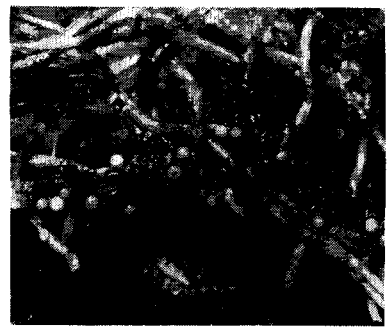


golden nematode cysts

The SOIL PEST COMPLEX

A STAFF REPORT

NEMATODES, BACTERIA, FUNGI equal the soil pest complex. This simple (but debatable) equation is now getting enthusiastic attention from agricultural chemical manufacturers, extension specialists, agricultural researchers all over the U. S. What exactly constitutes the complex depends on whom you're talking to and where he comes from. Soil insects are often included. Latest thinking treats the complex as a unit, both for characterization and treatment.

Members of the soil pest complex work closely together; so little is known about them that their cost to agriculture can only be guessed. Aim of many researchers today is a chemical that will control all soil pests. Soil fumigants are the best weapon found so far, are effective mostly against the nematode fraction, are still expensive, difficult to use, not 100% effective.

Many plant ills are known to be more serious when several soil pests can act in concert. Black shank of tobacco, a fungal disease, is many times more devastating in the presence of nematodes than in their absence. Pathogenic soil fungi, important facet of the complex, are much more effective on plants weakened by nematode attack. Brown root rot of tobacco and *Fusarium* wilt of cotton are fungal in origin, but compounded by presence of certain plant-parasitic nematodes. A severe nematode attack may weaken the plant to the point where it succumbs to a weakly pathogenic organism which would ordinarily be ineffective. An important factor in the soil fungi control problem is the difficulty of finding broad spectrum control agents. Most compounds or formulations now in use are specific against certain fungus diseases but no more than partially effective against others.

One of the effective agents now on the market is Olin Mathieson's pentachloronitrobenzene (PCNB), which now is commercially available on a limited scale and is in the process of getting USDA registrations—some of which have cleared while some are in process. It is effective against the fungus disease part of the complex and is specific against southern blight and potato scab as well as crown rot of clover and club root of crucifers. With the damping-off complex where the fungi are *Rhizoctonia* or *Sclerotinia* control is good. *Pythium* diseases are not well controlled by PCNB. This is one of the disadvantages of the compound, which is nontoxic, formulates well and appears to give no off-flavors.

Such situations suggest that the real answer may be found in a mixture of specific compounds to give broad spectrum coverage.

Nematodes Are Major Factor in Complex

Nematodes—only one facet of many—are receiving the lion's share of the attention being given to the soil pest complex. Those best acquainted with nematodes and the damage they cause think they should get more consideration, research, and control. Evidently, there are good reasons.

In the agricultural West, for example, California, which has the largest agricultural income of any state in the U. S., is a good starting point for evaluation. Said Dewey J. Raski, chairman of the department of nematology, University of California, to vegetable growers and seed company officials at a crops field day last year: "Root-knot nematodes are so widespread in California and attack such a wide range of plants that they probably cause more damage to agricultural crops than any other single disease or pest."

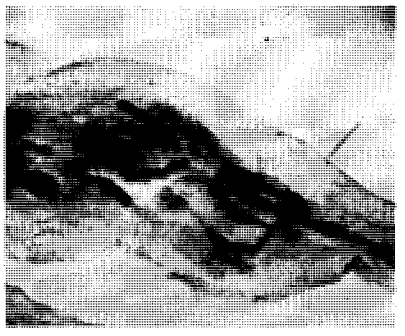
Damage from nematodes is not new; nor is it restricted to any one area, state, or country. In fact, it has been said that information accumulated during the past century indicates that all of the world's crops and ornamental plants can be attacked by plant parasitic nematodes, exceptions, if any, being few. While damage may be mild, it can, and often does, result in serious or complete loss of crop. Nematologists are careful in estimating the dollar damage to U. S. crops each year, but there seems to be general agreement that it is at least several hundred million dollars.

