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THE NEMATODE GALLWORM ON POTATOES AND
OTHER CROP PLANTS IN NEVADA.

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THE NEMATODE GALLWORM ON POTATOES AND OTHER CROP PLANTS IN NEVADA.¹

INTRODUCTION.

During the seasons of 1910 and 1911 there occurred in certain irrigated potato-growing districts of Nevada an outbreak of a potato disease known locally as the eelworm. Particular attention was attracted to the ravages of this disease because several carloads of potatoes shipped from Nevada into California during the winter of 1910-11 were condemned by certain county horticultural commissioners of California and were returned to Nevada to be disposed of elsewhere. A recurrence of the disease in the season of 1911 and the shipment of infected potatoes into California resulted in the issuance by the State Commissioner of Horticulture of California of an order establishing a quarantine against all potatoes shipped into that State from the counties of Lyon, Churchill, and Washoe, in the State of Nevada.²

Since California markets have afforded the chief outlet for the potatoes grown in Nevada in excess of local needs and since potatoes have been a very profitable crop in certain irrigated districts in Nevada, the closing of California markets to their potatoes has been severely felt by Nevada potato growers. The outbreak of the so-called eelworm disease or nematode gallworm disease in these Nevada potato fields has been so severe and the results so disastrous as to warrant bringing together the available information concerning this disease as it affects potatoes and other crop plants, for the assistance of the affected districts in Nevada. Some of this information may be applicable also to other sections of the country,

¹ Owing to a severe outbreak of a potato disease in certain irrigated districts in Nevada, caused by the nematode *Heterodera radiculicola*, there has been an urgent demand for information as to the cause of the disease, the probable extent of its spread, and the possible remedies. In order to meet this demand for information a committee was appointed, consisting of Dr. N. A. Cobb, Technologist, Prof. L. C. Corbett, Horticulturist, Dr. W. A. Orton, Pathologist, and Mr. C. S. Scofield, Agriculturist, all of the Bureau of Plant Industry, to bring together such available information as would be most useful to the potato growers and others concerned. While the present interest in this nematode is due to its attacks on potatoes, it should be clearly understood (1) that the same nematode is parasitic on many other important crop plants, where it may cause damage, and (2) that this is but one of a number of species of parasitic nematodes. It is important to keep these facts in mind to avoid serious mistakes in dealing with the present problem in Nevada and similar problems that may occur elsewhere.—B. T. GALLOWAY, *Chief of Bureau*.

² For further details in reference to this quarantine order, see Monthly Bulletin of the State Commissioner of Horticulture of California, vol. 1, December, 1911, pp. 26-30; and also the same publication for January, 1912, in which a modification of this order was published.

for the same nematode which has caused the potato disease in Nevada is widely distributed throughout the United States and is causing every year much more damage than is generally understood.

It is the purpose of the present publication to give some information concerning the parasite which is the cause of this potato disease, briefly describe its life history, indicate some of the sources of infection and methods of transferring the parasite from one place to another, and suggest remedial measures for combating the disease in Nevada.

It is of the utmost importance to those concerned to act intelligently in dealing with the present situation in Nevada. The potato crop is one of the most profitable crops at present produced on the irrigated lands of Nevada. When not injured by the gallworm the potatoes are of very high quality and usually command a higher price in California markets than potatoes from any other section. It is important, therefore, to prevent the further spread of this parasite in the potato-growing sections of the State and so to reduce its numbers where it now occurs that it will cease to be a serious pest. This can be accomplished through first locating all of the infested fields and then devoting these fields to the production of crops upon which the nematode can not live. This location of infested areas will require very thorough inspection of all the fields which have been used for potatoes within recent years. Such an inspection to be thorough must be made by examining the roots of plants that are susceptible to the attacks of this species of nematode. The inspection should go still farther and include a critical examination of all fields on which it is proposed to plant potatoes. The nematode gallworm is parasitic on so many plants that it may easily live in the soil for many years if plants which it can attack are present.

A critical inspection of the irrigated lands of Nevada will probably show that the nematode gallworm occurs only in small and restricted areas. If these infested areas are definitely located and precautions are taken to avoid carrying the worm to other fields where it does not now occur, and if at the same time these infested fields are devoted exclusively to crops which can not harbor the parasite, it should be possible in a few years to reduce its numbers to a point where it will cease to be a factor of importance.

CAUSES OF THE POTATO DISEASE.

