Using nematode count data in crop management decisions

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Nematode density and expected crop damage should be the basis for rational control decisions

A fundamental principle of crop and pest management is that management or control is unnecessary unless the pest is at a level expected to damage the crop. The more individuals there are of the pest population, the greater the expected damage (fig. 1). In some cases, any incidence of the pest or pathogen is intolerable, and preventive measures are required.

Knowledge of the relationship between the pest population density and the expected crop damage should form a basis for rational pest management decisions. Determination of these relationships (known as damage functions) may be difficult, however, and they vary with environmental and economic conditions. The relationships become more apparent as further information is gathered about the biology of the crop and pest systems. The basis for management decisions can be summarized as tables or graphs and can be put into a format for interactive access in computer-based models.

When decisions are based on the number of pest individuals present, the problem of population assessment arises. Use of a damage function relating the number of organisms to expected crop loss presupposes that the organism population is measured with the same efficiency, or at least is expressed in the same terms, as the population for which the damage function was developed. One can avoid potential errors by evaluating the efficiency of the population assessment technique and making appropriate corrections of data for this efficiency.

Since 1976, we have conducted studies on several annual crops in various California locations to determine the relationship between crop yield and density of the root-knot nematode, *Meloidogyne incognita*, in the soil before planting. Basing the prediction of yield or yield loss on a preplant sample of the nematode population is significant, because most management alternatives (soil fumigation, crop rotation, use of resistant varieties) require preplant decisions and commitments.

An equation predicting the timing or magnitude of crop yield and value based on a single observation of the pest population is known as a "critical point" model. Such models are appropriate for nematodes in annual crops, because they permit timely decisions and, further, because nematode generation times are relatively long and population assessment is not confounded by unpredictable immigration. The nematode population is relatively immobile and is already present in the soil at planting time.

In pest systems with greater volatility and uncertainty (unpredictable invasion times, rapid rates of population increase), a "multiple-point" approach to population assessment is necessary. This allows initial detection and determination of the rate of population change and damage with time. For nematodes, such approaches are necessary as a basis for management decisions on perennial crops.

To develop an equation for crop loss due to nematodes, we selected the model derived by J. W. Seinhorst (as published in *Nematologica* 11, in 1965). This model recognizes that, for some crop and nematode combinations, there may be a minimum yield (m) — some residual crop growth, even at high nematode population densities. Further, there may be a nematode density below which damage is not

measurable (the tolerance level, T). The effect of the nematode population on crop yield is measurable for all population densities above the tolerance level. The Z parameter is usually a value just less than 1.0. The closer the value is to 1.0, the lower the pathogenicity of the nematode on the crop in this environment. The model is based on the rationale that, if one nematode causes a certain proportional damage to the plant, there is that much less of the plant left for a second nematode to damage. Consequently, the contribution per nematode to the damage decreases as the nematode population increases (fig. 1).

In a series of experiments, we defined the parameters of the damage function (footnote, table 1) for several crops. We generated a range of root-knot nematode population densities in small plots (100 to 200 square feet) by differential crop rotations and suboptimal dosages of soil fumigants. Next we grew the test crops across the mosaic of nematode densities under standard cultural practices, and then used the model to relate final yields to initial population densities.

The model parameters show some predictable regional differences for particular crops (table 1). They reflect the suitability of the environment for the crop and the nematode. Where the crop is favored (climate, soil nutrient and moisture status), the tolerance level would be higher, the minimum yield higher, and the Z

value closer to 1.0, descriptive of reduced damage by the nematodes. In more marginal situations, the same crop would be less tolerant of the nematode population, resulting in a lower tolerance value, minimum yield, and Z value.

Interpretation of the potential impact of nematode population densities requires consideration of environmental conditions and their suitability for both the crop and the nematode. The predictive capability of nematode damage functions in annual crops is probably more likely in California than in most other regions of the world because of the relatively stable climate from year to year and the management of soil moisture through irrigation.