Plant parasitic nematodes have been known since about 1750; the wheat nematode was the first identified. Germany and Sweden were among the first to establish control laws. In Ireland, the golden nematode caused such serious losses that laws were passed permitting potatoes on any given plot of land only twice in eight years with non-host crops in the interim period. Similarly, Holland requires two non-host crops between potato plantings. Most European countries now have laws of this kind.

On Long Island, N. Y., where Irish potatoes have been a staple crop for years, the golden nematode was discovered in 1941. The U. S. Department of Agriculture annually spends about half a million dollars in attempting to prevent spread of this infestation to other areas; maintains a special laboratory studying golden nematode control. Long Island potato growers recently established a quarantine requiring all pota-

Examples of the subterranean menace

dagger nematode



knot nematode

Nematodes and their cohorts—soil fungi and bacteria—combine to provide a serious threat, possibly a limiting factor, for agricultural production

toes shipped out of Long Island to be packed in paper bags. This will prevent the export of golden nematodes in soil adhering to burlap bags.

The disease caused by root-knot nematode was observed in Florida as early as 1805, but the nematode wasn't discovered until 1879. Ten years later USDA indicated it was unknown in western states, but reports in 1907 showed its arrival. The sugar beet nematode was found there at about the same time.

Nematode Types and Scope of the Problem

The very nature of the nematode complicates an understanding of the pest, the degree of the damage it causes, and effective control of its infestations. The plant parasitic nematodes, known also as eelworms, are representatives of a large group of species that zoologists type quite differently from other worms. The length of the full grown and infesting adult may be less than one sixty-fourth of an inch in length and seldom exceeds one eight of an inch—a little too small to be seen easily with the naked eye even when isolated from the soil. It is therefore, in a class by itself, without close relatives, and is not even a close cousin to earthworms, flatworms, wireworms, or cutworms.

The nature and seriousness of the damage caused by nematodes varies with the type and the extent to which infestation is allowed to develop. Most common plant nematode types include: root-knot, sugar beet, golden, meadow or root-lesion, citrus, bulb or stem, spiral, dagger foliar, and external root feeders.

Root-knot nematode causes yield reductions up to total loss, as well as lower quality in marketed root crops. It penetrates the plant root causing knots or galls up to two inches in diameter and strangling the plant. Symptoms include stunting or dwarfing of plant tops, wilting, leaf discoloration and spots, swollen and distorted shoots. These as well as root knots are not specific, some may even be caused by low soil fertility, mineral imbalance, poor water conditions, or other pests, including other nematodes. Thus diagnosis is difficult, even for a nematologist.

Reproduction may take place within the root galls or knots. The female, unable to migrate from the point of feeding, stimulates the plant to form the knot in which she is embedded. Each female lays several hundred eggs. As soon as hatched, the young nematodes begin feeding on the roots. Completely within the knot, this nematode is less susceptible to control by use of chemicals than some other types, unless treatment is delayed until knots decompose.

Sugar beet nematodes are serious in nearly all U. S., Canadian, and European beet areas. Nematodes penetrate the plant, feeding until they can push through the outer root surface, but keep the head and neck embedded. Small plants are often killed; others have abnormal number of roots with small main root. Symptoms are yellow foliage and wilting. The sugar beet nematode female, with her head embedded in the beet root, may lay up to 100 eggs in a jelly-like substance attached to the end of the body. These eggs may hatch immediately but most are retained on the body of the mother, which develops into a thick, protective cyst. When the beet is removed from the ground or the root dies, the cysts containing eggs remain in the soil. If host plants are not replanted, only part of the eggs in the cyst will hatch, the balance awaiting a more favorable feeding season.

Meadow or root-lesion nematode, distributed throughout the world and occurring in practically all states of the U. S., causes localized lesions or wounds on the roots of its host plants. In infested areas, plants show yellow and sparse foliage, stunting, and reduced productivity as a result of reduced root systems. Feeder roots exhibit major damage, but the necrotic lesions are often very inconspicuous.

Citrus nematodes partially burrow into the tree root, killing plant cells, and destroying to various extent the outer root covering. Dieback of small twigs and branches, sparse foliage, and lowered production in citrus groves suggest the presence of this nematode. It is present in all citrus growing areas of the U. S.

