THE GOLDEN NEMATODE HANDBOOK
Survey, Laboratory, Control, and Quarantine Procedures

By
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FOREWORD

The history of nematology in the United States is characterized by its rapid growth and by general recognition by growers, industry, and agricultural workers of the importance of nematodes in limiting crop production.

The first regulatory activity against nematodes was in 1926 when the U.S. Department of Agriculture's Bureau of Entomology and Plant Quarantine imposed regulations against the bulb and stem nematode. Today, several hundred Federal and State people are engaged in regulatory nematology and are spending about $4.5 million a year on surveys, enforcement of quarantine regulations, and the application of nematocides.

Before World War II, about 35 people were engaged in nematological research, and the annual appropriation was less than $150,000. Today, at least 175 persons are working full or part-time on nematological research, and the annual expenditure is about $4 million.

The discovery of the nematocidal properties of dichloropropene-dichloropropane in 1943 marked the beginning of the present soil fumigation industry. For the first time farmers and nurserymen had a practical and economical means of controlling nematodes. About the time of this discovery the golden nematode was found on Long Island (1941). Although a handful of nematologists in the United States had been working on the nematode problem for a number of years, the discovery of the golden nematode brought the problem forcibly to public attention.

In 1953, nematologists discovered that the burrowing nematode, *Radopholus similis,* caused spreading decline of citrus, and in 1954, they discovered that the soybean cyst nematode, *Heterodera glycines,* was causing economic losses to soybeans.

After the discoveries in 1941, 1953, and 1954, survey, regulatory, and control programs were initiated and special methods were developed for large-scale control programs.

Regulatory measures and the laboratory and field techniques used to carry out the program against the golden nematode are described in this handbook. Most of the methods are suitable for use on a large scale and are applicable to most other cyst nematodes. No other publication includes such a comprehensive treatment of a nematode control program. The information will be valuable not only to those conducting regulatory and control programs involving the golden nematode, but also to agricultural administrators, plant protection officials, and students in many other areas of agriculture.

Joseph F. Spears is well qualified to write this handbook. He was one of the organizers of the program. He pioneered in the development of many of the program operations and has been associated with the work in some capacity for more than 20 years. He initiated the present chemical control program. In addition, he has had broad experience with large-scale plant protection programs involving other nematodes and other organisms, such as insects and fungi.

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PROTECT

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PREFACE

This handbook has been prepared to meet the needs of agricultural workers interested in the protection of crops from nematode outbreaks. Most of the procedures set forth in this handbook are the outgrowth of research conducted by the New York State College of Agriculture, Cornell University, and the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA). These methods and procedures have been successfully used for several years. Through the efforts of the scientists working on this problem these methods are constantly being improved.

Many people have contributed in various ways to make this handbook possible. The author is sincerely grateful to all of them. Special acknowledgment is made to personnel of the New York State Department of Agriculture and Markets; the Department of Plant Pathology, Cornell University; the Nematology Section of the Crops Research Division and the Plant Pest Control Division, ARS, USDA; and the Foreign Agricultural Service, USDA.

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INTRODUCTION

The golden nematode is undoubtedly the most serious pest threatening the American potato industry. It is recognized throughout the temperate regions of the world as one of the most difficult of all crop pests to control. It also attacks tomatoes, but it is not a major threat to this crop.

The golden nematode is the subject of stringent quarantine regulations in most countries where it occurs. Countries not known to be infested have rigid regulations governing the importation of potatoes or other products that might carry the pest. Agricultural officials in countries where the nematode occurs agree that potatoes cannot be grown economically on land containing large numbers of the nematode. Tuber yields of less than seed planted have been reported from fields heavily infested.

The golden nematode poses many problems in its control. It has a remarkable ability to survive under unfavorable conditions. It can remain dormant in the soil in the absence of host plants for many years because the unhatched nematode is protected by both the shell of the eggs and the durable cyst wall, which acts as a protection against adverse conditions. The lack of any one aboveground symptom to betray its presence is an aid to its survival. Thus, light or scattered infestations of the nematode reproduce and increase in the soil undetected. During this time of buildup, infestations may spread to new fields, and because the populations are low they will not be detected by the best survey techniques. This type of spread and slow buildup of populations is undramatic, and low levels of infestations are always one step ahead of survey. Crop reduction as a result is negligible. The buildup may require 5 to 7 years or more after introduction of the pest into a field before noticeable crop injury and reduction in yields occur. However, buildup of nematode population increases like compound interest until the crop is destroyed.

As the damage caused by plant nematodes is becoming more widely recognized, general interest in the problem is increasing and a mounting volume of questions are being asked by growers. Most countries now have nematologists devoting their efforts to problems caused by plant nematodes. More and more surveys are being undertaken in many countries to determine distribution and identification of plant nematodes.

Control of the golden nematode in most areas of the world still depends on crop rotation. However, scientists have been devoting more and more attention to the development of resistant varieties. Resistance-breaking biotypes of the golden nematode have now been reported from several countries, and investigators are devoting much attention to the influence this has on the problem.

The use of nematocides to control the golden nematode is also being investigated by workers in several countries. Some European countries are making limited use of these chemicals. However, the high cost of chemicals has been a factor in preventing large-scale use.

In the United States the use of nematocides is increasing annually for nematode control on many crops. Over 100 million pounds of nematocides are used annually in this country, principally on tobacco, pineapple, and vegetable soils. Nematocides are applied to about 1 million acres. In the United States and Canada, the use of nematocides has been adopted on a large scale in an effort to eliminate the golden nematode.

Continuing research will undoubtedly refine present methods of control. Basic information being gathered by nematologists will develop more efficient control measures. Screening of chemicals for control or eradication is being stepped up. As more effective and less expensive nematocides are developed, together with more efficient methods of applying them, the use of chemicals for nematode control will undoubtedly increase.

HISTORY AND ORIGIN OF THE GOLDEN NEMATODE

During Germany's campaign against sugarbeet nematodes in 1881, Julius Kuhn observed a cyst-forming nematode attacking potatoes. He recorded it as a curiosity—a possible subrace of *Heterodera schachtii* (*48*).[1]

That the nematode was actually a serious parasite of potatoes was not established, however, until 1913, when Massee (Scotland) and Zimmerman (Germany, 1914) proved Kuhn's "oddity" to be the real cause of what was then known as "soil sickness of potatoes" (*9*).

Within the following decade, the existence of the pest was discovered in England (1917), Sweden (1922), and Ireland (1922). Still thought to be a new species of *Heterodera schachtii*, the pest gained the common English name of "potato root eelworm" (*48*).

In 1923, however, Wollenweber observed that "potato larvae are slightly shorter than those of the sugarbeet nematode, and that their cysts are pear-shaped rather than lemon-shaped." Declaring that this was an entirely different species from that attacking sugarbeets, he proposed the name *Heterodera rostochiensis* since his specimens came from Rostock, Germany (*48*).

Despite Wollenweber's findings, scientific journals of the day continued to refer to the nematode as a race of the sugarbeet nematode (*15*). It was not until the excellent work of Franklin, years later, that *Heterodera rostochiensis* was given general recognition as a valid species.

The impact of the pest on the world's potato industry[2] has been spectacular since infested seed had been spread throughout much of the world long before *Heterodera rostochiensis* was named. Infestations have been discovered in such widely separated nations as Peru (1952), Iceland (1943), India (1961), and Panama (1967).

[1] Italic numbers in parentheses refer to Literature Cited, p. 77.

[2] For information on world potato production, see Appendix I.

Origin

For many years it was thought that the golden nematode originated in Europe. Some workers suggested that the nematode's sudden appearance was by mutation from a species of *Heterodera*, originally a parasite of some European garden weeds or ornamentals. Some advanced the theory that it was transported from an isolated area where the species may have lived on a sporadically occurring *Solanacaea*.

On April 3, 1951, a ship from Peru arrived at the port of Seattle, Wash. Plant quarantine inspectors of the USDA making routine inspection of the ship for plant pests collected soil from potatoes in the ship's stores and found the golden nematode. On September 25, 1951, a ship from Peru in the New York harbor was inspected and golden nematode cysts were found in the ship's stores in two different collections. These specimens were examined by USDA nematologists and were confirmed as being *Heterodera rostochiensis*. Since this pest had not been previously reported in Peru, a careful check was made of the ship's log to determine if the ship had taken on stores in other ports. All evidence pointed to the fact that the contaminated potatoes had originated in Peru.

A. L. Taylor of the Nematology Section, Crops Research Division, ARS, wrote to C. Bazan de Segura, Centro Nacional de Investigacion y Experimentacion Agricola de la Molina, Peru, advising of the finding of the golden nematode on ships from Peru and suggesting that a search be made in the country for the presence of the pest. As a result of this communication the nematode was found in February 1952 on potatoes from Tarma. A scientist from ARS, who was in Peru at the time the discovery was made, brought specimens back to Mr. Taylor in May 1952. Mr. Taylor confirmed identification as *Heterodera rostochiensis*.

The first account of this discovery was published in 1952 (*36*). The author, C. Bazan de Segura, stated that it was her opinion the *Heterodera rostochiensis* is indigenous to the

Andes. Later investigations conducted by Peruvian scientists determined that the nematode was widely distributed and was of an ancient origin.

Later, the nematode was discovered in the highlands of Bolivia and Argentina, where it is believed to be indigenous also.

The theory basing *Heterodera rostochiensis* origin in Peru is accepted by most nematologists today. Also, most botanists agree that the potato originated in Peru. Thus, one might logically ask why the golden nematode did not become a problem to European potato growers much earlier.

Potato tubers from South America had been well-distributed in Europe by early 1600. No doubt cysts of *Heterodera rostochiensis* were also distributed with these tubers, but under primitive cultural methods buildup was slow. By 1700 the potato had become a vital part of the basic food supply in Ireland, Scotland, Germany, and other western European countries.

However, little was done by agricultural scientists to improve the potato. Their interest was generally for its botanical characteristics. These earlier horticulturists did not seriously influence potato production or improvement of the few varieties that existed during this period. There was no serious attempt to develop new potato varieties until after the crisis in Ireland caused by late blight (1845). The potato famine that resulted gave the necessary stimulus to a new era of potato breeding, which led to commercial potato production.

From the mid-1800's to the end of that century there were revolutionary changes in potato growing. Plant breeders for the first time were guided by scientific principles of heredity and immunity in crop improvement. Between 1856 and 1876, large numbers of distinct varieties were produced and consumption of the potato in the people's everyday diet increased. It was probably during this period of intensified growing of potatoes and the distribution of seed for the establishment of commercial potato production that *Heterodera rostochiensis* was able to gain a foothold in Europe's potato fields.

Discovery in the United States

A farmer near Hicksville, Long Island, N.Y., was little concerned in 1934 when he noticed a few isolated spots in his potato field where vines were stunted and off color. Within 4 years, however, the spots had multiplied and commercial losses to his potato crop were being sustained. The farmer made repeated requests to his county farm bureau agent for

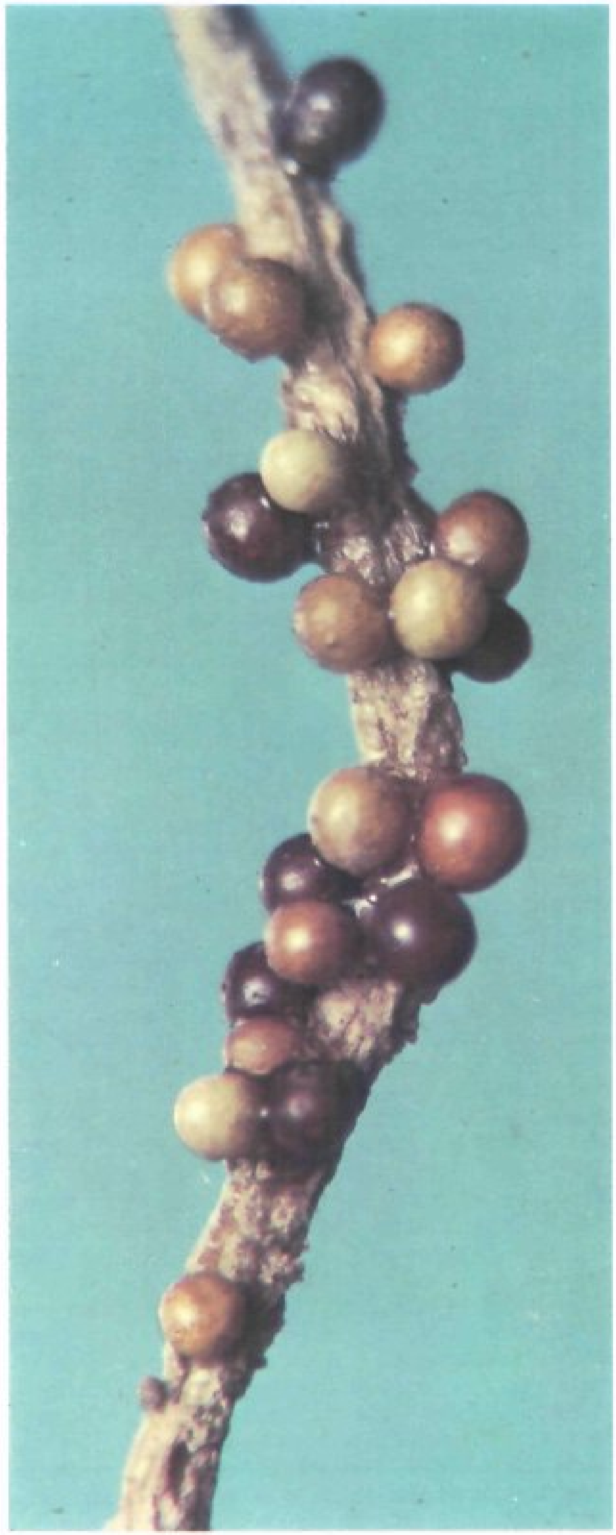

FIGURE 1.—Mature females attached to the roots become golden in color, hence the popular name "golden nematode" in the United States.

soil analysis or other explanation of his crop injury (*5*).

In July of 1941, Orson S. Cannon, a graduate student of the Department of Plant Pathology, Cornell University, attached to the Nassau County Farm Bureau, Long Island, visited the potato field and observed that the stunted and off-color appearance of the potatoes was similar to spots in sugarbeet fields infested with *Heterodera schachtii*, with which he was familiar (*4*). Cannon examined potato roots from the field and found numerous swollen female nematodes on the roots. Suspecting that this was the causative organism, he took specimens to the USDA Bulb Laboratory in Babylon, Long Island, where B. G. Chitwood, USDA nematologist, identified the specimens as *Heterodera rostochiensis* (*28*). Subsequent examination of the property showed that the entire field was infested and crop losses were as high as 70 percent; in an adjoining field, marked injury was apparent (*11*).

Available information on the distribution of the pest indicates that all Long Island infestations may have originated from this 40-acre field. The reuse of burlap bags for picking potatoes and the movement of farm machinery by renters were major factors in the local spread of the disease. More than 30 additional fields farmed by the operator of the original infested field have since been found infested. How and when the nematode gained entrance into the United States is not known. However, it could have been brought on military equipment being returned to Long Island military camps after World War I. From the extent of the infestation in 1941 and the history of the field, the nematode had probably been present for 20 years before it was identified (*13*).

H. rostochiensis is usually called the potato root eelworm in most European countries. However, to avoid confusion with other potato nematodes in the United States, Chitwood gave the pest its popular name of "golden nematode" (*7*) because the flask-shaped immature females attached to the roots become golden in color about the time the plants begin to bloom (fig. 1).

