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# Nematode Advisory Programs—Status and Prospects

Although soil fertility advisory services have been in use for many years, nematode advisory programs are a recent development in agriculture. A number of the sampling and assay techniques in use today were developed by N. A. Cobb, who also characterized the spotty or contagious distribution of plant-parasitic nematodes. Gerald Thorne was one of the first to use a sampling procedure as a basis for assessing potential nematode damage during the 1920s. He sampled for the sugar beet cyst nematode, *Heterodera schachtii*, in Utah and advised growers whether to plant sugar beets or to use alternate crops as he mapped infestations of this nematode. This pioneering advisory work was done before the relationships of crop yield to nematode numbers and host-parasite relationships were characterized.

The first structured nematode advisory programs were developed during the 1950s and 1960s in Europe, the most prominent one being in the Netherlands (3,13). Most of the early nematode advisory activities in the United States involved diagnostic work and regulatory problems. Their potential was investigated in the mid-1950s in North Carolina by W. M. Powell and C. J. Nusbaum. Although many problems were encountered, they showed that sampling and extraction of nematodes for predictive purposes had promise. Currently, about one-half of the states in the United States have some type of nematode advisory program, but some are diagnostic rather than predictive. These programs are usually a function of either the Agricultural Extension Service or research nematologists. The program in North Carolina is managed by the state department of agriculture. Private consultants offer these services on a limited basis. One of the most unique advisory programs around the world is in Australia (16; R. H. Brown, *personal communication*). Two private Australian companies offer an advisory for the cereal cyst nematode, *H. avenae*, in which recommendations are based on numbers of cysts developing on bioassay plants.

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## Characterizing Populations of Nematodes

**Spatial and temporal distribution patterns.** The patterns of nematode occurrence over space and time must be considered carefully in characterizing their populations for advisory purposes. Various sampling studies (2,3,10) indicate that plant-parasitic nematodes typically have a patchy or contagious type of horizontal distribution in field soil (Figs. 1 and 2). This poses difficulties in sampling as well as in designing experiments for research on nematodes and their management.

The vertical distribution of plant-parasitic nematodes is usually related to root distribution. Nevertheless, the mobility of nematodes and environmental influences may modify this relationship. Most nematode species occur in the upper 30 cm or the plow layer of soil, but some may be found at depths of 100 cm or greater where deep-rooted plants are grown in certain soils. Some species, such as *Paratrichodorus minor*, can move from greater soil depths and feed on plants, which poses difficulties in sampling and control (18).

The spatial distribution of nematodes also may be influenced by their biological properties and their hosts. Such highly virulent nematodes as *Meloidogyne arenaria* may cluster to a greater degree than less virulent species because of associated root decay, plant death, or severe restriction of root growth. The type of egg deposition, whether in masses or individually, also influences the horizontal distribution. Other factors include soil type, topography, and management practices.

Major influences on seasonal fluctuations of nematode populations are basic nematode biology (especially reproductive and survival characteristics), various management practices, and environmental parameters. The temporal population changes of *M. incognita* are typical of most nematodes. This species builds up to very high populations during the growing season, particularly on annual plants, then declines (Fig. 3A). A few species, such as *Xiphinema vuittenezi*, have only one life cycle per year and relative temporal stability. The life span of some *Xiphinema* species may be from 2 to 5


**Fig. 1. Clustered horizontal spatial pattern of nematodes: (A) Spotty growth of wheat parasitized by *Heterodera avenae*. (Courtesy R. H. Brown) (B) Similar growth pattern of soybean affected by *H. glycines*. (Courtesy D. P. Schmitt)**

years, whereas that for *Meloidogyne* species may be less than 6 months. Various cultural practices and the use of nematicides also influence the temporal distribution of nematodes. The number of nematodes in chemically treated soil may be greatest at harvest, whereas the population in untreated soil may be highest at or near midseason. Thus, crop losses in the next susceptible crop after nematicides are often greater than in the previous season. Destroying host roots, especially those with perennial growth, markedly favors population decline.

**Sampling.** Carefully collected representative soil and/or plant samples are essential for meaningful nematode assays. The contagious spatial patterns of these pests and the limitations of present sampling equipment pose the greatest barriers to securing the most desirable samples (2,10).

