A Guide to the Development of a Plant Nematology Program

J. N. Sasser
C. C. Carter
A. L. Taylor

INTERNATIONAL MELOIDOGYNE PROJECT
IMP
Contract No. AID/ta-c-1234

A Cooperative Publication
of
The Department of Plant Pathology
North Carolina State University
and
The United States Agency for
International Development
Raleigh, North Carolina
1982

Designed and Printed by
North Carolina State University Graphics
Raleigh, North Carolina 27650
United States of America

For information on the availability of
this publication, write to
Dr. J. N. Sasser, Department of Plant Pathology
North Carolina State University
Raleigh, N.C. 27650, U.S.A.

PREFACE

The primary objective of this guide is to assist International *Meloidogyne* Project cooperators and other nematologists, especially in third world countries, in the initial design and implementation of a plant nematology program. For many developing countries, programs in nematology are just beginning, and as these grow, thought and planning will be necessary if they are to be effective. Nematologists, when asked to develop a research, teaching and/or extension program in areas where little previous work has been done, may have difficulty in deciding where to start. Furthermore, preliminary assessment of the problems may appear so overwhelming as to cause frustration and discouragement. Oftentimes, graduates from major universities who may have had at their disposal sophisticated equipment and facilities to conduct their thesis research find that such conveniences are not available in their new position. Attempts to acquire similar facilities and equipment for their own laboratories may not be successful because of the lack of funds thereby causing further disillusionment and delay. Such frustration is understandable, but can be handled once the scientist views his own situation realistically and devotes his time to "getting on with the job" despite economic constraints. The first objective of this guide is to help the beginning nematologist with various aspects of the new job, whether it be in coping with the scope and intricacies of the nematode problems or with restrictions imposed on the program by limited resources.

A second objective is to outline available management options for initiating a nematode control program. Advising growers and encouraging them to adopt known and proven practices, such as appropriate cropping systems and resistant cultivars, develop grower confidence and provide immediate relief to those growers experiencing serious losses due to nematode diseases. At the same time, the research nematologist can consider his own situation and build a sound, long-term program of teaching and research. In this guide, we have attempted to outline certain approaches which have been successful and, if followed, will lead to rapid program development with optimum use of available resources.

The authors wish to thank the following who have reviewed this guide and have made valuable contributions: Dr. D. F. Ritchie, Dr. C. J. Nusbaum, Dr. T. T. Hebert, Dr. D. L. Strider, Dr. P. Jatala, Dr. C. A. Main, and Dr. G. B. Lucas.

TABLE OF CONTENTS

Page

Part I. Aspects of Program Development 1
Introduction 1
Orientation & Organization 1
Evaluation of Nematode Problems 3
Development of Research, Teaching, and Extension Programs 3
Planning for Future Needs 4

Part II. Nematode Control 7
Introduction 7
Chemical Control 7
Safety Precautions 7
Economics of nematicides 7
Seedbed treatment 7
Land Management & Cultural Practices 8
Crop rotation 8
Fallow 10
Resistant cultivars 11
Time of planting & harvesting 11
Use of nematode-free planting stock 11
Sanitation 11
Physical Control 11
Desiccation 11
Barriers 11
Heat 12
Flooding 12
Regulatory Control 12
Integration of Control Measures 12

General References 14

Appendix I. Nematology Textbooks 16

Appendix II. Nematode Identification References 17

Appendix III. Professional Societies for Nematologists 18

Appendix IV. Nematological or Related Journals 18

Appendix V. Nematicide Suppliers 19

Part I. Aspects of Program Development

Introduction

Compared with most agricultural and plant protection sciences, plant nematology is relatively new. During the last 40 years, nematology has progressed from relative infancy to a full-fledged science. Nearly all of this technical growth has occurred in developed nations. Now, however, nematology is receiving increased attention in developing countries. This interest is especially timely because workers in these countries can now benefit from the accumulated experience and findings of nematologists in developed nations. Such experience and advice form the basis for the plan outlined in this guide.

Orientation & Organization

If a plant nematology program is to be realistic and functional, the developer must first assess available resources, both human and financial, and reconcile these with immediate goals. Limited financial resources actually can be an advantage in that they require the establishment of priorities from the onset, thereby ensuring more effective organization. Well-established plant nematology laboratories in the developed countries are expensive to maintain. However, labs that are just getting started can be productive with a small staff and only the basic necessities. Costly, technical equipment can be acquired later as the program grows and as needs increase.

Define goals. To define immediate and long-range goals, the program developer must be familiar with his own job description. The emphasis placed on teaching, research, and extension or ministry-of-agriculture duties generally indicates the relative amount of time and resources to be devoted to any one project. Newly established plant nematology programs usually emphasize diagnostic and advisory services but also may include some research, teaching, and/or additional extension responsibilities.

Assess resources. In developing countries, specialized scientific equipment can be difficult to obtain. Usually it must be ordered from other countries with delays of several months, even if funds are available. The nematologist, therefore, must improvise and build much of his equipment with supplies available locally. In warm climates, for example, all essential functions of a glasshouse can be served by a screenhouse with fine mesh nylon or metal screens to keep out birds and insects. Tin cans with holes punched in the bottoms for drainage substitute satisfactorily for clay or plastic pots. Plastic bags can also be used for this purpose.

Library facilities, another important resource, govern access to pertinent research findings (Peachey, 1969). Basic nematology texts and abstract journals useful in a professional library are listed in Appendices I and IV. Reprints acquired gradually help build a specialized personal library.

Meet agriculturists. Professional contacts with various agriculturists, growers, extension or ministry-of-agriculture personnel and researchers at agricultural institutes prove valuable for exchange of ideas and information. The experience of these persons can be drawn upon to define and resolve problems and devise solutions. Professional organizations and journals also function in this regard (Appendices III & IV). Not only should societies of nematologists be considered, but also those International Agriculture Research Centers (IARC's) with emphasis on important crops or the specific geographic region (Table 1).

Table 1. International Agriculture Research Centers (IARC's)

IARC Names/Locations	*Principal Research Programs*
Centro Internacional de Agricultura Tropical (CIAT) Apartado Aéreo 6713 Cali, Colombia	Cassava, field beans, rice, tropical pastures
Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) Londres 40 Mexico D.F., Mexico	Maize, wheat
Centro Internacional de la Papa (CIP) Apartado 5969 Lima, Peru	Potato
International Board for Plant Genetic Resources (IBPGR) Crop Ecology and Genetic Resources Unit Food and Agriculture Organization of the United Nations Via delle Terme de Caracalla 00100 Rome, Italy	Collection, evaluation, utilization of genetic resources of important species
International Center for Agriculture Research in the Dry Areas (ICARDA) P.O. Box 114/5055 Beirut, Lebanon	Farming systems, cereals, food legumes (broad bean, lentil, chickpea), forage crops
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Patancheru P.O. Andhra Pradesh 502 324, India	Chickpea, pigeonpea, pearl millet, sorghum, groundnut, farming systems
International Rice Research Institute (IRRI) P.O. Box 933 Manilla, Philippines	Rice
International Institute of Tropical Agriculture (IITA) P.O. Box 5320 Ibadan, Nigeria	Farming systems, maize, rice, roots and tubers (sweet potato, cassava, yam), food legumes (cowpea, lima bean, soybean)
West Africa Rice Development Association (WARDA) E. J. Roye Memorial Building P.O. Box 1019 Monrovia, Liberia	Rice
Asian Vegetable Research & Development Center (AVRDC) P.O. Box 42, Shanhua Tainan 741, Taiwan Republic of China	Tomato, Chinese cabbage, sweet potato, mungbean, soybean

Evaluation of Nematode Problems

After objectives and available resources have been assessed, the next step is determination of the nature and magnitude of current nematode problems and of their economic importance. A general census of the plant-parasitic nematode communities in the area can be accomplished by systematic surveys of the various crops and soil types, using suitable sampling and assay techniques. Various keys, monographs and other kinds of literature on species identification, and professional collaborators are available for verification. The relative economic importance of each problem identified will then determine where the proper emphasis should be placed.

The nematologist must spend as much time as possible in the field to learn which crops are showing symptoms of nematode attack and how they are being damaged. Lack of equipment and facilities should not deter this effort. Much useful data can be gathered with improvised or borrowed equipment.

A survey for nematodes requires a minimum of equipment, including a spade to dig roots, plastic bags to put them in, tags to identify the samples, and a plastic bucket to carry them. To examine roots and classify degree of infection in the laboratory, a nematologist needs only a table, a chair, two or three buckets and a water supply. Both dissecting and compound microscopes are necessary for identification of the species present. Extra care should be expended in selection of microscopes since these instruments represent a large percentage of the initial investment and must remain in good condition for many years. The equipment necessary for sampling and nematode identification has been outlined in several useful publications (see Appendix I, especially Ayoub, 1980; Filipjev, 1941; Hooper, 1969; and Taylor, 1967).

Several factors should be considered in the initiation of a survey (Main and Proctor, 1980). Before work begins, the objectives of the survey must be defined. For a nematode problem that is regional in scope, a pilot survey may be conducted to provide a working data base. The advice and cooperation of a statistician with prior experience in sample surveys should be enlisted. This assistance will be most valuable if the statistician is given a tour of diseased fields and allowed to view first hand the cropping pattern and nature of the problem. If possible, local crop specialists can also be encouraged to become involved in the gathering of data for the survey. In such cases, training sessions in sample survey methods can be conducted for these personnel.

