Nematology—Status and Prospects: Practical Implementation of Quantitative Approaches to Nematology[1]

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Abstract: The main components of the decision process in nematode pest management are the value of the predicted damage and the cost of the management alternative. The relationships involved are affected by such environmental parameters as soil texture and physiographic region. There is a general intuitive understanding of the nature of the relationships and of the effects of the environmental parameters. Some nematode damage functions have been developed through quantitative research. A conceptual framework is developed herein which promotes rational use of available experimental results, supplemented by intuitive understanding of nematodes and crops, in arriving at a pest management decision. Gaps in available data point the need for additional research within the framework. The approach allows and encourages immediate implementation. Interactive computer programs are seen as a potential vehicle for weighting the variables involved in the decision and for storing, manipulating, and delivering the necessary data and information. *Key Words:* pest management, population dynamics, economics, damage functions, control costs.

There is an urgent need in applied nematology to attain and maintain credibility by implementation of quantitatively based advisory capabilities. Explosive developments in the minicomputer and microcomputer industries in recent years have generated exciting possiblities in pest management. These include the ability to store and manipulate large amounts of data in files and to use computer terminals on an interactive basis with a self-prompting program located in a central computer.

It can be argued that the quantitative data available for nematode pest management decision processes are limited. Since these data originate from experiments conducted in specific situations, extrapolations to locations with differing environmental conditions is usually avoided. I choose to disagree with this conservatism and would argue that by developing a few simplistic notions it should be possible to use available data on nematode damage functions, nematode biology, and crop production economics to make rational management decisions. Use of the best available biological evidence and experience-based intuition will allow immediate implementation. Fine tuning of the system will follow with time.

This presentation develops a conceptual framework within which available data can be quantified and implemented in nematode pest management decisions. The basic premise is that the relationship between plant yield and nematode population densities, the damage function, can be identified and defined. Several models have been proposed for this relationship (6,8), but the exact nature of the model is unimportant in developing the argument. What is important is that the model defining the relationship between a specific nematode pest and host plant is valid and predictively reliable.

There are certain advantages in predicting damage due to nematodes rather than other pests. These include the relative lack of motility of nematodes so that the population present in the soil prior to planting is generally the population which is damaging to the plant; invasion by winged stages at an indefinite time during the growing season, or by physically borne inoculum, is unlikely. Further, population increase in nematodes is relatively slow, and there are seldom more than three or four generations during a crop season. It should be possible in annual crops to translate the initial nematode population into some measure of expected crop damage (6,8). The damage function can be used to determine the economic threshold. The nematode population at which the cost of the management alternative under consideration is equal to the value of the damage caused by the population represents the *economic threshold*. If the population is above this threshold level, the management

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approach under consideration is justifiable. If the population is below the threshold, an alternative management should be considered.

We might consider the nematode damage function to be a linear relationship between the log-transformed initial nematode density and the expected crop yield, as proposed by Oostenbrink (6). However, the same reasoning could be applied to the Seinhorst (8) model. In the Oostenbrink model there are two parameters which describe the damage function: (i) the slope of the regression line and (ii) the tolerance limit, the nematode population at which damage is first measurable. Several environmental influences affect and dictate the slope and position of the damage function. These include soil edaphic factors, the physiographic region in which the nematode community exists and the crop is to be grown, and perhaps the growing conditions of the particular crop season. If we select some method of quantifying the environmental conditions—for example, soil texture—it may be possible to describe a relationship between the soil texture value and the expected tolerance limit for a specific crop-nematode combination or the expected slope of the damage function for this combination (Figs. 1 and 2). These relationships can be developed based on (i) current biological knowledge of the effects of soil texture on the biology and ecology of various nematode species and (ii) upon the environmental suitability of different soil textures to the crop under consideration.

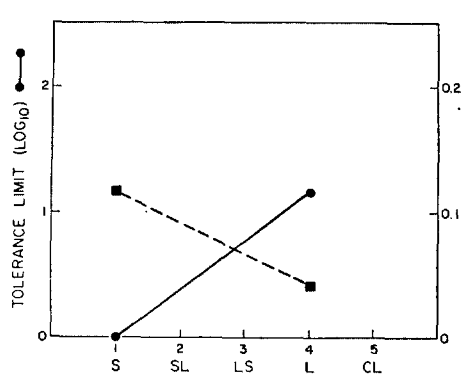

FIG. 1. Interpolated relationships between parameters of the nematode damage function (tolerance limit and slope) and soil texture for sweet potatoes. S = sand, SL = sandy loam, LS = loamy sand, L = loam, CL = clay loam.

