Nematology—Status and Prospects: The Role of Nematology in Integrated Pest Management[1]

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Abstract: Integrated pest management (IPM) is an interdisciplinary science dealing with the development, evaluation, and implementation of pest control strategies that result in favorable economic, ecologic, and sociologic consequences. IPM has received considerable attention during the past few years, and this has led to recommendations directly related to the growth of the science of nematology. This report describes the current state of IPM in relation to the role of nematology, with special emphasis on scientific personnel requirements. All current indications are that IPM will continue to grow, very likely at an increased rate. This will place additional research, extension, and teaching demands on current nematology programs and should result in an expended resource base for nematology.

Integrated pest management (IPM) is an interdisciplinary science (4). It deals with the development, evaluation, and implementation of pest control strategies that result in favorable economic, ecologic, and sociologic consequences (1,2). IPM has received considerable attention during the past few years, including several major reviews (1,5,7,9,10,13). In his 1977 environmental message to Congress, President Carter instructed his Council on Environmental Quality (CEQ) to complete its review of IPM and recommend action designed to encourage the development and application of IPM procedures (12). IPM was also discussed in the 1979 environ-

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mental message to Congress (11). In 1977 the Secretary of the U.S. Department of Agriculture (USDA) indicated the intention "to develop, practice, and encourage the use of IPM methods, systems, and strategies that are practical, effective, and energy-efficient" (17). This report describes the current state of IPM in relation to the role of nematology, with special emphasis on scientific personnel requirements.

INTEGRATED PEST MANAGEMENT

The components of IPM programs usually include biological monitoring systems, environmental monitoring systems, pest-crop ecosystem models, production system management recommendations, and information delivery systems (2,3,6,8,15). IPM programs should be designed to optimize harmonious synchrony among the components of human societies and the natural environment (Fig. 1). This usually requires a transdisciplinary approach (4). Scientists from different disciplines must work as a team with continuous conceptual synthesis and intellectual interchange. The process should include a mutually accepted set of systems objectives developed within the general framework of the principles of systems science (the coordinated study of the structure and interactions among related entities). The majority of scientists engaged in public sector IPM activities have disciplinary backgrounds in entomology, plant pathology, nematology, or weed science. Professional economists, ecologists, sociologists, meterologists, and system scientists are also essential for successful development and implementation of IPM programs.

IPM programs must be economical and operational within the overall objectives of production systems (2). This requires proper interfacing of public sector and private sector activities. Implementation includes the following:

1) Collection and delivery of information required by the management system.
2) Employment of appropriate IPM procedures.
3) Evaluation of the impact of IPM on the production system and natural environment.
4) Use of evaluation information for selection of additional implementa-

