERIMENTS ON THE CONTROL OF THE ROOT-GALL NEMATODE IN SOUTH INDIA

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Introduction. The control of the Root-Gall Nematode worm *Heterodera Radicicola*, Gr.* has been the subject of extensive and earnest investigations for the last fifty years in many countries both in Europe and America. Since this worm has been for long recognised as the cause of one of the most serious diseases which crops are subject to, a good deal of literature has arisen and many useful facts have been accumulated on the question ; consequently the problem has advanced to a great extent along many and varied paths of enquiry. One of the

† A paper read before the Indian Science Congress, 1932.

* The correct name for *H. Radicola Greeff* appears to be *Heterodera marioni* (Cornu, 1879) Goodey, 1932 the specific name *radicicola* being preoccupied by the Genus *Anguillulina* [J. B. A. P., 5, 1932].

most interesting and fruitful lines of research among these has been the increased attention paid to the bionomics of the pest which might provide the key to the problem of its control.

The Nematode is essentially (in the free-living condition) a soil inhabiting organism. The main objective of the studies, therefore, has been confined to the eradication of the pest from infested soil which has been one of the most important and perrennial sources of infection and spread of the disease. The Nematodes are microscopic and cannot, therefore, be tackled in the field. It is also impracticable to treat live plants after infestation. Hence the soil has been the main target of attack and various are the methods devised against the evil effects of the organism among which sterilisation of soil by chemical heat or cultural means has attracted the greatest attention. Numerous experiments in the treatment of the soil by the use of chemicals in solid, liquid and gaseous conditions have been in the past carried out intensively in various parts of the world but the need for further investigation is in no way diminished as no effective, cheap and practicable method of complete eradication of the pest, which can be of universal application, has been evolved yet.

In a previous paper (3) contributed to the Indian Science Congress 1925 the results of the writer's preliminary studies on the subject such as the occurrence of the disease, its nature and symptoms etc. were embodied. Since then the work has been, though intermittently, continued. It is the aim of this paper to set forth the results of the subsequent studies with regard to the range of host plants and distribution in South India, seasonal variations, some resistant varieties of plants, mode of infestation and other related aspects as also to describe briefly some experiments on soil disinfection conducted to bring it under control under South Indian conditions.

Host Plants in South India. The Nematode is abundant and wide-spread in South India and the extent of injury to economic crops is appreciable in many instances. Unfortunately however, no reliable data on these aspects are available in South India although numerous instances of its ravages on a variety of crops have been known from different parts of the province. Since the publication of a preliminary paper on the subject, the Nematode has been observed on an extended range of host plants as well as the extent of its distribution in South India. With a view to present a full account as also to note the new localities where the parasite has been found to occur, a list of plants already known to be susceptible in South India has been advisedly included with a few photographs of infested plants. The list as presented below comprises mostly those noted by the writer and a few recorded by Barber (1). Thus the host range of *Heterodera radicicola* as far as is known has been brought up to [illegible] regard to this country.

New Host Plants Noted in South India.

Scientific name	Popular name
Pisum sativum	Peas
Antirrhinum majus	Snap dragon
Zinnia elegans	Zinnia
Phaseolus vulgaris	French bean
Tithonia diversifolia	Mexican sunflower
Impatiens balasmina	Balasam
Amarantus caudatus	Love-lies-breeding (Crimson)
Amarantus gangeticus	Thandu keerai (Tamil)
Braassica juncea	Mustard
Helianthus annuus	Sunflower
Lactuca sativa	Lettuce
Abutilon indicum	
Cucurbita maxima	
Chrozophora Rottleri	(A common weed)
Musa paradisica	Plantain
Vigna catjang	Cow pea
Cucumis sp.	Cucumber
Dioscorea alata	(Mal. Kachalkilangu)
Cyamopsis tetragonolobs	Cluster bean
Canavalia ensiformis	Sword bean

Host Plants Previously Noted from S. India.