Once available information on each nematode problem has been compiled, the problems are ranked according to the economic value of the host crop and the estimated yield loss due to the pest. Possible steps in a determination of economic importance include the following:

1) Field and lab work necessary to identify the disease agent and the degree of crop infection;
2) Identification and quantification of losses including yield reduction, loss of crop quality, and detrimental residual effects in soil or seed;
3) Conversion of losses into economic terms;
4) Consideration of available management options and their degree of effectiveness;
5) Estimation of costs and benefits;
6) Comparison of costs and benefits with those incurred under alternative management strategies.

For guidance in this subject, Grainger (1967), Society of Nematologists (1971), Khan (1972), Carlson and Main (1976), and Barker and Olthof (1976) can be consulted.

Development of Research, Teaching, and Extension Programs

Research. Once the plant nematology problems have been accurately diagnosed, a research plan emphasizing the most urgent needs can be developed. Host range studies, tests for cultivar resistance, nematicide-efficacy trials, and phytotoxicity studies can all be conducted independently. These areas of research can be strengthened substantially by formation of regional cooperative projects in association with other intra-country agricultural scientists. Collaboration with such specialists usually suggests even more areas for research. Work with plant breeders in the development of resistant cultivars, with pathologists in determination of disease complexes, and with other scientists and knowledgeable growers in cropping-systems research can be particularly rewarding cooperative endeavors.

Teaching. The principal task of a new nematologist is to instruct a diverse group of people. Scientific workers in other disciplines, supervisors and administrators often have had little or no training in nematology. In the early stages of program development, few people in the country may have any accurate idea of the magnitude of the problem. Farmers are often unaware that nematodes exist. Seminars conducted for colleagues, and field demonstration plots oriented toward supervisors, administrators, and farmers, help fill this educational need.

As the program becomes established, demand for introductory, college-level courses may develop. A class in nematode disease development, symptomatology, and management principles is often a good starting point. More in-depth material dealing with subjects such as nematode taxonomy, ecology and physiology can follow as numbers of students increase. In-country training of new nematologists is a worthwhile long-term goal, dependent primarily on the importance of the existing problem. Publication of training material and development of a graduate teaching program may be dependent upon the ability of the program developer to acquire grant support.

Extension. The transfer of useful scientific and technical information to the grower for practical use in crop production is known in some parts of the world as agricultural extension. In other parts, the same duties are performed by Ministries of Agriculture. Important tactics include short courses on diagnostic and sampling techniques, as well as field trials that demonstrate the benefit derived from control practices. As teaching methods, these two are "tried and true."

Education must start with fundamentals. Farmers must be educated as to what nematodes are and how to recognize symptoms of nematode damage in their field. Demonstration that nematode damage is related to reduced plant growth, quality, and yields is necessary. Even brief, simple bulletins published in farm journals or newspapers help accomplish this purpose. Pamphlets and other communication materials, illustrated and preferably translated into the more widely used local dialects, will speed up dissemination of information.

Severe problems with root-knot and other nematodes have often gone unrecognized for years until field experiments with nematicides have clearly shown nematicidal treatments to result in spectacular increases in crop yields. Even if use of nematicides is not profitable on particular farms, field demonstrations indicate the seriousness of the problem and stimulate interest in alternative control methods. Eventually, such demonstrations can lead to large changes in farming procedures which profit farmers and the community in general.

Demonstration plots are recommended to be at least 10 meters wide and 50 meters long, but size may have to be adapted to suit local conditions. At least two adjacent plots should be reserved for each crop: one to be treated with nematicide, the other to remain untreated. Both plots should be carefully plowed, planted, fertilized and cultivated alike, by means of the best local methods.

When conspicuous differences in growth between treated and untreated plots appear, the demonstration is ready for display. Just before harvest, the plots can be shown again. Complete yield data taken at harvest should indicate quality and value as well as quantity.

Demonstration plots can also display the relative effectiveness of tolerant and resistant cultivars in tolerating or reducing nematode damage. Such tests should be conducted in untreated, nematode-infested field plots. Adjacent plots should be planted with local susceptible varieties for comparison.

Farmers must be educated to use management methods on their own farms and must be given every form of assistance to make these efforts as profitable and as easy as possible. Local sources of resistant cultivars and of effective nematicides may need to be established. In addition, publication of basic identification and pest management information reinforced with photographs gives farmers additional confidence in diagnosing and managing the pest.

Identification and advisory service. In many cases, development of an identification and/or advisory service forms an integral part of a plant nematology program (Barker and Nusbaum, 1971). The diagnosis of problem fields, identification of nematodes, and the recommendation of basic management strategies are the essential aspects of this undertaking. Fortunately, the equipment to set up a diagnostic lab can be relatively simple. Expensive elutriators or centrifuges are not essential to the process of nematode extraction. However, good compound and stereoscopic dissecting microscopes are indispensable. Ayoub (1980) and Hooper (1969) have itemized basic laboratory equipment and procedures for nematode extraction processes.

Some of the common nematode species likely to be economically important on selected crops are listed in Table 2. Important reference material for use in nematode identification appears in Appendix II. Part II of this publication outlines and briefly addresses each of the various proven methods of control. The availability of diagnostic lab facilities and how the farmers can best benefit from them should be well advertised.

Planning for Future Needs

The continued growth and success of the established program reflects the professional success of its leader, who must keep abreast of recent research as well as publish personal findings. Membership in professional societies (Appendix III) provides excellent opportunities to pursue both of these activities. In addition, it is important to be familiar with professional journals (Appendix IV) and to strive to have work published in them. Sabbaticals or study leaves can give stimulating insights into current research conducted elsewhere. By keeping abreast of current research, the program leader can best guide future nematological studies in the region.

Table 2. Some Economically Important Plant-Parasitic Nematodes of Selected Crops

ALFALFA

Ditylenchus dipsaci
Meloidogyne hapla
Meloidogyne incognita
Meloidogyne javanica
Pratylenchus spp.
Paratylenchus spp.

BANANA

Radopholus similis
Helicotylenchus multicinctus
Meloidogyne spp.
Pratylenchus spp.
Rotylenchus spp.

BEANS & PEAS

Meloidogyne spp.
Heterodera spp.
Belonolaimus spp.
Helicotylenchus spp.
Rotylenchulus reniformis
Paratrichodorus anemones
Trichodorus spp.

CASSAVA

Rotylenchulus reniformis
Meloidogyne spp.

CEREALS

Anguina tritici (Emmer, rye, spelt, wheat)
Bidera avenae (oat, wheat)
Ditylenchus dipsaci (rye, oat)
Subanguina radicicola (oat, barley, wheat, rye)
Meloidogyne naasi (barley, wheat, rye)
Pratylenchus spp. (oat, wheat, barley, rye)
Paratylenchus spp. (wheat)
Tylenchorhynchus spp. (wheat, oat)

CITRUS

Tylenchulus semipenetrans
Radopholus similis
Hemicycliophora arenaria
Pratylenchus spp.
Meloidogyne spp.
Belonolaimus gracilis

CLOVER

Meloidogyne spp.
Heterodera trifolii

COCONUT

Rhadinaphelenchus cocophilus

COFFEE

Meloidogyne spp.
Pratylenchus coffeae
Pratylenchus brachyurus
Radopholus similis
Rotylenchulus reniformis
Helicotylenchus spp.
Hemicriconemoides spp.
Xiphinema spp.

CORN

Pratylenchus spp.
Belonolaimus spp.
Trichodorus spp.
Dolichodorus heterocephalus
Hoplolaimus galeatus
Xiphinema spp.

COTTON

Meloidogyne incognita
Belonolaimus longicaudatus
Rotylenchulus reniformis
Hoplolaimus galeatus
Pratylenchus spp.
Tylenchorhynchus spp.

GRAPES

Xiphinema spp.
Pratylenchus spp.
Meloidogyne spp.

GRASSES

Pratylenchus spp.
Longidorus spp.
Paratrichodorus christiei
Xiphinema spp.
Ditylenchus spp.
Meloidogyne spp.

PEANUT

Pratylenchus spp.
Meloidogyne hapla
Meloidogyne arenaria
Criconemella spp.

PINEAPPLE

Paratrichodorus christiei
Criconemella spp.
Meloidogyne spp.
Rotylenchulus reniformis
Helicotylenchus spp.
Pratylenchus spp.
Paratylenchus spp.

POTATO

Globodera rostochiensis
Globodera pallida
Meloidogyne spp.
Pratylenchus spp.
Trichodorus primitivus
Ditylenchus spp.
Paratrichodorus spp.
Nacobbus aberrans

RICE

Aphelenchoides besseyi
Ditylenchus angustus
Hirschmanniella spp.
Heterodera oryzae
Meloidogyne spp.

SMALL FRUITS

Meloidogyne spp.
Pratylenchus spp.
Xiphinema spp.
Longidorus spp.
Paratrichodorus christiei
Aphelenchoides spp. (strawberry)

SOYBEAN

Heterodera glycines
Meloidogyne incognita
Meloidogyne javanica
Belonolaimus spp.
Hoplolaimus columbus

SUGAR BEET

Heterodera schachtii
Ditylenchus dipsaci
Meloidogyne spp.
Nacobbus aberrans
Trichodorus spp.
Longidorus spp.
Paratrichodorus spp.

SUGARCANE

Meloidogyne spp.
Pratylenchus spp.
Radopholus spp.
Heterodera spp.
Hoplolaimus spp.
Helicotylenchus spp.
Scutellonema spp.
Belonolaimus spp.
Tylenchorhynchus spp.
Xiphinema spp.
Longidorus spp.
Paratrichodorus spp.