THE GENUS *HETERODERA*[3]

The golden nematode (*Heterodera rostochiensis* Wollenweber, 1923) (*51*) belongs in the "rostochiensis group" of the genus *Heterodera* Schmidt, 1871 (*35*). This group is typified particularly by the globular to ovate shape of the white females and cysts, and the character of the cyst wall pattern (fig. 2). Specific identification is based primarily on vulva-anal size and relationship, and to some extent, on morphological characters of the females and males, if these are available (fig. 3).

When *H. rostochiensis* nematode was first discovered in this country about 25 years ago, there was in the group only one other known and described species, *H. punctata* Thorne, 1928 (*46*). Since then several very closely related species have been found, and their accurate identification requires the efforts of someone thoroughly familiar with all the species.

In 1953, Cobb and Taylor (*16*) described *H. leptonepia* found in potatoes obtained from a ship's stores at Callao, Peru. This form is distinctive especially because of the strikingly slender larvae. Shortly after that, another species, *H. tabacum* Lownsbery and Lownsbery, 1954 (*25*), from tobacco in Connecticut was described. In 1959, a *Heterodera,* still undescribed and intermediate between *H. rostochiensis* and *H. tabacum* was found on horsenettle, *Solanum carolinense,* in Virginia; it is known to occur in other areas also. In 1961, another *Heterodera* in the *rostochiensis* group was found on tobacco in Virginia. These forms have been referred to, respectively, as the "horsenettle-cyst nematode" and the "Osborne cyst nematode" (*29*). The latter is closely related, and possibly identical, to *H. tabacum.*

Knowing of the above closely related nematodes and keeping in mind the very probable existence of still undiscovered new species in the "rostochiensis group," one should be very cautious and thorough before concluding that any globular cysts that might be associated with potatoes are actually the golden nematode.

Key to the Mature Cysts of the More Common Species of *Heterodera*[4]

This key is designed to facilitate identification of the more common species of *Heterodera* that might be encountered in soil samples collected during a survey. Only characters of the mature cysts and their contents—that is, eggs with second stage larvae—are used. Certain characters used in the key may not be visible on other than fully mature cysts.

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[3] Prepared by M. Golden, nematologist, Crops Research Division, ARS.

[4] Prepared by A. L. Taylor, nematologist, Crops Research Division, ARS. (Retired in 1967.)

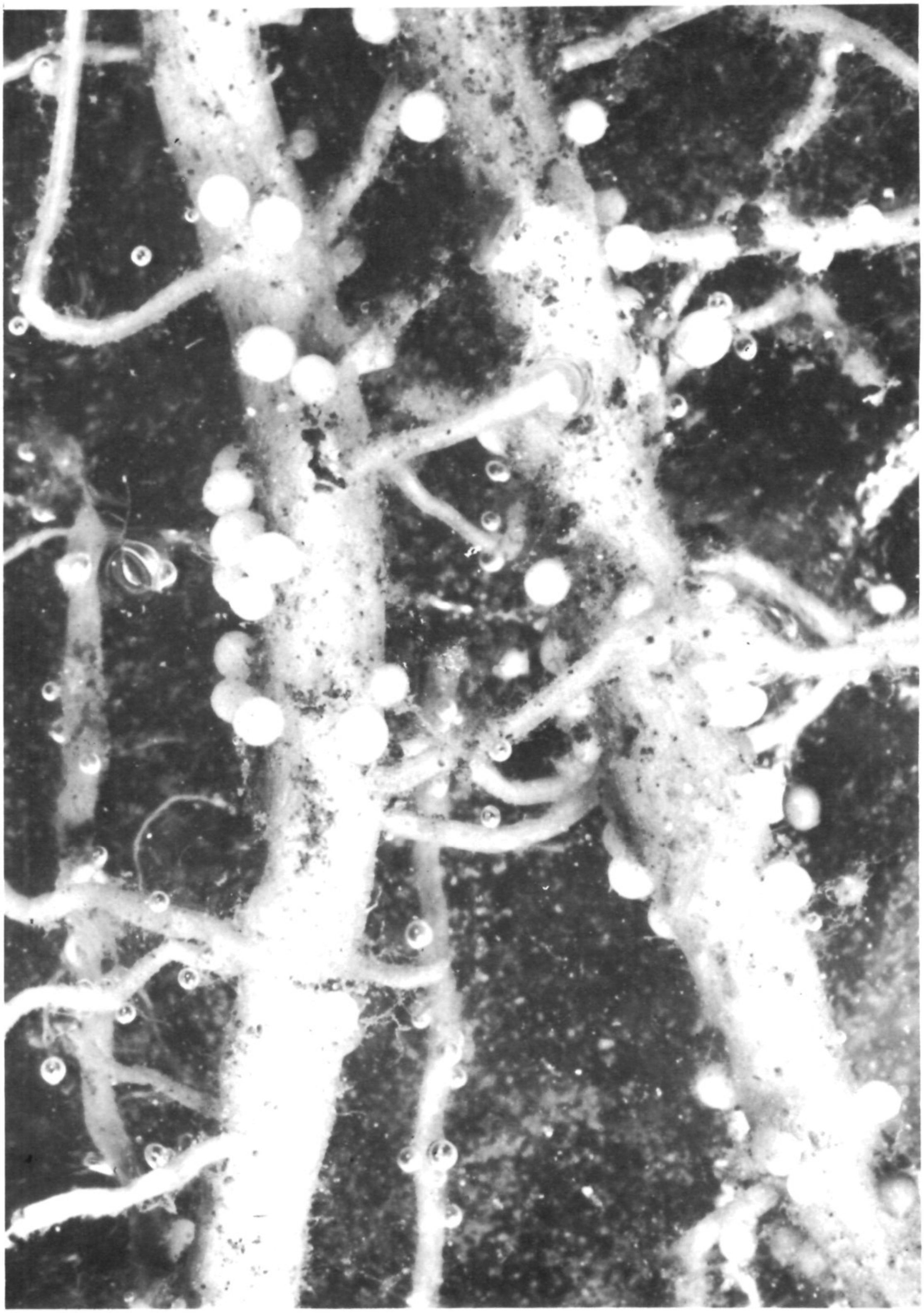

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FIGURE 2.—Numerous immature swollen females on the roots of a potato plant.

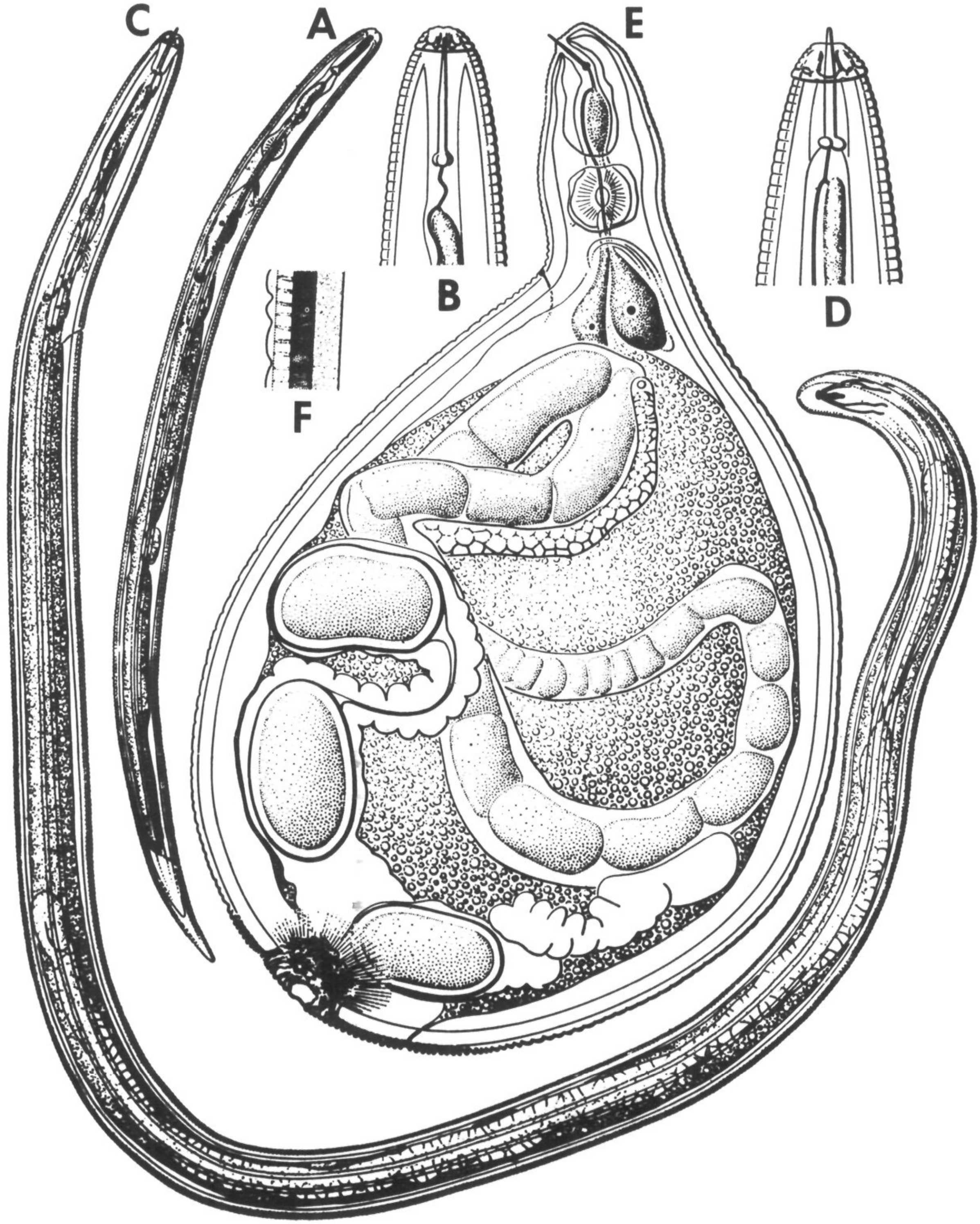

FIGURE 3.—The golden nematode of potatoes, *Heterodera rostochiensis* Wollenweber, 1923: (A) Infective larva, hatched from egg; (B) head of infective larva: (C) adult male; (D) head of adult male; (E) young adult female; (F) section of cyst wall (7).

Measurements of larvae are from Fenwick and Franklin (*18*) for most species, from Jones (*22*) for *H. carotae*, from Ichinohe (*21*) for *H. glycines*, and from Kirjanova (*23*) for *H. fici*.

1. Body of cyst, ovoid to globular, that is, with posterior portion rounded and vulva not located on a distinct protuberance ---------------------------- *Heterodera rostochiensis* group 4
   Body of cyst, lemon-shaped, that is, with vulva located on a distinct protuberance ----------------------------2
2. Basic element of pattern of outer layer of cyst wall at middle portion of cyst, short zigzag lines with little or no trace of regular transverse arrangement; sometimes modified to appear as network ----------------------------3
   Basic element of pattern at outer layer of cyst wall at middle portion of cyst, straight or wavy lines at right angles to axis of cyst; sometimes broken by short oblique or vertical lines; outer layer of cyst may have grainy appearance -------*Heterodera cacti* group 7
3. Mature cysts with dark bodies (brown knobs) and often sheaf-shaped object (lining of vagina) at posterior end. On immature cysts, these are seldom visible, and then do not appear dark ----- *Heterodera schachtii* group 8
   Mature cysts without brown knobs or sheaf-shaped object at posterior end -- *Heterodera gottingiana* group 11
4. *H. rostochiensis* group. Cyst often ovoid, anus located at a transparent spot on cyst so that anal and vulvar openings appear to be about the same size when seen by transmitted light. Hyaline portion of larval tail much longer than stylet -----------*Heterodera punctata*
   Cyst ovoid to globular; anal opening appears much smaller than vulva opening. Hyaline portion of larval tail about the same length as stylet --------------5
5. Larvae very slender; length about 39 times greatest width; orifice of dorsal oesophageal gland about two-thirds stylet length posterior to stylet knobs - *Heterodera leptonepia.*
   Length of larvae about 22 times greatest width; orifice of dorsal oesophageal gland about one-fourth stylet length posterior to stylet -----------------6
6. Distance between vulva and anus about two and one-half times diameter of vulva -------*Heterodera rostochiensis*
   Distance between anus and vulva about one and one-half times diameter of vulva -----------*Heterodera tabacum*
7. *H. cacti* group. Hyaline portion of larval tail about as long as stylet; stylet knobs concave anteriorly --*Heterodera weissi*
   Hyaline portion of larval tail usually shorter than stylet; stylet knobs convex anteriorly ---------*Heterodera cacti*
8. *H. schachtii* group. Cysts always with distinct, coarse punctation consisting of dots of uniform size but not in rows; brown knobs closely clustered around vulva. Hyaline portion of larval tail at least one and one half times longer than stylet ------------*Heterodera avenae*
   Cyst with or without punctation, fine and mostly in rows; brown knobs not closely clustered around vulva. Hyaline portion of larval tail about as long as stylet --9
9. Average length of larvae:
   480 microns ---------------------10
   about 460 microns *Heterodera schachtii*
10. Average length of larvae:
    484 microns ------*Heterodera glycines*
    502 microns -------*Heterodera trifolii*
    518 microns ---------------------- *Heterodera schachtii galeopsidis.*
11. *H. gottingiana* group.
    Average length of larvae:
    414 microns ---*Heterodera cruciferae*
    454 microns ------*Heterodera carotae*
    474 microns --*Heterodera gottingiana*
    405 microns ------*Heterodera humuli*
    406 microns ------- *Heterodera fici*

Type Host Plants [5]

Many lists of host plants of *Heterodera* species have been published, but it seems probable that many of these are inaccurate in that they include plants that are not hosts of the species discussed. This is true especially of the older lists and of those based on information compiled from the literature rather than from host tests. To avoid this particular error, the following list of host plants includes only the type host of each species and an indication of the other plants that it attacks, so far as there is general agreement or information on host tests available. That is, the list is not intended to be complete, but I believe it is accurate so far as what is included is concerned.

[5] Prepared by A. L. Taylor, nematologist, Crops Research Division, ARS. (Retired in 1967).

The species of *Heterodera* and their principal hosts are as follows:

H. schachtii. Type host, sugarbeet (*Beta vulgaris* L). Also other Chenopodiaceae, many species of Cruciferae and various species of other plant families (*47*). It seems possible that *H. schachtii* attacks a wider variety of plants than any other known species of *Heterodera.*

H. gottingiana. Type host, garden peas (*Pisum sativum* L.) and other Leguminosae. But according to Oostenbrink (*31*), this species does not attack beans (*Phaseolus vulgaris* L.), clover (*Trifolium* spp.), alfalfa (*Medicago sativa* L.), or soybeans (*Soya max* Piper).

H. trifollii. Type host, red clover (*Trifolium pratense* L.) and other Leguminosae, including beans (*Phaseolus vulgaris* L.) but not peas (*Pisum sativum* L.) alfalfa, or soybeans.

H. glycines. Type host, soybean (*Glycine max* L.) and snap bean (*Phaseolus vulgaris* L.), Adzuki bean (*P. angularis*), vetch (*Vicia* sp.), annual lespedeza (*Lespedeza stipulacea* Maxim.), henbit (*Lamium* sp.).

