Research on Integrated Crop Protection Systems with Emphasis on the

Root-Knot Nematodes (Meloidogyne spp.)

Affecting Economic Food Crops in Developing Nations

C. C. Carter
Research Assistant
and
J. N. Sasser
Principal Investigator

INTERNATIONAL MELOIDOGYNE PROJECT

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For information on the availability of this publi: 'ion, write to:

Dr. J. N. Sasser
Department of Plant Pathology
North Carolina State University
P.O. Box 5397
Raleigh, NC 27650-5397 USA

PREFACE

The International *Meloidogyne* Project (IMP) was initiated on July 1, 1975, and is funded by the United States Agency for International Development through a contract with North Carolina State University. During the first five years of operation, much progress has been made in the study of root-knot nematodes (*Meloidogyne* species), which are the most prevalent and destructive of all plant-parasitic nematodes. For the first time, distribution, host response, morphology, cytogenetics, biochemistry, and ecological relationships of the most common root-knot species have been studied intensively on a world-wide basis. This work will continue during a three-year extension of the Project. In addition, the findings of the previous five years will allow considerable emphasis to be placed on the development of root-knot resistant cultivars, cropping systems research for root-knot control, and transfer of technology to growers by research and extension workers in developing countries.

This revised and updated brochure describes, in general terms, the objectives and implementation of IMP. It is not a research publication, although some data are included to illustrate the types of investigations in progress. The aim of the brochure is to provide information on the scope of IMP research to government officials of developing countries; international development agencies and agricultural foundations; and agricultural scientists not currently involved in the Project, but who may wish to participate. To date, the IMP includes more than 100 cooperators from over 70 countries, primarily developing countries in the tropics and warmer parts of the temperate zone. In addition, research linkages have been established with the following International Agriculture Research Centers (IARC's): The International Potato Center (CIP), Peru; The International Crops Research Institute for Semi-Arid Tropics (ICRISAT), India; The International Institute of Tropical Agriculture (IITA), Nigeria; and The Asian Vegetable Research and Development Center (AVRDC), Taiwan.

The authors wish to acknowledge fellow cooperators A. C. Triantaphyllou, H. Hirschmann, J. D. Eisenback, and A. L. Taylor for their contributions to this brochure. Thanks are also extended to members of the departmental review committee: K. R. Barker, B. C. Haning, T. T. Hebert, D. F. Ritchie, D. L. Strider, and D. P. Schmitt.

THE PROBLEM

One of the major obstacles to the production of adequate supplies of food in developing nations is the damage caused by plant-parasitic nematodes, especially the "root-knot group," *Meloidogyne* species. International *Meloidogyne* Project cooperators estimate average field crop damage due to these pests at 15%, with damage in individual fields ranging as high as 60%. World-wide distribution, extensive host ranges and involvement with fungi, bacteria and viruses in disease complexes place these nematodes high on the list of disease agents affecting the world's food supply. Four species (*M. incognita, M. javanica, M. arenaria,* and *M. hapla*) account for more than 95% of the root-knot nematodes in agricultural soils and, collectively, attack nearly every crop that is grown. Not only are yields greatly affected, but quality is also reduced, especially for root crops such as potatoes, carrots, yams and peanuts (Figs. 1,2).

Figure 1. Uninfected carrot (left) vs. carrots damaged by root-knot nematodes (right). (Courtesy Dept. Plant Pathology, Univ. of Wisconsin.)

2A

2B

Figure 2. Root-knot nematode damage to food crops. A) Potatoes infected with *Meloidogyne incognita*, B) Peanuts infected with *M. arenaria* (left), uninfected pods (right).

INTERNATIONAL *MELOIDOGYNE* PROJECT

PRINCIPAL GOALS

- Increase production of economic food crops in developing nations.
- Upgrade crop protection capabilities of developing nations.
- Advance and disseminate knowledge about the world's most important group of plant-parasitic nematodes.