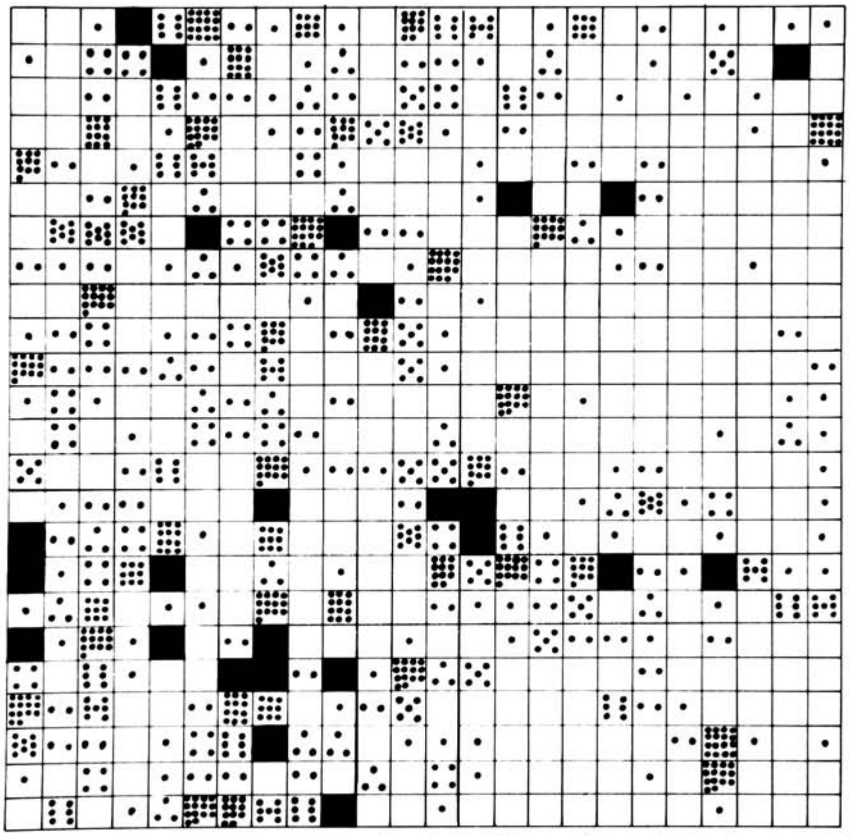

**Fig. 2. Contagious distribution of juveniles of *Meloidogyne incognita* (spring samples). Each dot in the 5 × 5 m quadrats represents 25 juveniles per 500 cm$^3$ of soil; dark quadrats had numbers of 400 or greater for same soil volume. Computer programs are now available for this type of mapping (10).**

The classical cylinder-type sampling tubes and augers are still in use as standard equipment for most nematologists and plant pathologists. Modifications of these tools have resulted in slight improvements, but few efforts have been directed toward the development of automated sampling devices (14). Although many of the modifications in sampling devices have been useful, the lack of a simple, tractor-mounted, automated sampling device is a barrier to effective use of nematode advisory services.

Knowledge of seasonal fluctuations of the target nematode is needed to determine appropriate sampling periods. Most nematode species reach maximum population densities in the fall, then decline during winter to levels that may be barely detectable by spring. Because of possible detection failures, many nematode advisory programs use fall sampling. With use of regression or other population models, spring population levels may be extrapolated from fall samples (Fig. 3B). Unfortunately, the slopes of such regressions depend on a number of variable environmental parameters and management practices (Fig. 3C).

Understanding the biology of the target nematode also is essential in choosing sampling time. This facet of sampling is particularly important with cyst nematodes, including *H. glycines*, whose eggs enter diapause in mid to late fall. Thus, sampling for the number of juveniles in early fall may be useful in estimating population levels; after diapause occurs, however, the number of eggs and/or cysts rather than the density of juveniles should be the basis of sampling.

The number of soil cores and the size of the sampling area for nematode assays vary among advisory programs. Sampling