H. major. Type host, oats (*Avena sativa* L.) and other Gramineae.

H. cruciferae. Type host, cabbage (*Brassica oleracea* L.) and other Cruciferae.

H. carotae. Type host, carrot (*Daucus carotae* L.). Wild carrot (*Daucus carotae*) is the only other known host (*22*).

H. humuli. Type host, hops (*Humulus lupulus* L.) and other Urticaceae.

H. galeopsidis. Type host, hemp nettle (*Galeopsis tetrahit* L.). Also other Labiatae and some species of Chenopodiaceae and Carophyllaceae (*22*).

H. fici. Type host, rubber plant (*Ficus* sp.).

H. weissi. Type host, knotweed (*Polygonum pensylvanicum* L.). No other hosts known.

H. cacti. Type host, Phyllocactus (*Epiphyllum ackermanni*) and other Cactaceae.

H. rostochiensis. Type host, potato (*Solanum tuberosum* L.). Also tomato (*Lycopersicon esculentum* Mill.) and a few other species of Solanaceae (*30*) but not tobacco (*Nicotiana tabacum* L.) (*45*).

H. tabacum. Type host, tobacco (*Nicotiana tabacum* L.) and tomato.

H. punctata. Type host, wheat (*Triticum vulgare* Vill.) and other Gramineae.

BIOLOGY

Life History

The golden nematode passes through the egg, larval, and adult stages in its development. From 38 to 48 days are required for the egg-to-adult cycle (*9*).

The eggs hatch within the dead, swollen bodies of fertilized females, which are called cysts. Cysts are flask shaped and are much smaller than a pinhead. Each cyst may contain up to 500 eggs. The cyst is a protective covering for the eggs and is resistant to chemicals, to drying, and to some soil organisms (fig. 4).

In the spring when the soil temperature is around 60° F. a chemical given off by potato or tomato roots stimulates larvae to hatch from the eggs, leave the cyst through an opening in the wall, and migrate to host plants. Larvae enter the roots where they feed. At temperatures below 55° F. there is little activity of the larvae (*10*).

In the roots, golden nematodes take up a position near the plant's vascular system and then undergo a series of changes. The females become stationary; they swell and break through the roots, to which they remain attached by a thin neck. The males retain their slender eellike form and mate with the females. After fertilization, several hundred eggs develop within the female whereupon the female dies.

The golden nematode cyst is visible to the unaided eye. At first, it is pearly white. Later, it turns golden, orange, and finally brown. Cysts become detached from the roots and remain in the soil after the crops have been harvested (*40*) (fig. 5).

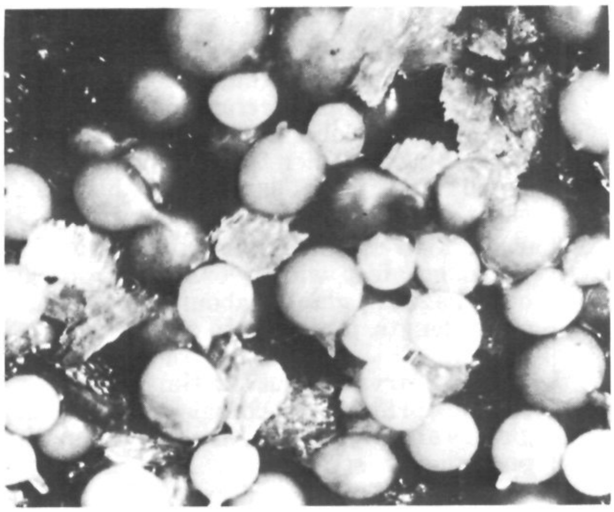

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FIGURE 4.—Golden nematode females washed from potato soil. Each cyst may contain up to 500 eggs.

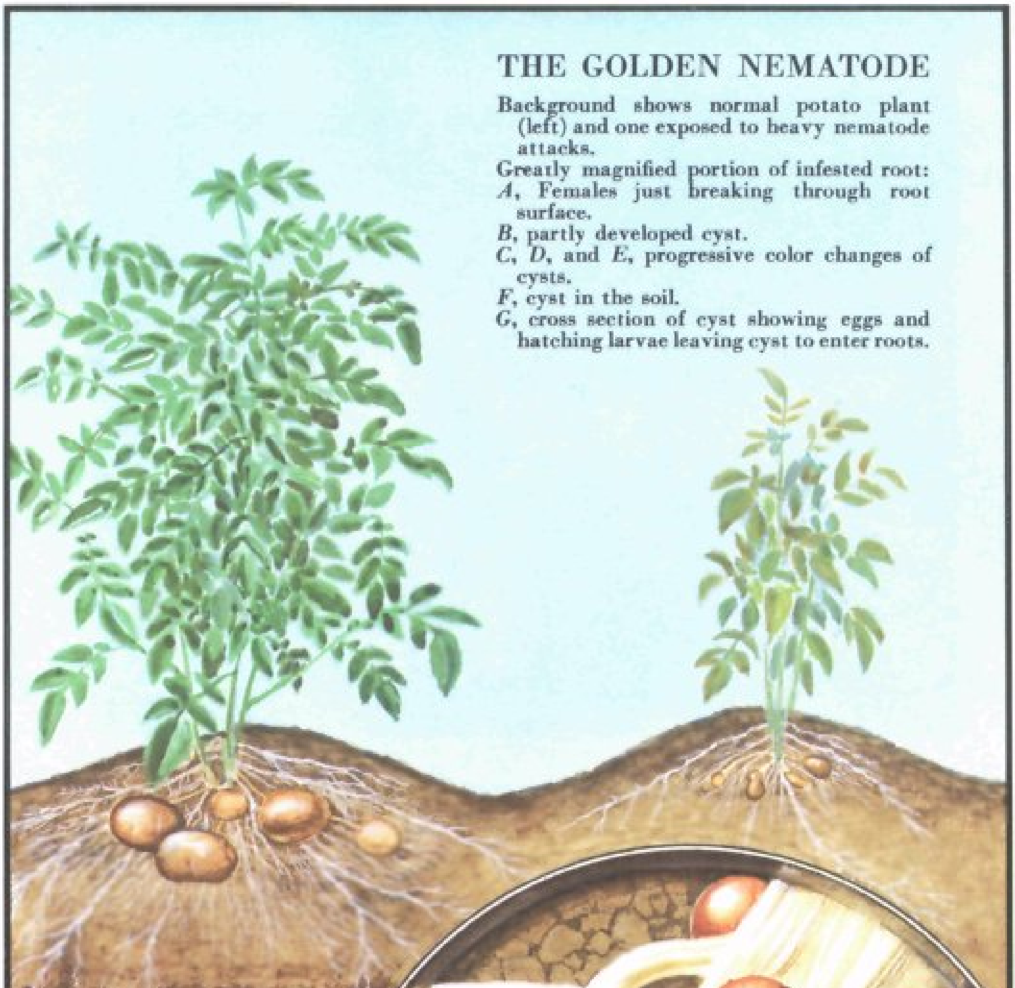

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FIGURE 5

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FIGURE 6.—Aboveground symptoms of golden nematode damage.

Symptoms of Infestation

Soil populations of the golden nematode sufficiently high to cause plant damage are produced only after buildup on several potato crops. At first there is no aboveground evidence of plant damage. This lack of distinguishable symptom of the early stages is an aid to the organism. After host crops have been repeatedly grown on infested land, then distinct aboveground signs of damage begin to appear (*40*) (fig. 6).

The first sign is poor growth of plants in small spots in the field. These spots are similar to that of plants in low spots in wet years and high spots during dry years. No one plant symptom alone can be relied upon as evidence of the disease. If the infestation grows, the spots become larger and additional spots appear (*27*).

Aboveground symptoms appear only in the presence of large numbers of nematodes in the soil. Heavy infestations cause considerable wilting of plants, especially during midday, stunting of growth, poor root development, and poor plant growth. Before enough nematodes develop in the soil to cause aboveground symptoms, immature females may be seen on the roots. By carefully removing the plants and roots at blossom time, the white, yellow, or golden flask-shaped females attached to the root may be seen with the unaided eye (*40*).

Populations of the golden nematode on Long Island are so low that aboveground symptoms seldom occur except in the experimental area of the golden nematode laboratory. In this area symptoms of heavily infested plants are generally evident the latter part of May and early June. Extensive soil surveys detect infestations as soon as they reach the discovery level.

The effect of the golden nematode on tomatoes is similar to that on potatoes. Growth of plants is retarded and wilting is particularly noticeable (fig. 7). Leaves of heavily infested plants are purplish, instead of yellowing as in potatoes, and the lower leaves may die (*38, p. 178*).

The nematode in the early stages of the attack on tomatoes causes slight swelling of the roots, which may be confused with galling caused by the root-knot nematode (*38, p 178*).

Host Plants

The only commercial crops known to be attacked by the golden nematode are *Solanum tuberosum* (potatoes), *Lycopersicon esculentum* (tomatoes), and *S. melongena* (eggplant) (*27*).

BN 29988

FIGURE 7.—*(Left)* Healthy tomato plants. *(Right)* Tomato plants stunted by the golden nematode.

Among other plants that may also become infected, thereby helping to propagate this pest, are *Solanum dulcamara* (bitter nightshade), *S. rostratum* (buffalo bur), *S. triflorum* (cutleaf nightshade), *S. elaeagnifolium* (silverleaf nightshade), *S. blodgettii, S. xanti* (purple nightshade), and *S. integrifolium* (tomato eggplant) (*15*).

Plant breeders have found about 90 species of the *Solanum* to be host of the golden nematode. Although most of these plants are wild species not occurring in the United States, most do occur in South America (*38 p. 176*).

Rate of Population Increase

Damage by the golden nematode to host crops is caused by mass invasion on the roots by nematodes that kill or damage the root system, depriving the plant of the necessary food.

The relative increase in the number of nematodes in the soil from the growing of a potato crop is greatest when the number of nematodes is low (*27*). This is because the plant is able to produce a vigorous root system, and the nematodes have an abundant root system on which to feed. The nematodes attacking the root are less concentrated, and thus few roots are killed. However, as the number of nematodes increases in the soil, the annual increase of nematodes from the continual growing of potatoes is less because more roots are killed and both the plant and the nematodes are deprived of an adequate food supply.

When the concentration of nematodes reaches a level to cause total failure of the potato crop, the number of living nematodes in the soil drops substantially (*27*). This, of course, is due chiefly to the lack of food to sustain the population. The following year it may be possible to grow a fair potato crop because enough nematodes have died so the plant can produce a root system to sustain itself. At these high degrees of infestation, the crop will always be irregular and always be poor.

In the absence of host crops, the rate of decrease in viable cysts may be as much as 50 to 80 percent the first year; however, the rate of decrease continues at a smaller rate with some viable cysts remaining for many years. Grainger (*19*) of the West Scotland Agricultural College reported that the golden nematode wastes away at a fairly standard percent annually in the absence of host plants, because of normal aging and ultimate death of the nematode and attack by other organisms.

Normal aging appears to be logarithmically dependent on temperature, being greater in warm climates than in cooler climates. Infestations of the golden nematode never assume very serious proportions in warm countries, where natural wastage is so high that even relatively short crop rotations would reduce populations to very low levels and longer rotations would eliminate them entirely. In cool areas, like Scotland, however, the annual wastage could be as low as 18 percent. Grainger also says that a moderate infestation of nematodes, still in a viable state, could be expected to cause serious disease "up to 30 years after the last potato crop." This expectation, according to Grainger, has been confirmed by careful checking of actual instances, which involved persistence of 27 to 28 years (*19*).

United States Department of Agriculture research workers Chitwood and Feldmesser (*14*) found the increase on one potato crop on Long Island to be about tenfold to twentyfold until approximately 50,000 cysts per plant were

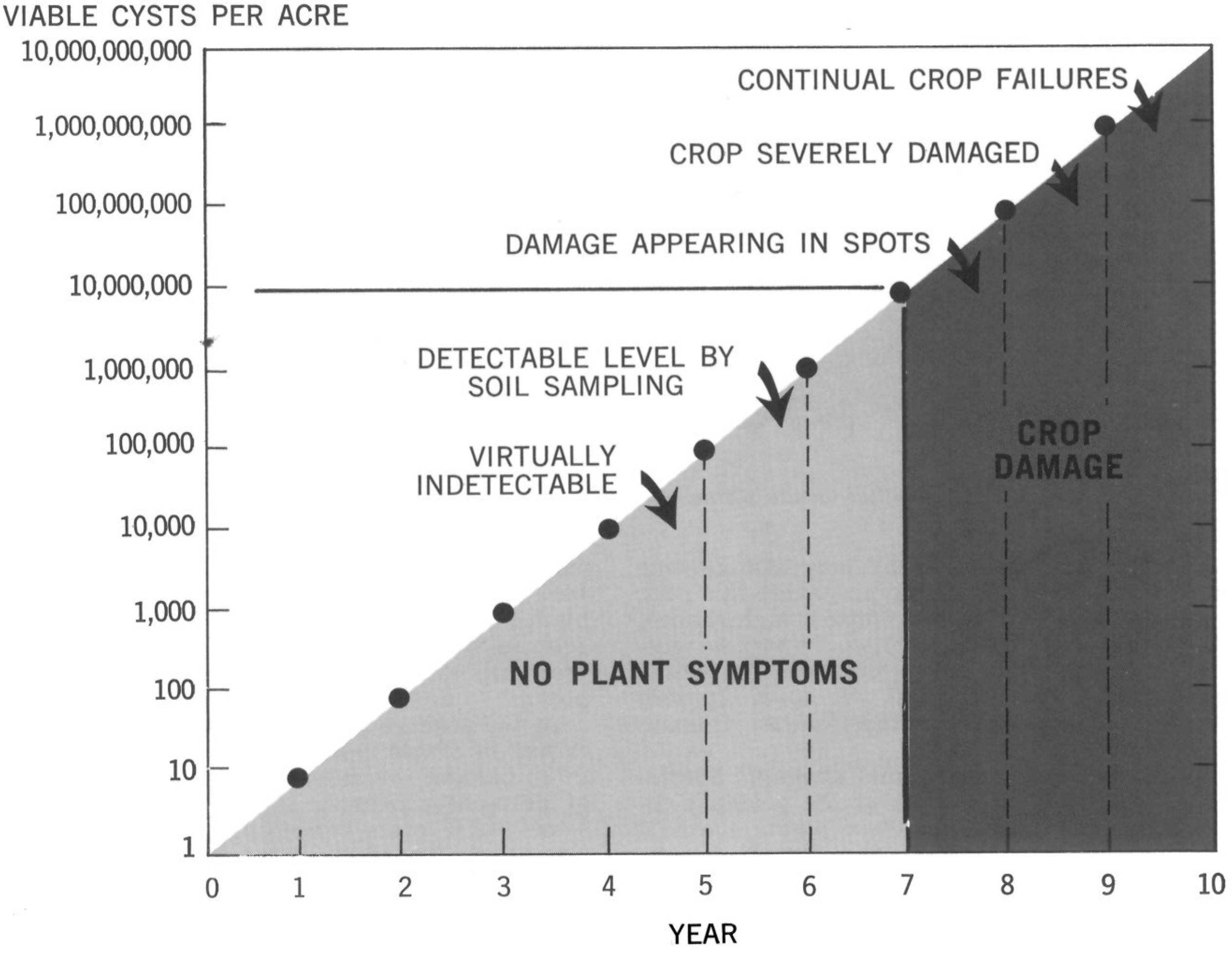


FIGURE 8.—Increase in golden nematode populations in a continuous potato culture, assuming a tenfold increase.

formed. Research workers in the Netherlands have, in general, agreed with USDA findings. In the Government-enforced rotation program, the Netherlands has assumed, for practical purposes, a tenfold increase of the nematode on a crop of potatoes and a decrease of 50 percent in the absence of a potato crop.