TEA

Meloidogyne spp.
Pratylenchus spp.
Radopholus similis
Hemicriconemoides kanayaensis
Helicotylenchus spp.
Paratylenchus curvitatus

TOBACCO

Meloidogyne spp.
Pratylenchus spp.
Tylenchorhynchus claytoni
Globodera spp.
Trichodorus spp.
Xiphinema americanum
Ditylenchus dipsaci
Paratrichodorus spp.

TOMATO

Pratylenchus spp.
Meloidogyne spp.

TREE FRUITS

Pratylenchus spp. (apple, pear, stone fruits)
Paratylenchus spp. (apple, pear)
Xiphinema spp. (pear, cherry, peach)
Cacopaurus pestis (walnut)
Meloidogyne spp. (stone fruits, apple, etc.)
Longidorus spp. (cherry)
Criconemella spp. (peach)
Tylenchulus spp. (olive)

Part II. Nematode Control

Introduction

Newly established nematology programs often must cope with a pressing need for a pest diagnosis and advisory service. To help meet the advisory needs, this section brings together current control information: a general outline of the basic methods plus a selected list of references which provides specific, up-to-date information. Such material equips the program developer to give general advice concerning management options. Of course with time, pest management strategies specifically adapted to the geographic area and its crops will be developed, but until then, general knowledge on the subject will help bridge the information gap.

Chemical Control

Since 1950, nematicide efficacy and mode of action have been studied intensely and hundreds of papers have been published on the subject. Many nematicides kill nematodes in the soil in a very short time; others interfere with the feeding habits of nematodes, eventually causing them to starve to death. Table 3 contains a list of nematicides which are available commercially. Names and addresses of manufacturers or distributors appear in Appendix V. All these chemicals have been extensively tested, both by the manufacturer and by experiment station personnel; all are effective if used properly. Since application rates vary with climate, soil type, crop, etc., general guidelines for recommending dosages are not possible. The most thorough way to select a nematicide is to obtain information on its effectiveness and ability to increase yields of the principal crop in a particular region. Taylor and Sasser (1978b) present practical information about nematicide application.

Nematicide usage can pose problems in areas of low rainfall. In regions where planting dates must coincide with rainfall, fields are often too dry to be treated beforehand. However, if chemicals are applied after the rainfall, the necessary delay in planting to avoid phytotoxicity could lead to crop failure due to insufficient soil moisture at planting.

Safety precautions. The nematicide label outlines application rates and methods, gives safety precautions and presents steps to follow in the case of an accident. It also lists crops on which the nematicide may be used. The label should always be read carefully before a nematicide is applied.

Nematicides are poisons and must be handled carefully. They should never come into contact with the skin or even with clothing. If this should occur, the clothing should be removed and the skin washed thoroughly. Contaminated clothing should not be worn again until it has been carefully cleaned. Fumes of liquid nematicides are also poisonous; therefore, liquids should be transferred, measured or handled only in open air, preferably with a gentle breeze blowing. Eating, drinking, and smoking should not be done when applying nematicides.

Cans, bottles and drums which have contained nematicides should not be used for any other purpose. They should be washed with water and the water spread over the soil. The containers should then be broken, bent, punctured, or otherwise made useless before being discarded in a safe place.

Economics of nematicides. Use of nematicides requires a comparatively large investment before the crop is planted. The grower must first ascertain whether the investment will be profitable. Calculations can be made as follows:

1. Cost of sufficient nematicide to treat the field is obtained from the local distributor. The costs of applying the nematicide to the field include expenditures for labor, equipment, fuel, etc. Also to be considered are land rental fees and/or taxes. The total cost of these items constitutes the investment.

2. Use of nematicides for field application is economically justified if the probable yield value increase sufficiently exceeds the investment. Detailed information on determination of the economic justifiability of disease management practices is given by Carlson and Main (1976). If the expected yield increase is only minimal, the prudence of the expenditure is doubtful. Adverse weather, phytophagous insects, and plant diseases all threaten crop production and can result in partial crop failure and loss of the investment in nematicide. High value crops such as fruits and vegetables give more return for the investment than do field crops such as beans or peas. Barker and Olthof (1976) and Elliott *et al.* (1982) provide guidelines for approximation of economic thresholds of selected nematode species.

Seedbed treatment. Though not always economical for general field usage, nematicides are nearly always profitable when applied to seedbeds. Plants grown in disinfested soil and transplanted into an infested field have a better chance of surviving and yielding well than plants grown from seed in infested

Table 3. Nematicides available on world markets

Common Name	Registered Trade Name Manufacturer	Chemical Name	Formulation and Classification
Aldicarb	(TEMIK) Union Carbide Corp.	2-methyl-2-(methylthio) propionaldehyde 0-(methylcarbamoyl) oxime	Granular nematicide/insecticide
Carbofuran	(FURADAN) FMC Corporation (FURADAN) Mobay Chem. Corp. (CURATERR) Bayer AG	2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate	Granular and flowable nematicide/insecticide
Chloropicrin	(CHLOR-O-PIC) Great Lakes Chem. Corp.	trichloronitromethane	Liquid fumigant nematicide/insecticide
1,3-D	(TELONE) Dow Chem. Co.	1,3-dichloropropene and related hydrocarbons	Liquid fumigant nematicide
DD Mixture	(DD) Shell Dev. Co. (VIDDEN-D) Dow Chem. Co. (VORLEX) NOR-AM Agricultural Products	1,3-dichloropene and 1,2-dichloropropane and related hydrocarbons	Liquid fumigant nematicide
EDB	(SOILBROM) Great Lakes Chemical Corp. (TERR-O-CIDE) Great Lakes Chemical Corp.	ethylene dibromide ethylene dibromide + chloropicrin	Liquid fumigant nematicide Liquid fumigant nematicide
Ethoprop	(MOCAP) Mobil Chem. Co.	0-ethyl S,S-dipropyl phosphorodithioate	Granular or emulsifiable liquid nematicide/insecticide
Fenamiphos	(NEMACUR) Mobay Chem. Corp. (NEMACUR) Bayer AG	ethyl 4-(methylthio)-m-tolyl isopropyl-phosphoramidate	Granular or emulsifiable liquid nematicide
Fensulfothion	(DASANIT) Mobay Chem. Corp. (DASANIT) Bayer AG (TERRACUR P) Bayer AG	0,0-diethyl 0-[p-(methylsulfinyl) phenyl] phosphorothioate	Granular nematicide
Methyl bromide	(DOWFUME MC-2) Dow Chem. Co. (BROM-O-GAS) Great Lakes Chemical Corp.	bromomethane + chloropicrin	Gas fumigant nematicide
Oxamyl	(VYDATE) E. I. duPont de Nemours and Co.	methyl N',N'-dimethyl-N-[(methylcarbamoyl) oxy]-1-thiooxamimidate	Granular or water-soluble liquid nematicide/insecticide
Terbufos	(COUNTER) American Cyanamid Co.	S-[[(1,1-dimethylethyl)thio]methyl] 0,0-diethyl phosphorodithioate	Granular nematicide/insecticide
Metam-Sodium	(VAPAM) Stauffer Chemical Co.	sodium N-methyldithiocarbamate	Water-soluble solid nematicide/fungicide/herbicide

soil. This management tactic not only increases yields, but also aids by deterring the spread of new infestations. As a result, investment costs would have to increase sharply before seedbed treatment would become unprofitable.

Land Management & Cultural Practices

Crop rotation. Rotations for nematode management are designed to permit the growth of a main crop as often as possible. This crop is the one most profitable to the farmer, or the one he prefers to grow for other reasons. If the main crop is infected by nematodes, crop rotation will help lower populations if the target species (species toward which management practices are aimed) has a narrow host range. To check the multiplication of nematodes by this method, it is necessary to grow highly resistant or non-host crops until natural causes decrease the nematode population by a large percentage, usually about 80% (Table 4). The main crop can then be profitably grown, but not for more than one year at a time. If continuous cropping occurs, populations of nematode, insect, disease, and weed pests will increase, thereby reducing yields and profits. Crop rotation, however, often cannot be used to control nematodes with broad host ranges, e.g. root lesion (*Pratylenchus* spp.) and lance (*Hoplolaimus* spp.) nematodes, because few non-hosts exist.