Nematode Control

Two cogent facts stand out when one considers the nematode problem. First: nematodes, which may number as many as a million in a cubic foot of soil, are for practical purposes immobile—most move within a radius of only a few feet during their entire lifetime. This means that while the population may increase tremendously in a restricted area, it is slow in spreading unless aided by man.

Any operation that moves dirt or plant parts from an infested field will carry nematodes. Thus the farmer, while plowing, weeding, or disking, can unknowingly spread an infestation which, on its own, might remain in a restricted area. Nematodes can also be carried with planting stock or seed from infected to clean ground. Potatoes, bulbs, and nursery stock are common carriers and must be carefully inspected if spread is to be prevented.

Second factor of great interest and importance is the fact that once established, a nematode infestation cannot be eradicated. While steam sterilization of greenhouse soils probably can accomplish complete eradication, there is no economical way for complete eradication in field soils. Control methods prevent spread and reduce seriousness of an infestation and can maintain effectiveness to a point where there is little economic loss, but, as of now, the infestation cannot be eliminated.

Control of nematode is by one of several means:

(1) Cultural practices (crop rotation, fallowing)

(2) Therapeutic treatment (hot water treatment of infected planting stock)

(3) Selection and breeding of resistant varieties

Carrots grown in the black muck soil in Michigan. Left, in a fumigated portion of the field; right, from an unfumigated portion of the field. Nematode injury made the visible difference

(4) Inspection of planting stock to ensure nematode-free material

(5) Chemical treatment (soil fumigation)

(6) Enemies and disease-causing agents (predatory nematodes and fungi).

A committee reporting to the state legislature on the status of the plant parasitic nematode situation in California in 1951 said that crop rotation is probably the most effective and economical method of controlling many of the most common species of plant parasitic nematodes.

There is evidence that some western farmers are finding rotation insufficiently effective and too time consuming against many soil diseases. However, a combination of rotations with soil treatments appears to be doing well.

Resistant varieties and rootstock are satisfactory methods of nematode control in some cases. Resistant plants may be either completely immune to specific plant parasitic nematodes or may tolerate their presence without noticeable effects or economic loss.

Considerable investigation and research has been directed to selection and breeding of resistant plants and much is still under way. There are many examples of success. Nemestan alfalfa is satisfactorily resistant to bulb and stem nematodes; Westan, a baby lima, is resistant to root-knot nematodes; Paradox, a cross between English and black walnuts, is used against meadow or root-lesion nematodes. In some cases, however, resistant species "lose their resistance" after a period of time and do not always produce a crop with highly desirable marketing qualities.

Fumigation Still in Infancy

Control of organisms in the soil through use of chemicals is new—considerable success has been realized, however, and much research is currently going to development of new, more effective, and less costly fumigants.

Considering that fumigation was first accepted as a practical method of pest control in 1945 and has grown into an $8 million dollar annual business, it can be assumed that though admittedly expensive, growers have found the procedure profitable. Acreage fumigated is increasing annually and many farmers testify to the fact that fumigation often means the difference between no crop at all and a very profitable crop. Yield increases of 25 to 50% after fumigation are common.

There is no doubt that fumigation will see increased growth if a lower cost product is developed. A farmer is usually discouraged by the thought of paying, for example, $35 an acre for dichloropropene-dichloropropane application. But when he can see an increase from 1200 pounds of tobacco per acre up to 1700 pounds per acre with tobacco selling for 50 cents a pound, the $150 return he gets for a $35 investment appears very attractive.

Above $35 per acre, the gamble doesn't seem so attractive because of weather and other risks. The breaking point on a good gamble is about four to one on such a material. If the farmer can't get back four times his investment, it is hard to sell.

Four types of soil fumigants are commonly in use today. These include—or have as their active ingredient—methyl bromide, chloropicrin, dichloropropene-dichloropropane mixture or D-D, and ethylene dibromide or EDB.

AG AND FOOD's editors, in surveying the field, have arrived at some unofficial estimates of the size of the fumigant business. Some industry sources contend that the market estimates are high. As the U. S. produces virtually the only supply of these materials, exports add a considerable amount to the figures shown.