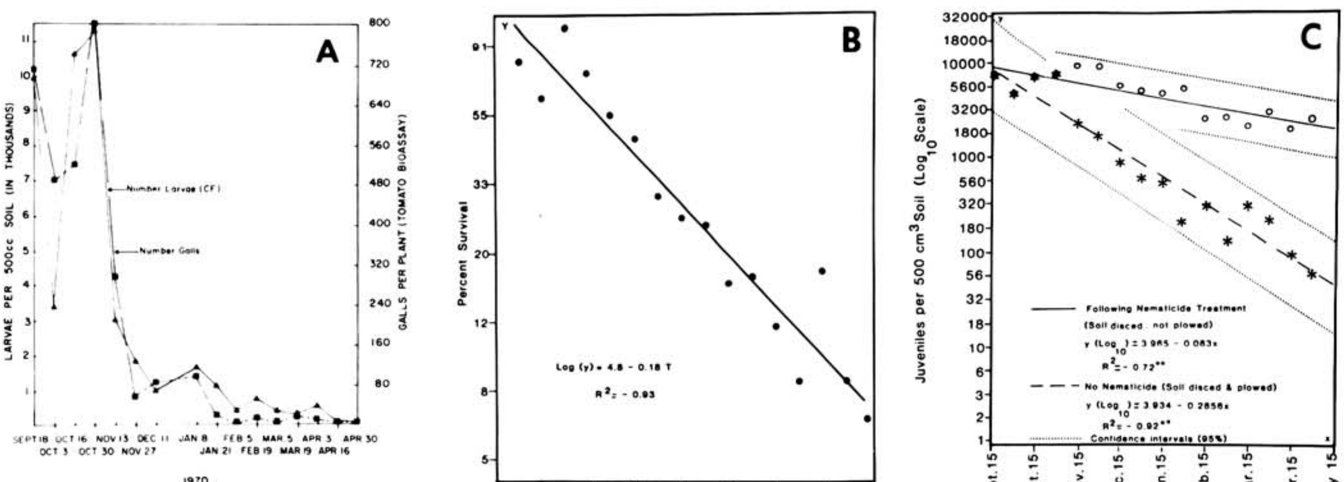


**Fig. 3. Field population-density changes of *Meloidogyne incognita* following tobacco: (A) Comparison of number of larvae (juveniles), extracted by centrifugal flotation (CF), and number of root galls in a tomato bioassay. (B) Transformation and regression of typical population change over winter. (C) Effects of management practices on survival. Slope of regression varies greatly with cultivar, chemical soil treatment, soil type, and other environmental factors; nematodes extracted by centrifugal flotation.**

areas of approximately 2 ha or less is usually recommended for advisory purposes. In sampling larger fields, 2-ha sampling units should be selected randomly from areas that have a uniform cropping history and soil type. The optimum sample size is determined by a number of factors, including population density, target species, and the relative aggregation (*k* value) of the populations for given fields (2,10,11). A sample comprised of 20–30 cores (2.5 cm diam) may be adequate in fields with high population levels, whereas 100 cores or more may be required in fields with low population levels. The generally recommended advisory sample of 20–50 cores provides a population estimate within 30–50% of the mean for row crops. The precision in solidly planted perennials such as alfalfa may be somewhat better (10). The number of cores (600–1,500) required to obtain an estimate within 10% of the mean in most fields is prohibitive.

Various sampling patterns have been recommended for nematodes and other soilborne organisms that have clustered distribution patterns. Some type of stratified or systematic procedure for composite samples usually is followed for advisory purposes because results are more reliable than those obtained by random sampling.

Plant-parasitic nematodes are aquatic microorganisms and must be handled carefully during collection and transit. Where shipment by mail is necessary, enclosure in polystyrene foam containers or other insulated materials greatly enhances nematode survival and thus recovery. Samples that must be stored should be placed in incubators at 10–15 C. This temperature range lowers the physiological activity of nematodes, and they stay active for several weeks. In contrast, storage of most species at 4 C, the typical temperature of refrigerators, may result in chilling injury and death of some species.

## Consideration and Selection of Assay Procedures

Knowlege of the biology and population dynamics of target nematodes aids in selecting the most appropriate extraction method for a given sampling time. Root and soil samples should be used for endoparasites and semiendoparasites when plants are present. Life stages of nematodes may occur as relatively motile to quiescent forms and include juveniles, adults, cysts, individual eggs, egg masses, and various combinations of these. Endoparasites occur in roots or in other plant parts during certain periods of the year, but ectoparasites are found primarily in the soil. Thus, the extraction method is selected according to the life stage of the nematodes present, whether they are motile or sedentary, and whether they are in the soil or in the plant parts.

