Nematode Diseases of Plants.

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Mr. President, Ladies and Gentlemen:

I wish to speak to you today about nematodes. In the first place, it may be well to attempt to explain to you just what a nematode is, although most of you are familiar enough with the work of one of them, the root-knot. Nematodes or ell-worms as they are sometimes called, are low animals, slender and worm-like, at least when young. Like the true worms they have no legs nor wings at any stage of their development. They differ from the latter in not being segmented and in having no jaws. They consist essentially of a tube-like skin lined with muscles; inside this is another tube, the alimentary canal, with various modifications along its course to act as gizzard, stomach, etc. Add a very simple nervous system and you have nearly all the essential features of a nematode. They should never be confused with the segmented earth-worms nor with the larvae of various insects, also, but erroneously, called worms.

Many species of nematodes are parasitic in animals, as, for example, the roundworm of the horse, the hookworm and trichina of man; many others live in various locations, both in the earth or in fresh or salt water, on decaying organic matter, a wellknown example being the harmless vinegar-eel; while still others attack living plants. The latter are entirely harmless to animal life, so that we need not fear their presence on that score. They are bad enough as it is, however.

With the exception of some that are parasitic in higher animals, nematodes are mostly minute. Those that attack plants are rarely over one-eighth of an inch in length, while some are many times smaller. Were it not for their great numbers they would scarcely require serious attention.

The principal disease of plants due to nematodes, at least in this country, is root-knot, in which the nematodes live within the root, causing it to enlarge, forming the characteristic knots. In addition to this disease, other species of nematodes cause abortion of the flowers of grasses, distortion of leaves and flowers through their presence within the stem, stunting and malformation of plants through nematodes living within the stem, killing out of spots in leaves through nematodes in the tissues at these points, and injured canker-like spots on the roots. The latter are caused by nematodes attacking the roots from the outside without entering them.

The life history of the root-knot nematode is in short as follows: The eggs, which are about 1-300 inch long, hatch into little larvea about 1-100 inch long, and about 1-2000 inch thick. These possess at the anterior end, a stout spear. Crawling around in the soil they finally find roots, perhaps not for weeks after they are hatched. A larvae seeks out the root tip and bores into it by means of its spear, taking its place near the center, parallel to the axis of the root, with the anterior end directed away from the root tip. The necessary nourishment is sucked out of the surrounding tissue through the spear which is hollow. Growth is rapid now, and soon the nematode begins to increase in thickness more rapidly than in length. The tip of the root continues to grow. The tissue about the nematode owing to some stimulus, due to its presence increases rapidly in amount, forming a knot of soft watery cells. If but one nematode has entered, the knot remains small, usually, but often the infections are not single and several to many nematodes come to lie close together or at short intervals causing a large knot or a succession of smaller one to be formed. The nematode's increase in thickness continues until it is flask-shaped. At this stage the male and female begin to become differentiated in shape; the former performing a moult and again becoming a slender creature about 1-25 inch long and 1-500 inch thick. The female, on the other hand, continues to enlarge until she is as thick as long, and only at the anterior end shows any worm-like portion. At this stage the egg laying begins, and continues until 400-500 eggs have been laid. As these hatch they must bore their way out of the root tissue into the soil, and seek other roots or they simply find congenial places to develop in the same knot so that in one large knot can be found nematodes of all stages of development.

The time required for the development from the egg to the mature egg-laying individual depends to a great extent upon the temperature and upon the plant affected, being more rapid in warm weather. It probably never is less than four weeks, and sometimes requires eight weeks.

The injury to the plant is of two kinds, direct and indirect. As direct injury may be considered that due to the reduction or stoppage of the passage from the roots of water and dissolved mineral food-stuffs, due to the tangling and interruption of the water conducting vessels in the knotted roots, also the injury to the plant due to the diversion of food-stuffs to build up the tissue of the knot instead of building up the rest of the plant.