Methyl bromide (B.P. 40° F.) sees widespread use in seed beds for control of root-knot nematodes and other bed pests. Application involves evaporation of undiluted methyl bromide under gas-tight covers from shallow trays on the surface of soil. Generally, one to four pounds of methyl bromide is applied to 100 square feet, the cover remaining in place for 48 hours.

An estimated 1.8–2 million pounds of methyl bromide was used last year, chiefly for tobacco, celery, and other

Plant Parasitic Nematodes

Type	*Number of Species Known*	*Size of Adult*	*Common Host Plants*	*Geographical Areas of Infestation*
Root-knot	5	0.013 inch	Cotton, tomato, fig, peach, bean melon, grape, almond, sugar beet, celery, carrot, cucumber, strawberry, sweet and Irish potato, okra, gardenia, snapdragon, rose, peony, begonia, dahlia, carnation	Temperate and tropical parts of world; serious pests in Wyoming, Utah, California, Idaho, New Mexico, Oregon, Nevada, Arizona; also serious in southeastern states.
Sugar beet	1	0.013 inch	Sugar beet, table beet, cabbage, cauliflower, rutabaga, broccoli, radish, Brussels sprouts, turnip, rape, mustard, pigweed	Western Europe, western United States
Meadow or root-lesion	10	0.02 to 0.04 inch	Corn, peanut, grain, cherry, fig, apple, walnut, olive, strawberry, grape, tobacco, tuberous begonia, Croft lily, narcissus	All sections of U. S.; serious in California, Pacific Northwest; Europe, Asia
Citrus	1	0.02 inch	Orange, lemon, other citrus, olive	All citrus growing areas
Bulb or stem	1	0.04 inch	Onions, alfalfa, garlic, clover, strawberry, narcissus, ornamentals	California, Washington, Nevada Oregon, Idaho, Utah
Foliar	5	0.025 to 0.03 inch	Rice, tobacco, corn, cotton, strawberry, gioxinia, ferns, lily, African violet, peperomia, vanda orchid	World-wide
External root feeders	Many		Probably most plants	World-wide
Golden	1		Irish potato, tomato	North Ireland, Holland, Long Island, N. Y.; Europe

seed beds. Costing 75 cents a pound, MBr accounted for about $1.3–1.5 million of the fumigation business. Effectiveness of MBr is good, most insects as well as weed seeds are killed, and soil nematodes are satisfactorily brought under control. Obvious disadvantage is cost and inconvenience of application.

Chloropicrin, longest used of the soil fumigants, is also expensive and disagreeable to apply. Approximately one-half teaspoon is generally applied to injection points 10 to 12 inches apart, and the ground is sprinkled with water to give a water seal. Used chiefly in greenhouses, the dollar volume was about $0.5 million last year.

Neither of these fumigants or application techniques is used for field fumigation. However, D-D and EDB, common field fumigants, are used for seed bed fumigation as well, and account for a major part of the fumigation business. Shell Chemical makes D-D at an estimated rate of 15–18 million pounds a year, which, selling at about 16.5 cents a pound, racks up about $2.5–3 million annually on the fumigation ledger. Generally, the rate of application is about 200 pounds per acre which means that approximately 90,000 acres are fumigated with D-D annually.

EDB is used on about twice as many acres, with rate of application being about 54 pounds per acre. Last year an estimated 8–10 million pounds at 50 cents a pound was applied—a $4 to $5 million business.

Field fumigation with D-D and EDB is by one of two means—solid or broadcast application, or row application. Generally, in broadcast application, D-D (8 to 10 gallons per acre) is injected at 12 inch spacing with a tractor-drawn, chisel-type applicator, with the chisels set at depth of eight inches. EDB (83%) is generally injected at rate of 4.5 to 6 gallons an acre.

Row, hill, or bed application, advantage of which is lower cost, is seeing increased use. Method involves applying EDB or D-D in a single stream along each row at rate of approximately 8 gallons per acre. A somewhat better method is to apply two streams straddling the row. These methods have proved successful for root-knot nematodes on tomatoes, cotton, tobacco, and other crops. However, on other types, such as the stubby root nematode on sweet corn, the row application method failed as result of survival and spread of the nematode population in the untreated area. An important factor in failure to control this nematode is the very rapid reproduction of the species.