SPECIFIC OBJECTIVES

- Identify the species and races of root-knot nematodes in agricultural soils of each of the eight geographical regions (Fig. 3).
- Determine susceptibility or resistance of food crops in each region to the root-knot nematodes present, and identify sources of resistant germ plasm.
- Evaluate crop response information for the development and implementation of effective rotation schedules for control of root-knot nematodes in each region.
- Study variability within species and populations with reference to host reaction, morphology, cytogenetics, and biochemistry as a basis for species identification and understanding pathogenic behavior and phylogenetic relationships.
- Evaluate various factors of the environment (past cropping history, soil type, moisture, temperature, weed hosts, and type of agriculture) and the relationship to distribution, survival and pathogenicity.
- Use the information obtained from these cooperative international studies to develop, on a regional basis, effective integrated crop protection systems for reducing crop losses by root-knot nematodes.

SCHEDULE OF IMPLEMENTATION

Phase I

The Project Research Center was organized July 1, 1975, at North Carolina State University, Raleigh, N.C. International project regions were established; cooperators from these regions were recruited (Fig. 3).

REGION I—MEXICO, CENTRAL AMERICA, AND THE CARIBBEAN

Local Country Cooperators		Major Susceptible Crops
L. L. Burpee	Bermuda	banana
A. Figueroa	Costa Rica	bean
R. Lopez	Costa Rica	cassava
L. A. Salazar	Costa Rica	chayote
G. Anais	Guadeloupe	citrus
A. Kermarrec	Guadeloupe	coffee
P. Coates-Beckford	Jamaica	cowpea
S. Eason-Heath	Jamaica	guava
D. G. Hutton	Jamaica	maize
C. S. Moss	Mexico	pigeon pea
M. C. Vega	Nicaragua	pineapple
E. M. Candanedo Lay	Panama	plantain
A. Ayala	Puerto Rico	pumpkin
R. S. van den Oever	Surinam	rice
N. D. Singh	Trinidad	soybean
		sugar cane
		tomato
		yam
		other vegetables

REGION II—SOUTH AMERICA

Local Country Cooperators		Major Susceptible Crops
M. A. Costilla	Argentina	banana
G. M. de Sisler	Argentina	bean
G. Caero	Bolivia	cassava
P. D. Gallo	Chile	cocoa
H. M. Gonzalez-Rodriguez	Chile	coffee
M. O. Jimenez	Chile	cucumber
I. Moreno	Chile	eggplant
R. Barriga-Olivares	Colombia	grain legumes
R. Eguiguren-Carrion	Ecuador	grape
A. G. van Eck	Ecuador	Lu Lo (*Solanum quitoense*)
J. A. de Guerra	Peru	papaya
E. Herrera	Peru	peach
P. Jatala	Peru	pepper
L. M. de Perdomo	Uruguay	pineapple
Z. Suarez	Venezuela	plantain
		potato
		rice
		sugar cane
		sweet potato
		tomato
		watermelon
		other vegetables