Nematode assay methods have been summarized elsewhere (1,14) and will not be described extensively here. Migratory forms within plant tissues are extracted most efficiently by mist techniques as developed initially by J. W. Seinhorst. Of the many extraction techniques available for soil-inhabiting nematodes, some type of Baermann funnel modification is useful for obtaining the highly motile forms, and centrifugal flotation is satisfactory for most forms occurring in the soil. A semiautomatic elutriator (7), combined with centrifugal flotation and, where warranted, with the Seinhorst mist or NaOCl-egg extractions (1,14), has proved very satisfactory for assaying soil and root components of nematode populations in large numbers of samples in North Carolina. The NaOCl-egg procedure (1) is very effective for extracting eggs from *Meloidogyne* egg masses and *Heterodera* cysts.

Application of bioassays in advisory programs has been limited. The use of a suitable indicator host growing in a sample from a target field, however, has much potential for individual growers as well as for private companies. Gall indices from a bioassay for *M. incognita* on tomato closely parallel juvenile population shifts (Fig. 3A), and this relationship can be utilized for estimating yield losses as well as for detecting problems for the subsequent year.

Assay techniques used in advisory programs differ greatly in their efficiencies (14). Thus, the methods of reporting data per assay procedure need to be standardized. Communication among laboratories could be improved by noting the extraction techniques per nematode

**Table 1.** Comparison of damage thresholds (DT) to proposed nematode hazard indices (NHI) for selected crops

| | Damage thresholds (number of nematodes) and hazard indices (0–100) per nematode per crop | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soybean | | Corn | | Peanut | | Tobacco | | Cotton | | Peach | |
| Nematode species | DT[a] | NHI[b] | DT | NHI | DT | NHI | DT | NHI | DT | NHI | DT | NHI |
| *Meloidogyne arenaria* | 6–70 | 30–100 | 200 | 20–60 | 1–40++[c] | 0–100++ | 1–2 | >90 | + | 0 | 2 | 50–100 |
| *M. hapla* | 22–250 | 5–70 | + | 0 | 10–200 | 10–80 | 20–100 | 10–30 | + | 0 | 2 | 50–100 |
| *M. incognita* | 10–250 | 10–90 | 150–1,000 | 10–50 | + | 0 | 1–40 | 20–90 | 10–100++ | 0–90 | 2 | 50–100 |
| *M. javanica* | 6–50 | 30–100 | – | – | – | – | 1–2 | >90 | + | 0 | 2 | 50–100 |
| *Pratylenchus brachyurus* | 22–60 | 5–70 | 100 | 20–40 | 1–50 | 10–70 | 20–100 | 10–40 | 20 | 5–50 | – | – |
| *P. penetrans* | 22–60 | 5–70 | – | – | 10–20 | 20–60 | – | – | – | – | – | – |
| *P. vulnus* | – | – | – | – | – | – | – | – | – | – | 200 | 20–50 |
| *P. zeae* | 60 | <5 | >200 | <5 | >100 | <5 | >100 | <10 | – | – | – | – |
| *Heterodera glycines* | 1–10 | >90 | + | 0 | + | 0 | + | 0 | + | 0 | + | 0 |
| *Belonolaimus longicaudatus* | 1–10 | >90 | 1–2 | >90 | 4–150 | >90 | + | 0 | 1–2 | >90 | – | – |
| *Rotylenchulus reniformis* | 1–40 | 20–90 | – | – | – | – | – | – | 1–2 | 50–90 | – | – |
| *Hoplolaimus galeatus* | 60–100 | 0–20 | 20–200 | 5–60 | – | – | – | – | >200 | 5–20 | – | – |
| *H. columbus* | 2–100 | 20–90 | 60 | 10–70 | – | – | – | – | 2–100 | 10–90 | – | – |
| *Tylenchorhynchus claytoni* | 60–200 | 0–10 | >40 | 10–30 | – | – | >200 | <5 | – | – | >200 | <5 |
| *Xiphinema americanum* | 40–100 | 5–10 | – | – | >60 | 5–20 | >200 | <5 | – | – | 50–100 | 10–90[d] |
| *Paratrichodorus minor* | >60 | 0–10 | 11–40 | 10–80 | >50 | 5–20 | – | – | 20–40 | 10–50 | – | – |
| *Helicotylenchus dihystera* | >200 | <5 | >200 | <5 | >200 | <5 | >200 | <5 | >200 | 0–10 | >200 | <5 |
| *Scutellonema* spp. | >200 | <5 | – | – | – | – | – | – | – | – | – | – |
| *Criconemella ornata* | >200 | <5 | 150–200 | 10–30 | 4–50 | 10–70 | + | 0 | – | – | – | – |
| *C. xenoplax* | – | – | – | – | – | – | – | – | – | – | 10–60 | 20–50 |

[a] Damage thresholds for nematode numbers per 100 $cm^3$ of soil (second-stage juveniles for *Meloidogyne* spp., eggs for *H. glycines*, mixed life stages for other taxa). Partially after data (fall) for North Carolina, Alabama, Georgia, and Florida as given by Rickard and Barker (14).