Table 4. Rotation Crops Effective Against Various Nematodes

Nematode	Non-host or resistant crops	Reference
Belonolaimus	tobacco, watermelon, *Crotalaria*	Holdeman & Graham, 1953
Criconemoides ornatus	cotton, soybean	Johnson *et al.*, 1975
Ditylenchus destructor	buckwheat, carrot, lupine	Efremenko & Burshtein, 1975
Ditylenchus dipsaci	barley, maize, vetch, oat, carrot, beet	Vladimirova, 1975
Globodera pallida	oat	Jatala, 1982
Globodera rostochiensis	oat	Brodie, 1976
Helicotylenchus	pangolagrass, tobacco, cassava	Smith & Thomas, 1969
Helicotylenchus multicinctus	pangolagrass	Stoyanov, 1973
Heterodera schachtii	onion, bean	Griffin, 1977
Hoplolaimus columbus	sweet potato	Lewis & Smith, 1976
Meloidogyne arenaria		
race 1	cotton	Taylor & Sasser, 1978a
race 2	cotton, peanut, pepper	*Ibid.*
Meloidogyne hapla	cotton, watermelon, corn; nearly all Gramineae, except *Zizania* (wild rice), and all Amaryllidaceae, except onion, are resistant.	*Ibid.* Ruelo, 1981
Meloidogyne incognita	barley	Carter & Nieto, 1975
race 1	peanut, cotton	Taylor & Sasser, 1978a
race 2	peanut, cotton	*Ibid.*
race 3	peanut	*Ibid.*
race 4	peanut	*Ibid.*
Meloidogyne javanica	cotton, peanut, pepper, strawberry	*Ibid.*
Meloidogyne naasi	potato, oat	Gooris & D'Herde, 1976
	corn	Gooris & D'Herde, 1977
Nacobbus aberrans	corn, wheat, oat, barley, alfalfa, clover, onion	Weischer & Steudel, 1972
Paratrichodorus christiei	peanut, soybean	Johnson *et al.*, 1975
Pratylenchus coffeae	peanut	Gotoh, 1976
Pratylenchus indicus	sesame, black mustard, barley, wheat, black gram	Prasad & Rao, 1978
Radopholus	tobacco, pangolagrass, cassava, grapefruit, sugar cane	Smith & Thomas, 1969
Radopholus similis	pineapple, papaya, passion fruit, sweet potato, litchi, radish	Milne & Keetch, 1976

Table 4 continued

Nematode	Non-host or resistant crops	Reference
Rotylenchulus	bermudagrass, dallisgrass, oat, corn & peanut	Birchfield & Brister, 1962
Rotylenchulus reniformis	corn, sorghum	Castillo, Bajet, & Hardwood, 1976
Xiphinema americanum	sorghum, rye	Riedel & Powell, 1977
Xiphinema diversicaudatum	hops, spring barley, potato, sugar beet, cabbage, winter wheat, winter beans	Cotten, 1977

Innumerable experiments have clearly shown that crop rotations of three or four years effectively manage populations of most nematode species. However, a few species are so persistent and long lived that management by rotation would permit the susceptible crop to be planted only once every seven or eight years. In such cases, other management strategies give quicker, more thorough results.

The selection of crops which can be profitably grown during the other two or three years of the cropping sequence often poses a problem. Studies of root-knot nematode population dynamics indicate that in a three-year rotation, the crop preceding the main crop should be a non-host or the most resistant cultivar available. The succeeding crop can be less resistant, but should not be moderately or highly susceptible.

In a region where beans are the main crop, and where cotton and peanut are acceptable alternate crops, the rotation might be beans the first year, followed by cotton the second year, peanut the third, and beans again the fourth year. This rotation would be effective if the field is infested with *Meloidogyne incognita* race 1 or 2 or with *M. javanica*. This example illustrates the process of selecting alternate crops for rotation with the main crop. Variations are numerous, and other factors must be considered, including insect pests, other disease pathogens, country, climate, markets and market prices for alternate crops, placement of crops into seasonal work schedules, and availability of labor and farm equipment.

Because of the numerous variables involved, detailed instructions for planning rotations cannot be written. However, the following general principles can be given.

1. Before appropriate rotation crops can be selected, the nematode species present must be known.
2. Efforts should be directed toward the most important pest species or race present.
3. The susceptible main crop should not be planted in the same field more often than once in three years.
4. Resistant crops chosen for use in a rotation should deter reproduction and development of the target nematode, improve or maintain soil quality, have a vigorous growth habit, and be profitable for production (Bessey, 1911).
5. The most resistant crop (the one that best prevents development and reproduction of the parasite) in the rotation should precede the main crop. The reaction of the chosen rotation crop to major insect pests and disease pathogens should be taken into account.
6. As the rotation proceeds, roots of all crops should be examined periodically during the growing season and again after harvest. While plants are still in the field, examinations can be made by digging a few plants at random and checking for galls, cysts, or other evidence of nematode infection. Degree of infection should be estimated; in the case of *Meloidogyne*, the gall or egg-mass index serves this purpose. If the degree of infection does not decrease when resistant crops are grown, a possible reason may be that another nematode species, experiencing less competition, has become more abundant than the target species. It could also be that the resistant cultivar in use does not have sufficient resistance to the target pest. A nematode identification lab can resolve this issue by determining which species are present.
7. The rotation should be altered as necessity and experience dictates.

Fallow. Fallow periods in cropping sequences can also reduce nematode populations. In temperate climates, fields left fallow during the growing season cause the grower to lose money. In the tropics, however, fallow periods often form an inherent part of the cropping system. If infected roots of previous crops are harvested or plowed and destroyed, fallow periods in such climates can substantially lower nematode populations.

The principle behind fallowing can be applied to site selection for a seedbed. Areas where no crops have been grown for several years, or even more suitable where animal pens were once located, are excellent choices for seedbeds. Soils of such sites are likely to contain only very low populations of plant-parasitic nematodes.

Resistant cultivars. In the past, resistant cultivars have been difficult to obtain, but plant breeders and seed suppliers have come to realize the existence of a sizeable and ready market. Crop cultivars resistant to common species of root-knot nematodes have been gleaned from professional literature and listed by Sasser and Kirby (1979). Though useful, this publication does not take into account the existence of host races of *Meloidogyne* spp., so additional testing is advisable. Names and addresses of some prominent seed suppliers around the world have also been provided by Sasser and Kirby (1979).

Nematologists in developing countries should test available cultivars in experimental plots to evaluate resistance to nematodes and adaptation to local climates. Prior to a recommendation for large-scale cultivation, the cultivar should be grown on preselected, representative sites so that its "total performance" in the area of intended introduction can be assessed. After introduction, a resistant cultivar should never be grown for more than two seasons in succession in the same field. Since fields typically harbor several nematode species, growth of a resistant cultivar for more than two seasons may cause rapid increase of the non-target species.

Time of planting and harvesting. Activities of many nematode species depend on soil temperature. Low temperatures, especially those of fall and winter in temperate climates, limit or prevent nematode activity. Therefore, crops which will grow at low temperatures, e.g. spring potatoes or sugar beets, may escape serious damage if planted early in spring before nematodes become active.

Use of nematode-free planting stock. This method is an effective means of limiting nematode populations and the spread of infestation. Cost is relatively low, yet many growers continue to use nematode-infected transplants or seed pieces. Probably the greatest damage occurs not to the plants on which the nematodes were introduced but to crops grown in subsequent years in the newly infested field. For methods of ensuring nematode-free planting stock, the paragraphs entitled seedbed treatment, barriers, heat, and/or desiccation can be consulted.

Sanitation. This term covers a wide range of cultural practices, including weed control, crop residue destruction and discriminate movement of farming equipment between heavily infested and uninfested fields. In monocultures, elimination of weedy hosts can play an important role in reducing populations of plant-parasitic nematodes. In mixed cropping systems, however, where many different types of crops are planted together, the presence of weeds is likely to be less crucial since a range of hosts is already available. A bibliography of weeds which act as reservoirs for various nematode species has been compiled by Bendixen, Reynolds, and Riedel (1979).

The root systems of certain crops will continue to live for several weeks or months after harvest. In temperate climates, plant-parasitic nematodes present in or around the roots may survive and potentially lead to the development of an additional generation or two between the end of harvest and the time the plant is killed by frost. In the tropics, nematodes may survive in crop plant residue from planting season to planting season. In either case, populations of some nematodes can be reduced if the stalks are cut and the root systems turned out soon after harvest. Two control principles are operative in this practice: 1) that of destroying host plants by cutting stalks and uprooting plants, thus preventing further reproduction of nematodes, and 2) that of killing large numbers of nematodes concentrated in the soil around the root system and in the roots through the drying action of the sun and wind.

Physical Control

Desiccation. Nematode larvae and eggs die quickly when exposed to sunlight and drying. Sunshine will kill nematodes in soil which is spread in a thin layer to dry. Also, in climates where there is no rainfall for several months, some nematode populations can be reduced (not eliminated) by plowing several times during the dry season. The danger of wind erosion must be considered in such cases.

Barriers. Small-scale production of nematode-free seedlings of perennial plants can be accomplished by planting the seedlings in plastic bags of about 100-cm^3 capacity filled with uninfested soil. The bags should not be placed on the soil surface, but on boards supported about 20 cm above the soil. In this way, reinfestation can be prevented. Plastic bags placed on the soil often develop small breaks through which nematodes from the soil can enter.

Heat. Excellent reduction in populations of plant-parasitic nematodes can be achieved through the use of heat. Steam, released from pipes buried 20- to 40-centimeters deep in soil, has long been used to sterilize soil in glasshouses, seedbeds, and bins of potting soil. Though effective if properly used, steam is expensive due to the present cost of fuel. As a result, it has been replaced in many cases by treatment with methyl bromide which is nearly as effective, simpler, and less expensive. Steam can be economical when it is easily available from a heating or power installation, but the equipment costs too much to be installed for nematode control only.

Hot water treatment of bulbs, root crops, or rootstocks infected with endoparasitic nematodes is an effective disinfection technique. Essential enzymes in nematodes are inactivated at temperatures near 50°C, and the nematodes die. At such temperatures, plant enzymes are not destroyed if the hot water treatment is properly applied. Each plant-nematode combination has its own temperature-time requirements and treatment must be done fairly precisely, or disinfection will not be complete. Specific details of treatments have been worked out for several crops (Table 5). Since results vary, valuable material should not be treated with hot water without preliminary trials.