Figure 8 shows graphically an increase of golden nematode infestation in a continuous potato culture assuming a tenfold increase (*44*).

THE POTATO AND TOMATO INDUSTRIES

The economic potential of the golden nematode, if left uncontrolled, can have serious effects on the potato industry. Potatoes are a major food crop in many countries.

Potato production in 1966 in the principal producing countries, estimated at 5,100 million hundredweight (100 lb.), was 1 percent above the 1965 crop but 2 percent below the 1960–64 average. Total acreage, estimated at 44 million acres, continued its gradual downward trend, whereas yields in general increased. Higher yields more than offset the effect of decreased acreage.

Tomatoes are not as widely grown as potatoes; however, they are an important crop for both the fresh market and for processing. Tomato production in 1965 in the principal producing countries of the world is estimated at 420 million hundredweight produced on about 2.5 million acres.

Europe leads the world in tomato production, followed by North America, the Near East, Latin America, the Far East, Africa, and Oceania. The 10 leading tomato-producing countries are United States, Italy, Spain,

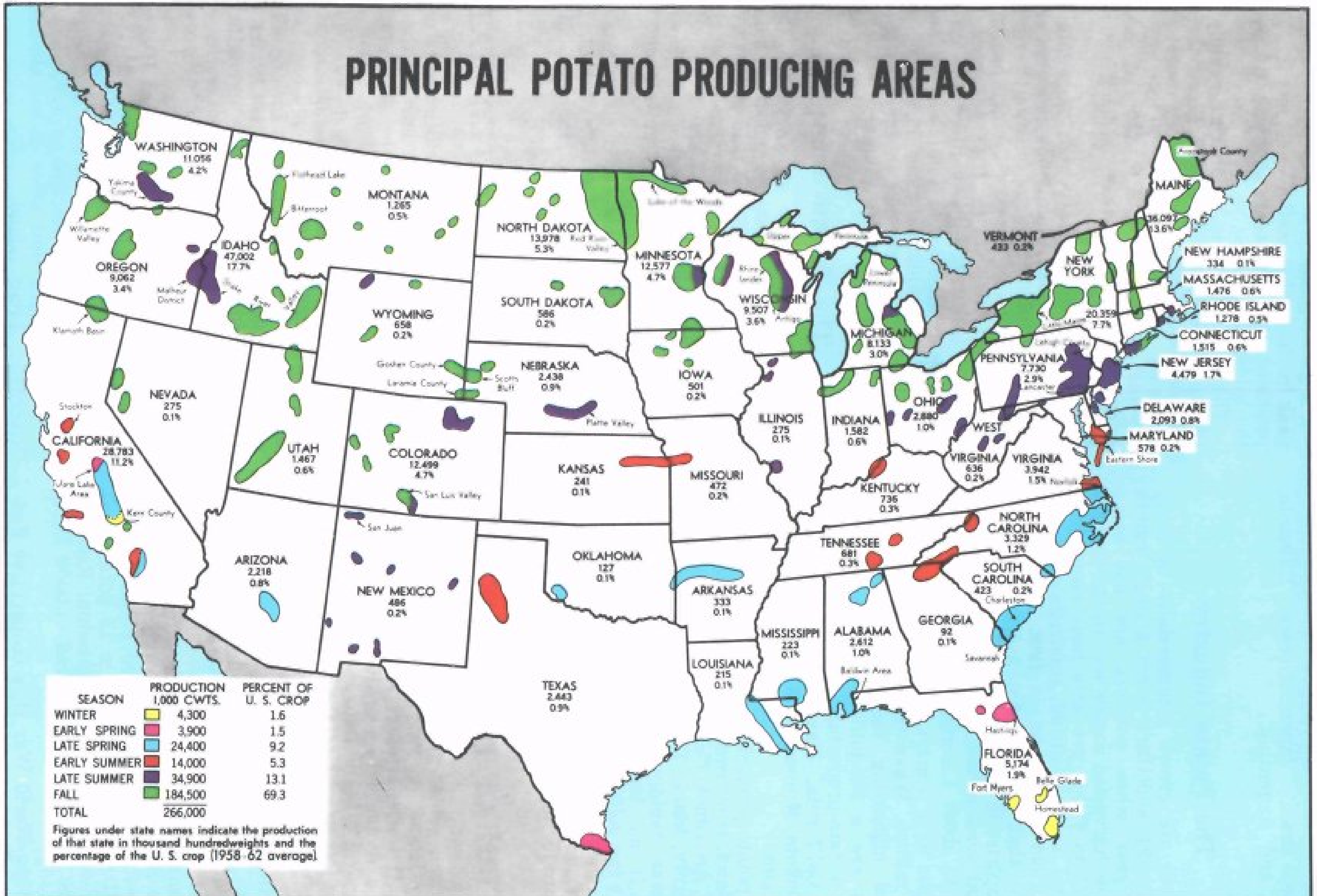

PRINCIPAL POTATO PRODUCING AREAS
WASHINGTON 11,056 4.2%
OREGON 9,062 3.4%
IDAHO 47,002 17.7%
MONTANA 1,265 0.5%
NORTH DAKOTA 13,978 5.3%
MINNESOTA 12,577 4.7%
WISCONSIN 9,507 3.6%
MICHIGAN 8,133 3.0%
SOUTH DAKOTA 586 0.2%
WYOMING 658 0.2%
NEBRASKA 2,438 0.9%
IOWA 501 0.2%
NEVADA 275 0.1%
CALIFORNIA 28,783 11.2%
UTAH 1,467 0.6%
COLORADO 12,499 4.7%
KANSAS 241 0.1%
MISSOURI 472 0.2%
ILLINOIS 275 0.1%
INDIANA 1,582 0.6%
OHIO 2,880 1.0%
KENTUCKY 736 0.3%
WEST VIRGINIA 636 0.2%
VIRGINIA 3,942 1.5%
PENNSYLVANIA 7,730 2.9%
NEW YORK 20,359 7.7%
VERMONT 423 0.2%
MAINE 36,093 13.6%
NEW HAMPSHIRE 334 0.1%
MASSACHUSETTS 1,476 0.6%
RHODE ISLAND 1,278 0.5%
CONNECTICUT 1,515 0.6%
NEW JERSEY 4,479 1.7%
DELAWARE 2,093 0.8%
MARYLAND 578 0.2%
NORTH CAROLINA 3,329 1.2%
SOUTH CAROLINA 423 0.2%
TENNESSEE 681 0.3%
ARIZONA 2,218 0.8%
NEW MEXICO 486 0.2%
OKLAHOMA 127 0.1%
ARKANSAS 333 0.1%
TEXAS 2,443 0.9%
LOUISIANA 215 0.1%
MISSISSIPPI 223 0.1%
ALABAMA 2,612 1.0%
GEORGIA 92 0.1%
FLORIDA 5,174 1.9%
SEASON | PRODUCTION 1,000 CWTS. | PERCENT OF U. S. CROP
WINTER 4,300 1.6
EARLY SPRING 3,900 1.5
LATE SPRING 24,400 9.2
EARLY SUMMER 14,000 5.3
LATE SUMMER 34,900 13.1
FALL 184,500 69.3
TOTAL 266,000
Figures under state names indicate the production of that state in thousand hundredweights and the percentage of the U. S. crop (1958-62 average)

FIGURE 9

Bulgaria, Brazil, Japan, Greece, Rumania, Mexico, and Argentina.

The Potato Industry

Potatoes are grown commercially in every State (fig. 9), and there is not a single month in the year when potatoes are not being planted or harvested somewhere in the country (*49*). Potato yields per acre have risen from a national average of 80 hundredweight per acre in 1940 to 210 cwt. in 1966. It has been predicted that the national average per-acre yield may rise to as much as 250 cwt. by 1975. The total acreage decreased from 2.8 million in 1940 to about 1.5 million in 1966.

Potatoes have a market value of about $600 to $800 million. When transportation, packaging, and marketing facilities are included, potatoes are a $3 billion industry. The 10 leading potato-producing States are Idaho, Maine, California, New York, Washington, North Dakota, Minnesota, Wisconsin, Colorado, and Oregon.

As a potato-producing area, Suffolk County, Long Island, is outranked in the United States only by Aroostook County, Maine, and Bingham County, Idaho. The potato acreage on the Island was rapidly expanded during World War II. It may have been during this expansion that the golden nematode spread from the original field in Nassau County to eastern Suffolk County—a distance of over 100 miles. Potato production on Long Island reached its peak in 1946, when well over 62,000 acres were produced. It decreased to about 40,000 acres in the midsixties.

The yield per acre, which rose rapidly during and following World War II, continues to increase but at a slower rate. In recent years, yields have averaged 250 to 260 cwt. per acre. Of this yield, about 235 to 240 cwt. may be sold; the rest is offgrade or used for home consumption.

Hicksville—once the center of potato production in Nassau County—is now the center of a large suburban area of New York City. The population of Nassau County has grown from about 400,000 in 1941 to more than 1,400,000 in 1967. Almost all of the infested potato fields in Nassau County have become house lots or industrial sites. The golden nematode, however, continues to threaten the potato industry in Suffolk County.

The Tomato Industry

Tomatoes are widely grown in the United States for both processing and fresh market. Most of the tomato crop is field grown. About 275,000 acres of tomatoes are grown for processing; the crop value is about $160 million. Tomatoes for the fresh market are grown on 170,000 acres; the annual value is about $190 million.

The 10 leading tomato-producing States are California, Ohio, Florida, New Jersey, Indiana, Illinois, Pennsylvania, Maryland, Michigan, and New York.

CONTROL OF THE GOLDEN NEMATODE IN THE UNITED STATES

When the golden nematode was discovered on Long Island in 1941, Cornell University and the U.S. Department of Agriculture undertook a cooperative research program, and the New York State Department of Agriculture and Markets and the USDA conducted surveys. With the involvement of the United States in World War II, however, the amount of attention that could be devoted to the problem was limited.

By 1944, it had become obvious that the nematode was much more widespread on Long Island than it had been thought at first. In that year, the State invoked a quarantine (*33*), and the Bureau of Entomology and Plant Quarantine, USDA, began a survey in 19 potato-producing States east of the Mississippi River to see if the nematode had spread outside Long Island (*10*).

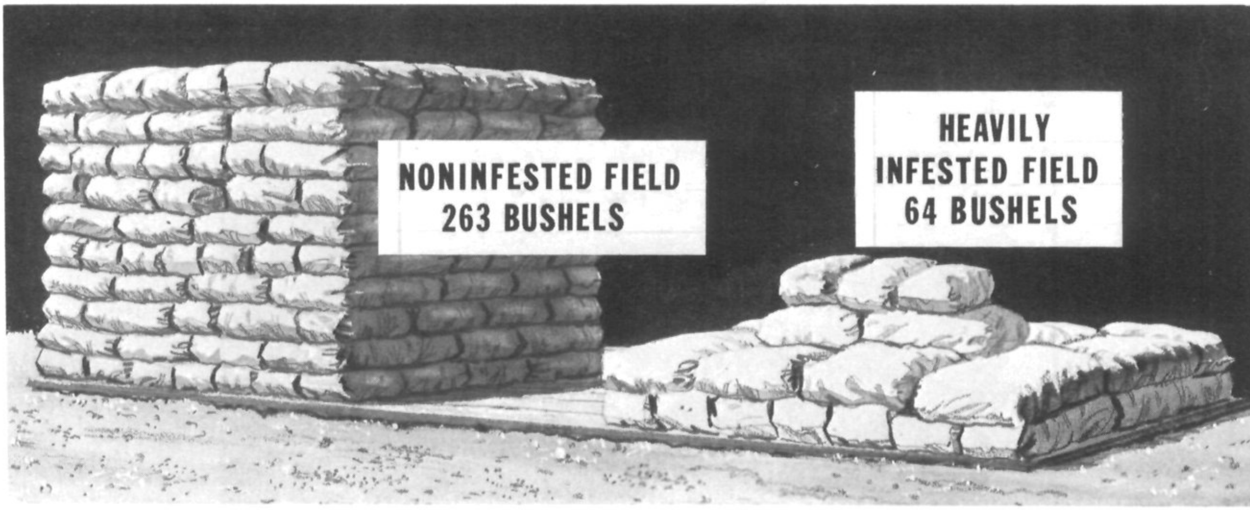
Following World War II, a cooperative Federal-State Golden Nematode Control Project was established. Research facilities were greatly expanded, and the staff to operate the program was also expanded. The program was divided into four main branches: Survey, laboratory processing of samples, quarantine enforcement, and research. Systematic soil surveys were begun of all fields on Long Island, and surveys were expanded to include all potato-producing areas of the United States (fig. 9). Quarantine regulations were strengthened.

The following offices and laboratories have been set up for the golden nematode program on Long Island:

(1) A headquarters building at Hicksville houses the program offices of both the USDA's Plant Pest Control Division and the New York State Department of Agriculture and Markets, a laboratory, and a storage garage.

(2) A work unit office is maintained at Riverhead, Long Island.

(3) New York State College of Agricul-



BN-28195

FIGURE 10.—Yields of Green Mountain potatoes per acre, based on a 5-year average.

ture, Cornell University, Department of Plant Pathology, maintains a laboratory and greenhouse facilities at Farmingdale. Approximately 8 acres of land is available here for field tests (fig. 10).

Research and Methods

The laboratory at Farmingdale investigates many phases of the golden nematode problem. But its primary concern involves (1) investigations into rotation and resistance, biotype buildup, race determination, and breeding of potato varieties resistant to the golden nematode, and (2) investigations into chemical control, which include screening of nematocides, evaluation of promising new nematocides, and determination of techniques and conditions for optimum nematocide effectiveness.

The Plant Pest Control Division's Methods Improvement Operations works closely with Cornell scientists in their research program. The Methods Improvement personnel develop and improve machinery for applying nematocides to the soil, ways of field-scale testing of candidate nematocides that show promise for use in a control program, and ways of field-scale testing of fumigants under tarpaulin seal; they also develop regulatory treatments to free of infestation nursery stock, farm machinery, burlap bags, and other commodities so that they may be safely moved.

Research has gone forward with very significant progress in various fields. A chemical treatment program and commercially acceptable varieties of potatoes resistant to the golden nematode have been the two most valuable findings in making a breakthrough in solving this pest problem.

Survey Results

During the first 10 years of the program the golden nematode seemed to be confined to western Long Island, mainly Nassau and western Suffolk Counties. The vast potato acreage of eastern Long Island remained free of the nematode until 1950, when several infested properties in Bridgehampton were found (fig. 11).

With establishment of systematic surveys in 1946, the number of properties known to be infested rose sharply. During the period 1946-52, the number of properties found infested averaged 34 annually, comprising 1,362 acres. Beginning in 1947 real estate interests bought up much of Nassau County's agricultural land for houses and by 1956 few potato fields remained. As farmland became scarce in Nassau County, builders began to purchase potato fields in western Suffolk County. During the period 1954-67, the average number of properties found infested each year dropped to 7, and the average acreage dropped to about 361 (fig. 12).