[b] Nematode hazard indices on a percentage basis of risk (actual risk dependent on several factors, including nematode numbers and races, relative virulence of specific nematode, previous crop, soil type, and temperature).

[c] + = Nonhost, ++ = host status dependent on nematode race, – = no information available.

[d] *X. americanum* may vector tomato ringspot virus, the cause of stem-pitting in peach.

species and efficiency (percent yield per species) for the specific soils involved.

## Nematode Population Densities and Crop Performance

**Nematode-host relationships.** Plant-parasitic nematodes may function as primary pathogens, as vectors of other pathogens, as predisposing agents, or as balanced parasites that cause little damage to crops. Typically, diseases caused by nematodes are insidious or chronic with nondescript symptoms of little diagnostic value. Other diseases, such as those caused by *Belonolaimus longicaudatus* and *P. minor* on corn (Fig. 4A) or *M. hapla* on carrot (Fig. 4B), have very striking tissue symptoms. A history of disease complexes involving nematodes is particularly important because much damage is associated with such maladies.

**Nematode numbers vs. plant growth and yield.** The growth and yield of annual crops are more or less inversely related to initial nematode population densities. The relatively low rates of movement and dispersal of nematodes, as compared with many pests, facilitate reasonably accurate prediction of population changes and resulting effects on crop growth. This relationship, however, may be more complex with perennial plants. Frequently, nondetectable numbers of highly virulent nematodes may build up or be introduced and cause problems on perennial crops. In contrast, increase of initially low levels of most species during the growing season is usually insufficient to cause significant damage on most annual crops.

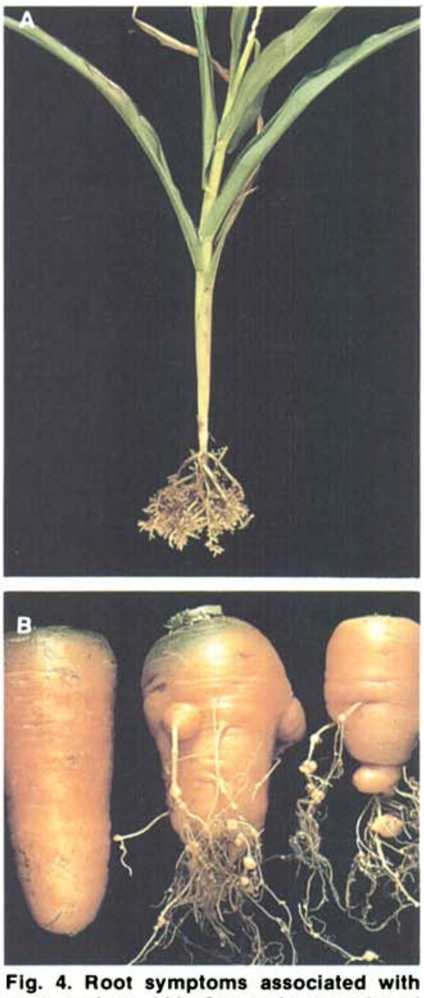

**Fig. 4. Root symptoms associated with nematodes: (A) Severely restricted "stubby" roots associated with *Belonolaimus longicaudatus* and *Paratrichodorus minor* on corn. (B) Root galls and damage associated with *Meloidogyne hapla* on carrot; healthy root on left.**

**Damage, economic, and action thresholds or ranges.** Much research has been done during the past decade on characterizing nematode-plant relationships in establishing damage thresholds or tolerance limits (4,9).

A number of useful experimental models have been developed for establishing tolerance limits as well as economic thresholds for different nematodes on various crops. One of the first useful models relating numbers of nematodes to crop yield or growth was provided by Seinhorst (15). This model provides a basis for establishing the tolerance level and the minimal yield for specific nematode-host combinations:

$$y = m + (1 - m)z^{P-T},$$

where y = yield on a scale of 0–1, m = minimal yield on a scale of 0–1, T = tolerance limit, P = population level, and z = a constant less than 1 (equal to proportion of plants not attacked at density P = 1). This model is very useful for research purposes and provides a standard for evaluating crop responses to a given nematode in various habitats. Other models also are utilized for these purposes (4,6).