Using the damage functions

The damage functions are based on calculated, absolute preplant population densities of root-knot nematode eggs and second-stage juveniles, with crop yield expressed on a 0-to-1 relative scale. For management decisions, the damage function is multiplied by the expected dollar value for the crop in that field and that year without the nematode stress. The estimated dollar value for the crop in the presence of the current nematode population is then used to calculate, by subtraction, the value of the crop loss.

The crop loss value is used as a basis for considering the economics of the management decision. If the predicted crop

loss were $200 per acre, for example, a soil fumigation treatment costing $100 per acre would be economically justifiable, assuming that the treatment prevented the crop loss. If the option were to grow an alternative nonhost crop valued at $300 less than the crop of interest, the cost of this option would be $300. This alternative would not be acceptable, since the crop would yield a lower value than the crop of interest, even in the presence of the nematodes.

In each case, the decision involves measurement of the preplant population density and its correction for extraction efficiency to put it on the same scale as the population density for which the damage function was developed. The extraction or recovery of nematodes from soil samples varies with the technique used and the type of nematode. Data must be adjusted to a standard. Examples of expected damage to tomatoes and cotton at different preplant population densities of
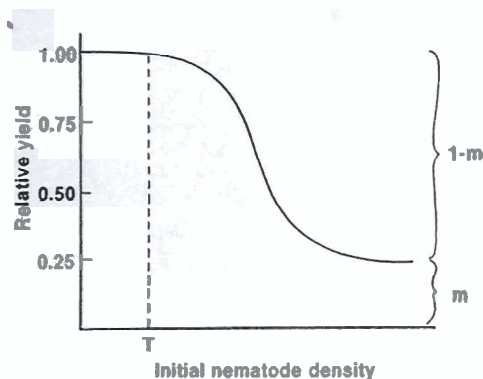

Fig. 1. Although expected damage increases with the number of nematodes, the damage per nematode decreases. (m = minimum yield; T = crop tolerance)

TABLE 1. Parameter values of the damage function and the nematode multiplication function for the root-knot nematode, *Meloidogyne incognita*, for various crops, soil textures, and locations.

Crop	Variety	Soil*	Location†	Damage function parameters‡			Multiplication function parameters§		
				T	Z	m	a	c	b
Bell pepper	Yolo Wonder	2	3	65	0.9978	0.868	595.6	28.0	0.55
Cantaloupe	PMR 45	2	3	0	0.9953	0.692	585.8	1.0	0.66
Cantaloupe	PMR 45	4	3	20	0.9991	0.10	100.0	1.5	0.55
Carrot	Imperator	4	3	0	0.99	0.60	17.6	1.0	0.15
Chile pepper	Green Chile A2	2	3	39	0.9934	0.69	377.6	13.3	0.7
Cotton	SJ2	2	2	65	0.998	0.55	270.0	35.4	0.85
Cotton	Deltapine	2	1	50	0.9972	0.65	500.0	18.8	0.75
Cowpea	Blackeye #5	2	2	22	0.9816	0.96	21.3	6.87	0.59
Potato	Most varieties	4	3	18	0.99	0.494	148.3	9.21	0.75
Snapbean	Greencrop	2	3	14	0.9978	0.572	708.9	5.74	0.63
Squash	Fordhook Zucchini	4	3	0	0.9898	0.00	494.7	1.0	0.49
Sugarbeets	US H-10	2	3	0	0.9988	0.90	200.0	1.0	0.17
Sugarbeets	US H-10	4	3	0	0.9922	0.874	718.6	150.0	1.19
Sweet potato	Goldenpride	2	3	0	0.9910	0.146	1663.0	20.28	0.92
Sweet potato	Goldenpride	4	3	0	0.9965	0.79	584.5	42.7	0.91
Tomato (process)	UC82	2	3	25	0.9996	0.403	860.0	9.42	0.69
Tomato (process)	UC82	2	2	45	0.9990	0.62	1006.3	17.3	0.74
Tomato (process)	Roma	4	3	84	0.9988	0.43	544.3	108.8	1.06
Tomato (process)	Roma	2	3	20	0.9996	0.402	700.0	12.0	0.80
Tomato (process)	Niagara	2	2	35	0.9997	0.50	1154.0	30.6	0.95