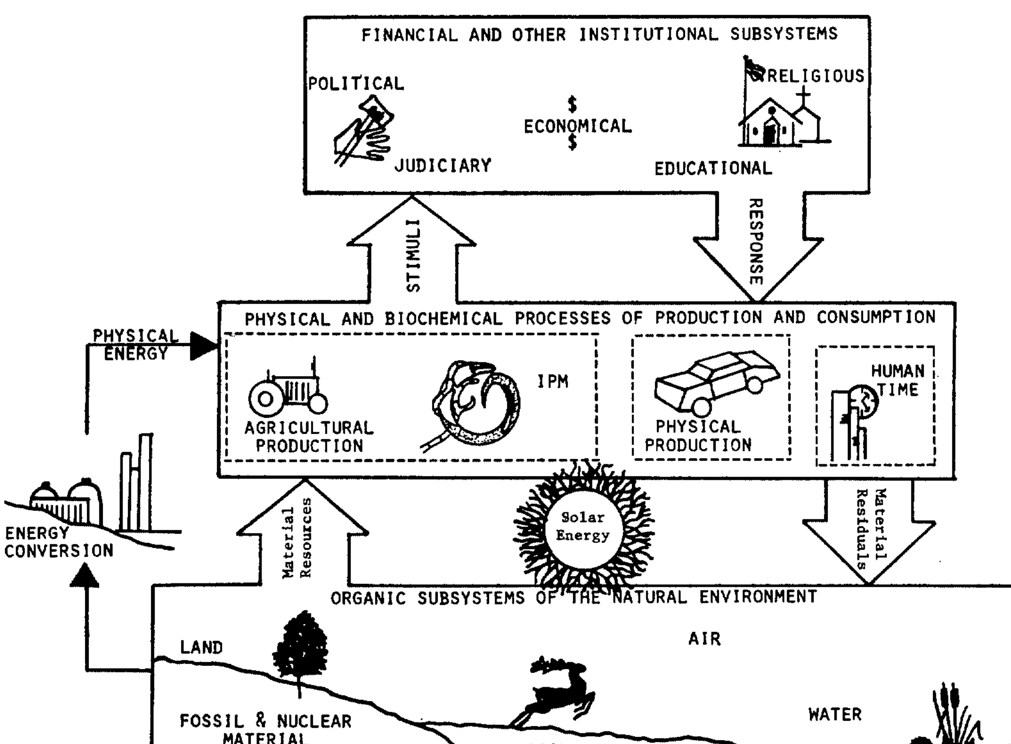

FIG. 1. Conceptual elements of the relationship between human societies and the natural environment.

tion procedures and development of future IPM programs.

The production system owner, or his representative, is usually the manager of pests at the farm or enterprise level (Fig. 2). Production enterprises may employ private consultants or custom applicators for recommendation and implementation of IPM strategies. Private enterprise should be the basis of most IPM implementation programs. Public sector involvement in IPM is most effective if the purpose is to provide district IPM information to the private sector and to maintain appropriate programs at the county, district, state, and regional levels (Fig. 2).

NEMATOLOGY RESEARCH

Nematology is a young science with a definite lack of research resources. Nematology grew rapidly between 1950 and 1965, but during the past decade in the United States, various externalities caused a decrease in the rate of growth. A number of geographical regions and agricultural disciplines have an inadequate awareness and understanding of the role of plant parasitic nematodes in agroecosystems. This is substantiated by the fact that only 60% of the Agricultural Experiment Station (AES) units responding to a recent IPM research priority survey indicated the existence of nematology programs or future research needs (9). The survey was conducted by the Intersociety Consortium for Plant Protection (ISCPP) for the Land Grant University Experiment Station Committee on Organization and Policy (ESCOP). The 27 AES units with programs in nematology reported a total of 62.0 nematology research years for 1978. This number is greater, however, than the 42.8 AES research years reported in a 1979 USDA Science and Education Administration (SEA) IPM report (15). Relatively few states in the United States have significant numbers of nematologists. In most cases, all aspects of the discipline are handled by two or three scientists. A few states have no full-time professional nematologists. The USDA SEA IPM document reported that the annual nematology research re-