REGION III—BRAZIL

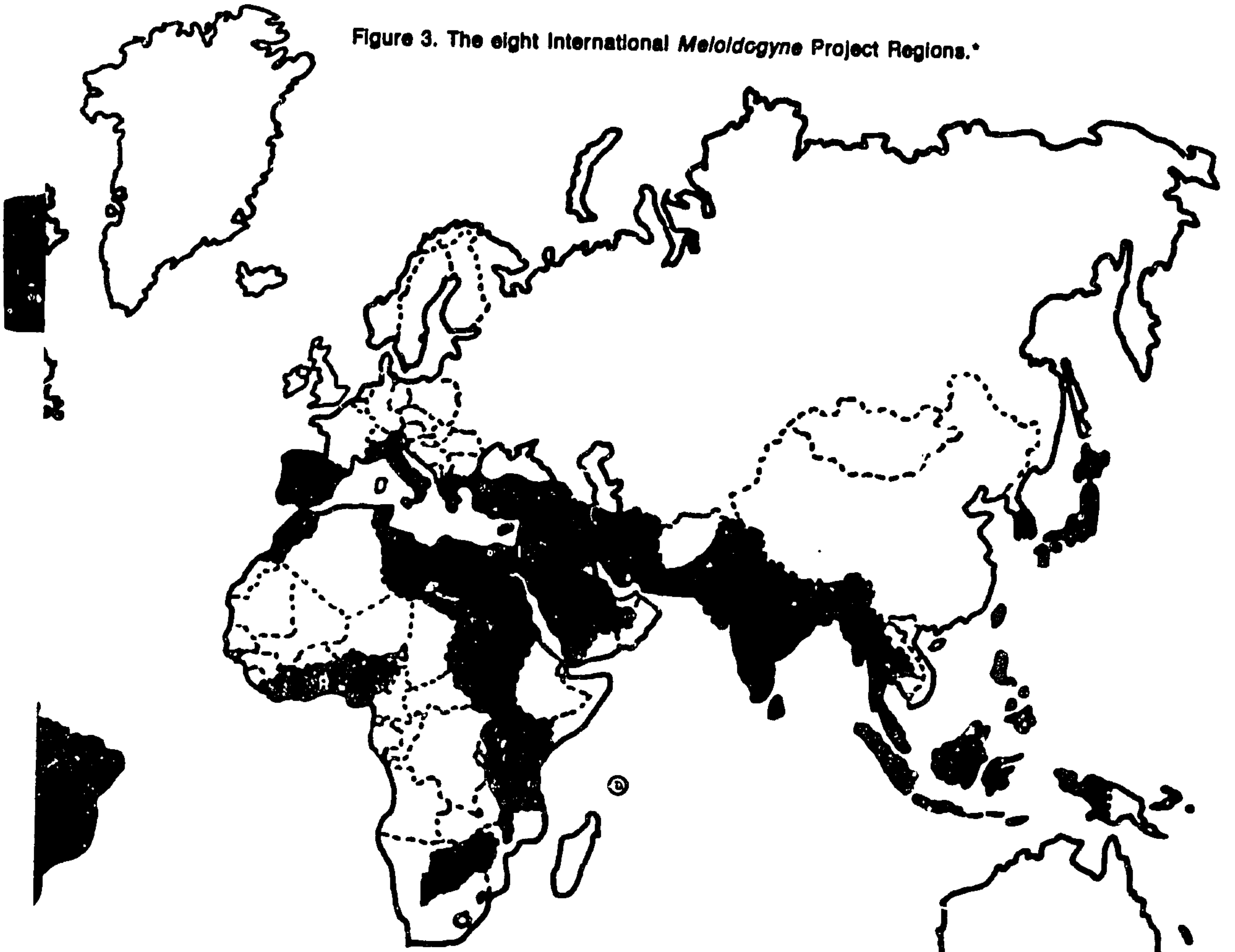
Local Country Cooperators		Major Susceptible Crops
H. Antonio	Brazil	banana
J. I. Boneti	Brazil	bean
V. P. Campos	Brazil	cassava
S. M. Curi	Brazil	citrus
R. M. de Moura	Brazil	coffee
S. Ferraz	Brazil	cotton
C. Huang	Brazil	grape
R. R. A. Lordello	Brazil	papaya
W. R. T. Novaretti	Brazil	rice
		soybean
		sugar cane
		tomato
		yam
		other vegetables

REGION IV—WEST AFRICA

Local Country Cooperators		Major Susceptibl
T. Zannou	Benin	banana
B. M. S. Hemeng	Ghana	bean
O. B. Hemeng	Ghana	carrot
M. Diomande	Ivory Coast	cocoyam
S. O. Afolami	Nigeria	cowpea
J. O. Amosu	Nigeria	eggplant
U. T. Atu	Nigeria	lima bean
O. Babatola	Nigeria	lowland rice
F. E. Caveness	Nigeria	maize
O. Egunjobi	Nigeria	melon
B. Fawole	Nigeria	okra
A. A. Idowi	Nigeria	papaya
E. Nwauzor	Nigeria	peanut
R. A. Odihirin	Nigeria	pigeon pea
R. O. Ogbuji	Nigeria	pineapple
A. O. Ogunfowora	Nigeria	plantain
T. O. Olowe	Nigeria	soybean
		sweet potato
		tomato
		upland rice
		yam

* In addition to the 61 countries listed above, root-knot samples for IMP ecological surveys have at some time been recei