Dry heat can also be used to reduce nematode populations. Burning of wood or brush on infested planting sites is a cultural practice which operates by this principle. Unfortunately, burning of this type destroys valuable organic matter in the soil. However, small quantities of soil can be sterilized over a fire in an open metal pan.

Flooding. Plant-parasitic nematodes which normally live in fields where the soil is seldom saturated do not infect plants when flooding occurs. Even so, a large proportion of the nematodes do not die until the soil has been flooded for several months. Though effective, management by this method is possible only if the soil surface is level and an abundant water supply is available, as in rice paddies.

Regulatory Control

Numerous attempts have been made to prevent the introduction of nematodes into countries or provinces by means of quarantine. Quarantines are established by legislative action in parliaments, etc., and usually give quarantine authorities power to make and enforce regulations to accomplish the purpose. Such regulations usually prohibit bringing infected plants into protected areas where similar crops might become infected.

To be effective, a quarantine must employ people trained to recognize symptoms of nematode infection, find nematodes, and identify them in the laboratory. Symptoms of root-knot and cyst nematodes are comparatively easy to recognize. Other species require microscopic examination, which is time consuming and expensive.

Integration of Control Measures

Utilization of the best combination of available management strategies for the pest complex at hand (nematodes, insect pests, disease organisms, weeds, etc.) constitutes an integrated crop protection system. Resistant cultivars, crop rotation, pesticides, and sanitary and cultural practices can all be employed to the best possible advantage. An integrated management strategy prevents the excessive buildup of any single nematode, insect, or disease population and minimizes the development of pest resistance to any single tactic.

Integrated pest management systems require flexibility and depend upon the specific pest problem and locally available management options. A fixed set of recommendations may keep a pest complex in check for a limited period of time, but as the pest population shifts, recommendations will have to change also. Therefore, system development takes into account many factors including the species and race(s) of pests present, the availability of resistant host plants, the longevity of the pest, and the crops, cropping systems, and climate of the geographical region. The end result is a management strategy tailored to fit the unique circumstances of each pest situation.

Table 5. Hot-water immersion treatments for control of nematodes in planting material

Planting Material	Nematode Species	Temp (°C)	Time (min.)	Reference
Citrus spp. (nursery stock)	*Tylenchulus semipenetrans*	49	10	Stoyanov & Gandoy, 1973
	Tylenchulus semipenetrans	46.7	10	Ayoub, 1980
	Tylenchulus semipenetrans	45	25	*Ibid.*
(bare-rooted nursery stock)	*Radopholus similis*	50	10	*Ibid.*
Dioscorea spp. (yam tubers)	*Meloidogyne* spp.	51	30	Hawley, 1956
	Scutellonema bradys	50-55	40	Adeniji, 1977
Fragaria chiloensis (strawberry roots)	*Meloidogyne* spp.	52.8	5	Goheen & McGraw, 1954
	Pratylenchus penetrans	49.4	7	Ayoub, 1980
	Ditylenchus dipsaci	48	15	Bobrysheva, 1972
	Ditylenchus dipsaci	50-52	5-7	Trushechkin, 1971
	Aphelenchoides fragariae	46-47	13-15	Trushechkin, 1971
Humulus lupulus (hop rhizomes)	*Meloidogyne* spp.	51.7	5	Maggenti, 1962
Ipomoea batatas (sweet potato)	*Meloidgyne* spp.	46.8	65	Nat. Acad. Sci., 1968
	Meloidogyne spp.	50	3-5	Martin, 1970
Musa spp. (banana corms)	*Meloidogyne incognita*	55	20	Gupta, 1975
	Helicotylenchus multicinctus	55	20	*Ibid.*
	Pratylenchus brachyurus	55	20	*Ibid.*
	Radopholus spp.	55	20	Decker, *et al.*, 1971
	Pratylenchus spp.	55	20	*Ibid.*
	Helicotylenchus spp.	55	20	*Ibid.*
Oryza sativa (rice seeds)	*Aphelenchoides besseyi*	52	10	Nandakumar, *et al.*, 1976
Prunus avium (cherry rootstocks)	*Meloidogyne* spp.	50-51.1	5-10	Nyland, 1955
Prunus persica (peach rootstocks)	*Meloidogyne* spp.	50-51.1	5-10	Nyland, 1955
Rubus spp.	*Pratylenchus penetrans*	46.7	15	McElroy, 1973
Solanum tuberosum (Irish potatoes)	*Meloidogyne* spp.	46-47.5	120	Martin, 1968
	Pratylenchus coffeae	52	15-20	Gotoh & Ohshima, 1965
	Pratylenchus coffeae	53	10-15	*Ibid.*
Vitis vinifera (grape rootstocks)	*Meloidogyne* spp.	52.7	5	Meagher, 1960
	Meloidogyne spp.	54.4	3	*Ibid.*
	Meloidogyne spp.	47.8	30	Lear and Lider, 1959
	Meloidogyne spp.	50	10	*Ibid.*
	Meloidogyne spp.	51.7	5	*Ibid.*
	Meloidogyne spp.	52.8	3	*Ibid.*
	Xiphinema index	52	5	Moller & Fisher, 1961
	Xiphinema index	52	10	Vega, 1978
Zingiber officinale (ginger rhizomes)	*Meloidogyne* spp.	45-55	10-50	Colbran & Davis, 1969
	"nematodes in general"	50	10	Fiji Dep. Agr., 1971

General References

Adeniji, M. O. 1977. Studies on some aspects of control of the yam nematode, *Scutellonema bradys*. Acta Horticulture 53:249-256.

Ayoub, S. M. 1980. Plant Nematology: An Agricultural Training Aid (revised). Nema Aid Publications, Sacramento, Calif. 195 pp.

Barker, K. R. and C. J. Nusbaum. 1971. Diagnostic and advisory programs, pp. 281-301 *In* Plant Parasitic Nematodes, Vol. I, ed. B. M. Zuckerman *et al.* Academic Press, N.Y. 345 pp.

Barker, K. R. and T. H. A. Olthof. 1976. Relationships between nematode population densities and crop responses. Annu. Rev. Phytopathol. 14:327-363.

Bendixen, L. E., D. A. Reynolds, and R. M. Riedel. 1979. An annotated bibliography of weeds as reservoirs for organisms affecting crops. I. Nematodes. Ohio Agr. Res. and Development Center Res. Bull. 1109. 64 pp.

Bessey, E. A. 1911. Root knot and its control. U.S. Dep. Agr. Bur. Plant Indus. Bull. 217. 39 pp.

Birchfield, W. and L. R. Brister. 1962. New hosts and nonhosts of reniform nematode. Plant Dis. Reporter 46:683-685.

Bobrysheva, M. N. 1972. [Production of healthy planting material of strawberry in the Krasnodar territory.] Sbornik Nauchnykh Rabot Nauchno-Isseldovatel'skogo Zonal'nyogo Instituta Sadovodstva Nechernozemnoi i Polosy 5:155-159.

Brodie, B. B. 1976. Managing population densities of *Heterodera rostochiensis*. J. Nematol. 8:280.

Carlson, G. A. and C. E. Main. 1976. Economics of disease-loss management. Annu. Rev. Phytopathol. 14:381-403.

Carter, W. W. and S. Nietro, Jr. 1975. Population development of *Meloidogyne incognita* as influenced by crop rotation and fallow. Plant Dis. Reporter 59:402-403.

Castillo, M. B., N. B. Bajet, and R. R. Hardwood. 1976. Nematodes in cropping patterns. I. Population of *Rotylenchulus reniformis* on successively monocultured crops. Philippine Agriculturist 59:288-294.

Colbran, R. C. and J. J. Davis. 1969. Studies of hot-water treatment and soil fumigation for control of root-knot in ginger. Queensland J. Agr. Anim. Sci. 26:439-445.

Cotten, J. 1977. Effect of annual and perennial cropping regimes in microplots on the population density and vertical distribution of *Xiphinema diversicaudatum* and on soil porosity. Ann. Appl. Biol. 86:397-404.

Decker, H., R. Casamayor Gracia, and M. E. Rodriguez Fuentes. 1971. Nuevas investigaciones sobre tratamentos de los rizomas del platano con agua caliente y nematicidas contra nematodos parasitos. Revista Agropecuaria 3:27-35.

Efremenko, V. P. and Kh. S. Burshtein. 1975. [Penetration routes of *Ditylenchus destructor* Thorne, 1945, into potatoes and agro-technical control of this infection.] Byulleten' Vsesoyuznogo Instituta Gel'mintologii im K. I. Skryabina No. 15:47-51.

Elliott, A. P., T. C. Edens, G. W. Bird and D. L. Haynes. 1982. Dynamics of economic thresholds for *Pratylenchus penetrans* associated with dry bean production. PM Tech. Report 34, Michigan State University, East Lansing, MI. 35 pp.

Fiji Dep. Agr. 1971. Report for the year 1970. Fiji Parliament. 34 pp.

Goheen, A. C. and J. R. McGrew. 1954. Control of endoparasitic root nematodes in strawberry propagation stocks by hot-water treatments. Plant Dis. Reporter 38:818-826.

Gooris, J. and C. J. D'Herde. 1976. Situation hivernale de *Meloidogyne naasi* Franklin et lutte par rotation cultural. Bull. OEPP 6:289-296.

Gooris, J. D. and C. J. D'Herde. 1977. Study on the biology of *Meloidogyne naasi* Franklin 1965. Ghent, Belgium; Ministry of Agriculture, State Agr. Res. Centre. 115 pp.