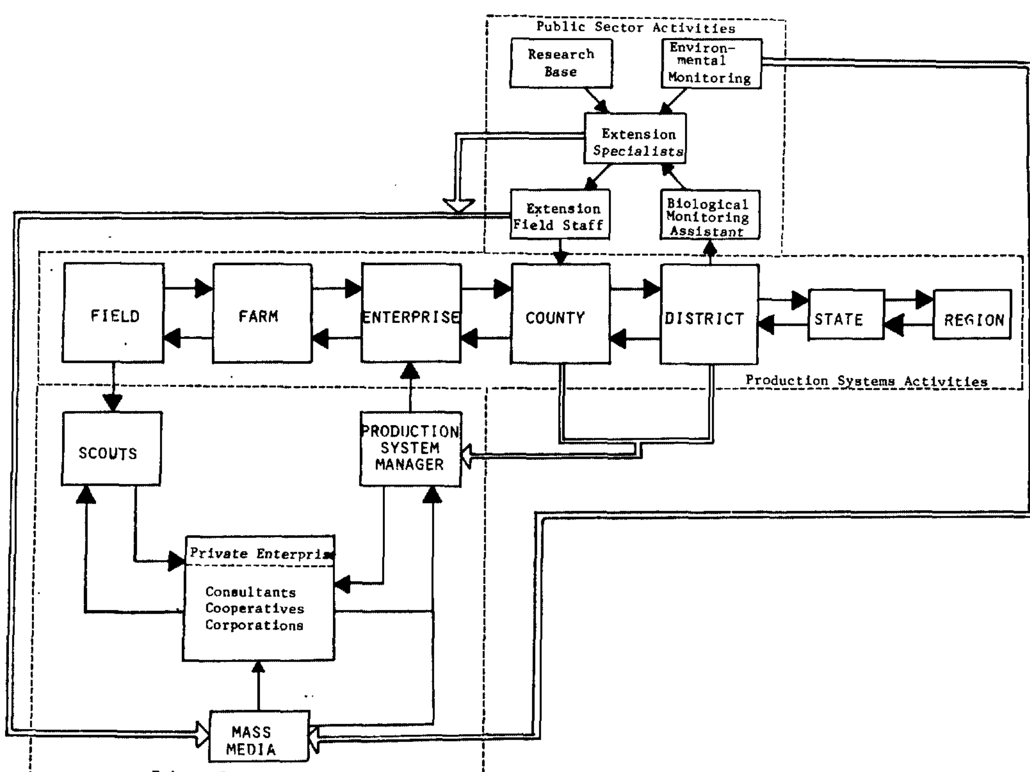

FIG. 2. Conceptual diagram of the relationship between public sector, private sector, and production systems activities associated with pest management.

sources for the United States were $4,304, 700, with $2,966,024 for AES and $1,338,676 for USDA SEA Agricultural Research (15).

The ISCPP-ESCOP IPM research priority report divided nematology research into five subdisciplines: basic biology, ecology, host-parasite relationships, management, and implementation (9). These were subdivided into 73 areas. A questionnaire was used to survey all departments with crop protection responsibilities in the U.S. 1862 Land Grant Universities and the directors of research in the U.S. Colleges of 1890. The questionnaire was completed by 153 chairmen, a return rate of 87%. Priority research areas were calculated from the survey results using a priority index $PI = N(19 - \overline{X}P)$, where 19 was the number of priority options on the questionnaire, P the priority assigned to each areas, and $\overline{X}$ the sum of the priority numbers divided by N, the number of mentions.

Research needs exist in all areas of nematology interfacing with IPM (9). The most important research need during the next decade is in the area of basic nematode biology, with special emphasis on population dynamics (Table 1). This is followed in descending order of priority by research in other aspects of nematode ecology, development of population management procedures suitable for use in IPM programs, pest-crop ecosystem modeling and host-parasite relationships, and pest management implementation. Since greater understanding of the fundamental biology is needed before significantly improved nematode population management strategies can be incorporated into IPM programs, eight high-priority biology areas were identified (Table 1). Progress in this area should be greatly enhanced by increased interest in selected nematodes as models for basic research on metazoan systems. Nematology input outside agriculture in genetics, developmental biology, gerontology, biophysics, physiology, behavior, and endocrinology should significantly enhance the science of nematology.

Proper characterization of interactions among nematodes and their environment is

TABLE 1. Agricultural Experiment Station nematology research priorities resources and needs.*