NOTE: The population measurement, Pi only, is the absolute population of *M. incognita* eggs and juveniles per kg of soil (corrected for extraction efficiency) for all data presented in this paper.
* Soil index: 2 = loamy sand; 4 = loam.
† Location index: 1 = southern desert valleys; 2 = southern San Joaquin Valley; 3 = south coastal.
‡ The damage function is $y = m+(1-m)z^{Pi-T}$ for $Pi>T$, $y = 1.0$ for $Pi \le$ where 'y' is relative yield (0-1 scale), 'Pi' is the absolute preplant population of *M. incognita* eggs and juveniles per kg of soil, m is the expected minimum yield at high nematode densities, 'T' is the tolerance limit — the population level at which damage is first observed, and 'Z' is a measure of nematode pathogenicity to the plant (see text).
§ The multiplication function is $Pf/Pi = a.c.Pi^{-b}$ where 'Pf' is the final population, 'Pi' is the initial population, 'Pf/Pi' is the multiplication rate, 'a' is the maximum expected multiplication rate at low initial population levels (Pi) and 'c' and 'b' are crop and nematode-specific constants. The final population for any Pi is given by $Pf = a.c.Pi^{(1-b)}$, with a maximum level of $Pf = a.Pi$.

TABLE 2. Predicted percent relative yield of cotton and tomatoes, nematode multiplication, and final population on sandy loam soil in the southern San Joaquin Valley for various preplant population densities of root-knot nematode.

Pi*	% max. yield	Pf/Pi	Pf†
Cotton Acala SJ2			
10	100.0	270.0	2,700
20	100.0	270.0	5,400
40	100.0	270.0	10,800
60	100.0	270.0	16,200
80	98.7	230.5	18,443
100	97.0	190.7	19,071
200	89.3	105.8	21,160
500	73.8	48.6	24,278
1,000	61.9	26.9	26,938
Tomato UC82			
10	100.0	1,006.3	10,063
20	100.0	1,006.3	20,126
40	100.0	1,006.3	40,252
60	99.3	841.3	50,477
80	98.3	680.0	54,397
100	97.3	576.5	57,647
200	92.8	345.2	69,031
500	81.7	175.2	87,600
1,000	69.2	104.9	104,900

* Initial population per kg of soil
† Final population per kg of soil

the root-knot nematode in table 2 are based on the appropriate damage function parameters from table 1.

Nematode reproduction

The economic decision process based on nematode damage functions, as outlined, may maximize returns for the current year but aggravate problems in subsequent years by allowing the nematode population to increase. The single-season optimization might thus result in a different management choice than would a multiple-season optimization.

To consider multiseason optimization, one must predict the increase of the nematode population during the crop season. The size of the population increase will vary with the crop because of differences in host status to nematodes. It also will vary with the degree of competition among nematodes for available resources. The population will increase at a greater rate at low initial population densities than at high densities when crop damage may be occurring and less food is available per nematode.

The multiplication taking place during a single season can be measured by the ratio between the final and the initial population densities. If this multiplication rate is plotted against the log of the initial population density, a negative exponential relationship emerges (fig. 2 and table 1 footnote). The parameters of this model have been determined on many of the crops in locations for which damage functions have been determined.

The use of these multiplication relationships allows projection of the expected final nematode population for any given initial density on any crop (see examples, table 2). Assuming an approximate 10 percent overwinter survival, one can estimate the initial population density for the next crop. Such projections allow choice of optimum multiple-season cropping sequences (fig. 3). In the cropping sequences depicted, a poor host (blackeyes) to the cotton root-knot nematode must be grown at least two years out of three to maintain profitability when population levels are initially high. At moderate population densities, one year of rotation to the poor host is necessary. Continuous culture of susceptible crops (cotton and tomato) would be nonprofitable, even at initially low population densities. The use of nematicides in the system could also have been considered in the economic analysis. Annual monitoring of the nematode population would be advisable to reevaluate the multiseason trajectory.