Figure 3. The eight International *Meloidogyne* Project Regions.*



PROJECT CENTER—RALEIGH, N. C.
N.C. STATE UNIVERSITY

Personnel	Area of Responsibility
Dr. J. N. Sasser***	Principal Investigator
Dr. A. C. Triantaphyllou*	Cytogenetics
Dr. H. Hirschmann*	Morphology-Taxonomy
Dr. J. D. Eisenback**	Morphology-Taxonomy
Mr. Phillip Esbenshade**	Biochemistry-Physiology
Mr. A. L. Taylor**	Special Consultant
Dr. L. A. Nelson*	Statistics
Kerrick Hartman**	Crop Resistance
Cathy Carter**	Technology Transfer
Patricia Scales**	Research Technician
Margaret Moore**	Research Technician
Ellen Mester**	Research Technician
Mary M. Zirakparvar**	Research Technician
Gean Cliff***	Graduate Research Assistant
James P. Noe**	Graduate Research Assistant
Milly Oldham**	Secretary

Dr. M. A. Smith — Project Manager
USAID, Washington, D.C.

Other Affiliated Cooperators

Dr. P. Goldstein* — Cytology
UNC-G, Greensboro, N.C.

Dr. A. Mehlich* — Soil Analysis
Agronomic Div., NCDA
Raleigh, N.C.

*Cooperators
**Full support from project
***Partial support

REGION V—EAST AFRICA

Local Country Cooperators		Major Susceptible Crops
B. C. Busang	Botswana	banana
B. W. Ngundo	Kenya	barley
V. W. Saka	Malawi	bean
G. C. Kingsland	Seychelles Islands	cassava
A. S. S. Mbwana	Tanzania	citrus
I. Swai	Tanzania	coffee
N. D. Bafokuzara	Uganda	maize
J. A. Shepherd	Zimbabwe	mung bean
J. I. Way	Zimbabwe	oat
		okra
		peanut
		pineapple
		potato
		rice
		soybean
		sugar cane
		sweet potato
		tea
		tomato
		wheat
		other vegetables

e Crops

ved from the following countries: Australia, Belize, Bulgaria, Canada, China, El Salvador, Guatamala, Liberia, the Netherland

REGION VIII—INDIA

Local Country Cooperators

Not activated yet

Major Susceptible Crops

barley	linseed	potato	tea
cassava	maize	rice	wheat
chickpea	millet	sesame	
cotton	peanut	sugar cane	
lentils	pigeon pea	sweet potato	

REGION VII—MIDDLE EAST

Local Country Cooperators

J. Philis	Cyprus
M. F. Eissa	Egypt
I. K. A. Ibrahim	Egypt
B. A. Oteifa	Egypt
E. Pyrowolakis	Greece (Crete)
C. Ahivardi	Iran
H. Mojtahedi	Iran
Z. A. Stephan	Iraq
M. DiVito	Italy
W. A. Gharbieh	Jordan
M. W. Khan	Libya
M. Ammati	Morocco
A. Janati	Morocco
M. S. N. de A. Santos	Portugal
A. Al-Hazmi	Saudi Arabia
L. M. Beringola	Spain
R. Rodriguez	Spain
M. A. Siddig	Sudan
A. M. Yassin	Sudan
A. Tayar	Syria
R. Vandevelde	Tunisia
H. S. Yuksel	Turkey
R. A. Sikora	Yemen

Major Susceptible Crops

alfalfa
banana
bean
chillies
cotton
eggplant
fig
garlic
grape
kenaf
maize
melon
olive
peanut
pistachio
pomegrante
rice
sorghum
sugar beet
tobacco
tomato
wheat
other fruits
other vegetables

REGION VI—ASIA

Local Country Cooperators

B. C. Choudhury	Bangladesh
M. T. Aung	Burma
Y. Y. Myint	Burma
F. Vilsoni	Fiji Islands
A. W. W. Hadisoeganda	Indonesia
M. Herman	Indonesia
I. Noverda	Indonesia
H. Inagaki	Japan
T. Shiga	Japan
Y. E. Choi	Korea
A. R. Razak	Malaysia
L. N. Bhardwaj	Nepal
C. H. Hogger	Nepal
K. P. Sharma	Nepal
M. A. Maqbool	Pakistan
M. Saeed	Pakistan
R. G. Davide	Philippines
E. T. Rasco	Philippines
T. T. Reyes	Philippines
R. B. Valdez	Philippines
P. Sivapalan	Sri Lanka
Bie-Yun Tsai	Taiwan
C. Chunram	Thailand
T. Lavapaurya	Thailand
S. Sontirat	Thailand

Major Susceptible Crops

bean
black pepper
cassava
Chinese pechay
citrus (Taiwan)
coconut
corn
eggplant
gourd
melon
mung bean
papaya
peanut
pineapple
rice
sorghum
soybean
sugar cane
sweet potato
tea
tomato
yam (Indonesia)
other vegetables

Senegal, USA, West Germany, Western Samoa, and Zaire.