The concept of a damage threshold or tolerance limit refers to the population density above which some damage could be expected. But such a parameter applies to only a specific cultivar under a given set of environmental conditions. Thus, damage thresholds developed for one location may not necessarily apply to a large number of other situations. Similarly, economic thresholds, which refer to number of nematodes where control becomes justified, also may vary with environment and cultivar. Because these parameters are not constant, use of action thresholds or ranges that allow the grower considerable flexibility has been suggested (17). With the variability of crop responses to given levels of nematodes, even in the same location from season to season and from field to field, the use of probability indices for various hazard levels has merit. This system would provide a weighted recommendation based on the available knowledge from the standpoint of crop production practices, environmental parameters, presence of other pathogens, or potential for disease complexes, as well as number of nematodes. Damage thresholds and hazard indices for selected crops are compared in Table 1.

Ferris (9) provided a dissertation on economic thresholds. As with other economic thresholds, the value of the crop, the cost of corrective actions, and associated damage with varying levels of the nematode or pests are considered in calculating the point at which treatment would be warranted.

The clustered distribution patterns of most plant-parasitic nematodes also should be considered in determining damage or in estimating the damage caused by given population levels. Population means for fields with highly aggregated communities of nematodes may result in an overestimate of the actual associated damage (J. P. Noe, *personal communication*). This overestimation comes about because the relative effect of nematodes may decrease as their numbers increase at a given point in a field.

Other factors that may affect the basic relationship between initial number of nematodes and crop performance must be evaluated. For example, cultivars of a given crop may have highly variable levels of tolerance to a nematode species. The association of other pathogens must be considered for nematodes that may be involved in disease complexes. And finally, the effects of environmental parameters, including soil texture, nutrient levels, and moisture availability, may alter these relationships.

Crop losses caused by a given species of nematode can be exacerbated by environmental stress. In a sandy soil in eastern North Carolina, any detectable population of *M. incognita* suppressed the yield of tomato (5). In contrast, only slight to moderate yield losses were brought about by moderate to high levels of this organism in the mountains of North Carolina, where the amount of rainfall was high and the fine-textured soils had a high water-holding capacity. Thus, damage thresholds or hazard indices developed for one location cannot be applied a priori in other regions.

**Relating symptoms and signs to crop yield.** Root-gall and root-necrosis indices can be used for assessing damage caused by certain nematodes such as *Meloidogyne* species. Gall indices on a 0–100 scale (6) obtained after midseason can be useful in evaluating nematicides or assessing yield losses. Yield losses increase linearly as gall or necrosis indices increase. The slope of such regression lines may be relatively sharp in areas such as the Coastal Plain of North Carolina with a coarse-textured sandy soil. In contrast, in fields in the Piedmont of North Carolina, where the soils are finer and the temperature is lower than in the Coastal Plain, increases in gall indices have only a moderate effect on the yield of such crops as tobacco. As with nematode population numbers, such relationships between disease symptoms and yield vary with climate or geographic location.

Assessing root galls and necrosis is useful in determining the magnitude of infestations of nematodes on perennial crops, such as peach or other fruit. The approach is also very useful in states and countries where no nematode advisory programs are available. Growers may use this type of assessment based on symptoms in the field.

The only ongoing nematode advisory program based on symptoms or signs is the one developed in Australia for the cereal cyst nematode, *H. avenae* (16). Two private companies currently provide this service for this important nematode problem in Australia. Basic approaches for the system, named SIRONEMA, developed by Australian nematologists in the Commonwealth Scientific and Industrial Research Organization involve the collection of soil samples from subject fields and the use of appropriate bioassay cultivars of wheat. Numbers of cysts determined after a period of time are used directly to assess the potential hazard.

**Table 2.** Nematode management based on hazard level as determined by population density assays and/or symptoms

| Hazard level[a] | Corrective action |
|---|---|
| 1: None to minor (<10% risk) | Rotation where warranted |
| 2: Slight to moderate (10–50% risk)[b] | Multipurpose chemical soil treatment<br>Fumigant chemical soil treatment<br>Nonfumigant chemical soil treatment<br>Rotation<br>Resistant cultivar |
| 3: Severe (>50% risk) | Fumigant chemical soil treatment<br>Multipurpose chemical soil treatment<br>Resistant cultivar<br>Rotation |

[a] Dependent on precision of predictive data available.
[b] Corrective action dependent on nematode species and race; cultivar; history of wilt and/or root disease; soil texture, nutrients, and organic matter; mean rainfall and temperature; and cost of corrective action vs. crop value.