Scientific Name	Popular or Common Name
Capsicum annuum	Chillies
Nicotina tabacum	Tobacco
Canna indica	Indian shot
Curcuma longa	Tumeric
Brassica oleracea (var)	Cauliflower
Brassica oleracea	Cabbage
Apium graveolenes	Celery
Brassica caulorapa	Knol-khol
Daucus carota	Carrot

Host Plants Previously Noted (contd.)

Scientific name	Popular name
Beta vulgaris	Beet
Piper betle	Betel
Piper nigrum	Pepper
Sesbania aegyptiaca	Dainchu
Hibiscus esculentus	Bhendai
Hibiscus cannabinus	Gogu
Coleus parviflorus	Koorkai (*Mal.*)
Dioscorea	"
Cucumis sativus	Cucumber
Camellia [illegible]	Tea

Cinchona sp.	Cinchona
Impaticus kleinii	"
Sida rhombifolia	"
Triumfetta rhomboidea	"
Centratherum reticulatum	"
Emilia zeylanica	"
Oldenlandia sp.	"
Desmodium sp.	"
Ageratum conyzoides	Goat weed
Mullungo pentaphylla	
M. stricta	

Extent of The Disease and Personal Activity. The disease, as may be apparent from its occurrence in very widely different localities, is common throughout South India and it sometime develops into a serious malady causing severe losses. During certain seasons of the year the Nematodes appear to be less numerous and active. As a result of observation for many years it may be noted that in South India these multiply and thrive well in the period extending approximately between the months of August and February although isolated cases of their occurrence may be seen all the year round.

Some Nematode Resistant Plants. In nature among cultiveted crops certain varieties of plants are seen to be comparitively resistant to *Heterodera* as may be evident from the absence of any trace of root-galls in certain plants growing in infested soil. By the cultivation of such plants in infested localities for a few years it has been found that the nematode population in a given plot may be considerably reduced and possibly completely starved out in the course of time. When susceptible crops are scrupulously eschewed and such resistant varieties are persistently grown in the soil, the activity of the worm may continue for some time with the available food in the soil, but sooner or later the store of food reserves will be depleted with the result that worms are slowly killed by starvation. Such beneficial results have been noted by the writer in the course of his limited observations though no systematic efforts in this direction have been carried out. In a plot which was observed to be badly infested, cholam (*Andropogon sorghum*), ragi (*Elusine corocana*), red gram (*Cajanus indicus*) and maize (*Zea mays*) were grown though not by design and these were repeatedly examined to see if they are subject to the attentions of the pest. These have always been found to be free and therefore the writer has concluded that these may be included among the disease resistant crops in South India. In such a plot the most susceptible crops such as knol-khol, tomatoes and other crops have been grown later. On examination of these plants the writer noted that the attack has been generally less severe indicating thereby that the Nematode population of the area has been greatly reduced. It is clear therefore that a [illegible] and judicious rotation