The so-called eelworm or gallworm disease (also called "root-knot") is caused by a minute nematode worm (*Heterodera radiculicola* (Greef.) Müll.). Figures 1 and 2 show the two sexes of this worm enlarged to illustrate various features which are so small as to be

almost invisible to the naked eye. The mature female is nearly pear shaped, as shown in figure 1, being less than a millimeter in length, more often about three-fourths of a millimeter long, the body cavity

FIG. 1.—Female of the nematode gallworm (*Heterodera radiculicola*) magnified 85 diameters: *a*, Mouth; *b*, spherical sucking bulb; *c*, *c'*, ovaries, as seen through the body wall; *d*, anus; *e*, small white spots showing approximately the natural size of these worms. They are usually white. It is generally not difficult to isolate them in water by breaking open the galls containing them. (After N. A. Cobb.)

will reveal the presence of the mature females and the young larvæ. In figure 4 are shown the larvæ and the eggs of the gallworm as seen through the microscope from a preparation made from a diseased potato. One of the eggs seen in figure 4 is shown still further enlarged in figure 5.

LIFE HISTORY OF THE GALLWORM.

The larvæ of the gallworm upon hatching from the egg, which hatching sometimes occurs within the body of the parent, ultimately escape from the host plant and live for a period in the surrounding soil. These larvæ, although very active, have but little power of progressive locomotion, and the spread of infection from place to place must depend upon the transportation of infested soil or infected plants. Soon after emerging from the parent and the tissue of the host plant these larvæ seek other

being occupied by eggs and larvæ. The male is a slender, thread-like worm, from 1 to 1.5 millimeters in length (see fig. 2). The development of the female takes place within the underground tissues of the host plant and its presence in these tissues is indicated by enlargements or malformations. Figure 3 shows a potato which is badly infected with gallworms. The skin is roughened and broken in patches. Not all infected potatoes show the same symptoms. Often the gallworm is found in potatoes of which the skin is nearly smooth, and in such cases the presence of the parasite can be detected only by cutting the potato. In the infected tubers there is usually a ring of darkened tissue just under the skin, and a microscopical examination of this tissue

FIG 2.—The adult male of *Heterodera radiculicola*, or gallworm: *I*, Worm in profile view; *II*, head of the same, more highly magnified; *III*, middle region of the worm showing blind ends of the sexual organs; *IV*, posterior extremity. The drawings were prepared from stained specimens, examined in carbolic-acid solution.

a, Lips; *b*, œsophageal tube; *c*, median bulb; *d*, excretory pore; *e*, spear; *f*, intestine; *g*, blind ends of testicles; *h*, testicles; *i*, spicula; *j*, rudimentary bursa; *k*, anus. (After N. A. Cobb.)

roots and bore their way into the plant tissues by means of a spear-like structure, which is protruded from the mouth. They feed upon the cell sap of the host plants.

After fertilization takes place the females begin reproduction by forming eggs within the body. These eggs are laid at the rate of from 10 to 15 a day, and it is estimated that one female may lay as many as 500 eggs. After completing the egg-laying process the female dies, the male having died soon after fertilizing the female.

FIG. 3.—Potato infected with the gallworm. This shows the rough character of the surface, which indicates the presence of these worms. The knobs, or warts, are often much more strongly developed than in the above. Gallworms in seed potatoes are particularly dangerous, for if infected potatoes are used for seed the land will be inoculated. If infected potatoes are used as food, the refuse parts should be cooked or destroyed. Otherwise they may spread the disease. (After F. B. Headley.)

The worm lives from one season to the next, either in the egg stage or in the larval stage within the host plant. The life of the individual worm is short (only a few weeks), when temperature and moisture conditions are such as to favor growth.¹ It is possible, therefore, to greatly reduce the numbers, if not to exterminate the worm entirely, by keeping the infested land free from plants upon which the worm can feed.

SOURCES OF INFESTATION.