Since the golden nematode program began, 387 properties consisting of 17,151 acres, have been found infested (table 1 and fig. 12). Of this total about 11,413 acres of infested agricultural land have been permanently removed from agriculture for real estate development (table 2). Of the remaining infested acres, 4,389 have received soil treatment and have

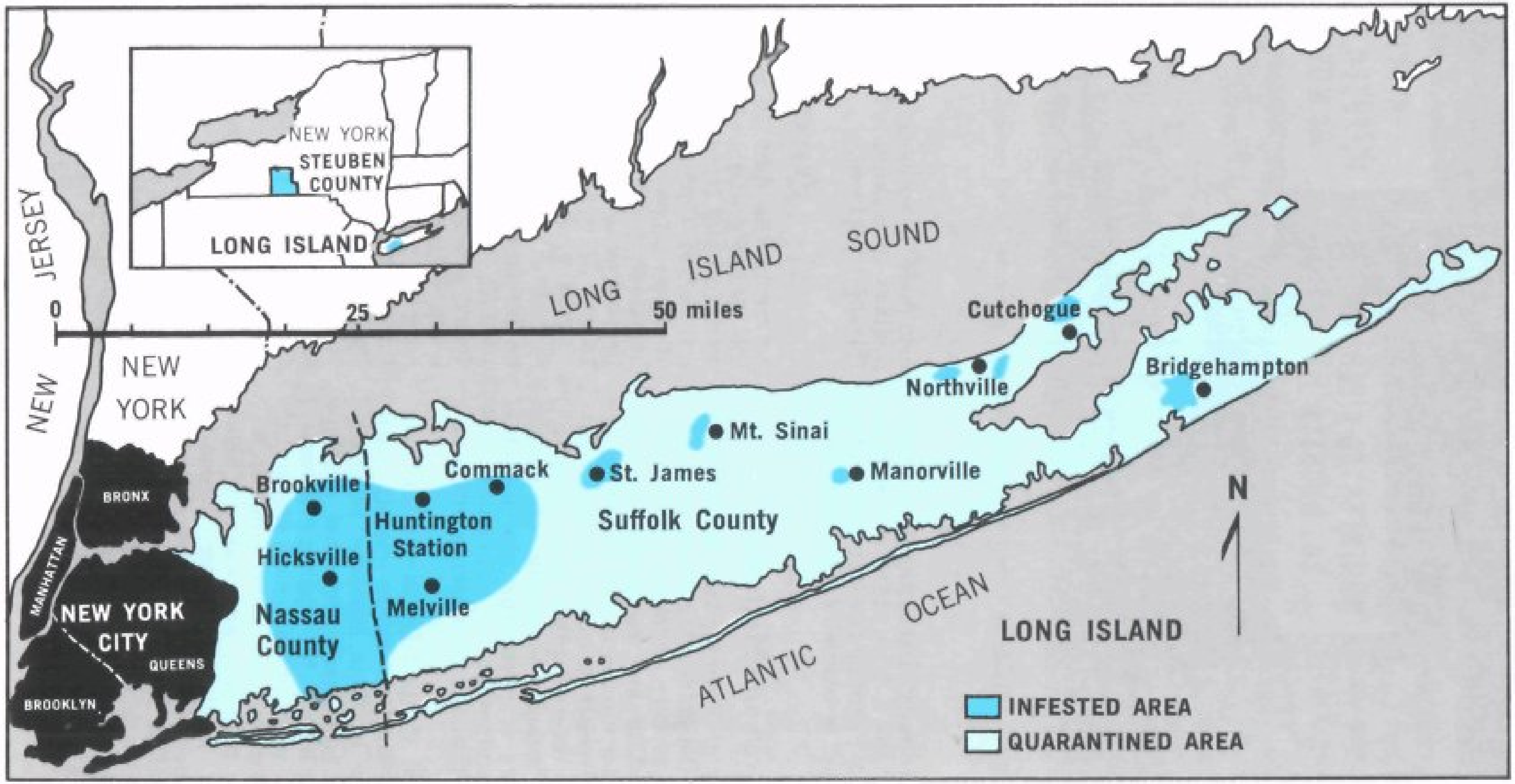

NEW YORK
STEUBEN COUNTY
LONG ISLAND
NEW JERSEY
NEW YORK
0
25
50 miles
LONG ISLAND SOUND
BRONX
MANHATTAN
NEW YORK CITY
QUEENS
BROOKLYN
Brookville
Hicksville
Nassau County
Huntington Station
Melville
Commack
St. James
Suffolk County
Mt. Sinai
Manorville
Northville
Cutchogue
Bridgehampton
ATLANTIC OCEAN
LONG ISLAND
N
INFESTED AREA
QUARANTINED AREA

FIGURE 11

been released for agricultural use, thus leaving 1,350 acres of agricultural land to be treated.

The following tabulation shows the status on January 1, 1968, of the infested land remaining to be treated:

Land use	*Acres*
Vegetable crops	577.74
Potato land (Steuben County)	55.00
Cultivated sod	281.74
Pasture	108.87
Pending development (for real estate purposes)	326.67
Total	1,350.02

Early regulatory action and the strict enforcement of the State quarantine has played a large part in restraining the spread of the golden nematode. The withholding of potatoes and tomatoes from infested land has been the most important single thing done to control the spread. Fortunately, the infested fields had low nematode populations, and the fields were on an island.

However, administrators of the quarantine had recognized, before discovery of the golden nematode on Long Island or the enactment of strict quarantine regulations, that the pest could be transported to other potato-growing areas.

During the early 1940's a few Long Island farmers either moved to western New York or operated farms both in western New York and on Long Island. Because of the operational exposure of these farms, surveys are made annually in western New York.

On December 2, 1967, the golden nematode was found on a 55-acre field in Steuben County, N.Y., near the town of Prattsburg. The in-

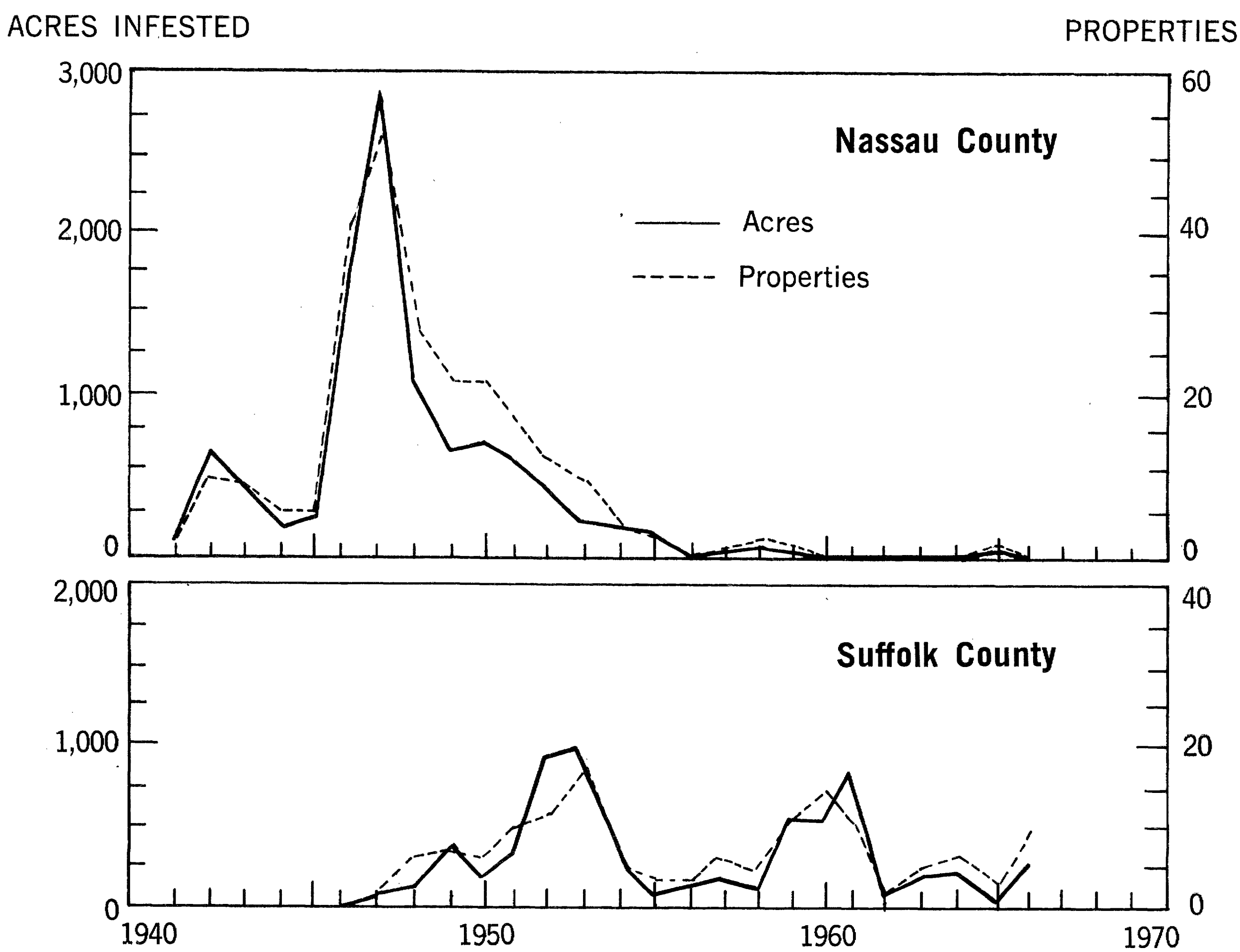


FIGURE 12.—Results of Long Island nematode survey. Number of properties and gross acreage infested, Nassau and Suffolk Counties, 1941–66.

TABLE 1.—*New infestation of golden nematode in Nassau, Suffolk, and Steuben Counties, by years, 1941–67*

Year	Nassau County		Suffolk County		Steuben County		Total properties	Gross acres [1]	Remarks
	Properties	Acreage infested	Properties	Acreage infested	Properties	Acreage infested			
1941	2	115.66	0	0	0	0	2	116	First discovered in U.S.
1942	9	541.86	0	0	0	0	9	542	Plant pulling or irregular pattern of soil sampling, 1941–45.
1943	8	437.36	0	0	0	0	8	437	
1944	5	142.98	0	0	0	0	5	143	
1945	5	165.88	0	0	0	0	5	166	
1946	41	1,656.50	0	0	0	0	41	1,656	Golden nematode project established—systematic soil sampling began.
1947	52	2,793.28	1	30.00	0	0	53	2,823	First Suffolk County.
1948	27	1,034.66	6	216.95	0	0	33	1,252	Commack, N.Y.
1949	22	663.00	7	350.15	0	0	29	1,013	
1950	22	660.56	6	232.88	0	0	28	893	Bridgehampton, N. Y.
1951	16	544.75	10	302.80	0	0	26	848	Cutchogue, N. Y.
1952	13	261.12	12	790.61	0	0	25	1,052	Mt. Sinai, N. Y.
1953	8	167.43	18	989.20	0	0	26	1,157	
1954	3	143.24	5	266.00	0	0	8	409	
1955	2	130.00	3	85.30	0	0	5	215	St. James, N. Y.
1956	0	0	3	153.00	0	0	3	153	None in Nassau County.
1957	1	7.92	7	263.70	0	0	8	272	
1958	2	181.00	4	322.94	0	0	6	504	
1959	1	72.00	11	629.75	0	0	12	702	
1960	0	0	14	629.39	0	0	14	629	
1961	0	0	10	827.63	0	0	10	828	
1962	0	0	2	113.00	0	0	2	113	
1963	0	0	6	304.95	0	0	6	305	
1964	0	0	7	339.62	0	0	7	340	
1965	1	30.00	4	116.85	0	0	5	147	Manorville, N. Y.
1966	0	0	10	382.36	0	0	10	382	
1967	0	0	0	-------	1	55	1	55	First infestation found off Long Island.
Total	240	9,749.20	146	7,347.08	1	55	387	17,151	

[1] Rounded to nearest acre.

TABLE 2.—*Infested land at beginning of each year, land found infested during year, land removed from agriculture by real estate development, land treated and released for potato production, and agricultural land remaining to be treated, Long Island, 1955–67*

Year	Infested land at beginning of each year	Land found infested during year	Land removed from agriculture by real estate development	Land treated and released for potato production	Agricultural land remaining to be treated
	Gross acres	*Gross acres*	*Gross acres*	*Gross acres*	*Gross acres*
1955	[1] 12,722.17	0	6,832.18	0	5,889.99
1956	12,722.17	153.00	796.96	10.00	5,236.03
1957	12,875.17	271.62	103.37	0	5,404.28
1958	13,146.79	503.94	0	10.61	5,897.61
1959	13,650.73	687.30	691.47	67.32	5,826.12
1960	14,338.03	643.84	876.57	656.31	4,951.53
1961	14,996.32	827.63	107.20	1,275.63	4,381.88
1962	15,809.50	113.00	624.17	783.11	3,087.60
1963	15,922.50	304.95	451.06	511.50	2,429.99
1964	16,227.45	339.62	517.45	360.04	1,892.12
1965	16,567.07	146.85	252.00	240.87	1,546.10
1966	16,713.92	382.36	29.00	429.14	1,470.32
1967	17,096.28	55.00	131.10	44.20	1,350.02
1968	[2] 17,151.28	------	------	------	------

[1] Cumulative figures for 1941–55. See table 1.
[2] Includes infestation found in Steuben Co., N. Y.

festation was detected by Plant Pest Control Division personnel who had conducted surveys in western New York potato-growing counties in October and November.

Survey Procedures

The undramatic nature of the pest in its early stages is an aid to its survival. It is very important that the organism be recognized before crop damage becomes apparent; therefore, it is necessary that a constant alert be maintained for its presence throughout the potato- and tomato-producing areas of the country. Small or isolated infestations may exist unnoticed, since plant symptoms are not reliable in the detection of the golden nematode. In the early stages, buildup of populations is slow, and crop damage may not be noticeable for several years.

The most reliable method for the detection of the golden nematode is the collection of soil samples and the microscopic examination of the washed residue. Yield losses are quite evident when the concentration of cysts reach approximately one billion per acre. However, the presence of the golden nematode may be detected before the concentration of the cysts in the soil reach the level where they will cause crop loss.

From the records of more than 100 fields of the many hundreds surveyed on Long Island, it has been determined that, with the survey procedures herein outlined, cysts of the golden nematode may be found on the average when the concentration is approximately one million per acre. Assuming 10 viable cysts were initially introduced into a field and there was a tenfold increase per year, it would take approximately 6 years for a cyst population to build up to the discovery level. Crop damage may not become apparent for another 3 years, during which time the cyst population may build up to a billion per acre (fig. 8).

From this evidence it can easily be understood that a large number of cysts may exist in a potato field in which no symptoms are noticeable on the tops or the tubers. For this reason nematodes may be found in a field that has been surveyed with negative results for several years. This is also the reason that surveys must be conducted continuously and systematically.

Survey Crew

Soil survey crews normally consist of three or four men, one of whom is designated as the crew leader. The number of men assigned to survey a given property or area will vary with the district in which they operate and the scope of such operations. One man can survey about 25 acres per day; therefore, the crew may be varied from one to several men, depending upon the size of fields to be surveyed (fig. 13).

Equipment

Each crew is provided with a map of the area to be surveyed, a supply of No. 12 wet-strength, fungusproof, double-wall paper bags, a felt marker or wax marking crayon, a long-handled (28-inch) pointing trowel for each member of the crew, wire staplers or tape for sealing the bags, a bristle brush for cleaning shoes and equipment, and forms on which to record field survey operations (fig. 14).