Then direct injuries, although undoubtedly harmful, rarely cause the death of the affected plants. The indirect injuries are due to the fact that the soft abnormal tissue of the knot is attacked by various organisms of both fungous and animal nature, causing decay to set in which may involve the whole root system and thereby kill the plant. Many fungi find easy entrance in this way. So, for example, the fungus causing wilt of cotton attacks plants suffering with root-knot much more vigorously and destructively than those that are not so infested.

Many plants are attacked so slightly that the injury is very slight or not even apparent. Such plants, however, owing to the large number of eggs laid by a single worm, serve the purpose of keeping the soil well stocked with nematodes.

I have been making a list of all plants on which I have seen root-knot or on which it has been reported to occur. This list now contains about 300 species of plants, including most of those commonly cultivated. Among those that may be seriously injured, may be mentioned the following: fig, peach, European grape, roselle, banana, pawpaw, tomato, egg-plant, rose, carnation, tuberose, violet, jasmine, cowpea, soy-bean, cotton, and most of the garden vegetables, especially cucumber, squash, pumpkin, water and muskmelon. On the other hand, the injury has been but slight in those cases where I have observed it on the following: various grasses, as Bermuda, crowfoot, fescue, orchard grass, German millet, persimmon, sawbrier, wormseed, chufa, bush-clover, etc. I have yet to see a case of true root-knot on any of the citrus trees, velvet-bean, Florida beggar-weed, oats, rye, barley, sorgum, hog-millet, etc.

Many ideas have been advanced as to how this pest should be combated but many of them are based on experiments made with the closely related sugarbeet nematode of Germany. But little actual experimental work has been done. One method is that of soil sterilization, i. e. freeing the soil of the noxious organism by direct means. I shall mention various suggested means of doing this.

Chemical Means.—The most efficient of these is the use of carbon bisulphide injected into the soil to a depth of several inches at close intervals and allowed to diffuse there throughout the soil. If enough is used this is effective. It has several serious objections; it is expensive, so expensive in fact, that it would probably take several hundred dollars worth to treat one acre, not to speak of the labor of applying it. It is also poisonous to roots. A large fig tree will stand it sometimes, but the check to the growth is great. It is highly inflammable. It does not mix with water, and so cannot be used in wet soil. Formalin in dilute solution is equally effective if applied in sufficient quantity. However, to wet dry soil to the depth of a foot would require about five gallons of solution to a square yard costing $150 to $200 per acre. My experiments to determine whether a lesser quantity will be sufficient are now under way. This solution is also harmful to vegetation, but if kept from the growing part of the plant is not as injurious as carbonbisulphide. Lime, gas-lime, gas liquor, oils, etc., have been tried on the sugar-beet nematode without effect. I am now trying some of them on the root-knot.

Heat is the most efficient means yet found for killing out all kinds of pests, including the root-knot nematode. Thanks to Stone and Smith in Massachusetts, the problem has been settled as far as nematodes in green-houses are concerned. Steam is passed at high pressure through tiles or perforated iron pipes running through the soil. This effectually kills all animal and fungous parasites. It seems doubtful whether that method will ever become of use in the open, unless it be for seed-beds or for truck farms where the income is very high. It would probably cost not less than $2,000 per acre to establish such a sterilizing apparatus. The often recommended building of large fires upon the spot to be sterilized is to be discouraged, for the injury to the soil is too great.

Freezing, formerly supposed to be fatal to the root-knot nematode, is considered so by me no longer since I obtained authentic record of peony plants going through a winter temperature of 35 degrees below zero without even a mulch protection and showing root-knot again that summer. That was not in Florida.

In Java where the dry season is well marked and is really dry, it has been found possible to exterminate the root-knot nematode by drying out the soil. This is done by keeping it in fine tilth during the whole dry season by means of repeated plowings, and harrowings.

Strange to say, the root-knot nematode is easily killed by drying out, although many of its close relatives are dried without injury, and can remain alive for years in that condition, reviving again upon being moistened up. Paradoxical as it may seem, moisture will also kill the root-knot nematode. It has often been found that wet lands are free from nematode injury while dryer lands adjacent suffered badly. In one case I learned of some very badly infected land flooded by a spring freshet for several days. Always thereafter it bore crops showing no sign of root-knot. In Java this method had also been tried and found to be successful. The land must be submerged at least five to eight days.