Gotoh, A. 1976 [A note on the control of injurious nematodes by crop rotation in Kyushu.] Proc. Assoc. for Plant Protection of Kyushu 22:123-126.

Gotoh, A. and Y. Ohshima. 1965. [Studies on the ecology and control of the root-lesion nematode, *Pratylenchus coffeae* (Zimmerman) on potato.] Japan Agr. Forest. and Fishery Res. Council & Nagasaki Agr. & Forest Exp. Sta. Bull. 5. 77 pp.

Grainger, J. 1967. Economic aspects of crop losses caused by diseases, pp. 55-98 *In* FAO Symposium on Crop Losses. FAO, Rome.

Griffin, G. D. 1977. Influence of nonhost cultivars on the population dynamics of *Heterodera schachtii* and growth of sugarbeets. J. Nematol. 9:269-270.

Gupta, J. C. 1975. Evaluation of various treatments and varietal resistance for the control of banana nematodes. Haryana J. Hort. Sci. 4:152-156.

Hawley, W. O. 1956. Hot-water treatment for the control of root-knot nematodes on *Dioscorea floribunda*. Plant Dis. Reporter 40:1045-1046.

Holdeman, Q. L. and T. W. Graham. 1953. The effect of different plant species on the population trends of the sting nematode. Plant Dis. Reporter 37:497-500.

Hooper, D. J. 1969. Extraction and handling of plant and soil nematodes, pp. 20-36 *In* Nematodes of Tropical Crops, ed. J. E. Peachey. Commonwealth Bureau of Helminthology, St. Albans, Herts, England, Tech. Communication No. 40. 355 pp.

Jatala, P. 1982. (Personal communication). International Potato Center (CIP), Lima, Peru.

Johnson, A. W., C. C. Dowler, and E. W. Hauser. 1975. Crop rotation and herbicide effects on population densities of plant-parasitic nematodes. J. Nematol. 7:158-168.

Khan, M. H. 1972. Economic aspects of crop losses and disease control, pp. 1-16 *In* Economic Nematology, ed. John M. Webster. Academic Press, London. 563 pp.

Lear, B. and L. A. Lider. 1959. Eradication of root-knot nematodes from grapevine rootings by hot water. Plant Dis. Reporter 43:314-317.

Lewis, S. A. and F. H. Smith. 1976. Host plants, distribution, and ecological associations of *Hoplolaimus columbus*. J. Nematol. 8:264-270.

Maggenti, A. R. 1962. Hot water treatment of hop rhizomes for nematode control. California Agr. 16:11-12.

Main, C. E. and C. H. Proctor. 1980. Developing optimal strategies for disease-loss sample survey, pp. 118-123 *In* Crop Loss Assessment, Proceedings of E. C. Stakman Commemorative Symposium. Univ. Minnesota Agr. Exp. Sta. Misc. Pub. 7.

Martin, G. C. 1968. Control of *Meloidogyne javanica* in potato tubers and *M. hapla* in the roots of young rose bushes by means of heated water. Nematologica 14:441-446.

Martin, W. J. 1970. Elimination of root-knot and reniform nematodes and scurf infections from rootlets of sweetpotato plants by hot water treatment. Plant Dis. Reporter 54:1056-1058.

McElroy, F. D. 1973. Control of *Pratylenchus penetrans* in raspberry root cuttings. Plant Dis. Reporter 57:492-495.

Meagher, J. W. 1960. Root-knot nematode of the grape vine. Victoria Dep. Agr., J. Agr. 58:419-423.

Milne, D. L. and D. P. Keetch. 1976. Some observations on the host plant relationships of *Radopholus similis* in Natal. Nematropica 6:13-17.

Moller, W. J. and J. M. Fisher. 1961. Hot water treatment effective for nematode infested grapevine rootings. J. Dep. Agr. S. Australia 65:38.

Nandakumar, C., J. S. Prasad, Y. S. Rao, and J. Rao. 1976. Investigations on the white-tip nematode (*Aphelenchoides besseyi* Christie, 1942) of rice (*Oryza sativa* L.). Indian J. Nematol. 5:62-69.

National Academy of Sciences. 1968. Principles of plant and animal control, Vol. 4: Control of plant-parasitic nematodes. NAS Pub. 1696. 172 pp.

Nyland, G. 1955. Killing root-knot nematodes in some stone fruit tree root stocks. Plant Dis. Reporter 39:973-975.

Peachey, J. E. 1969. Sources of information in plant nematology, pp. 346-355 *In* Nematodes of Tropical Crops, ed. J. E. Peachey. Commonwealth Bur. Helminthol., St. Albans, Herts, England, Tech. Comm. 40. 355 pp.

Prasad, J. S. and Y. S. Rao. 1978. Influence of crop rotations on the population densities of the root lesion nematode, *Pratylenchus indicus* in rice and rice soils. Annales de Zoologie Ecologie Animale 10:627-633.

Riedel, R. M. and C. C. Powell. 1977. Chemical control of *Pratylenchus penetrans* and cultural control of *Xiphinema americanum* in *Rhamnus frangula*. J. Nematol. 9:281.

Ruelo, J. S. 1981. Host range studies of *Meloidogyne hapla* in Taiwan. Plant Dis. 65:500-501.

Sasser, J. N. and M. F. Kirby. 1979. Crop cultivars resistant to root-knot nematodes, *Meloidogyne* species, with information on seed sources. Coop. Pub. of the Dep. of Plant Pathology, North Carolina State University, and the United States Agency for International Development, Raleigh, N.C. 24 pp.

Smith, L. R. and W. H. Thames. 1969. Plantain nematodes and preliminary crop-rotation studies for their control in the Dominican Republic, pp. 84-88 *In* Proc. Symp. on Trop. Nematol., 29 Nov. - 1 Dec., 1967, Univ. of Puerto Rico.

Society of Nematologists Committee on Crop Losses. 1971. Estimated crop losses from plant-parasitic nematodes in the United States. Soc. of Nematol. Spec. Pub. No. 1. 7 pp.

Stoyanov, D. 1973. Control de los nematodos parasitos del platano por medio de rotaciones y sus duración en tierra sin hospederos. Serie Agricultura, Academia de Ciencias de Cuba 20:1-8.

Stoyanov, D. and P. Gandoy. 1973. Algunos aspectos bioecologicos de *Tylenchulus semipenetrans* y sus posibilidades de control. Revista de Agricultura, Academia de Ciencias de Cuba 6:18-27.

Taylor, A. L. and J. N. Sasser. 1978a. Biology, identification and control of root-knot nematodes (*Meloidogyne* species). Coop. Pub. of the Dep. of Plant Pathology, North Carolina State University, and the United States Agency for International Development, Raleigh, N.C. 111 pp.

Taylor, A. L. and J. N. Sasser. 1978b. Experimental and agronomic use of nematicides. Coop. Pub. of the Dep. of Plant Pathology, North Carolina State University, and the United States Agency for International Development, Raleigh, N.C. 20 pp.

Trushechkin, V. G. 1971. [Major aspects of soft fruit growing in the central zone of the USSR.] Sbornik Nauchnykh Rabot Nauchno-Issledovatel'skogo Zonal'nyogo Instituta Sadovodstva Nechernozemn i Polosy 3:28-42.

Vega, E. 1978. Replantation des vignobles et désinfection des sols en Argentine. Bull. de l'O.I.V. 51:250-262.

Vladimirova, L. A. 1975. [Susceptibility of plants to infection with stem nematode.] Vestnik

Sel'skokhozyaistvennoi Nauki Kazakhstana 18:46-50.
Weischer, B. and W. Steudel. 1972. Nematode diseases of sugar-beet, pp. 49-65 *In* Economic Nematology, ed. J. M. Webster. Academic Press, New York. 563 pp.

APPENDIX I

Nematology Textbooks

Ayoub, S. M. 1980. Plant Nematology: An Agricultural Training Aid (revised). Nema Aid Publications, Sacramento, Calif. 195 pp.

Bird, A. F. 1971. The Structure of Nematodes. Academic Press, New York. 318 pp.

Caveness, F. E. 1974. A Glossary of Nematological Terms, 2nd edition. Internat. Inst. Trop. Agr. (IITA), Ibadan, Nigeria. 83 pp.

Chitwood, B. 1975. An Introduction to Nematology. University Park Press, Maryland. 334 pp.

Christie, J. R. 1959. Plant Nematodes: Their Bionomics and Control. Florida Agr. Exp. Sta., Gainesville. H. & W. B. Drew Co., Jacksonville, Fla. 256 pp.

*Crofton, H. D. 1966. Nematodes. Hutchinson & Co. Ltd., London. 160 pp.

Croll, N. A. (ed.). 1976. The Organisation of Nematodes. Academic Press, London. 439 pp.

Croll, N. A. and B. E. Matthews. 1977. Biology of Nematodes. John Wiley & Sons, New York. 201 pp.

Dropkin, V. H. 1980. Introduction to Plant Nematology. John Wiley & Sons, Inc., New York. 293 pp.

*Filipjev, I. N. and J. H. Schuurmans Stekhoven. 1941. A Manual of Agricultural Helminthology. E. F. Brill. Leiden, Holland. 878 pp.

*Goodey, J. B. 1963. Soil and Freshwater Nematodes. John Wiley & Sons, Inc., New York. 544 pp.