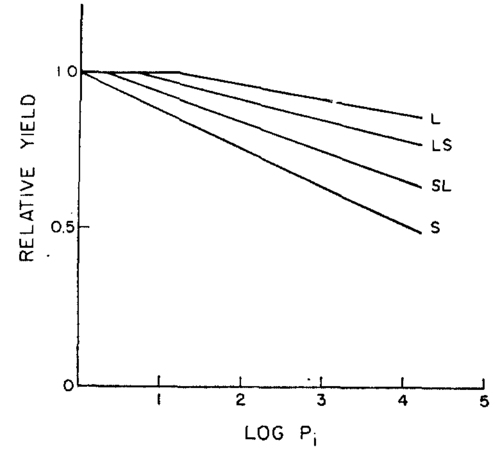

FIG. 2. Damage functions in a range of soil textures for sweet potatoes. Initial nematode level (P_i) expressed as total community adjusted in *Meloidogyne incognita* equivalents. S = sand, SL = sandy loam, LS = loamy sand, L = loam.

Such relationships might be developed based on a rather limited amount of field data and on basic biological information already available. The relationships allow estimation of the two parameters of the nematode damage function for a specific set of edaphic conditions in this case and, therefore, estimation of the damage function itself. A similar approach can be taken to the problem of regional influences on the nematode damage function.

Nematode damage functions are usually generated in microplot or small plot studies using single populations of plant-parasitic nematodes (1). However, nematodes seldom occur in monospecific communities in agricultural fields (6). It would be extremely difficult, both logistically and in terms of interpretation, to develop nematode damage functions with every possible combination of nematodes likely to occur in an area. An alternative approach is to develop the damage functions for a species which might be considered a major pathogen and then to rank the other potential parasites of that crop in terms of their pathogenic ability relative to the major pathogen. If *Meloidogyne incognita* were selected as the major pathogen, it would represent a pathogen of the vascular region causing major morphological and physiological disruption to the root system. On a 0–1 scale relative to *Meloidogyne*, *Pratylenchus* as a cortical feeder might be represented by a value of 0.5. In other words, one *Pratylenchus* could be expected to do 0.5 of the damage of one *Meloidogyne* individual. Similarly, a single *Tylenchorhynchus* browsing on root hairs and epidermal cells might have a value of 0.05 on the same scale. Much of the data for determining these relative pathogenic ratings is already available in the literature from multispecies and interaction experiments and should be relatively easy to extract.

The approach requires weighting of the nematode counts from soil samples in terms of the relative pathogenic rating of the populations present (Table 1). Since the total community is thus assessed in terms of its equivalence to the major pathogen for which the damage function was established, the same damage relationship could be used. Of course, this damage relationship has already been modified according to the specific physiographic and edaphic conditions of the field under consideration (Fig. 2). There is some precedence for the pathogenic equivalent approach in the work of Hijink (4) who found in experiments with *Pratylenchus penetrans* and *Rotylenchus robustus* on *Valeriana officinalis* that a linear damage function was valid if the *Rotylenchus* counts were multiplied by 0.2 before being added to the *Pratylenchus* counts.

In determining the pathogenic equivalence of the nematode community, the suitability of the particular environment to the component species of that community must be considered. The individual species may vary in their pathogenic impact, measured on a 0–1 scale, relative to soil texture, for example (Table 2). This effect has already been considered for the species on which the damage function is based by modification of that function (Fig. 2), but the other species of the community should be appropriately weighted. The weighted totals adjusted to a damage function developed for *Meloidogyne* (Table 2) represent the sum of the products of (i) the nematode counts for each species, (ii) the pathogenic rating for that species (Table 1), and (iii) the environmental suitability to that species. The environmental suitability to *Meloidogyne* is not included in this value, as it is already considered in the modified damage function. Similar considerations should be made for physiographic region effects and the season in which the crop is being grown. These will not be considered here because of their geographic specificity. Note that construc-

TABLE 1. Adjustment of a nematode community count for use with damage functions developed for *Meloidogyne* and *Pratylenchus* (hypothetical example).