5a

Phase II

A one-week planning conference (Fig. 4) was held in January 1976, at North Carolina State University, Raleigh, N.C., during which time regional investigators, Research Center scientists, and internationally known authorities reviewed the current state of knowledge concerning the root-knot nematode and discussed the scientific aspects of the project.

Figure 4. Planning conference in Raleigh.

Phase III

Research conferences (Fig. 5) were first held in 1976 and continue to be held periodically in each of the international project regions for the purpose of outlining research goals and objectives with special emphasis given to such research methodology as collecting and maintaining inoculum, inoculation techniques, species identification, evaluation of host-plant resistance, and interpretation of results.

5A

5B

Figure 5. Regional conferences. A) Region II conference in Cali, Colombia—March 1976, B) Regions IV & V conference in Ibadan, Nigeria—November 1981.

Phase IV

In cooperating countries within each established region, research has been initiated on *Meloidogyne* species identification, host ranges, differential host tests, screening for resistance, development of cropping systems for root-knot control, and technology transfer.

Research Emphasis
Project Center—Raleigh, N.C.

Much research at IMP headquarters centers on identification and ecological characterization of *Meloidogyne* samples from around the world. The differential host test, in combination with perineal pattern morphology, is the initial tool in identification. If this approach proves inconclusive, further morphological, cytological, and biochemical studies are made. Soil samples, crop history, and climatological data form the basis for ecological characterization of the samples.

- *Differential Host Tests.* Unidentified populations are increased on Rutgers tomato or other suitable hosts. Each of six differential host plant cultivars are inoculated with the unknown population. About 50 days later, the host roots are examined and rated for both galls and egg masses. The resistance or susceptibility of the various hosts gives a *preliminary indication* of the species or combination of species present and may even indicate pathogenic variation among populations of the same species. For the most part, each of the four major species and their races reacts uniquely and characteristically to this test (Table 1). However, test results must be checked against other identification techniques, such as perineal pattern morphology, for identification of species in mixed populations and for confirmation of single populations.

Table 1. Differential Host Test Reaction Chart.

Meloidogyne species and races	Differential Host Plants*					
	Cotton	Tobacco	Pepper	Watermelon	Peanut	Tomato
M. incognita	**					
Race 1	[−]	[−]	+	+	−	+
Race 2	[−]	[+]	+	+	−	+
Race 3	[+]	[−]	+	+	−	+
Race 4	[+]	[+]	+	+	−	+
M. arenaria						
Race 1	−	+	+	+	[+]	+
Race 2	−	+	−	+	[−]	+
M. javanica	−	+	[−]	+	−	+
M. hapla	−	+	+	[−]	[+]	+

* Plant varieties include: Cotton, DeltaPine 16; Tobacco, NC 95; Pepper, California Wonder; Watermelon, Charleston Grey; Peanut, Florunner; Tomato, Rutgers.
** Box indicates key differential host plants.

- *Perineal Pattern Morphology.* Females of each of the four major *Meloidogyne* species have a distinctive perineal pattern: that is, an external, fingerprint-like series of markings in the vicinity of the anus and vulva. The markings are readily visible under a light microscope (Fig. 6). Though species are distinguishable on the basis of perineal patterns, or other morphological features, races are determined solely on the basis of host test results.

Figure 6. Light microscope photograph of the perineal pattern of *Meloidogyne incognita.*

• *Morphological Characters other than Perineal Patterns.* A search for new and more reliable morphological characters that are useful for species identification is in progress. In addition to perineal patterns, the shape of the heads of males and stylet morphology (Fig. 7) are considered valuable taxonomic characters. Heads among species differ in size and shape of the head cap, annulation of the head region, width of the head cap relative to the head region, and width of the head region relative to the first body annule. A technique has been developed for the removal of the stylet from the nematode. Removed stylets are examined with a scanning electron microscope. They differ in the shape and size of the cone, shaft, and knobs as well as the distance of the dorsal esophageal gland orifice from the stylet base.