Field Soil Sampling

Upon arrival at the premises to be surveyed, the crew leader should look over the property and determine the boundaries, size, and shape of the field, and plan how the field will be surveyed. If the owner or operator has not been previously contacted, the crew leader should do so before beginning work.

It is advisable to divide the field into several small subdivisions or working units. With such subdivisions, it will be possible to return to a given unit to pinpoint an infestation should cysts be found in the sample. They also permit a systematic survey of the field and give the laboratory soil samples of proper size for processing.

In the initial survey, the field is divided into working units of approximately three-fourths to one acre each. The survey is usually conducted in a grid pattern; about a tablespoon of soil is collected on the end of the trowel about every eight paces. This procedure is

BN-29989

FIGURE 13.—Survey crew collecting soil samples.

commonly referred to as the 8 × 8 block method. By this method, one composite sample weighing 4 to 6 pounds will be collected from every three-fourths to one acre of soil inspected.

If a more intensive survey is desired, soil is collected on a 4 × 4 pace interval. By this system, four times the volume of soil will be collected as by the 8 × 8 pace method.

For a still more intensive survey, soil may be collected on a 2 × 2 pace interval. By this procedure, 16 times the volume of soil will be collected as by the 8 × 8 pace method. The 4 × 4 and 2 × 2 pace methods of survey are generally used for pinpointing an infestation following the initial discovery by the 8 × 8 pace method or for collecting samples for viability purposes following field soil fumigation.

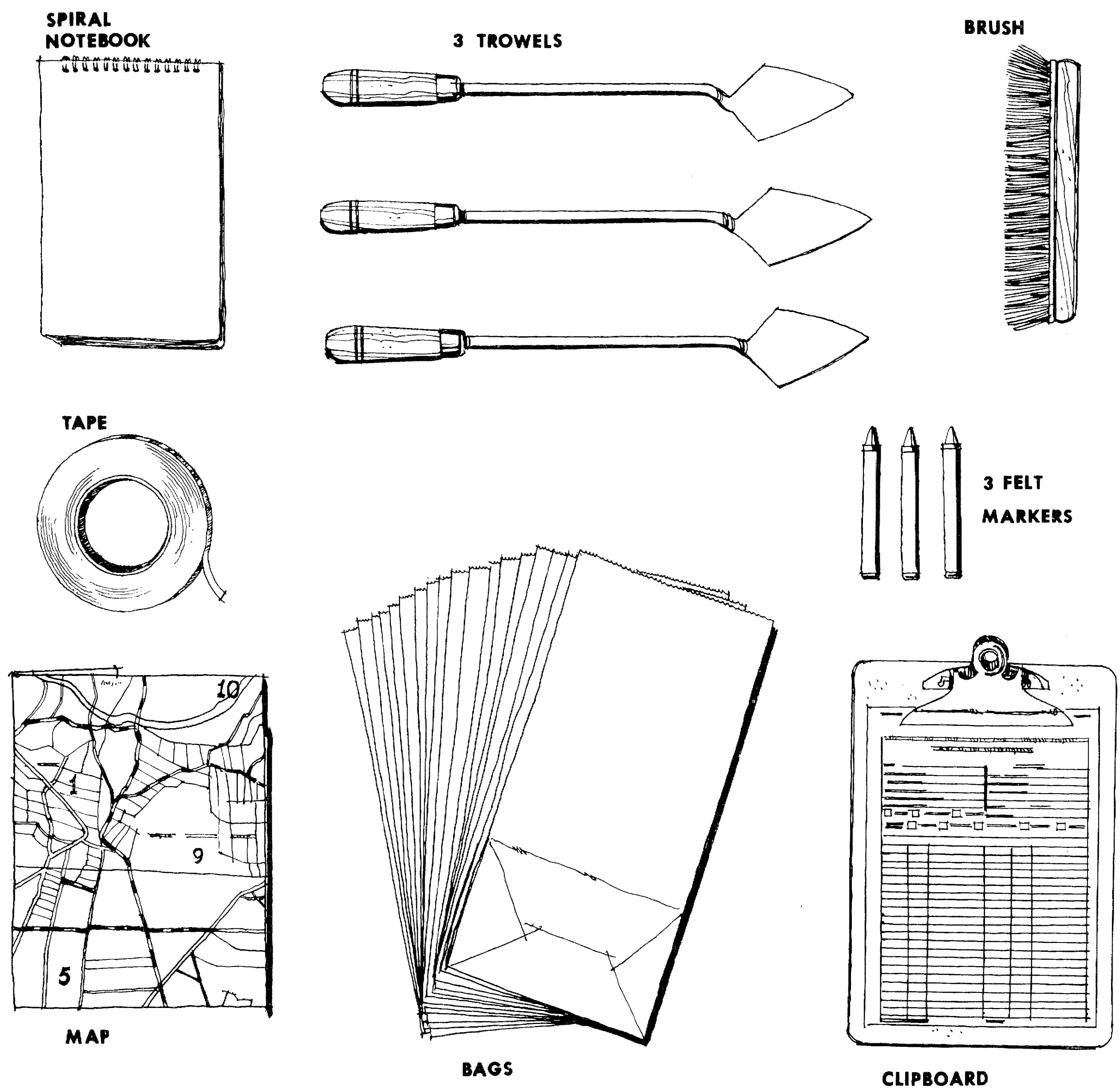


FIGURE 14.—Soil survey equipment: Notebook; pointing trowels; bristle brush for cleaning shoes and equipment; tape for sealing bags; felt markers; map of area to be surveyed; No. 12 wet-strength fungusproof, double-wall bags; and record forms.

N–9204

FIGURE 15.—Plant root examination for nematode cysts.

Plant-Root Examination

The following method of examining potato roots for nematodes may be used to advantage under certain conditions. The best time is while the nematodes are in the white or orange stage. On Long Island this is about the last 2 weeks in June. The cysts are generally in this stage when the potatoes begin to blossom. Fields are looked over carefully, and patches showing plants with weak, spindly stems and stunted tops are selected. Plant-root examination should also be made around buildings or where grading debris has been disposed of. The plant is carefully removed from the ground with a pointing trowel. The roots are separated from the soil, but no attempt is made to remove soil that is clinging to individual roots, as unnecessary handling causes the nematodes to fall from the roots (fig. 15). With the aid of a hand lens, the root system is examined carefully for female cysts. Specimens collected in this manner are placed in vials containing 15 percent formalin or equal parts of rubbing alcohol and water, labeled, and sent to the laboratory for determination.

Labeling and Recording

It is very important that samples be properly labeled and adequate records prepared to clearly identify the samples from each property inspected. Each sample should be labeled in such a manner that all information is visible after the bag has been sealed (fig. 16). The inspector's collection number, which consists of his initials followed by a number, is recorded on the top of the sealed bag. For example, the first collection made on a survey in the calendar year is No. 1. Each collection thereafter, regardless of the State or county, is numbered in a series for the same calendar year. Thus, the inspector's first collection appears as "RAL–1," his second collection "RAL–2," and so on throughout the year. The name of the farmer, the map designation, or the field number is placed on the second line. The date is recorded in the lower right-hand corner of the bag. As the samples or bags of soil are collected in a given field, they are also numbered in a series beginning with No. 1. On the last sample in a series from a particular farm, the notation "End" is made following the sample number.

The collected soil sample is only as good as the records kept of its origin. Thus, in addition to labeling the collected sample another important step in any survey is good recordkeeping (fig. 17). If the collected sample is found in the laboratory to contain golden nematode cysts, one should be able to return to the location in the field from which the sample came. A field survey form should be kept and it should include all necessary details, such as the date sample was collected, collection number, acres surveyed, number of samples

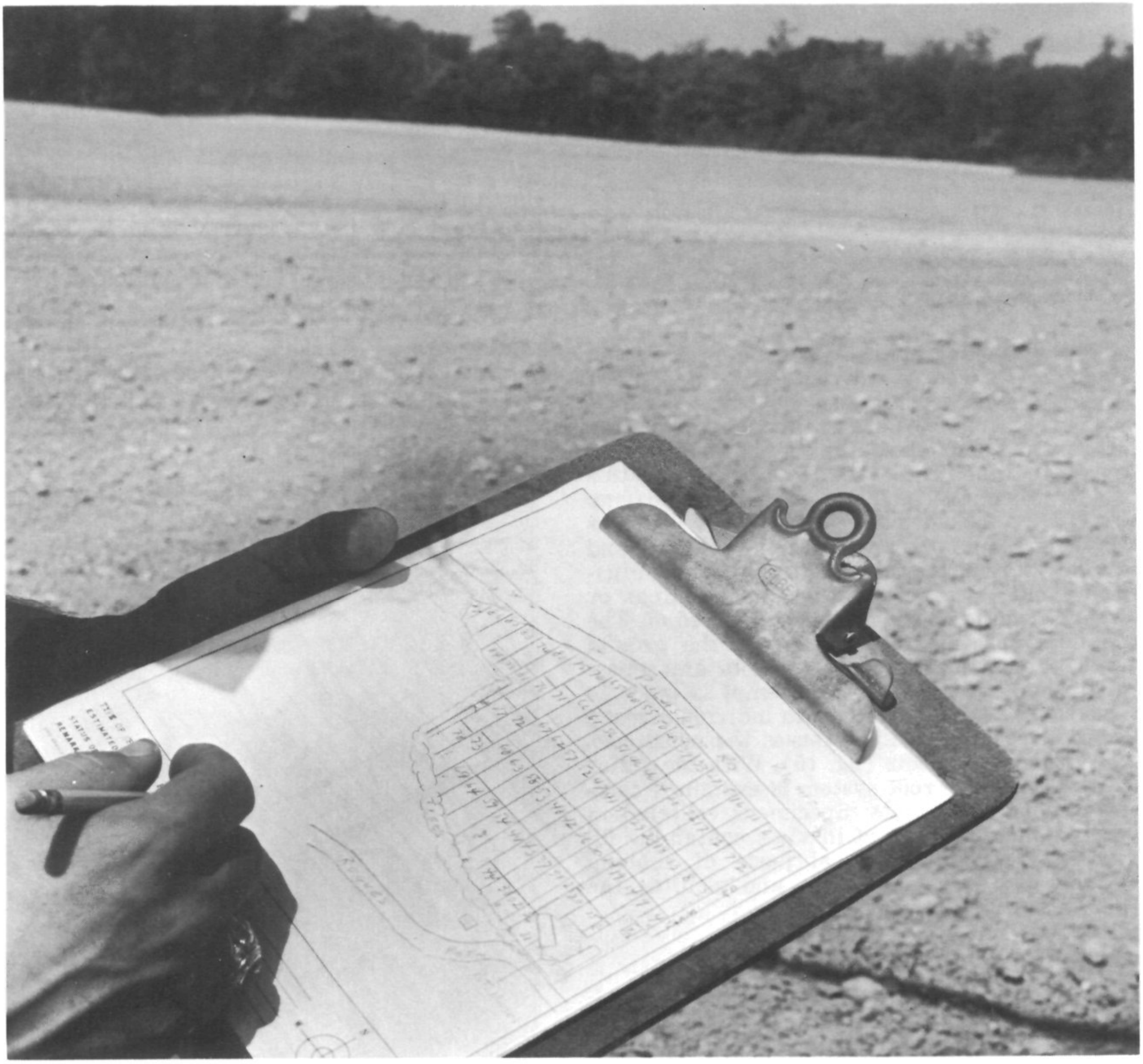
N–38185

FIGURE 16.—An important job of the survey crew is to see that bags are properly labeled.

collected, survey pattern—that is, 8 × 8, and so forth—name of farm operator, mail address, field location including map designation (if any), State, county, and the names of the inspectors that collected the samples (fig. 18). On the reverse of the survey form a sketch should be made of the field, showing the property location, definite landmarks, and the location in the field from which each sample was collected.

Sanitation

Every reasonable precaution should be taken to prevent the spread of this organism. Vehicles assigned to a survey should not be permitted to enter any property. They must remain on highways or thoroughfares, and must be kept clean at all times (fig. 19). Trowels must be free of soil collecting recesses and grooves and should be cleaned when taken from a field. The inspector should clean his shoes with a



N-38191

FIGURE 17.—A sketch should be made of the field to show the property location, land marks, and location in the field from which each sample was collected.

PPC 3-12
(4-57)

U.S. Department of Agriculture A.R.S. Plant Pest Control Division

CYST NEMATODE SURVEY

GOLDEN ☐ SOYBEAN ☐ OTHER ____

DATE 7/18/67 SHELF NO. 31-32 B

MAP DESIGNATION 52-W-7 FARM OPERATOR JOHN DOE

COLLECTION NO. R.A.L. 176 MAIL ADDRESS 100 WEST ST. & RURAL AVE.

ACRES SURVEYED 25 FIELD LOCATION N.E. COR. WEST ST. & RURAL AVE. RURALTON

NO. SAMPLES COLLECTED 34 STATE N.Y. COUNTY NASSAU

SURVEY PATTERN 8 x 8 INSPECTORS BENNETT - JONES

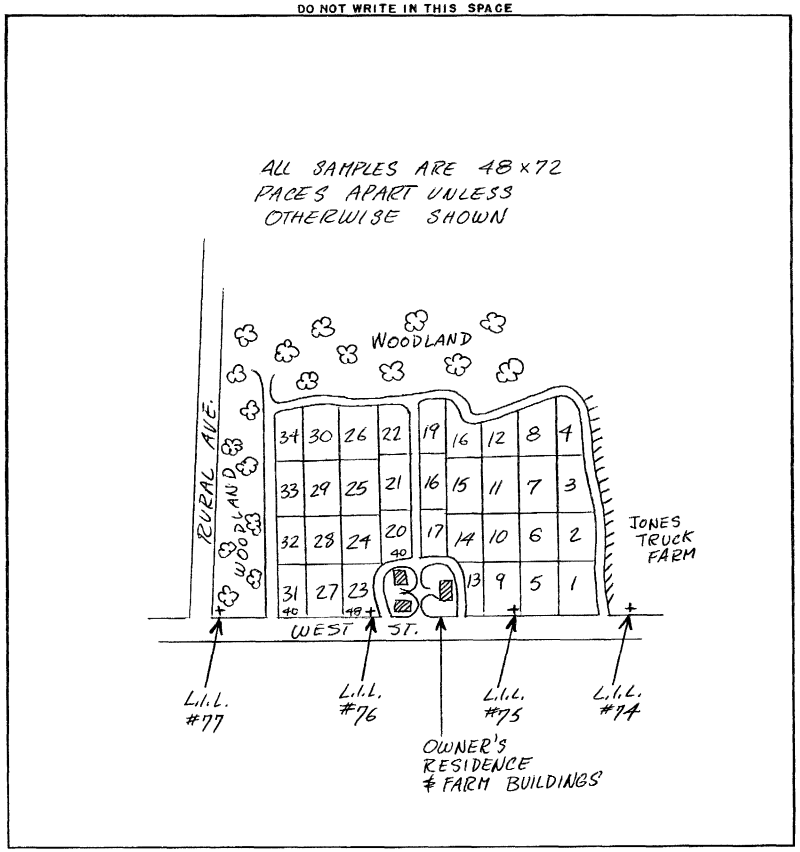
Initial ☑ Confirmatory ☐ Delimiting ☐

KIND OF SURVEY: PLANT ☐ NURSERY ☐ CROPLAND ☐ SOIL ☐ GREENHOUSE ☐ OTHER ☐

POSITIVE SAMPLE NO.	NO. OF CYSTS	IDENTIFICATION NO. OF SLIDES & VIALS FILED	POSITIVE SAMPLE NO.	NO. OF CYSTS	IDENTIFICATION NO. OF SLIDES & VIALS FILED
13	1	A 17-20 H. ROS.			
14	5	5 CYSTS - VIAL 12			

DETERMINED BY D. O. Betz DATE 12/5/67

DO NOT WRITE IN THIS SPACE



TYPE OF CROP(S) ON PROPERTY 25 ACRES OF POTATOES

ESTIMATED ACREAGE OF EACH ____

STATUS OF FIELD AT TIME OF SURVEY HARVESTED

REMARKS ____

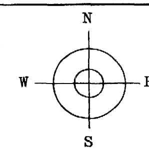


FIGURE 18.—*(Left)* Front of Plant Pest Control form PPC 3-12 used for recordkeeping in nematode survey. *(Right)* Back of form PPC 3-12, showing how form is used to identify samples collected from a farm.