Nematode	Count	Pathogenic rating	Adjustment to *Meloidogyne**	Adjustment to *Pratylenchus*†
Meloidogyne incognita	100	1.0	100	200
Pratylenchus penetrans	100	0.5	50	100
Tylenchorhynchus cylindricus	100	0.05	5	10
Weighted totals			155	310

*Assuming damage function developed for *M. incognita*.
†Assuming damage function developed for *P. penetrans*.

TABLE 2. Hypothetical weightings of a nematode community relative to the suitability of edaphic conditions.

Nematode species	Count	Soil textures				
		Sand	Sandy loam	Loamy sand	Loam	Clay loam
M. incognita	100	1.0	1.0	0.8	0.6	0.4
P. penetrans	100	0.8	1.0	1.0	0.8	0.5
T. cylindricus	100	1.0	1.0	1.0	1.0	0.8
Weighted total		280	300	280	260	200
Adj. to *Meloidogyne*		145	155	155	145	129

tion of the charts (Tables 1 and 2) demands that factors be quantified for each condition. This allows the use of experimental data but also draws upon intuitive knowledge of nematode biology and accumulated field experience. It also focuses research goals and approaches. Where data and experience are not available, the worst case would be assumed.

A problem arises in that cultivars of a crop vary in their host status, susceptibility or tolerance, to a nematode species. The approach here would be to consider that all cultivars for which no data were available were intolerant to that nematode species, so that the fullest extent of its pathogenic equivalence would be expressed, assuming the crop to be a host of the nematode. If there were data available in the literature or from experiments showing that a particular cultivar had a level of tolerance to the nematode, then the host status would be expressed by some factor less than 1. In other words it would be ranked in terms of the intolerant condition. Thus, if a particular cultivar had a host status rating of 0.8 to a nematode species of pathogenic rating 0.4, the product of these two factors would represent the expected influence of that nematode to the cultivar under consideration: that is, 0.32. One hundred nematodes of this species would then represent 32 nematodes in their expected effect on the crop relative to the major pathogen for which the damage function was established (Table 3). It is then necessary to describe a nematode characteristic for each crop potentially grown in a geographic region. This characteristic would list all the nematode species known to occur in that region and to express the general host status—that is, host or nonhost—of the crop to each nematode species. Individual cultivars which varied from the general host status by having some level of tolerance to the nematode would be listed separately.

If one of the management alternatives under consideration was crop rotation or the use of a resistant cultivar, it would be necessary to have some information on the expected survival of the various species relative to physiographic and edaphic conditions so that the management practices for subsequent years could also be examined (3). Similar information on nematode multiplication under different crop hosts could be utilized in this framework.

In general, much of the data necessary for the quantification approach to the nematode pest management decision process are already available in the literature or are intuitively understood by practicing nematologists. What is needed is this development of a framework within which the data can be categorized for utilization. The approach should allow some rational prediction of the expected damage from any nematode community in any soil texture in any physiographic region on any crop, provided there has been some work done on the relationship between that crop and one of its major nematode pathogens. Fine tuning of the system will occur as research progresses, data are accumulated, and gaps become apparent and are filled.

There is another aspect to the pest management decision process not yet considered. That is the efficiency and cost of the management alternative considered relative to the physiographic and edaphic conditions of the environment in question. For example, data are available from McKenry (5) showing, for different soil textures, the moisture limit and temperature limit beyond which the use of fumigant nematicides is inadvisable. The data also show the amount

TABLE 3. Assessment of the effective adjusted nematode community, relative to the tolerance of two cultivars of a crop.

Nematode	Count adj. to *Meloidogyne**	Host status cv 1	Adj. count cv 1	Host status cv 2	Adj. count cv 2
M. incognita	100	1.0	100	0.8	80
P. penetrans	40	1.0	40	1.0	40
T. cylindricus	5	0.0	0	0.2	1
Weighted totals			140		121

* From Tables 1 and 2.

of chemical required to achieve the same level of control in various soil textures. This amount increases as the soil particle size decreases towards a clay. Hence, for a specific set of edaphic conditions it should be possible to interpolate not only the nematode damage function, and, therefore, the expected damage from the prevailing nematode community, but also the amount of chemical required in that situation to achieve a prespecified level of control.