Fumigation Agent for Perennials Not Developed

All of the currently used fumigating materials are highly phytotoxic. If properly applied, all plants in treated areas are killed and application must, of course, be before planting. Since proper soil condition is an important factor in successful soil fumigation, this often means costly delays in planting schedules. It also means that perennial crops cannot be fumigated until an infestation becomes so bad and crops are so poor that the grower pulls out his trees in the infested area, fumigates, replants, and waits for the new trees to become producers.

Cost for fumigating an orchard from which trees have been pulled is $50 to $200 an acre, not including cost of replanting. While pull-out is common in citrus, peach, and walnut areas, fumigation is still sufficiently new that economics have not been proved. However, most growers think it will pay off, and, within a few years, it should be established whether or not a pull-out, replant program is economically sound. In the meantime, nematologists are hopeful that a fumigant can be developed which will kill the nematode but not be toxic to plants. Many think we are on threshhold of solution for perennials. Experimental compounds, including Stauffer's N-869, have given control for living plants without undue injury. Another product of interest in the orchard is Shell's 1,2-dibromo-3-chloropropane, a new nematocide previously known as Shell experimental nematocide OS 1897. Satisfactory field tests conducted in various parts of U. S. on several crops during 1953 and 1954 season showed the most promising and unique property of the material to be its low phytotoxicity on plants with established root systems.

One of the newest nematocides is a phosphorous compound recently announced by Virginia-Carolina Chemical Corp. and registered in the states of Virginia and Florida for use on turf and ornamentals. Studies are now under way in Florida and eastern U. S. on citrus and truck crops but the company is doing nothing about commercial sale for such uses until it has clearance from the Food and Drug Administration. The new compound is *O*-2,4-dichlorophenyl-*O*,*O*-diethyl phosphorothioate. The 75% emulsifiable concentrate has been given the trade name V-C 13 Nemacide. In practice use on greens and turf, excellent nematode control has been achieved with 125 to 250 pounds per acre of the 75% product. No root damage was found at much higher rates.

Nematodes that live inside their plant host are at least partially protected from both their natural enemies and from chemical control measures. Systemic poisons, some of which are closely akin to antibiotics, have shown promise against embedded living nematodes. A systemic nematocide, harmless to the plant, could be the ultimate solution to the problem.

Another direction today's research is taking is in development of absorbents for hard-to-handle nematocides. Both natural and synthetic silica compounds are being studied, promise to combine easier handling with better dose control.

Nematodes can have a dire effect on cotton, as shown by the comparison between an untreated area and one treated with ethylene dibromide. Cotton is one of the crops which offers a great potential market for a low-cost nematocide

Many of the compounds now being evaluated are effective against other factors in the soil pest complex; some, in fact, are more effective against ubiquitous soil fungi than they are against nematodes. Others, such as Stauffer's new Vapam, sodium *N*-methyldithiocarbamate dihydrate, are active against a range of soil denizens, including nematodes, fungi, bacteria, insects, and weed seeds. Stable in concentrated solution, this compound decomposes rapidly upon dilution in the soil, releasing a penetrating gas which fumigates and dissipates within a few days. It can be applied through irrigation systems as well as to the plow sole while plowing or directly to the soil surface for working in with a rototiller.

Carbide & Carbon's experimental 3,5-dimethyl-1,3,5 2-*H*-thiadiazine-2-thione, a solid, is said to be an excellent fungicide and nematocide. Many other chemical companies are actively working in the field, leading Rhode Island University nematologist A. C. Tarjan to say "effective chemicals should be appearing on the market within the next two years." Tarjan warns against using nematode-toxicity as the only yardstick for nematocide evaluation, says that chemicals which might prevent female nematodes from reproducing or block enzyme processes essential for nematode feeding would be just as useful for control.

Chemical control has already enabled growers to harvest greater yields than ever before. Lower costs and improved application methods will make soil pest control available to new markets, such as the nation's 20 million cotton acres.