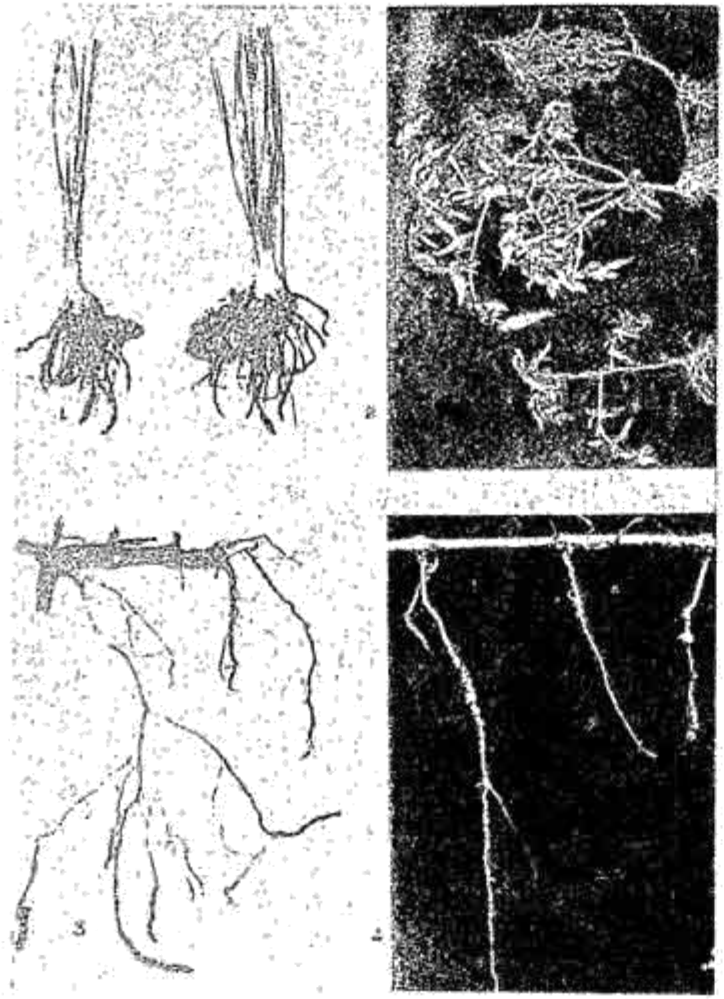

Plate B.

Plate A.

Plate A.

Development and life-cycle of H. radicicola (Greef) Muller. original (all drawn from author's own slides).

1 to 7. Eggs in various stages of segmentation (greatly enlarged).

8 to 9. Young worm coiled inside egg membrane in different stages of growth. (enlarged).

10 (a, b, c, d). Various forms of immature larvae.

11 to 14. Various stages in the distension of the larvae.

15 to 16. Young female cyst in different stages.

17 to 18. Female showing genital tubes and ovaries small and large ova.

19 to 20. Male undergoing transformation. (metamorphosis).

21 to 22. Fully formed mature male. (enlarged).

Plate B.

1. Roots of Turmeric (Curcuma longa) infested with *Heterodera radicicola* showing enlargements (original).
2. Tomato plants (Lycopersicum esculentum) showing nature and symptoms of attack by H. radicicola
   Left—Moderately attacked.
   Middle—Unaffected.
   Right—Thoroughly infested. (original).
3. Betel vine roots (Piper betel) showing enlargements caused by H. radicicola. (originnal).
4. Adventitious roots of cucurbita maxima (sweet gourd) heavily attacked by H. radicicola. (original).

of such immune varieties like cholam, red-gram, ragi, and maize for a few years may prove an easy and effective method for a gradual elimination of the pest from the soil. But it is doubtful whether such plants will ever remain immune to the attack of worms, especially in the light of reports that some plants considered to be resistant proved to be susceptible later on

Some Control Experiments. *The Experimental Plot and Host History*: Various measures of control against these plant-parasites have been recommended, but the efficacy of none has been proved under South Indian conditions. Hence some experiments including a few chemical treatments of soil were planned to be carried out in the Botanical gardens attached to the Agricultural College, Coimbatore. Before embarking on a description of the experiments it may be of interest to record the spread of this disease in this garden in view of the emphasis laid on a knowledge of the host history of the particular strain or population of Heterodera experimented with. Although the presence of this pest was known by isolated cases of occurrence the writer ventures to suggest that this pest was first discovered by him in the garden about ten years back in cauliflower roots. How long prior to this period the parasite has been in the garden soil or how it has gained entrance are only matters of conjecture as the organism is a stealthy foe. The spread of the disease in the garden and the variety of plants attacked later on may have a bearing on the history of host selection and specialisation, a study whose significance has been markedly brought out by Steiner (4). It is noted that it spreads rapidly and its progress cannot be easily arrested. From a knowledge of its life history (*Vide* life history plate) the pest is noted to be prolific, each female being capable of producing about 500 eggs and of undergoing nearly ten generations a year. It may be noted here that the mechanical injury caused to the plant tissue by "mouth spear" is probably insignificant compared to the toxic effect produced by their salivary secretions. The reaction set up by the latter coupled with that of their excreta may be the real cause of the development of the galls so characteristic of the affection. To follow the course of its progress provides interesting reading. From cauliflower the parasite soon extended its range to its near allies such as cabbage, knol-khol, carrot, radish etc. in a few months. A little later it began to show its preference to tomatoes grown in the neighbourhood as was evident from the numerous large galls on their roots. After a season brinjals suffered badly by their attentions. These plants grown in a fairly large plot were heavily attacked without any exception. The ravages of the pest on these plants accentuated the need for control measures. Subsequently crops like peas, amaranthus and various ornamental and flower plants like balsam, sunflower etc. suffered in quick succession in varying de-