Interestingly, with many nematode species the damage function shifts to the right with decreasing particle size, and the slope of the function becomes less acute. This relates to the suitability of those soil textures to different nematode populations and also to the moisture and nutritional stress which the plant is under in sandy soils. Therefore, in finer textured soils, more nematodes need to be present to cause the same amount of damage as in coarse textured soils (Fig. 2). At the same time the amount of chemical needed to achieve the same level of control in fine textured soils as in coarse textured soils is much greater, and, therefore, the cost of the control is greater (5). Since the economic threshold is the nematode population at which the expected damage is equal to the cost of control, in the hypothetical situation developed the economic threshold will increase with decreasing soil particle size. Obviously the economic threshold is a dynamic concept, and by quantifying the nematode pest management decision process we are actually developing a customized economic threshold for a specific field-crop-nematode community situation, while at the same time considering prevailing costs of the management materials.

By way of example, the pest-management decision economics are examined for the nematode community considered in Table 1 for a sweet potato variety with the host status characteristics of cv 1 (Table 3). The tolerance limit and slope of the damage function have been determined for sand and loam soils in one physiographic region (2), allowing generation of Fig. 1. Here the relationship between tolerance limit or slope and soil texture is based only on two points and is expressed linearly. This is a simplistic initial interpolation; more data may show that the relationships are nonlinear. The graphs in Fig. 1 are used to generate damage functions for different soil textures (Fig. 2). The functions for the intermediate soil textures represent estimations based upon rational use of available experimental evidence.

Estimated potential crop value of $2,500 per acre (7) is used to generate expected crop damage on sweet potatoes for different soil textures in one physiographic region (Table 4). The cost of a 1,3-D nematicide treatment at recent commercial rates, adjusted according to McKenry (5), was determined for the range of soil textures under similar moisture and temperature conditions (Table 4). In other words, Table 4 represents situations in which all conditions except soil texture are held constant. The treatment costs are translated into economic threshold levels expressed as equivalents of the species for which the damage functions were developed (*M. incognita* in this case). Extrapolation beyond the range of the experimental data to a clay loam texture is used to exemplify the condition when the nematode community was below the eco-

TABLE 4. Analysis of a nematode pest management decision for sweet potatoes in one physiographic region with differing soil textures, considering treatment with 1,3-D nematicide.

Soil texture	Tolerance level	Slope*	Pathogenic equivalent†	Crop damage‡	Treatment cost	Econ. thresh. equivalent‡
Sand	0	–.12	140	644.76	62.46	1
Sandy loam	1	–.09	150	422.54	74.16	4
Loamy sand	5	–.07	150	245.14	85.85	18
Loam	14	–.04	140	97.31	97.55	115
Clay loam	35	–.02	125	27.20	109.24	9,072

Soil moisture 8%, soil temperature 16C, max crop value $2,500/acre.
*From Fig. 1 and Fig. 2.
†From Tables 1, 2 and 3. Note effect of assumed nonhost status to *T. cylindricus*.
‡From Fig. 2.

nomic threshold. This was due to the decreased expected damage and increased cost of achieving a prescribed level of control.

There has been some theoretical consideration of optimization of the nematode pest-management decision process (3). It is recognized that the cost of control relative to the amount of control achieved is probably not linear and that control costs increase tremendously as extermination of a nematode community is attempted. Returns to the grower are maximized when the difference between the cost of reducing a nematode community to a certain level and the crop value allowed by that community at that level is at a maximum. This concept involves knowledge of the nematode damage function and the control cost function. It is apparent from the preceding discussion that both of these are influenced by environmental and edaphic conditions. It is also apparent that by partitioning the influences of each factor on the damage function, on the individual species in the nematode community, and on the cost of control, we should be able to use the current state of our biological knowledge to reach some rational decision on the optimum alternatives for nematode pest management in a specific field and crop situation.