The gallworm discussed in this paper is one of a large number of species of nematode worms. This particular species occurs very generally

throughout the southern United States. In many sections it is found in such large numbers as to be a serious pest to many crop plants, such as the peach, the fig, cowpeas, cotton, and many vegetables. It may be transported from place to place on any of these plants which it infests or in soil from infested fields. Probably the most common method of transporting the worm is through the shipment of nursery stock and of potatoes. The distribution of the worm

¹ Additional information concerning the life history of this parasite, with a list of susceptible plants and details of experiments in controlling the nematode in the southeastern United States, may be found in Bulletin 217 of the Bureau of Plant Industry, entitled "Root-Knot and Its Control," by Dr. Ernst A. Bessey, issued November 21, 1911.

from field to field in any particular district may be accomplished by carrying soil on agricultural implements, on the feet of animals or men, or by transplanting plants from one field to another. In fact, there are so many ways in which infestation can be accomplished that the greatest precautions should be used to prevent the distribution of infested earth or plants into uninfested areas. The careless disposal of garbage containing infected potato peelings or the spreading of manure from yards where infected roots or tubers have been used as stock feed may transport the worm and develop serious infestation.

FIG. 4.—Microphotograph of the eggs of the gallworm and the young worms just hatched, taken from a potato. This appearance is often seen in microscopic preparations made from infested areas of roots. (After F. B. Headley.)

All classes of nursery stock, including strawberry plants, tomato plants, and small fruits, should be examined with great care if they are to be set in fields which it is desired to keep free from this parasite.

UNINFECTED SEED POTATOES ABSOLUTELY ESSENTIAL.

In attempting to control this disease it is, of course, absolutely essential to plant uninfected potatoes as seed. It is not enough to be sure that the potatoes planted do not show superficial evidences of the disease; it should be determined beyond doubt that there is absolutely no infection present. This can best be assured by securing

clean and healthy seed from fields where a critical inspection shows that the disease has not been present.

All culled potatoes from the field should be examined, for even when disease is present the bulk of the crop may be unaffected. The gallworm does not occur in the potato-growing districts of the Northern States, particularly North Dakota, Minnesota, Wisconsin, and Maine. Seed obtained originally from these States and grown on fields that are free from the gallworm should be safe to use in planting other uninfested fields. Too much stress can not be laid upon the importance of securing for planting potatoes which are uninfested and in planting them on uninfested land.

FIG. 5.—Newly deposited egg of the gallworm. These eggs are distinctive features of the nematode disease. They occur in large numbers, as shown in figure 4. (After N. A. Cobb.)

LOCALIZATION OF INFESTED AREAS.

The practical problem which confronts the potato growers of Nevada is the location of all fields which are infested with this parasitic nematode. The present indications are that the nematode infestation is by no means general in irrigated land. The nematode has probably existed in some of the older irrigated lands of the State for many years, but there is much new land being put under irrigation in Nevada, which it seems probable is entirely free from this worm. If all of the infested areas can be located by a critical inspection, it will be possible to produce potatoes in large quantities on uninfested land and devote the infested land to crops which are resistant to the parasite.

There are probably some fields in the State which have been devoted to potatoes during the last year or two on which the parasite does not occur, and from these uninfested fields seed might be secured. It would be much safer, however, to obtain seed from the Northern States, such as Minnesota, Wisconsin, or North Dakota, with which to plant new land, rather than to risk the infestation of the new land with local seed. But it will be impossible to proceed intelligently in combating the ravages of the gallworm until the infested areas have been located, so that the danger of infestation, not only by means of potatoes but in many other ways, can be fully ascertained.

SUSCEPTIBILITY OF OTHER PLANTS.

In view of the fact that the gallworm is parasitic on many plants other than potatoes, it is important not to foster the parasite by the culture of plants which are subject to its attacks. The following is a list of some of the plants which are readily and seriously attacked by the gallworm and which should never be grown on infested fields

or transplanted into uninfested land from any land that may possibly be infested:

Beets, carrots, celery, cucumbers, eggplant, lettuce, muskmelon, pumpkins, potatoes, salsify, squash, tomato, watermelon, clover, cowpeas, rape, soy beans, catalpa, cherry, elm, peach.

The following are subject to attack by nematodes and, although these plants are not themselves liable to serious injury, they should not be planted on infested soil for fear of keeping the gallworm alive:

Alfalfa, vetch, sweet clover, asparagus, cabbage, cauliflower, garden peas, horseradish, strawberries, kale, Lima beans, onions, radish, spinach, sweet potatoes.

FIG. 6.—Roots of peach, showing enlargements caused by the gallworm. Dr. Neal, investigating this disease in 1888, expressed the opinion that large numbers of peach trees in the southern United States had been killed by the gallworm. In short, agriculturists, seedsmen, nurserymen, and general merchants should be specially cautioned against rearing, buying, or selling trees, plants, or tubers which show any swelling on the roots except such as are well known to be natural to them. (After J. C. Neal.)