Subdiscipline and area	Priority index	Scientific years		
		Current	1980-84	1985-89
Nematode biology	100	15.6	34.6	47.9
1. Population dynamics	316	6.6	13.0	19.1
2. Survival	125	0.9	2.2	3.4
3. Taxonomy	109	2.4	5.6	8.4
4. Developmental Biology	77	1.2	3.3	4.8
5. Behavior	65	1.0	2.3	2.9
6. Physiology	61	2.3	4.3	5.3
7. Geographical distribution	27	0.2	0.7	0.8
8. Genetics	20	1.0	3.2	3.2
Nematode ecology	72	4.3	13.5	20.1
1. Physical & chemical parameters	150	1.5	5.3	8.3
2. Biological parameters	131	2.4	5.6	7.0
3. Environmental monitoring systems	39	0.1	1.0	1.7
4. Biological monitoring systems	31	0.3	1.6	3.1
Management procedures	61	29.2	62.0	92.3
1. Resistant cultivars	95	6.5	19.6	33.7
2. Chemical nematicides	71	15.0	22.7	29.4
3. Biological	64	4.4	8.9	14.1
4. Cultural	45	3.3	10.8	15.1
5. Regulatory	0	0.0	0.0	0.0
Host-parasite relationship modeling	56	6.8	18.0	27.4
System implementation	51	6.1	12.1	17.9
Total		62.0	140.2	205.6

*Data from the Intersociety Consortium for Plant Protection—Experiment Station Committee on Organization and Policy. Integrated Pest Management Research Priority Report, 1979.

important for IPM. High priority was given to the research on the influence of physical, chemical, and biological parameters (Table 1). A much lower priority, however, was given to the development of environmental and biological monitoring systems, indicating that research in nematode ecology must be interdisciplinary and will depend on concomitant development in various aspects of nematode biology and appropriate technology transfer from numerous physical, chemical, and biological sciences.

Development of new and improved nematode management procedures was identified as an important general research category (Table 1). Increased research on nematode resistant cultivars was a very high priority. It may be possible to reorient existing AES personnel to fulfill some of the research needs in this area. The need for the development of diverse and selective chemicals for management of plant-parasitic nematodes ranked second among the specific nematology research priorities. It is important that this include the necessary interdisciplinary interaction for development of multispectrum pesticides suitable for use in IPM programs. A number of recent developments indicate that biological control of plant-parasitic nematodes may have an important role in future IPM programs and that natural enemies commonly reduce nematode populations to a greater extent than previously documented. A significant increase in research on biological control of nematodes is essential. Research on the role and use of crop rotation is very important. No AES units reported research plans for the area of regulatory nematology.

Historically, interactions between plant-parasitic nematodes and their hosts have been researched in the subdisciplines of host-parasite relationships and pathogenesis. The complexity of this topic requires a systems approach for the development of pest-crop ecosystem models and supporting biology research. While considerable effort has been devoted to nematode-host relationships during the past three decades, the role of systems modeling is relatively new. Three components of this research category (development of nematode damage thresholds, economic thresholds, and pest-crop ecosystem models) were identified as important research priorities. The need for interfacing nematode and crop models is recognized by nematologists; however, there are few current plans to utilize nematology resources for crop modeling. This means it will be necessary for nematologists, system scientists, and whole-plant physiologists to work in an interdisciplinary mode to develop pest-crop ecosystem, production system, and crop loss assessment models. The commitment necessary for this research objective goes far beyond nematology and agricultural research. Current institutional constraints to interdisciplinary activities are often substantial and difficult to alleviate.

EXTENSION NEMATOLOGY

IPM can be implemented most successfully if adequate resources are available for demonstrations, state-wide educational programs, and appropriate production system service programs. In the United States this is the responsibility of the Cooperative Extension Service (CES). During the past 8 years USDA SEA Federal Extension has provided resources for implementation of IPM. These amounted to $4,400,000 in 1978. Institutional constraints have prevented uniform development of extension nematology programs throughout the United States, and nematology has not been represented in all of the federally sponsored CES IPM programs. This situation has improved significantly during the past few years and will continue to do so within the limits of existing and future disciplinary personnel. In 1978 the CES Committee on Organization and Policy (ECOP) outlined an 8-year national extension IPM program (7). It was estimated that annual resources of $58,140,000 are necessary for proper implementation of public sector IPM activities in the United States.

ACADEMIC INSTRUCTION

The Land Grant University Resident Instruction Committee on Organization and Policy (RICOP) sponsored a conference on IPM teaching in 1972 and conducted a survey of IPM teaching programs in 1979 (14). During this 7-year period, the number of universities with academic instruction programs in IPM increased from 9 to 39 and interdisciplinary course development progressed slowly. Thirteen institutions reported M.S.-level programs in IPM. These programs have significantly increased the number of students subjected to formal training in nematology, and the trend is likely to continue.