Conclusions

Multiplication and damage functions provide a rational basis for nematode
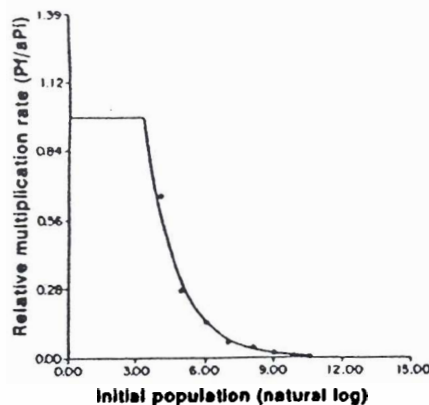
Seasonal increase in root-knot nematodes on south coast tomatoes (fig 2, left). Fig. 3, right, shows profit projections for four cropping sequences (indicated by letters), at various nematode densities. Arbitrarily selected crop values and production costs were: cotton (C), $882 and $729; blackeyes (b), $686 and $588; tomatoes (T), $1,100 and $935.

management decisions. The variability in crop environments, which influences both crops and nematodes, requires that some subjective decisions be made on the expected magnitude of damage function parameters for specific locations. The predictive capabilities of the models will improve with time and use. They now represent the analyses of data derived from some specific locations and for specific crop varieties.

A primary requirement for the use of this decision-making framework for crop management is that the nematode population be expressed in absolute terms (that is, the counts corrected for extraction efficiency) and per kilogram of soil. We are learning more about the distribution characteristics of plant-parasitic nematodes and the sampling intensity required to measure populations with acceptable precision for management decisions.

A further problem is time of sampling. Since the nematode population declines during the winter in annual cropping systems, the preplant population density estimate depends on the time the sample was taken. The damage function parameters presented are based on actual population densities at planting time. In practice, not all crops can be sampled at this time and, in fact, several management alternatives require that the decision be made somewhat before planting. Studies are investigating the rate of nematode population decline during the winter to allow projection of preplant population from a measurement at a specified time after the previous crop.

The damage functions presented were developed in experiments in which other pests and diseases were eliminated. The effect of one pest on crop growth can be intensified by the presence of other stresses, both biological and environmental. If such other stresses are anticipated in the
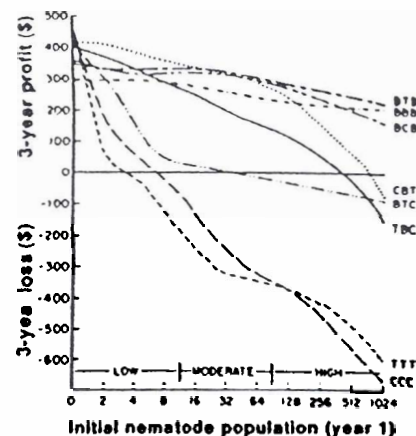
field, the predicted damage to the crop should be inflated. For example, if the *Fusarium* soil fungus is present in a cotton field, crop loss will be much more severe than that predicted by the damage function for root-knot nematodes alone.

These damage functions, further, were developed only on the basis of one nematode species. They will, without doubt, vary with the species and with the composition of the nematode community. Several approaches to dealing with these problems have been explored, including the assignment of equivalence values for other nematode species so that they can be expressed as "root-knot equivalents" and their expected contributions to the yield loss calculated.

The critical point models we have described have been used as the basis for a nematode management decision model installed on the computer network of the University of California Integrated Pest Management Project. The computer model allows testing of the relative benefits of various nematode management alternatives (nematicides, crop rotation, resistant varieties) for specified crops and plant-parasitic nematode communities. It allows adjustment of expected crop damage and nematode multiplication and survival rates based on geographic location and environmental suitability. As with the damage functions, the models will improve with further field testing and validation, but they represent a compilation of current research results and expert opinion as a basis for rational nematode management decisions.

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