## Current Advisory Programs

Nematode assays can be classified into three categories: diagnostic, regulatory, and predictive. Laboratories that use assays for predictive purposes and offer advice are discussed here.

Several laboratories in the United States assay samples for phytoparasitic nematodes, but the number of comprehensive advisory services is relatively small. In a survey conducted in 1980 by G. A. Carlson (*personal communication*), 32 public and 53 private laboratories were listed as doing nematode assays. The former represented 31 states (two were reported in Tennessee), but only 14 processed in excess of 2,000 samples during 1979. The total number assayed by these 14 laboratories was about 70,000. The six programs with the highest number of assays (55,000, or 79% of the total) were located in the southeastern United States, in Arkansas, Florida, Georgia, Mississippi, North Carolina, and South Carolina. A few new laboratories have begun operation since this survey, eg, in Idaho and Virginia. In a recent survey, Evans-Ruhl (8) collected data on plant disease clinics and found that 56 of 83 public and private clinics offered nematode assays.

The majority of the high-volume public nematode advisory laboratories are located in a few southeastern states. Public laboratories associated with plant disease clinics and private laboratories predominate in the remaining states. A number of public laboratories assay nematode samples for regulatory action and/or certification. For example, the state departments of agriculture in Florida and California each assay more than 10,000 samples per year for these purposes.

Most public advisory services charge a fee for nematode assay. The amount varies greatly and may differ with the type of assay. For example, Arkansas charges $8 for a general assay and $15 for a soybean cyst nematode race determination. Plant disease clinics also frequently charge a fee for nematode assays because of the time and equipment required (8).

The source of samples varies with the particular advisory service. Public services not associated with disease clinics frequently accept samples only through the county extension agent. A few advisory programs assay samples from any in-state source. Limiting sample acceptance to those submitted via the county extension agent or other farm advisors is generally believed to result in better control over the quality of the sample—a weak link in advisory services. However, most grower-submitted samples in North Carolina appear to be equal in quality to those from extension personnel. Constraints placed on sample acceptance will automatically limit advisory program usage, since the number of samples extension personnel can handle is certain to be far less than the number of candidate fields.

Available data suggest that only a small portion of the total acreage planted is assayed for nematodes in any one year. Estimations of samples assayed in various regions of the United States (G. A. Carlson, *personal communication*) reflect service availability. There is about one nematode assay for every 520–620 crop acres in production in the southeastern United States and adjacent areas with large-volume assay services. The Pacific Coast region has about the same ratio (one assay for every 584 acres), but 80% of the samples are run by private laboratories. The Northern Plains region, with a dearth of advisory laboratories, has one nematode assay for about every 30,300 acres.

About 22,000 samples are assayed annually for nematodes in North Carolina. The number of acres per assay is considerably lower than in other states. Sweet potato fields are most extensively sampled (about one-third), followed by Irish potatoes (20%) and peanuts (14%). Tobacco, cotton, and cucumbers are assayed at similar rates, approaching one-tenth of the fields each year. The relatively large acreages of corn and soybeans are not as extensively sampled, with one assay for each 430 and 470 acres, respectively. The low percentage of soybean fields assayed is remarkable in light of the fact that the soybean cyst nematode is a severe problem in many parts of the state where soybean is grown.

The limited use of currently available advisory services is not an indication of their utility. G. A. Carlson (*personal communication*) obtained information from the laboratory directors as to why they felt growers failed to assay their fields. By nearly a 10-to-1 margin, the most common reason given was that growers were not convinced that nematodes damaged their crops. Paradoxically, the second most common was that growers routinely applied nematicides and therefore felt no need to sample their fields. Unawareness of the service was rated third.

A recent limited survey of tobacco growers in North Carolina (12) indicated that frequent use of our advisory service is restricted primarily to IPM program participants and users of multipurpose chemical soil treatments. The majority of tobacco farmers routinely used pesticides without scouting or monitoring methods. Primary reasons for low usage were pesticide reliability and lack of conviction that nematodes affect yields. Interestingly, of those growers who used multipurpose soil fumigants for control of soilborne disease, one-half assayed their fields for nematodes at least every 2–3 years and used the results in selecting a chemical soil treatment.