N–38189

FIGURE 19.—All vehicles must remain on highways or thoroughfares.

brush when he leaves fields or storage houses (fig. 20).

Laboratory Procedures

Procedures outlined for recovering nematode cysts from soil samples are based on the fact that dry cysts will float in water. A machine has been developed by ARS, USDA, to float out these cysts and separate them from most of the extraneous material. To prevent contamination, equipment is thoroughly washed after the processing of soil samples from each field; shelves and racks bearing samples are brushed and washed before being reloaded with new samples (fig. 21); when infested material is found, sieves in use at the time are replaced until they have been thoroughly cleaned and inspected.

Testing sieves currently in use are made from medium-gage tin and brass screening by tinsmiths. The sieves are 4 inches deep. The bottom diameter is 10½ inches. For this purpose such a sieve is superior to the factory-made nesting type of testing sieves, because it has a greater capacity and is more rugged.

N–38190

FIGURE 20.—Survey crews should clean shoes and equipment thoroughly before proceeding to the next property.

N–38209

FIGURE 21.—Storage racks containing soil samples for processing.

Soil Processing

The identity of every soil sample must be maintained throughout the washing procedure. It is important that the beaker bears the same number as the sample and that the technician makes certain that he is washing the sample into the proper beaker (fig. 22).

Before a sample is introduced into the soil processing machine (fig. 23), the slow overflow valve (No. 5) is opened. This keeps the apertures through which the water enters the flotation tank from being contaminated and clogged with soil. By the time the paper bag containing the soil is opened, enough water is in the flotation tank so that the fast acting overflow valve (No. 6) may be opened and the soil introduced (fig. 24A). The fast valve serves to roil and stir the soil. This action is best obtained if the soil is poured in gradually. The fast valve is closed as soon as material starts to overflow into the top sieve.

Overflowing is allowed to continue until the water runs fairly clear or until no floating material can be seen on the surface. Material clinging to the sides of the tank is dislodged and directed through the overflow spout with the hand spray (No. 14). The spray should be directed laterally along the surface of the water so it will not submerge floating particles (fig. 24B). Material in the top sieve should be sprayed thoroughly with the hand spray to

N–38210

FIGURE 22.—Soil samples are washed and residues placed in beakers. Identity of every soil sample must be maintained throughout the laboratory processing.

wash cysts through to the screen below (fig. 24C). Tests have shown that cysts tend to become trapped in the coarse material in the top sieve.

When the flotation tank is free of floating material, it is emptied and cleaned by turning it upside down and opening the fast overflow valve (fig. 24D). The tank is then allowed to pivot back to its normal position and the spout is washed outward with the hand spray. Be sure the tank is washed clean.

Again, the material in the top screen is washed, using full force on the hand spray. The screen is then held over the sink and all surfaces washed, inside and out, with the hand spray. Using medium force from the hand spray, the material in the bottom sieve is washed and then transferred to a 600-ml. beaker until the beaker is about three-fourths full (fig. 25A). This sieve is washed and sprayed in the same manner as the top sieve (fig. 25B). After each screen is washed, its holding receptacle should be sprayed clean. The shelf holding the beaker should also be sprayed clean after each transfer of material to a beaker.

The machine is now ready for the next sample (fig. 26).

Examination of Soil Samples

The soil samples are examined to recover, for identification, nematode cysts that may be present (fig. 27). The equipment needed includes a microscope (binocular with 15 × magnification), small 80-mesh sieve (about the size of a muffin tin), examining dishes, scalpel, forceps, needle, 50-ml. bulb syringes, 600- and 250-ml. beakers, 500-ml. metric bottles, and a lamp (fig. 28).

Floating material, which has been transferred into 600-ml. beakers by the washers, is poured into the small 80-mesh sieve (fig. 29). While the material is being poured, the beaker is rotated to clear the sides of adhering material. A scalpel is used for transferring this material into the examining dishes. The correct amount of material per dish is about one-half teaspoonful. Using the bulb syringe, particles adhering to the scalpel and sieve are rinsed into one of the dishes. Sufficient water is added to float the material near the brim of each dish. A probing needle should be held in the free hand for use in spreading clumps of material and for closer inspection of cystlike objects.

A standard Syracuse dish may be used for examining screened flotsam; however, a special plastic dish developed by personnel at the golden nematode laboratory is better (fig. 30). The dish is divided into three sections. Each section of the dish is the width of the view through the examiner's binocular microscope.

Upon completion of the examination, all equipment is thoroughly washed to avoid contaminating the next sample. Suspect cysts are transferred to frosted dishes or vials and identified with collection and sample numbers. Cysts, or objects suspected of being cysts, should be given to the supervisor. All 80-mesh sieves that have contained positive material must be examined under the microscope before they are used for another sample (fig. 31).

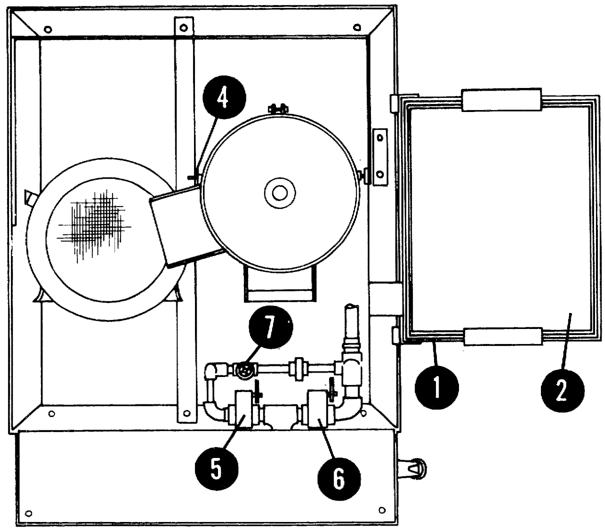
Checking Specimens for Viability

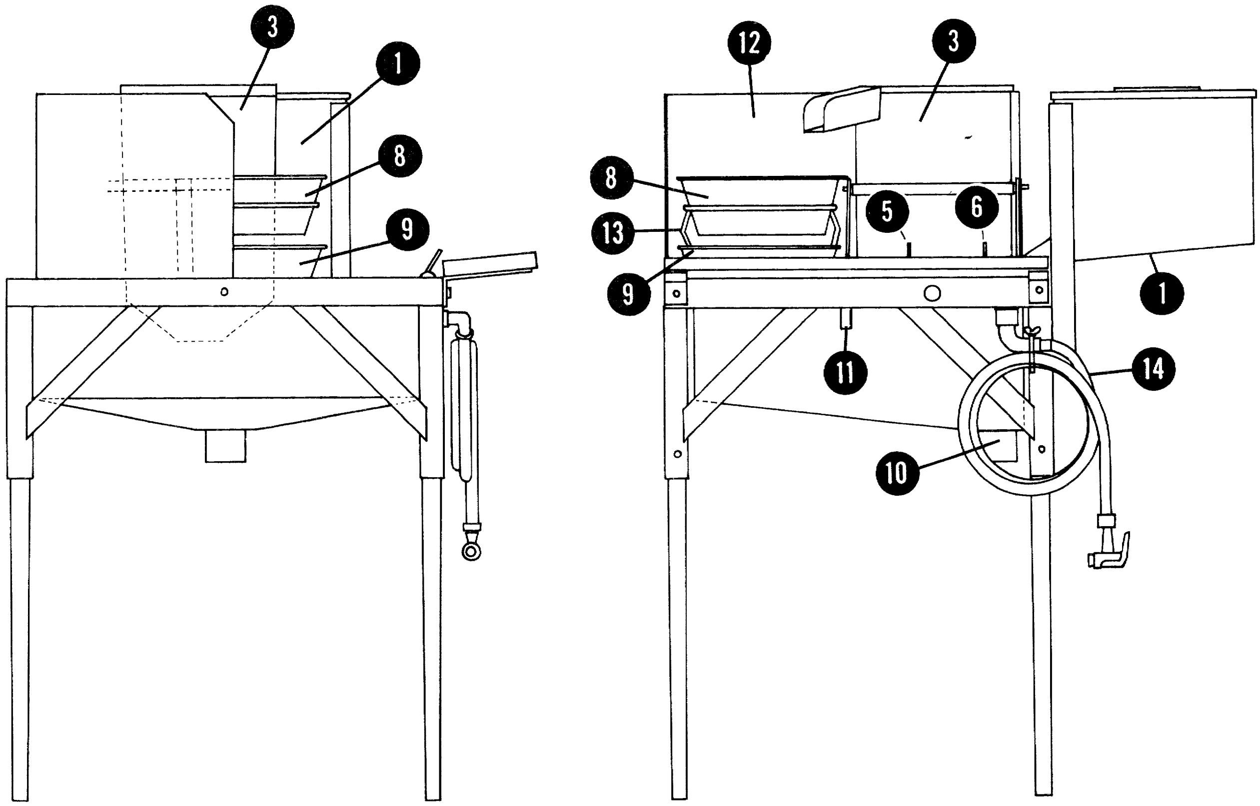
It is necessary to determine whether golden nematode cysts were viable at the time of collection, since quarantine and control action may depend upon such determination. Except for specimens originating in fields fumigated at the level recommended for eradication, the viability of the cysts is based on the appearance of the larvae within. Cysts recovered from areas that were fumigated at the approved

SOIL WASHER ASSEMBLY

1. SINK
2. REMOVABLE WASHER
3. FLOTATION TANK
4. SPOUT
5. SLOW OVERFLOW, VALVE 1
6. FAST OVERFLOW, VALVE 2
7. ADJUSTING VALVE
8. 20-MESH SIEVE
9. 60-MESH SIEVE
10. DRAINAGE BASIN AND SPOUT
11. HOSE FITTING
12. SPLASH SHIELD
13. SIEVE RECEPTACLE
14. HAND SPRAY