SUMMARY

Significant research priorities exist in all areas of nematology interfacing with IPM. The greatest problem is the lack of scientific resources for nematology to become extensively involved in IPM. M.S., Ph.D., and post-doctoral programs in nematology are adequate for maintenance of the current state of the science; however, they are not designed to meet the projected needs of nematology in conjunction with IPM. It must be assumed that increases in IPM activities will result in corresponding needs for increases in research, extension, and academic instruction programs in nematology.

In 1979 the USDA SEA report divided public sector IPM activities into the following categories (16):

1) *Basic research*—generates the knowledge required to understand pests and to develop control strategies for individual pests and pest complexes.
2) *Control components research*— develops specific control techniques and related technologies.
3) *IPM level I systems research*—consists of research to integrate two or more control techniques to manage one or more species of the same pest groups, such as *Pratylenchus penetrans* and *Meloidogyne hapla*. Such programs are referred to as integrated nematode management systems.
4) *IPM level II systems research*—consists of research to integrate two or more management systems for two or more pest groups, such as nematodes and insects, or nematodes and weeds.
5) *Extension level I*—delivers technology in a systematic manner for managing pests of one group, such as insects, weeds, diseases, or nematodes, on one or more commodities.
6) *Extension level II*—delivers advanced management systems for pests belonging to two or more groups, such as nematodes and insects, or nematodes and weeds, on one or more commodities.
7) *Academic instruction*—development and support of university-level programs of academic instruction for IPM.

These seven categories were used for the ISCPP-ESCOP recommendations and modified for this report (Table 2).

TABLE 2. Land Grant university scientist year (SY) increases recommended for nematology, 1980-1989.*

IPM Topics†	SY (noncumulative) 1980/84	1985/89
Basic research		
Nematode biology	5	6
Nematode ecology	5	6
Host-parasite relationships	5	6
Taxonomy	2	3
Ontogeny	2	2
Behavior	2	2
Physiology	2	2
Genetics	2	2
Subtotal	(25)	(29)
Control components research		
Resistance	8	10
Chemical	4	5
Biological	4	5
Cultural	4	5
Regulatory	0	0
Subtotal	(20)	(25)
IPM level I research		
Ecology	4	4
Control strategy	10	15
Implementation	1	1
Subtotal	(15)	(20)
IPM level II research		
Pest-crop ecosystem models	4	4
Implementation	1	1
Subtotal	(5)	(5)
IPM level I extension‡	10	5
IPM level II extension‡	5	5
IPM academic instruction‡	15	10
Scientist year totals	95	99
Resource requirements ($\$1.0 \times 10^6$)	9.5	9.9

*Developed from data presented in the 1979 IPM Research Priority Report developed by the Intersociety Consortium for Plant Protection for the Experiment Station Committee on Organization and Policy.

†Topics correspond to the USDA SEA IPM Coordination Team Report of Feb. 2, 1979, entitled "Integrated Pest Management Program."

‡Recommendation estimated for this publication.

It can be assumed that by 1989 institutions with limited nematology resources and needs will require 3.0 scientist years (SY) allocated to nematology, with 2.0 for research, 0.5 for teaching, and 0.5 for extension. This minimal level of research would allow approximately 0.5 SY for IPM Systems Level II Research. Institutions with fewer resources in nematology may have difficulty in developing balanced IPM programs. This increase would result in a twofold increase in United States Land Grant University nematology resources by 1984 and a threefold increase by 1989. Although these recommendations may not be realized in the near future, it is significant to note that nematology is well represented in the national planning process for IPM research, extension, and academic instruction priorities. The IPM reports discussed here, plus the 1979 IPM reports issued by the Office of Technology Assessment (United States Congress) and the United States President's Council on Environmental Quality, should result in increased resources for the science of nematology (10,5).

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