Favourable Conditions and Means of Dissemination: The raid increase of the pest and the widening of the range of host plants naturally led the writer to investigate the conditions favourable to its multiplication and dissemination. The soil in the garden is most conducive to its prolonged life and activity being a sandy and porous loam of loose texture with sufficient moisture. In contrast to this they are not so abundant in other portions of garden as has been gathered from the degree of infestations in plants in portions of garden having heavy clayey soil or in spots which are sometimes either waterlogged or completely dry. Coupled with these conditions there is a constant and uninterrupted supply of food in the gardens. In short, all conditions and practices conducive to better and intensive farming such as irrigation, good drainage, etc., all appeared favourable to the growth and multiplication of the organism.

As to the means of the transmission of the nematode to fresh localities, observations indicate that the main cause is to be traced in this country to heavy rains and consequent flow of water from place to place. Irrigation, of course, forms an important means of infestation. To a certain extent the transportation of movables—such as agricultural implements, manure heaps from infested soil, affected roots of live and dead plants, are also potent causes of its spread to different localities. Animals and man treading infested and free soils also help the transference of the pest through the moist soil clinging to the limbs. Fortunately, by its efforts the parasite is known to move for only short distances within a few feet, which adds additional proof to show that the main causes of dissemination are those detailed above.

Treatments. This heavily infested garden soil afforded an ideal ground for the conduct of these experiments. Beyond doubt the soil was literally alive with Heterodera. The experiments were actually commenced by the end of the year 1924 and continued up to the beginning of 1926. A strip of ground sufficiently large in extent was divided into rectangular areas of 5 x 4 feet and each plot was isolated from the rest by means of four broad wooden plants sunk to a depth of a foot and a half into the soil along the sides of the plot. This resulted in a box-like arrangement for each of the fifteen plots. Five of these plots were reserved as controls. Two were kept for partial sterilisation and trap-crop. Each one of the eight remaining plots was treated with one of the following substances, the rate, the number of treatments and the intervals between treatments being as indicated below. The soil in each plot was saturated with the required quantity of solution after ascertaining the same by actual trial with small samples of soil.

Substance	*Proportion*	*No. of treatments and intervals*
Carbolic acid	1 in 15 parts of water	three times with an interval of 9 days between treatments
Kerosine	2 gals. for the whole area	once
Formalin	1 in 25 parts of water.	do
Potassium cyanide	200 lbs. per acre	Two treatments with an interval of 8 days
Carbon bisulphide	4 oz. per sq. yard	once
Lime	27 lbs. for whole area	do
Sulphuric acid	1 in 80 parts of water	do
Ranicide	½ oz. per sq. feet	do

Partial Sterilisation : The soil in one plot was sterilised by burning cholam stalks and other materials ; then it was loosened and spaded at intervals. The process was repeated thrice with an interval of two days between treatments.

Trap Crop. As suggested by Kuhn the method of trapping the worms by growing a very susceptible crop along with the valuable crop and uprooting and destroying the "catch" or "lure" plants in time before the worms have begun to emerge from the roots and reinfest the soil, was given a trial in one of the plots. Hence one of the cruciferae namely *knol-khol* was grown along with the test crop.

Sowing and subsequent observations. Various lengths of time had to be allowed to elapse after each treatment before the planting of the test crop, and the treatments themselves were so timed as to allow planting of all plots simultaneously. Accordingly all the plots were sown with peas on 10—2—25 but as peas failed to grow well brinjal plants grown in free and uninfested soil elsewhere and found to be free from elworms after examination were planted. These plants were found to grow well though not very vigorously. After the lapse of about one month, one plant from each plot was dug up with roots intact and examin d. Thereafter periodical examinations of the plants from the several plots was continued for several months. The results of the examination can be roughly expressed as follows:— The plants from the control plots invariably showed a heavy infestation compared with those in the experimental plots. Those in the experimental plots exhibited different degrees of attack which is very difficult of interpretation. The plants from carbon bisulphide plots showed a doubtful infection and plants from kerosene plot showed infestations more or less similar to the controls indicating thus the other extreme and the utmost that could be done by a very wide stretch of the results is to group the other treatments into three or

four categories between these extremes. Those that are grouped together showed no marked differences in the degree of infestation as noted from the galls produced. But yet the writer feels that the effects of the different treatments may approximately be expressed in the following manner arranged in the descending order of severity of attack:—

Kerosene—More or less severe attack having many galls.