FIG. 7.—Roots of grape (Black Hamburg), showing enlargements caused by the gallworm. The total damage to various crops wrought by the gallworm amounts annually to an enormous sum of money. (After J. C. Neal.)

FIG. 8.—Roots of weeping willow, showing enlargements caused by the gallworm. The worm thrives in the moist sandy soils favorable to the growth of most willows. (After J. C. Neal.)

The following plants are, so far as known, seldom or never affected by the gallworm and may be used on infested land with the expectation of greatly reducing the numbers of the worms, particularly if the land is at the same time kept free from weeds and other plants which may be attacked:

Barley, oats, wheat, rye, corn, sorghum, milo, kafir, timothy, and redtop.

In view of the importance of recognizing promptly the presence of this nematode, the accompanying text figures are presented to show some of the malformations on the roots of different plants resulting from nematode attacks.

In figures 6, 7, 8, 9, and 10 are shown the results of gallworm injury on the peach, the grape, the willow, the fig, and cotton. These plants are all distinctly susceptible to gallworm injury and may serve to indicate the presence of this worm if it occurs abundantly in the soil. Figure 11 shows the enlargements on the roots of a cowpea caused by the nematode. These enlargements are characteristic and need not

FIG. 9.—Roots of the fig, showing enlargements caused by the nematode gallworm. The fig is very susceptible to the attacks of this parasite and, though when the roots are severely infested the tops may continue to grow when conditions are favorable, in times of drought or in cold weather the diseased plants suffer severely. (After J. C. Neal.)

FIG. 10.—Roots of cotton, showing enlargements caused by the gallworm. Owing to the wide prevalence of this worm in the southeastern United States, the aggregate annual damage which it causes on cotton is very large, though not generally appreciated. (After George F. Atkinson.)

FIG. 11.—Roots of the cowpea, showing enlargements caused by the gallworm. With the exception of one variety (the Iron cowpea) this plant is very susceptible to the gallworm, and the use of susceptible varieties as green-manure crops in peach orchards and in rotations just preceding cotton in the South is to be avoided. (After J. C. Neal.)

be confused with the nodules caused by the nitrogen-gathering bacteria which inhabit the roots of this plant. The nodules caused by the nitrogen-fixing bacteria are small and spherical and are attached to the side of the rootlets, while the nematode causes the swelling of the root itself. Figures 12 and 13 show the effect of the attack of the gallworm on red clover and also the worm as it is found in the roots. In figure 12 the enlargements on the roots are shown, while in figure 13 the sections of the root show the presence of the gallworm larvæ. Figure 14 shows the enlargement caused by the gallworm on the roots

of sugar cane. Many plants of the grass family are practically immune to this parasite, as has already been indicated. Figure 15 shows the distortion and enlargement of the roots of the tomato caused by the gallworm. One of the dangerous sources of infestation of new land is through the transplanting of tomato plants grown in hotbeds, where conditions favor the development of the gallworm, and a careful inspection should be made of all tomato plants set in uninfested soil. Figure 16 shows the enlargement of the roots of the radish caused by the gallworm. This quick-growing vegetable may be used to advantage as an indicator to determine whether or not the

FIG. 12.—Root system of a young red-clover plant, with swellings caused by the gallworm. These enlargements should not be confused with the beneficial root nodules caused by nitrogen bacteria nor with the disease known as crown-gall. (After B. Frank.)

FIG. 13.—I. Longitudinal section of root tip of red-clover plant, showing a young gallworm (*Heterodera radicicola*) embedded in the tissues. (After B. Frank.) II. Longitudinal section of root tip of red-clover plant, showing four young gallworms (*Heterodera radicicola*) in the tissues. (After B. Frank.) III. Longitudinal section of root of red-clover plant, near the tip, showing enlargement caused by the gallworm (*Heterodera radicicola*) and a portion of the young worm. (After B. Frank.)

nematode occurs in any particular soil, though it would be unsafe to assume that a soil was free from nematodes if these enlargements were not conspicuous on the roots of the radish. Figure 17 shows a distortion of the parsnip caused by the gallworm, while figure 18 shows the same condition on salsify. Figures 19, 20, and 21 show the effects of the gallworm on the roots of the okra, cucumber, and lettuce.

POSSIBILITY OF ERADICATION.