Goodey, J. B., M. T. Franklin, and D. J. Hooper. 1965. The Nematode Parasites of Plants Catalogued Under Their Hosts, 3rd ed. Commonwealth Agr. Bureaux, Farnham Royal, Bucks, England. 214 pp.

Grasse, P. O. (ed.). 1965. Traite de Zoologie. Anatomie, Systématique, Biologie (volume 4, 2nd & 3rd fascicules). Masson & Cie., Paris. 1497 pp. (In French)

s'Jacob, J. J. and J. V. Bezooijen. 1970. A Manual for Practical Work in Nematology. Internat. Agr. Centre, Wageningen, Holland. 66 pp.

*Jenkins, W. R. and D. P. Taylor. 1967. Plant Nematology. Reinhold Publ.Corp., New York. 270 pp.

Lamberti, F. and C. E. Taylor (eds.). 1979. Root-knot Nematodes (*Meloidogyne* species) Systematics, Biology and Control, Academic Press, London. 477 pp.

Maggenti, A. 1981. General Nematology. Springler-Verlag, New York. 372 pp.

Mai, W. F. and H. H. Lyon. 1975. Pictorial Key to Genera of Plant-parasitic Nematodes. Comstock Publ. Assoc., Ithaca, N.Y. 219 pp.

National Academy of Sciences. 1968. Principles of plant and animal control, Vol. 4: Control of plant-parasitic nematodes. NAS Pub. 1696. 172 pp.

Nicholas, W. L. 1975. The Biology of Free-living Nematodes. Clarendon Press, Oxford. 219 pp.

*Paramonov, A. A. 1962 (translated 1968). Plant-parasitic Nematodes, ed. K. Skrjabin. Israel Program for Scientific Translations Ltd., Jerusalem.

Peachey, J. E. (ed). 1969. Nematodes of Tropical Crops. Commonwealth Bur. Helminthol. St. Albans, Herts, England, Tech. Comm. 40. 355 pp.

*Sasser, J. N. and W. R. Jenkins (eds.) 1960. Nematology—Fundamentals and Recent Advances with Emphasis on Plant Parasitic and Soil Forms. The Univ. of North Carolina Press, Chapel Hill. 480 pp.

Smart, G. C., Jr. and V. G. Perry (eds.). 1968. Tropical Nematology. Univ. of Florida Press, Gainesville. 152 pp.

Southey, J. F. (ed.). 1978. Plant Nematology. Ministry of Agriculture, Fisheries and Food Tech. Bull. 7. Her Majesty's Stationery Office, London. 440 pp.

Tarjan, A. C. and B. E. Hopper. 1974. Nomenclatorial Compilation of Plant and Soil Nematodes. Society of Nematologists. 419 pp.

*Taylor, A. L. 1967. Introduction to research on plant nematology. An FAO guide to the study and control of plant-parasitic nematodes. Rome: Food and Agriculture Organization of the United Nations. 133 pp.

*Taylor, A. L. 1968. Introducción a la nematologia vegetal aplicada. Roma: Organización de las Naciones Unidas para la Agricultura y la Alimentación. 131 pp.

Taylor, A. L. and J. N. Sasser. 1978. Biology, Identification and Control of Root-knot Nematodes (*Meloidogyne* species). Coop. Pub. of Dep. Plant Pathology at North Carolina State Univ. and the U. S. Agency for International Development. NCSU Graphics, Raleigh, N.C. 111 pp. (Soon available in Spanish.)

---

* These references (and perhaps an additional few) are out of print; however, they should be available for reference in most major libraries.

*Thorne, G. 1961. Principles of Nematology. McGraw-Hill Book Co., Inc., New York. 553 pp.
*Wallace, H. R. 1963. The Biology of Plant Parasitic Nematodes. Edward Arnold Ltd., London. 280 pp.
Wallace, H. R. 1973. Nematode Ecology and Plant Disease. Crane Russak & Co., London. 228 pp.
Webster, J. M. (ed.). 1972. Economic Nematology, Academic Press, New York. 563 pp.
Zuckerman, B. M., W. F. Mai, and R. A. Rohde (eds.). 1971. Plant Parasitic Nematodes, 2 Vols. Academic Press, New York. 345 & 347 pp.
Zuckerman, B. M. and R. A. Rohde (eds.). 1981. Plant Parasitic Nematodes, Vol. 3. Academic Press, New York. 508 pp.

APPENDIX II

References—Identification

Allen, M. W. 1955. A review of the nematode genus *Tylenchorhynchus*. Univ. California Pub. Zool. 61:129-165.
Canto-Saenz, M. and M. M. de Scurrah. 1976. Races of the potato cyst nematode in the Andean region and a new system of classification. J. Nematol. 8:281-282.
Castillo, M. B. and T. T. Reyes. 1972. Philippine soil nematodes: inventory, classification and key to their identification. Philippine Phytopathol. Soc. 57 pp.
Colbran, R. C. 1971. Studies of plant and soil nematodes. 15. Eleven new species of *Radopholus* Thorne and a new species of *Radopholoides* de Guiran (Nematoda: Tylenchoidea) from Australia. Queensland J. Agr. Anim. Sci. 27:437-460.
Corbett, D. C. M. 1969. *Pratylenchus pinguicaudatus* n. sp. (Pratylenchinae: Nematoda) with key to the genus *Pratylenchus*. Nematologica 15:550-556.
Dasgupta, D. R., D. J. Raski, and S. A. Sher. 1968. A revision of the genus *Rotylenchulus* Linford and Oliveira, 1940 (Nematoda: Tylenchidae). Proc. Helminthol. Soc. Washington 35:169-192.
Eisenback, J. D., H. Hirschmann, J. N. Sasser, and A. C. Triantaphyllou. 1981. A guide to the four most common species of root-knot nematodes (*Meloidogyne* species) with a pictorial key. Coop. Pub. of the North Carolina State Univ. Dep. of Plant Pathology and Genetics and the U.S. Agency for Internat. Development. Raleigh, N.C. 48 pp.
Geraert, E. 1965. The genus *Paratylenchus*. Nematologica 11:301-334.
Grisse, A. de and P. A. A. Loof. 1965. Revision of the genus *Criconemoides* (Nematoda). Meded. Landb Hoogesch. Opzoek Stns Gent 30:577-603.
Hackney, R. W. 1977. Identification of field populations of *Meloidogyne* spp. by chromosome number. J. Nematol. 9:248-249.
Hechler, H. C. and D. P. Taylor. 1965. Taxonomy of the genus *Seinura* (Nematoda: Sphelenchoididae), with descriptions of *S. celeris* n. sp. and *S. steineri* n. sp. Proc. Helminthol. Soc. Washington 32:205-219.
Jairajpuri, M. S. 1964. Studies on Nygellidae n. fam. and Belondiridae Thorne 1939 (Nematoda: Dorylaimoidea) with description of ten new species from India. Proc. Helminthol. Soc. Washington 31:173-187.
Loof, P. A. A. 1960. Taxonomic studies on the genus *Pratylenchus* (Nematoda). Tijdschr. PlZiekt. 66:29-90.
Loof, P. A. A. 1968. Taxonomy of *Hemicycliophora* species from West and Central Europe (Nematoda: Criconematoidea). Meded. LandbHoogesch. Wageningen 68:1-43.
Mai, W. F. and H. H. Lyon. 1975. Pictorial Key to Genera of Plant-parasitic Nematodes. Comstock Publ. Assoc., Ithaca, N.Y. 219 pp.
Mehta, U. K. 1971. Revision of the genus *Criconema* Hofmanner and Menzel, 1914 and other related genera (Criconematidae: Nematoda). Indian J. Nematol. 1:145-198.
Olowe, T. 1976. Practical guide for identification of common plant parasitic nematodes. Federal Dep. Agr. Res. Memorandum. Ibadan, Nigeria. 42 pp.
*Paramonov, A. A. 1968. Plant-parasitic nematodes. Vol. I. Origin of nematodes. Ecological and morphological characteristics of plant nematodes. Principles of taxonomy, ed. K. Skryabin. Israel Program for Scientific Translations, Jerusalem. 390 pp. (Original version in Russian.)
*Paramonov, A. A. 1972. Plant-parasitic nematodes. Vol. III. Systematics of nematodes. Superfamily Tylenchoidea, ed. K.I. Skryabin. Israel Program for Scientific Translations, Jerusalem. 200 pp. (Original version in Russian.)
*Paramonov, A. A. 1976. Plant parasite nematodes. Vol. II. Partial taxonomy, ed. K. I. Skryabin. Indian National Scientific Documentation Centre, New Delhi, India. 570 pp. (Original version in Russian)

* These references (and perhaps an additional few) are out of print; however, they should be available for reference in most major libraries.

Raski, D. J. and A. M. Golden. 1966. Studies on the genus *Criconemoides* Taylor, 1936 with descriptions of eleven new species and *Bakernema variabile* n. sp. (Criconematidae: Nematoda). Nematologica, year 1965, 11:501-565.

Sher, S. A. 1963. Revision of the Hoplolaiminae (Nematoda). II. *Hoplolaimus* Daday, 1905 and *Acrolaimus* n. gen. Nematologica 9: 267-295.

Sher, S. A. 1964a. Revision of the Hoplolaiminae (Nematoda) III. *Scutellonema* Andrássy, 1958. Nematologica, year 1963, 9:421-443.

Sher, S. A. 1964b. Revision of the Hoplolaiminae (Nematoda) IV. *Peltamigratus* n. gen. Nematologica, year 1963, 9:455-467.