Sulphuric acid, Ranicide, Carbolic acid, Pottassium cyanide } Not so severe—fewer galls.

Partial sterilisation, Trap crop. } Mild—a few galls.

Formalin Lime } Slight—(There were galls).

Carbon bisulphide—Doubtful attack.

Although these observations were continued for a long time no further comparisons could be made as all plants in some plots died. In November 1925, the plants in carbon bisulphide plot were seen to have clearer infestation showing that this plot also has not escaped the attentions of the Nematode.

Interpretation of Results. The microscopic and other examinations of the plants in the different treated and control plots from time to time and a comparison of the same as far as possible did not lead to any definite conclusions as was anticipated but it must be admitted that these served to throw light on the intricacy of the problem in question. It was not possible under the conditions of the experiment and the unexpected difficulties and complications that cropped up in its course to calculate the percentage of attack or accurately demonstrate the relative values of the chemical heat and trapping treatment by reliable data or concrete figures. The best method of expressing results would be a comparison of respective yields but under the circumstances that was obviously out of the question. It was only possible in an approximate and empirical manner to estimate the extent of infection and express the effects of treatments in terms of degrees as severe, medium, and mild or slight. It was even difficult in some cases to differentiate the degrees of infestation in certain treatments and hence these have been grouped together as having more or less similar infestation. Certain facts have however been brought to light as for instance that *all treated plots with the exception of kerosine were generally better than the controls* as seen not merely from the less severe attack but also from the time taken to develop the galls in a few cases. It can also be seen that the effect of the various treatments continued to last though in diminished extent for varying periods ranging from two months to six months

To be more precise, as infestation occurred both in control and treated plots though in the latter in varying degrees of severity it may be safely concluded that none of the treatments have been effective in the complete eradication of *Heterodera*. The treatments, at least some of them, certainly caused a reduction in the population of the worms in the treated soil for the time being as shown by the diverse degree of infection and varying lengths of time taken to produce the characteristic galls. It is also evident that within a short time i. e., a few months, the Nematode is able to restock the treated plots with the normal population. Evidence then indicates that such sterilisations of soil by treatments can only be of temporary benefit and the relief obtained lasts only for a few months, the period of duration of such a beneficial condition, varying with different treatments and probably also with different concentrations of the same substances. Hence such treatments can be utilised to minimise damage to valuable crops which under the circumstances, *is not a mean* achievement.

The other causes of a partial failure of the experiments were inherent in the methods of control themselves. The first and foremost cause under this category that suggests itself more prominently than others is that, since the several plots were more or less well isolated, the worms or eggs were not completely killed by the treatments either because they were hardly enough to withstand the effects of chemicals etc., or they were at depths beyond the reach of the application. Another probable reason for their presence may be that certain stages in their life are such as to have some means of protection against adverse effects.

The investigations by Godfrey (2) in regard to the depth distribution of *Heterodera radicicola* clearly show that these are distributed in the soil in varying depths according to the conditions of soil, season and availability of moisture, etc., and the efficacy of any treatment is to be judged by the depths to which the treatments can extend their influence. Hence to determine the depth to which the treatment has to be extended, it is necessary to make a study of each locality in regard to the Nematode content of soil at varying depths in different seasons. This is one line of investigation which requires urgent attention if any success is to be had in the control of these worms.