Besides these direct means for freeing the soil of nematodes several indirect ones have been suggested, and it is by some of these that I believe our main salvation can be attained. The first to be mentioned is the starvation method; i. e. growing nothing on the land that can serve as food for the nematodes until all has perished. How long this would require for the root-knot nematode has not been determined; for its close relative, the sugar-beet nematode, it is not under two years. To keep the land entirely fallow this length of time is, of course, not to be thought of, but the same results can be attained by cultivating only plants not attacked by root-knot even in the slightest degree. Hence comes the great importance of numerous experiments to determine which plants are and which are not susceptible. Of those which so far I have found to be free from root-knot, are crabgrass, the small grains, velvet bean, Florida beggarweed and but few others. Such information bearing on the subject as I can obtain from you will be gratefully received. In view of the facts known the practise of many of allowing the land to grow up thickly to crabgrass in the summer, is one that ought to tend to keep the root-knot nematode in check. If that could be combined with the use of velvet bean for a season or two, or if small grains were sown as winter crops for two years followed in the summer by velvet beans it looks to me as if favorable results should be obtained. I have such experiments already under way.

Another method of combating the pest, which promises very good results for certain annual crops, is that of breeding up resistant races. Thus the Iron cowpea, if obtained pure, is not attacked by root-knot. Unfortunately, however, most of that obtainable in the markets or even some of that sent out from other sources, contained some admixture of other varieties vitiating the results. Mr. W. A. Orton has demonstrated that this quality of resistance is transmissable to crosses with other sorts. Doubtless some results of value can be obtained by selecting seed from plants least affected in a field known to be full of root-knot. Such plants, when in flower, should be crossed, if possible, with similar resistant plants in same field. In this way a nematode resistant sugar-beet has been obtained.

The influence of increased amounts of certain elements of fertilizers on the amount of injury caused by root-knot has received, I find, practically no attention. It has been investigated very carefully in Germany in connection with the sugar-beet nematode. There it has been found that by greatly increasing the potash the injury is to a large extent, decreased. I am now beginning similar experiments with the root-knot.

The method, however, that has perhaps

been most successful of all against the sugar-beet nematode is the use of Trap-crops. Strange to say, although this has often been recommended for root-knot, I have yet to find a single case where it has ever been tried even as an experiment. I am making some experiments this season. The method consists essentially, in planting thickly in close rows, some crop known to be very susceptible to the nematode, allowing the nematodes to enter it and before they have developed far enough to lay eggs, and so increase the number in the soil, to destory the crop. This is repeated several times during the season, and so reduces the number of nematodes still left in the soil that it requires several years before they become very destructive again. Certain cautions must be carefully observed, however, or the use of this method will increase instead of decrease the number of nematodes. It is necessary to remove or entirely turn under and kill the plants about four weeks after they come up. If left too long the nematodes will have developed too far and will have begun laying, if not long enough they will still be in the motile stage and will crawl out again and reinfect the soil.

What to do with a peach orchard, for example, where the root-knot is bad is a serious question. In the first place we will take it for granted that the orchard, even in its diseased state, represents too much money to permit it to be cut down. It might be well, then, to try watering the trees heavily before the buds open, either early in the spring or late in the fall, with a dilute solution of formalin, so as to kill the nematodes in the knots. For such I would prefer the cowpea (not the Iron.) But unless they are removed in time these trap crops will do more harm than good. When the orchard is cut down the land should be freed from nematodes by some of the means above mentioned, before setting again to peaches. Avoid cowpeas, except possibly Iron, as they propagate the nematode rapidly. Use velvet beans or beggar-weed instead. These are but suggestions, please understand, not from the result of actual personal experience, but as a result of fair acquaintance with the habits of the nematode. I trust some of you may have the courage to try these in a corner of your orchard and report to me the result.