Sher, S. A. 1965a. Revised key to the *Scutellonema* Andrássy, 1958. (Hoplolaiminae: Nematoda). Nematologica, year 1964, 10:648.

Sher, S. A. 1965b. Revision of the Hoplolaiminae (Nematoda) V. *Rotylenchus* Filipjev, 1936. Nematologica 11:173-198.

Sher, S. A. 1966. Revision of the Hoplolaiminae (Nematoda). VI. *Helicotylenchus* Steiner, 1945. Nematologica 12:1-56.

Sher, S. A. 1968a. Revision of the genus *Hirschmanniella* Luc & Goodey, 1963 (Nematoda: Tylenchoidea). Nematologica 14:243-275.

Sher, S. A. 1968b. Revision of the genus *Radopholus* Thorne, 1949 (Nematoda: Tylenchoidea). Proc. Helminthol. Soc. Washington 35:219-237.

Sher, S. A. and M. W. Allen. 1953. Revision of the genus *Pratylenchus* (Nematoda Tylenchidae). Univ. California Pub. Zool. 57:441-470.

Siddiqi, M. R. 1974. Systematics of the genus *Trichodorus* Cobb, 1913 (Nematoda: Dorylaimida), with descriptions of three new species. Nematologica 19:259-278.

Tarjan, A. C. 1964. A compendium of the genus *Tylenchorhynchus* (Tylenchidae: Nematoda). Proc. Helminthol. Soc. Washington 31:270-280.

Tarjan, A. C. 1966. A compendium of the genus *Criconemoides* (Criconematidae: Nemata). Proc. Helminthol. Soc. Washington 33:109-125.

Thorne, G. 1964. Nematodes of Puerto Rico: Belondiroidea new super-family, Leptonchidae Thorne, 1935, and Belonenchidae new family (Nemata, Adenophorea, Dorylaimida). Puerto Rico Agr. Exp. Sta. Tech. Paper 39. 51 pp.

Thorne, G. 1967. Nematodes of Puerto Rico: Actinolaimoidea new super-family with a revision of its genera and species with addenda to Belondiroidea (Nemata, Adenophorea, Dorylaimida). Puerto Rico Agr. Exp. Sta. Tech. Paper 43. 48 pp.

APPENDIX III

Professional Societies for Nematologists

American Phytopathological Society
Asociación Peruana de Fitopatología
Association of Applied Biologists
Brazilian Society of Nematology
European Society of Nematologists
Helminthological Society of Washington
Japanese Nematological Society
Mediterranean Nematological Society
Nematological Society of India
Nematological Society of Southern Africa
Organization of Tropical American Nematologists
Pakistan Society of Nematologists
Societa Italina Di Nematologia
Society of Nematologists

APPENDIX IV

Nematological or Related Journals

Annals of Applied Biology
Annals of the Phytopathological Society of Japan
Fitopatologia
Fungicide & Nematicide Tests
Indian Journal of Nematology
Japanese Journal of Nematology
Journal of Nematology
Nematologica
Nematologica Mediterranea
Nematropica
Netherlands Journal of Plant Pathology
Phytoparasitica
Phytopathologica Mediterranea
Phytopathologische Zeitschrift (Journal of Phytopathology)
Phytopathology
Phytophylactica
Phytoprotection
Plant Disease (formerly Plant Disease Reporter)
Plant Pathology
Proceedings of the Helminthological Society of Washington
Revue de Nematologie
Rivista di Patologia Vegetale

Translations, Abstract Compilations, and Other Secondary Sources

Bibliography of Agriculture
Biological Abstracts
Bio Research Index
Bio Systematic Index
Commonwealth Agricultural Bureaux (C.A.B.) Abstract Journals
Current Contents (Life Sciences)
Dissertation Abstracts
Helminthological Abstracts, Series B
Science Citation Index
Zoological Record

APPENDIX V

Addresses of Manufacturers or Suppliers of Nematicides

Manufacturers or Suppliers	Addresses
*Bayer AG	Sparte Pflanzenschutz, Vertrieb, 5090 Leverkusen, Federal Republic of Germany
American Cyanamid Company	Wayne, NJ 07470, U.S.A.
Cyanamid Australia Pty. Limited	P.O. Box 584 Crows Nest, NSW 2065, Australia
Cyanamid Canada, Inc.	2255 Sheppard Avenue East Willowdale, Ontario M2J 4Y5, Canada
Cyanamid Taiwan Corporation	P.O. Box 1057 Taipei, Taiwan, Republic of China
Cyanamid Transnational Corporation	P.O. Box 47341 Nairobi, Kenya
South African Cyanamid (Pty.) Ltd.	P.O. Box 7552 Johannesburg, 2000 Republic of South Africa
Cyanamid S.A.	74 Rue D'Arcueil, Silic 275 94578 Rungis Cedex, France
Cyanamid Overseas Corporation	38, Kifissia Avenue Paradissos, Amaroussion Athens, Greece
Cyanamid Italia S.p.A.	Via delle Sette Chiese 233 00147 Rome, Italy
Cyanamid International Corporation	P.O. Box 832 Zurich, Switzerland
Dow Chemical Co.	Agricultural Dept., P.O. Box 1706 Midland, MI 48604, U.S.A.
Dow Chemical of Canada, Ltd.	P.O. Box 1012, Sarnia, Ontario, Canada
Dow Chemical Europe S.A.	Bachtobeletrasse 3, Horgen, Switzerland
Dow Products Quimicos, Limitada	Av. Paulista, 1938-19 Andar, Caixa Postal 30.037, Sao Paulo, Brazil
Dow Chemical Pacific, Ltd.	New Henry House, 6th Floor, P.O. Box 711, Hong Kong, B.C.C.

* Contact Bayer AG for addresses of suppliers of NEMACUR in countries other than the United States and Canada.

Manufacturers or Suppliers	Addresses
E. I. duPont de Nemours & Co.	Biochemical Dept., 1007 Market Street, Wilmington, DE 19898, U.S.A.
E. I. duPont de Nemours & Co., Inc. Latin America—Coral Gables Office	2121 Ponce de Leon Blvd., Suite 600, Coral Gables, FL 33134, U.S.A.
DuPont Far East, Inc., Singapore Branch	Maxwell Rd., P.O. Box 3140, Singapore 9051, Republic of Singapore
DuPont de Nemours International S.A.	50-52 Route des Acacias, P.O. Box CH-1211, Geneva 24, Switzerland
FMC Corporation	Agricultural Chemical Group 2000 Market St., Philadelphia, PA 19103, U.S.A.
FMC Corporation (Latin American Office)	Agricultural Chemical Group, 9400 S. Dadeland Blvd., Suite 321 Miami, FL 33156, U.S.A.
FMC do Brasil	AVDA, Paulista, 1274-7 Andar 01310 Sao Paulo, Brasil
FMC Europe, S.A.	Agricultural Chemical Group 177/179 Chausée de la Hulpe 1170 Brussels, Belgium
FMC International S.A.	MCC P.O. Box 1964 Makati, Metro Manila Philippines D-3H7
FMC International A.G.	Athens Tower B-605 Athens 610, Greece
Great lakes Chemical Corp.	Agr. Chem. Res. and Dev., P.O. Box 2200, West Lafayette, IN 47906, U.S.A.
Mobay Chemical Corporation	Chemagro Agr. Div., P.O. Box 4913 Kansas City, MO 64120, U.S.A.
Mobil Chemical Co.	P.O. Box 26683, Richmond, VA 23261, U.S.A.
NOR-AM Agricultural Products	350 W. Shuman Boulevard, Naperville, IL 60540, U.S.A.
Shell Chemical Co.	Agricultural Chemicals, One Shell Plaza Box 3871, Houston, TX 77001, U.S.A.
Shell International Chemical Co.	Shell Center, London SE 1 7PG, England
Stauffer Chemical Co.	Nyala Farm Road, Westport, CT 06880, U.S.A.
Union Carbide Corp.	Agricultural Products Division, P.O. Box 12014, Research Triangle Park, NC 27709, U.S.A.
Union Carbide Australia, Ltd.	G.P.O. Box 5322, Sydney, N.S.W. 2001, Australia
Union Carbide S. Africa Ltd.	P.O. Box 27675, Sunnyside 0132, Pretoria, Transvaal, Republic of South Africa
Union Carbide Middle East Ltd.	P.O. Box 740, Athens, Greece
Union Carbide Europe Societe Anonyme	P.O. Box 1211, Geneva 17, Switzerland
Union Carbide do Brazil, S.A.	Avenida Paulista, 2073-17° Andar, Horsa II, Sao Paulo, Brazil

Appendix V continued

Manufacturers or Suppliers	Addresses
Union Carbide Inter-America, Inc.	Agricultural Chemicals, Los Nardos 1018, Lima 27, Peru
Union Carbide Eastern Incorp.	Agricultural Products, P.O. Box 818, Hong Kong
National Carbon Company Otd.	P.O. Box 4785, Karachi, Pakistan
Union Carbide India Ltd.	Agricultural Products, P.O. Box 533, New Delhi-1, India
Union Carbide Philippines, Inc.	P.O. Box 56, Commerical Center Post Office, Makati, Metro Manilla, Philippines 3117
Unicar, S.A.	Edificio Real Reforma, 7-B, Ave. La Reforma 13-70, Zona 9, Guatemala City, Guatemala, C.A.
Union Carbide Mexicana, S.A.	Depto. Quimicos Agricolas, Ave. Presidenta Masaryk No. 8, Mexico 5, D.F.