In order to see whether the eggs or larvae of these worms in the soil develop any protective structure while in the soil, so as to withstand any adverse effect of heat or chemical, it is necessary to know more about the life history of the worm in the soil. All that is known is that larva is unable to develop beyond the larval stage until it gains access into the root of a host plant, and then passes through several stages in the root and ultimately develops into a male or female as the case may be. But so far as the writer has been able to gather from

literature on the subject none of the previous workers have directed their attention to the possibility of the young worm remaining in the soil for long periods in a slightly different condition from the one supposed to exist.

Other Methods of Control. Various other methods of control are being tried in other countries among which the breeding of Nematode resistant varieties of plants is a very promising field of investigation. Another method which has been suggested but not demonstrated to be effective, is that known as biological control whereby a voracious species of Nematode *Mononchus papillatus* is sought to be utilised, for exterminating Heterodera on account of its predaceous instinct. Flooding the infected portions of fields with water for a week or two, and drowning the worms has been recommended but it is not always practicable. Hot water treatment and steam sterilisation of soil have been reported to be effective in the case of limited areas of infested land.

Conclusion. The experiments described in the paper although unfortunately few in number and inconclusive in results, may, it is hoped, serve at least the purpose of bringing into prominence the serious nature of the problem in South India as also the various factors which have to be taken into account in devising control measures and the unexpeted developments that have to be guarded against in the course of trials. The foregoing paragraphs may also serve to show how little is known of this serious pest in India and that the problem, though not easy of solution, affords a highly promising field for exploration. Sufficient, it is believed, has been said to induce interest in the subject and to indicate the lines along which further investigations may profitably be accomplished and the writer will feel more than satisfied, if by these attempts, the problem has been brought any the nearer of solution. Opportuniiy is taken here of expressing the writer's deep indebtedness to the Govt. Entomologist, M. R. Ry., Rao Sahib Y. Ramachandra Rao Garu, and to the Principal, M. R. Ry., C. Tadulinga Mudaliar Avl., for affording facilities for the investigation and to all those whose writings have been drawn upon in preparing this paper. The writer's most sincere thanks are tendered to Dr. T. V. Ramakrishna Iyer for his unfailing kindness and encouragement in this as well as similar studies.

Note:—Since presenting this paper for the Indian Science Congress the writer had an opportunity of seeing (by the kind courtesy of Col. A. Olver, C. B. O. B. E., etc., of the Imperial Council of Agricultural Research in response to writer's request) a monograph on "the Root-infesting Eelworms of the genus Heterodera" published by the Imperial Bureau of Agricultural Parasitology, London (1931) which gives an up-to date and exhaustive list of host plants so far noted all over the world together with a complete list of Bibliography the value and usefulness of which can never be over estimated for workers in this field. It is obvious that the writer could have saved much time and labour had he come across this important publication before the preparation of this paper especially in the matter of hunting up the scattered literature on the subject.

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NATIONAL WELL-BEING & AGRICULTURAL IMPROVEMENTS

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We have, in common, with the rest of the world, been passing through an unprecedented economic depression for the past two years. Following, as it did, on the heels of post-war years of high prices and apparent prosperity, the effect of the depression seems to have been magnified more than it would have appeared under normal pre-war conditions. No two economists are agreed either as to the real causes for the depression or with regard to its remedy. Some say that it is due to over-production of commodities more than is justified by world demand, some say that its cause is to be traced to reparations and war debts, while others say that it is due to the combined effect of world-wide over-mechanisation of the means of production resulting in unemployment of man and animal labour and the natural increase of world's population. It seems to me that all the above factors either singly or in combination have contributed in varying degrees to the present depression. It is reported that the International Statistical Institute estimates that between the years 1920 and 1928, 125,550,000 had been added to the world's population. The Indian contribution to this increase has been in the neighbourhood of 25,000,000. The remedies suggested for getting over the economic ills of the world are also of various kinds, removal of tariff walls, organisation of exchanges on a new basis like the bartex sponsored b. the London Chamber of Commerce, 'Erne' proposed by Dr. Fowler in India, actual barter of commodities between nations as the exchange of American wheat and cotton for Brazilian coffee, and Russian petrol for Egyptian cotton and international agreements imposing restrictions on the production of commodities like sugar in Java, Cuba and Europe, rubber in Dutch East Indies, Malaya and other rubber producing countries.

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