TOP VIEW

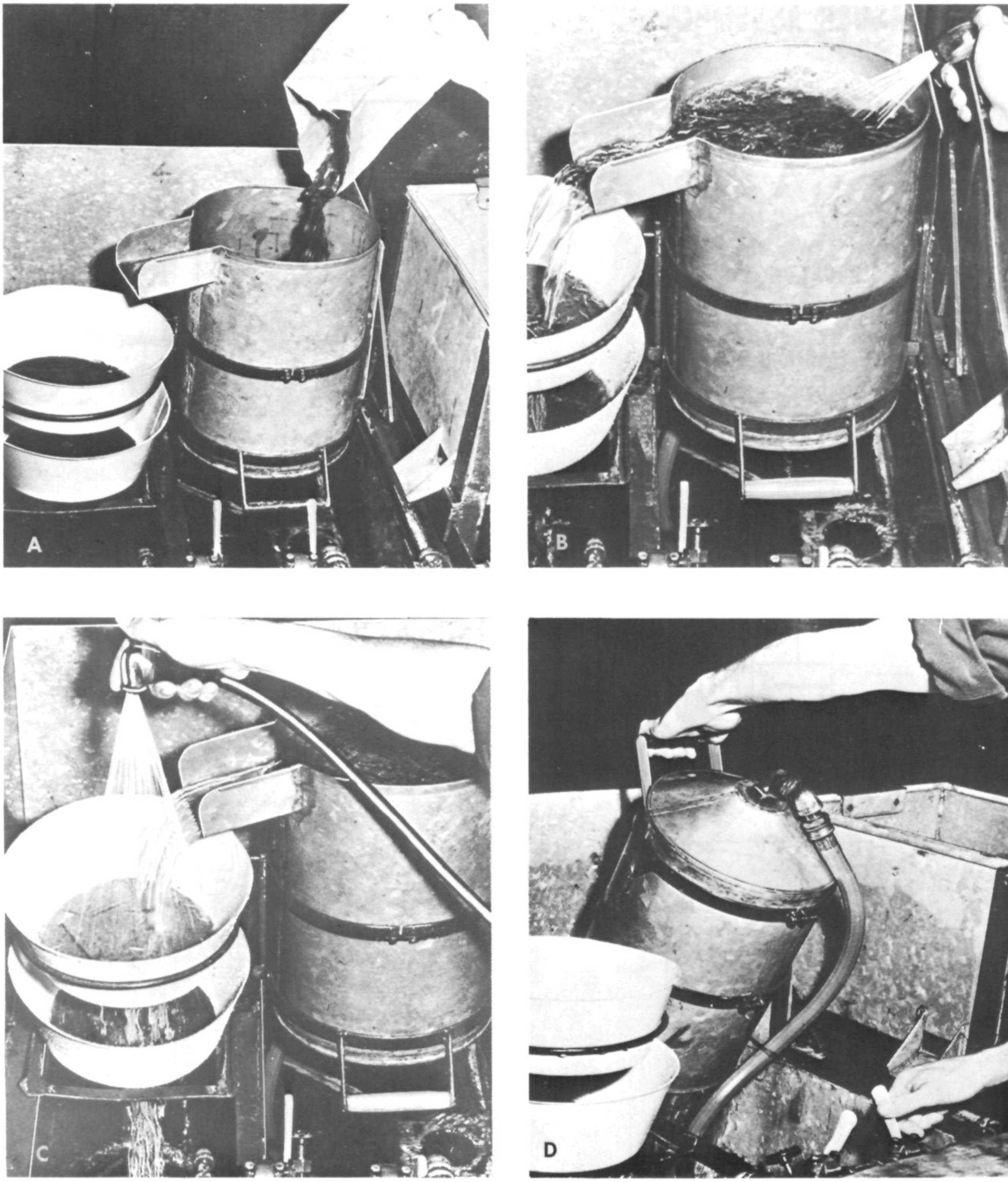




LEFT SIDE VIEW

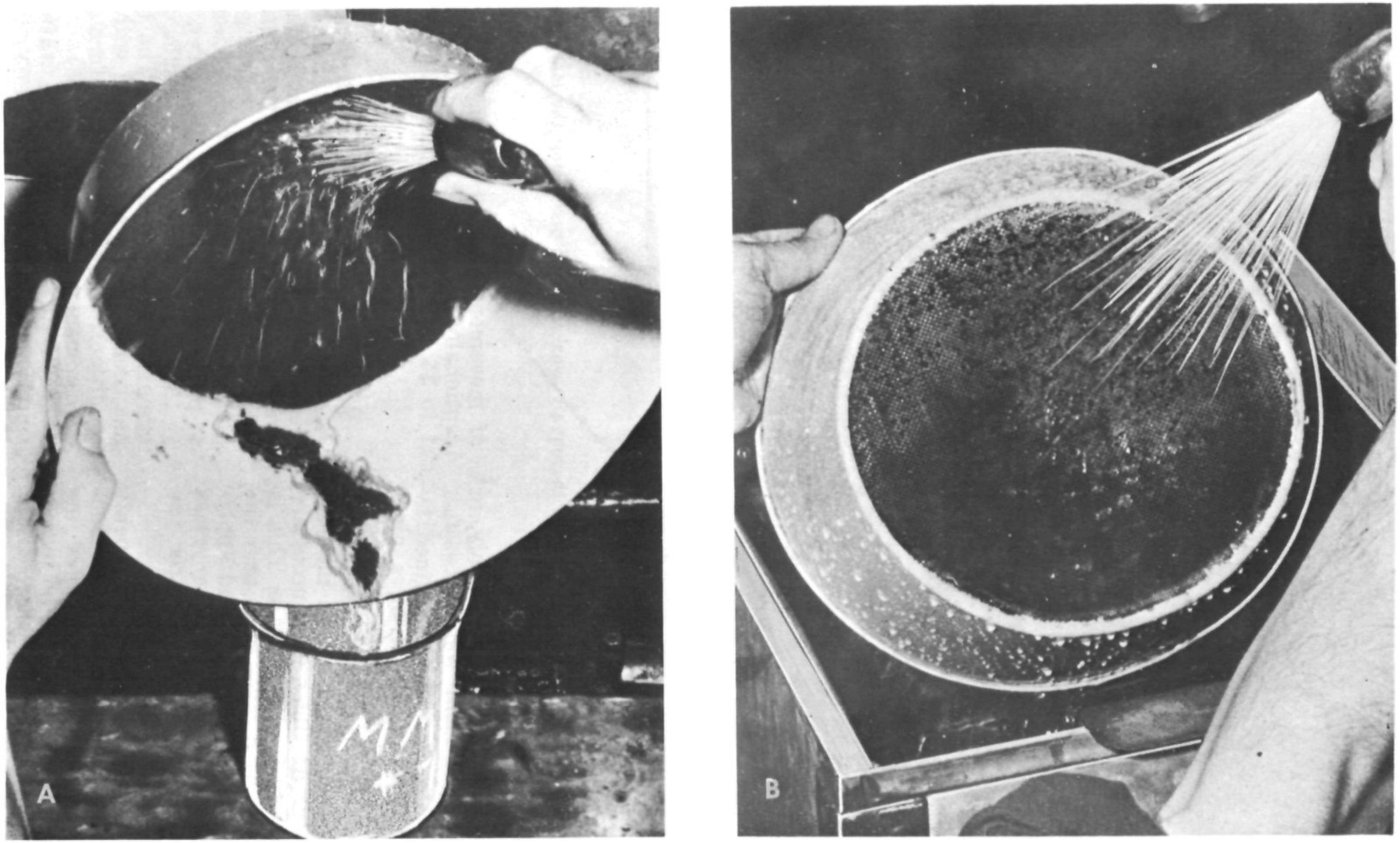
FRONT VIEW

FIGURE 23.—Soil washing machine.



(A) BN–28191, (B) BN–28190, (C) BN–28189, (D) BN–28192

FIGURE 24.—(A) Soil sample being placed into soil processing machine. (B) Surface debris is directed to overflow spout by hand spray. (C) Top sieves are sprayed directly with hand spray to wash cysts through to the screen below. (D) Flotation tank is cleaned by turning it upside down and opening the fast overflow valve.



(A) BN–28194, (B) BN–28193

FIGURE 25.—(A) The washed residue is transferred to a beaker. (B) Each sieve is carefully washed after transfer of flotsam.

N-38212

FIGURE 26.—The machine and all equipment is thoroughly washed after processing the last sample.

level must be examined more thoroughly to determine whether treatment was successful.

The viability of the cysts is determined by placing them in a drop of water on a glass slide. With the aid of a 90-power dissecting stereo microscope and a surgical lance or an iris knife, the cysts are cut open and the eggs and larvae removed. At times it is necessary to rupture the eggs to free the larvae. This is accomplished by placing a cover glass over the drop of water containing the eggs and applying just enough pressure on the cover glass with the eraser end of a pencil to free the larvae.

In those fields where eradication treatments have not been applied, the specimens are considered viable if the internal structure of one or more larvae is intact and there is no indication of any breakdown. In fields where eradication treatments have been applied but the larval specimen(s) is intact and there is no indication of breakdown, further checks must be made to determine that the larva is capable of movement. As the golden nematode is exceptionally sluggish, it may at times take from 1 to 24 hours before any movement is noted.

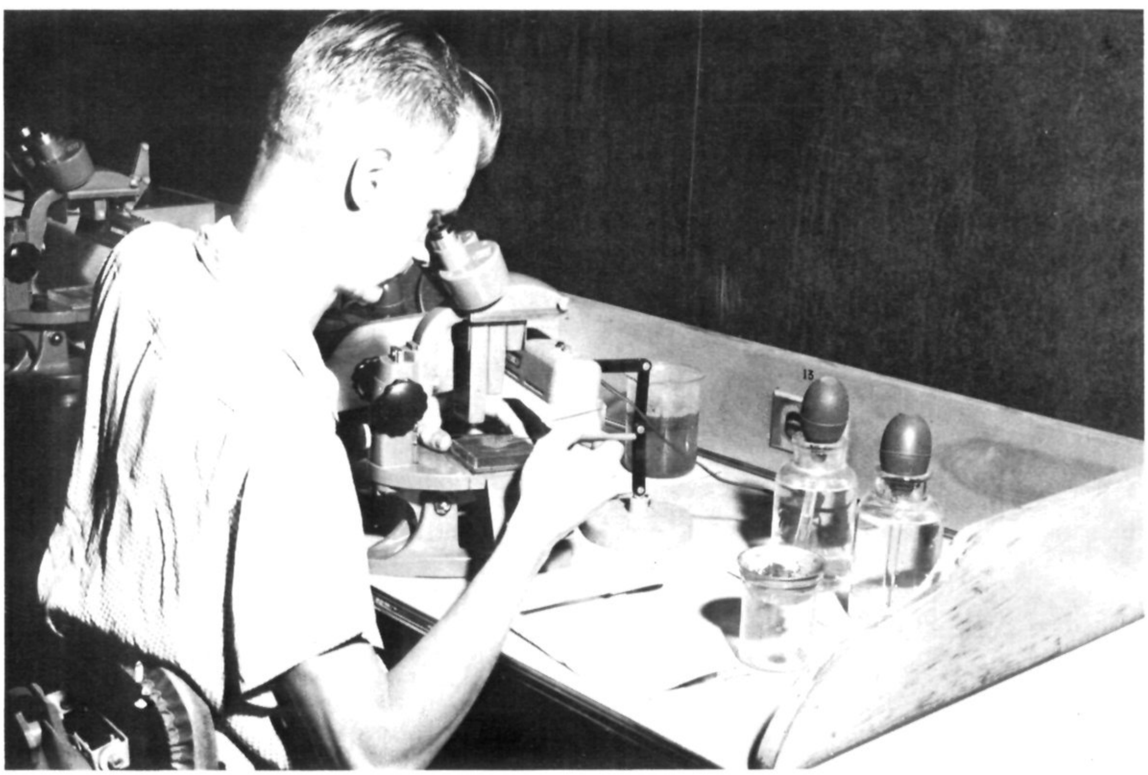
Regulatory

Soon after the golden nematode was discovered in the United States, the New York State Department of Agriculture and Markets, under the broad coverage of the State's "Agriculture and Markets Law" relating to insect pests and plant diseases, took action designed to prevent the spread of the golden nematode. In 1944, the State enacted a specific quarantine against the golden nematode. The quarantine has been modified and amended with changing conditions, receipt of new information, and development of treatments (*28*).

The State's quarantine was drafted in consultation with USDA's regulatory officials. The Plant Pest Control Division has been a full partner with the State and has cooperated in the administration and the enforcement of the quarantine.

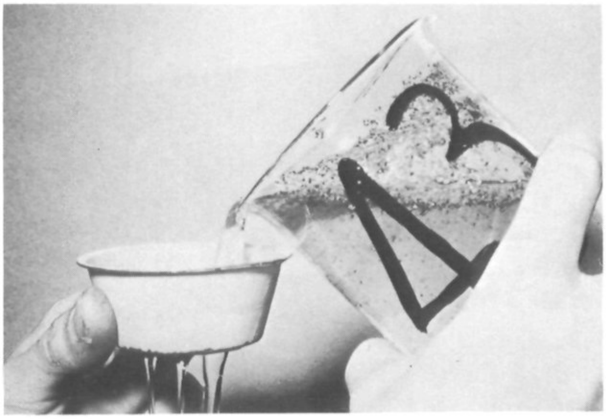
N-38214

FIGURE 27.—Technicians examining flotsam for nematode cysts.



N-38215

FIGURE 28.—Laboratory technician with equipment needed for detecting nematode cysts.



BN-30007

FIGURE 29.—Floating material is transferred from beaker to 80-mesh sieve.

FIGURE 30.—Flotsam is transferred to each section of the dish, and water is added for microscopic examination.

The Golden Nematode Act

In 1948, the Federal Government, through the Congress of the United States, announced the Government's policy for the protection of the potato and the tomato industries from the golden nematode should further action become necessary. The Government's policy was set forth in the Golden Nematode Act, Title 7, U.S. Code, Sec. 150-150g. The act stated, "It is the policy of the Government of the United States independently or in cooperation with State or local governmental agencies and other public and private organizations, associations and individuals to eradicate, suppress, control, and to prevent the spread of the pest." The Secretary of Agriculture is empowered, either independently or in cooperation with States and other agencies, to make inspections, apply suppressive measures, enforce quarantine, enforce restrictions on planting tomatoes and potatoes, destroy tomatoes and potatoes growing in soil found infested with or exposed to infestation of the golden nematode, and compensate growers in areas infested with or exposed to infestation of the golden nematode for not planting tomatoes and potatoes or for losses resulting from destruction of crops. The mandatory restrictions on planting or destruction of crops must be supported by similar State authorizing legislation.

Quarantine

The following are the basic provisions of the New York State Golden Nematode Quarantine:

1. All lands within the boundary of Nassau and Suffolk Counties on Long Island, the towns of Prattsburg and Wheeler in Steuben County, and the town of Italy in Yates County are placed under quarantine.
2. All potatoes grown within the designated area on "clean" land shall be packaged in an approved paper bag or other approved container for movement within the continental United States and Canada (fig. 32).
3. Potatoes grown on lands which become part of a regulated area after planting shall be packaged in paper bags or other approved containers, restricted in movement to approved outlets and moved only under permit, or washed in approved manner under supervision, packaged in paper bags or other approved containers and shall move only under permit, or shall be subjected to such procedures and safeguards which may be prescribed and shall move only under permit.
4. No potatoes shall be grown on any land known to be infested with the golden nematode or dangerously exposed to infestation except where such lands have received a prescribed treatment and have been declared safe, following soil sampling, for growing potatoes.

BN–28899

FIGURE 31.—A microscopic view of golden nematode cysts in flotsam.

5. The golden nematode in any state of development may not be moved or transported except as authorized.
6. There shall be no movement of hay, straw, or plant litter from regulated area except in accordance with an agreement and under permit.
7. Vegetable root crops, transplants, nursery stock, bulbs, corms, and tubers are all subject to appropriate sanitation regulations or treatment when grown on land infested or dangerously exposed to infestation.
8. Potato grading stations shall be operated under permit, which provides for the safe disposal of grader dirt and other waste.

9. Top soil and sod shall be moved under permit only to designated locations in accordance with an agreement and under permit.
10. Used farm equipment, construction, equipment, used containers or any other articles that may be contaminated shall not be moved from the area until they have been disinfested in accordance with prescribed procedures and a permit issued.

Approved Regulatory Treatments

Portable steam generators mounted on pickup trucks are used for cleaning farm machinery. Methyl bromide may be used to fumigate equipment, burlap bags, tools, crates, or other contaminated materials. The following treatment schedules have been worked out for freeing materials and commodities from the golden nematode.

ST 617-4

FIGURE 32.—All potatoes on Long Island are shipped in nonreusable paper bags.

Type of enclosure or material to be treated	*Temperature (° F.) of enclosure or material*	*Exposure period (Hr.)*	*Treatment*
Chamber or tarpaulins	60° or above	16	23 lb. methyl bromide per 1,000 cubic feet.
Chamber or tarpaulins	60° or above	2	46 lb. methyl bromide per 1,000 cubic feet.
Vacuum chamber (27 inches sustained vacuum).	60° or above	16	8 lb. methyl bromide per 1,000 cubic feet.
Gastight chamber (less than 10 cubic feet).	60° or above	3	1 lb. methyl bromide per 1,000 cubic feet.
Gastight chamber (100 cubic feet or more).	60° or above	3	4.6 lb. methyl bromide per 100 cubic feet.
Gastight chamber (100 cubic feet or more).	60° or above	16	2.3 lb. methyl bromide per 100 cubic feet.
Dry oven (preheat)	221°	1	Dry heat.
Dry oven (preheat)	237°	¾	Dry heat.
Greenhouse benches or large containers of soil.	180°	1	Live steam injected throughout soil mass.

The following dips have been developed for treatment of bulbs and corms.

Commodity	*Treatment*
Gladiolus corms, hyacinth, iris, or tulip bulbs, and narcissus bulbs.	1-hour dip in 1-pct. aqueous solution of Aaventa 46N or 0.5 pct. for 3 hr. or 0.25 pct. for 6 hr.[1]
Lily-of-the-valley pips	Separate bundles one from another just before treatment begins. Without preliminary warmup, submerse in hot water at 118° F. for 30 min.; follow with 5-min. drain, and finish with 5-min. cooling dip or hosing in tapwater.
Potato tubers	Wash free of soil, then submerge for at least 5 min. in water maintained at a temperature of not less than 132° F.

[1] Request for registration has not been presented in U.S.A.

Compensation

To aid growers whose income was drastically cut because infestations were found on their farms, the State of New York enacted legislation in 1946 to compensate them for withholding their lands from potato and tomato production.

Funds for this purpose were provided solely by the State of New York until 1948 when the Golden Nematode Act was passed by the 80th Congress. This act authorized Federal participation in an owner-operator compensation program. In 1948, Federal and State funds were made available for payments to owner-operators at the rate of $150 per acre, each cooperator paying $75 per acre. Under an agreement, the State assumed full payment to renters on the basis of a fair rental value as determined by the Commissioner of the New York State Department of Agriculture and Markets.

In 1950, payments to owner-operators were reduced to $120 per acre, each cooperator paying $60. In 1951, payments were reduced to $80 per acre, each cooperator paying $40. In 1952 and 1953, the payments were $60 per acre, Federal and State Governments each paying $30. In 1953, the State of New York and the U.S. Department of Agriculture agreed that the Federal Government would withdraw from the compensation program but would increase its participation in surveys and certain regulatory activities. Beginning in 1954, the State of New York assumed the total cost of the compensation program, paying owner-operators of infested land $60 per acre.

The compensation program provided a very useful means whereby farmers were able to adjust farm operations. Growers were encouraged to plant their infested potato land to pasture, small grain, or field corn. The growing of these crops entitled the grower to receive compensation; however, if he elected to grow high-value crops, such as vegetables, compensation payments were not made.

With the advent of the field soil fumigation program in 1955 and the returning of potato land to production, the need to compensate growers no longer existed and the amount of compensation paid to growers decreased to a very low level.