So far as known there are no effective means of completely eradicating the gallworm from infested fields. It has been found practicable to eradicate it from the soil of greenhouses, hotbeds, and cold

frames by methods of sterilization with steam or chemicals: but such methods are too expensive for field application. Where the gallworm occurs in fields, its subjugation can be accomplished only by slower methods. In some cases it may be possible to flood land with irrigation water and keep it submerged for a period of several months, and thus destroy the living nematodes and the eggs; but in view of the fact that nematodes are usually more abundant on light sandy soils than on heavy soils such protracted flooding is not often practicable.

It may also be possible in some cases to keep the infested field in clean fallow long enough to starve out all the nematodes: but this is hardly practicable in any region where the soil is light and subject to wind erosion.

FIG. 14.—Roots of sugar cane, showing enlargements caused by the gallworm. This worm is common and destructive in the Tropics. Many plants of the grass family resist the disease. (After N. A. Cobb.)

FIG. 15.—Roots of tomato, showing enlargements caused by the gallworm. Tomatoes sometimes suffer severely from this disease. (After George F. Atkinson.)

CROPS SUGGESTED FOR INFESTED AREAS.

Probably the best means of combating the nematode is by planting crops which are not subject to its attacks. Such crops as corn, sorghum, wheat, rye, oats, and barley are among the most promising for this purpose. Corn and sorghum are particularly desirable, because they permit clean tillage, and thus all weeds and other plants on which the nematodes might live may be kept out. It should be particularly noted that the sugar beet is susceptible to the nematode and should not be planted on fields known to be infested.

SUMMARY.

During the seasons of 1910 and 1911 there has been a serious infestation of certain potato fields in Nevada caused by a nematode gallworm known as *Heterodera radicum*. This has resulted in hindering the marketing of Nevada potatoes in California, where the crop has been sold heretofore.

FIG. 16.—Radish showing root enlargements caused by the gallworm. Care should be taken not to confuse these enlargements with those of clubroot, a disease occurring on cabbage, turnips, and related plants. (After J. C. Neal.)

FIG. 17.—Parsnip attacked and deformed by the gallworm. This disease attacks the roots of hundreds of other kinds of plants. If such roots are used for food the refuse should be cooked or destroyed. Such material can not be introduced into New South Wales and other progressive States. (After N. A. Cobb.)

FIG. 18.—Roots of salsify, showing enlargements caused by the gallworm. A number of foreign countries have legislated against the introduction of plants and farm produce infested with this disease. (After George F. Atkinson.)

The parasite causing the disease is a very small unsegmented worm which invades the roots of many different plants, causing malformations and often seriously hindering the growth of the plants. The nematode multiplies very rapidly under favorable conditions. The life cycle may be completed within a few weeks and each female may lay as many as 500 eggs.

The nematode may be carried from place to place in the roots of living plants, in potatoes, on soil on the roots of nursery stock, or with potted plants. It may also be carried from one field to another in earth on farm implements or in irrigation water. Manure from yards where diseased roots or tubers have been fed may carry the

FIG. 19.—Roots of okra, showing the enlargements caused by the gallworm. The nematodes producing this disease are to be found in the root enlargements. (After J. C. Neal.)

worm, and garbage containing peelings of diseased potatoes is also a prolific source of infestation.

The use as seed of any infected potatoes is to be strongly condemned. No effort should be spared to locate all infested fields in a district where the nematode is known to occur, and seed potatoes should be secured from fields known to be uninfested or, better still, from a region where,

FIG. 20.—Roots of cucumber, showing enlargements caused by the gallworm. Nearly all other common garden plants are similarly attacked. There are many thousands of the worms in the nodules upon such a root system. (After Kati Marcinowski.)

FIG. 21.—Roots of lettuce, showing enlargements caused by the gallworm. Many plants are killed in the seedling stage by the gallworm. (After Kati Marcinowski.)

because of adverse climatic conditions, the nematode is unknown.

A thorough inspection should be made of all fields in each district where the nematode is suspected to occur, and all infested fields should be devoted to crops

which the nematode does not attack. There are many plants besides the potato which are susceptible to nematode injury, and these should never be planted or allowed to grow in fields where the gallworm is found. There are a number of crops that are not attacked by this parasite, and these only should

be grown on infested fields until the nematode is practically starved out.

It is very difficult to eradicate the nematode completely when it is once well established in a field, but its numbers may be so reduced by the use of immune crops that susceptible crops may be grown again without serious injury.

Approved:

JAMES WILSON,

Secretary of Agriculture.

WASHINGTON, D. C., *February 10, 1912.*

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