Informal surveys of growers of other crops in North Carolina who routinely assay their fields for nematodes indicate a high degree of grower confidence in the advisory service. Utilization of advisory services should increase as growers become more aware of the frequent, insidious yield losses attributable to nematodes and of their interactions with other pathogens and as economics make it less desirable to use "insurance" applications of nematicides. An efficient automated sampling device would add much to the attractiveness of nematode as well as soil-nutrient advisory services.

Advisory programs perform other useful functions. One is the development of an extensive nematode population data base. At least two programs (North Carolina and Virginia) use computerized data storage, which could be very helpful in determining geographic distributions and population shifts and in estimating crop losses. Another is the identification of new nematode problems and determination of their distribution.

**Table 3.** Major positive and negative factors relating to advisory programs

| Positive factors | Negative factors |
|---|---|
| Preplant nematode numbers closely related to crop yield, especially annuals | Preplant nematode numbers poorly related to long-term damage to perennial crops |
| Management decisions made before establishing annual crops | Damage often dependent on environmental factors as well as preplant nematode numbers |
| Soil nutrients and nematodes sampled in one operation | Automated sampling device needed |
| Precision level of sampling adequate for limited management tactics | Precision usually limited to 30–60% of mean because of clustered nematode distribution patterns |
| Bioassay or nematode population assay can be used for some species | Fall sampling often required to detect highly virulent species (not detectable at planting time) |
| Limited use of hazardous chemicals facilitated | Few advisory programs available |
| More accurate data on nematode damage becoming available | Required research and advisory programs very expensive and time-consuming |

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## Challenges and Prospects

The challenges to nematode advisory services and supporting research scientists are manyfold. These include the development of effective and simple sampling procedures, reliable and efficient assay methods, precise damage threshold data, knowledge and understanding of the factors influencing the relationship between preplant nematode population density and crop loss, and better understanding of the role of concomitant microorganism populations. There frequently is a gap between what advisory service nematologists need to know and what data are available. For example, sampling strategies must be sufficiently simple and economical for grower usage and still give reliable samples. Time becomes an important factor when assaying very large numbers of samples. All procedures must be designed to permit the highest quality assay in the minimum laboratory time. The difficulties in the practical application of the concepts of damage and economic thresholds must be resolved.

Nematode advice may be based on qualitative and/or quantitative information. Much of the advice is still qualitative or semiquantitative, however, because the level of precision in present sampling schemes is lower than desired, the information on nematode damage functions is limited, and cultivar and environmental parameters influence these functions. Despite these limitations, the programs have much to offer a grower. The simple detection of low numbers of a highly virulent species may require a shift in the crop or in management tactics. High numbers of the same species may require long-term rotations, use of fumigant nematicides, or a combination of control tactics.

Although population assays usually are not sufficiently precise to base advisory recommendations on a narrow damage threshold, carefully done nematode assays do yield sufficiently reliable data for differentiating at least three hazard levels: none to minor, slight to moderate, and severe (Table 2). These evaluations of potential hazards should be qualified according to the precision of available damage functions and related information. One approach involves determining the level of the risk involved and the corrective action needed (Tables 1 and 2). For example, the presence of any number of the highly virulent nematode *B. longicaudatus* poses a major risk (>90%) for peanut. In contrast, the expected damage caused by *Criconemella ornata*, a mild pathogen, on peanut depends on the number of this nematode, previous crop, presence of other pathogens, and environmental parameters.

Thus, this lack of a definitive predictive value for *C. ornata* could be reflected with a broad hazard index (10–50% risk). This system would provide the grower a more realistic estimate of potential nematode hazards than fixed and sometimes misleading damage thresholds.

The use of bioassay systems as for *H. avenae* in Australia has promise for other cyst nematodes and *Meloidogyne* species. Soybean-grower groups could develop this type of program for the cyst nematode, *H. glycines*. This approach is especially attractive for regions with no organized advisory service. Farm advisers, with limited instruction, could assist growers in detecting these nematodes on plants during the growing season.

Current nematode advisory programs have many positive and negative features (Table 3). Although much research is still needed to resolve major problems, nematode advisory services are serving an important role in agriculture. The development and modeling of more reliable damage functions and improved sampling procedures, including an automated sampling device, will facilitate the progress of these services.

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