The use of interactive computer programs on minicomputers with terminals in outlying locations allows the manipulation of data files of nematode damage functions,

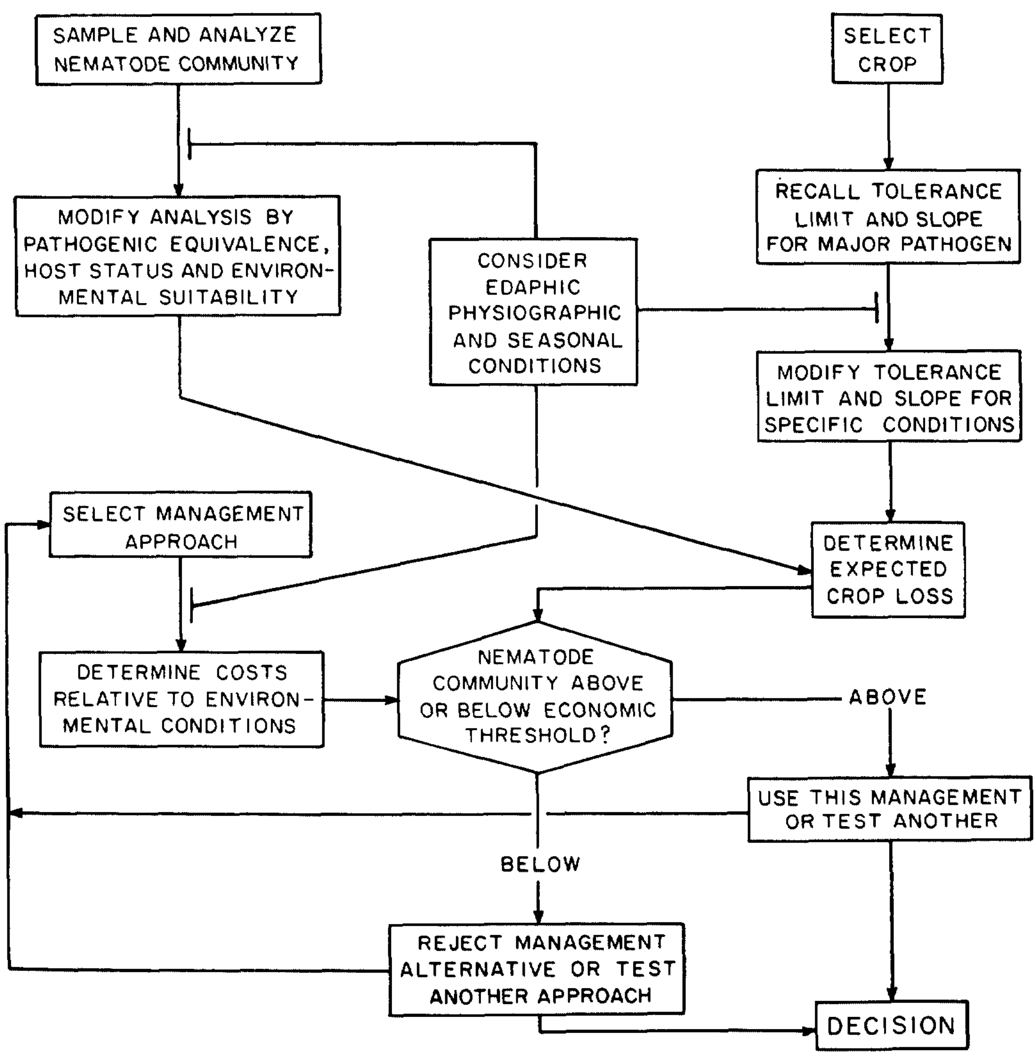

FIG. 3. Simplified flow chart of the decision process in nematode pest management.

relative pathogenicity of various nematode species, tolerance levels of individual host cultivars, and control costs based on knowledge of control efficiency and current costs of any materials used. By including all of the factors listed in the preceding discussion in a computer program, the pest-management decision is made through the regimentation of quantification whereby all aspects and parameters of the problem are considered (Fig. 3). With the development of a conceptual framework and the available technology, we can collect and catalog available documented information and research as outlined above, and practical experience, to implement this approach.

Field validation and further experimentation will undoubtedly reveal flaws in the simplistic notions developed in this presentation. They are intended to trigger consideration of the potential of quantitative approaches. The models will become more sophisticated with further research effort. The importance of reliable nematode sampling techniques as a basis for the pest-management decision is evident.

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