7A

7B

7C

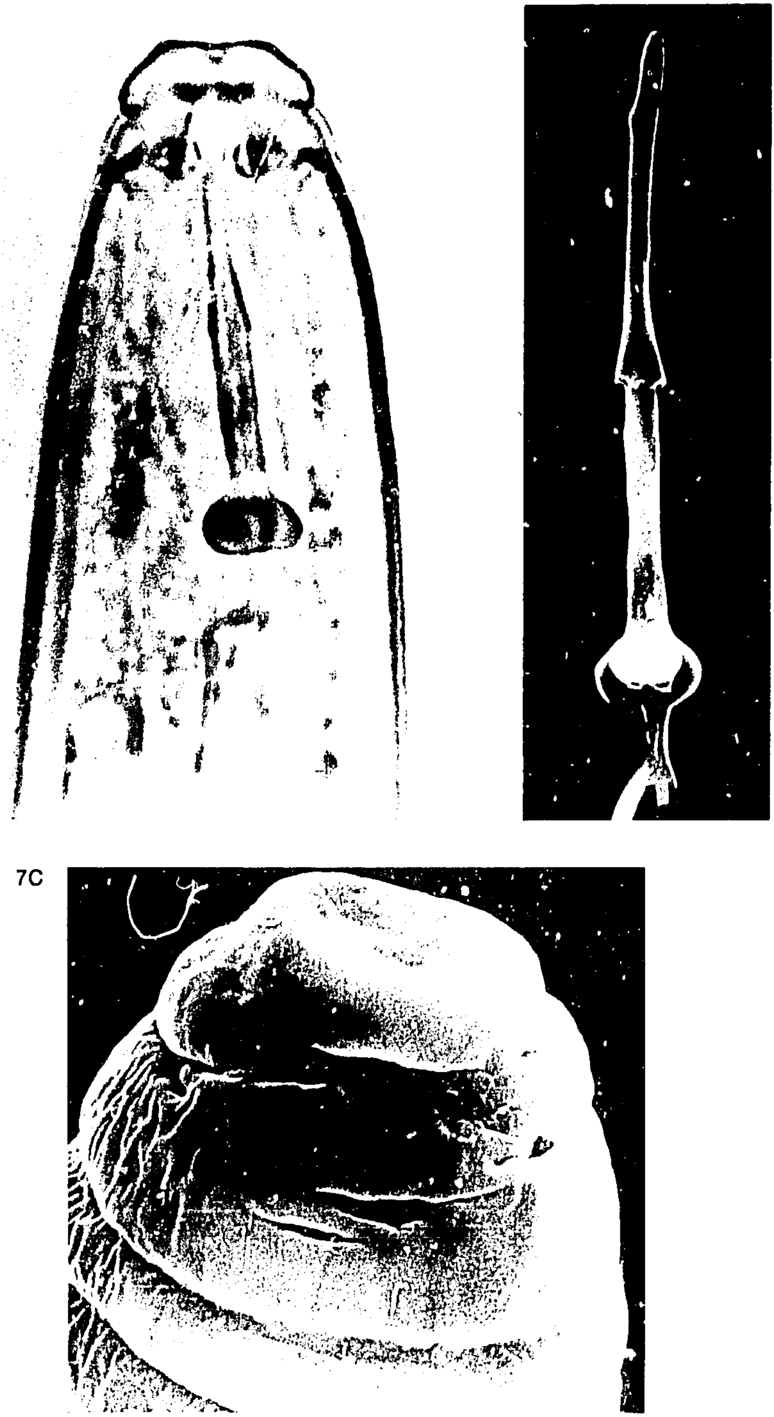


Figure 7. *Meloidogyne incognita* male. A) Head and stylet (light microscope), B) Excised stylet (scanning electron microscope, SEM), C) Head, laternal view (SEM).

Figure 8. Prometaphase chromosomes of the single maturation division of oocytes of *Meloidogyne arenaria*, triploid race A with 53 chromosomes.

- *Cytogenetic Studies.* Important cytogenetic characters used to differentiate species and races of root-knot nematodes are currently being studied; these include mode of reproduction, process of maturation of oocytes, chromosome number, and genetic basis of ability to reproduce on resistant crops (Fig. 8). Over 500 *Meloidogyne* populations have been characterized cytologically.
- *Biochemical Investigations.* Determination of soluble proteins and various specific enzymes are helpful in the identification of *Meloidogyne* species. The major bands of esterases, as revealed by acrylamide gel electrophoresis and α-Naphthyl acetate staining, are different for females of each of the four major species (Fig. 9). To date, studies have been conducted on over 150 populations.

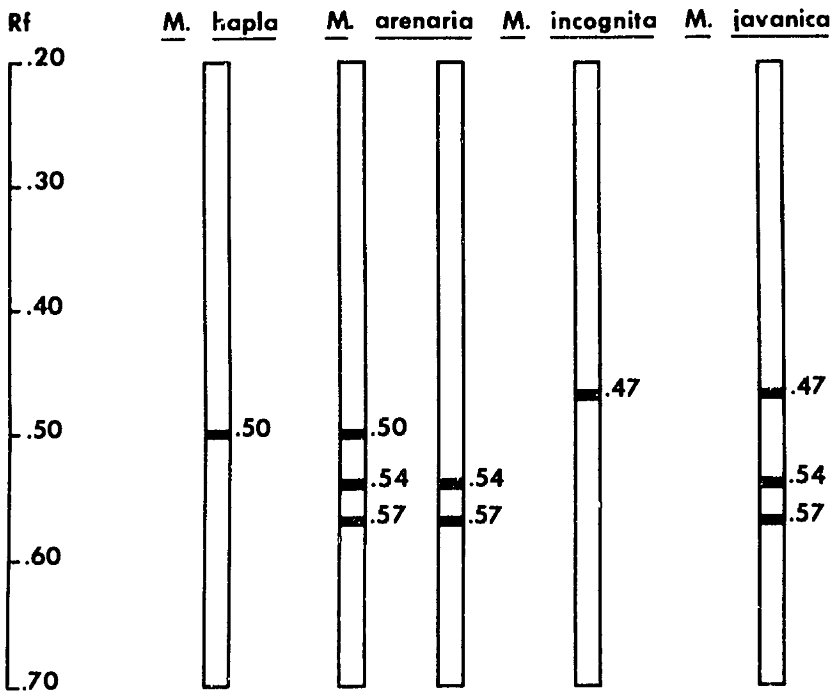


Figure 9. Major bands of esterases in females of four *Meloidogyne* species. (Adapted from unpublished data by Janati, Berge, Dalmasso, and Triantaphyllou).

- *Ecology.* Climatic data have been compiled for about two-thirds of the approximately 1,100 samples received to date. Data include average annual temperatures, temperatures for the coldest and warmest months of the year, average annual precipitation, and average monthly distribution of precipitation.

  Relationships between occurrence of the four common species and ecological factors have been analyzed. The results indicate that *M. hapla* possibly may be found as far north as agriculture extends in North America, Europe and Asia. *M. incognita*, *M. javanica* and *M. arenaria* do not exist in regions where the average temperature of the coldest month of the year (January in the Northern Hemisphere, and July in the Southern Hemisphere) is about 3°C, *i.e.*, where the upper 5 to 10 cm of soil freezes. Of these latter three species, *M. javanica* is best adapted for survival in warm, dry soil.

  In addition, soil samples from around the world have been analyzed for sand, silt, clay, pH, major and minor fertilizer elements, and organic matter. Sand, silt and clay data have shown that sand content of soil is not the most important factor determining occurrence and severity of root knot. The role of silt and clay content is now being more thoroughly evaluated. Soil pH, organic matter, and fertilizer elements have exhibited no strong correlation with root-knot nematode occurrence.

Emphasis now shifts to three major areas:

- *Evaluation for Resistance (Fig. 10).* Resistant germ plasm is provided by plant breeders working at the various International Agriculture Research Centers (IARC's). These materials are further evaluated against various species and races of *Meloidogyne* maintained at the research center in Raleigh. To date, resistance has been documented for several hundred crop cultivars.

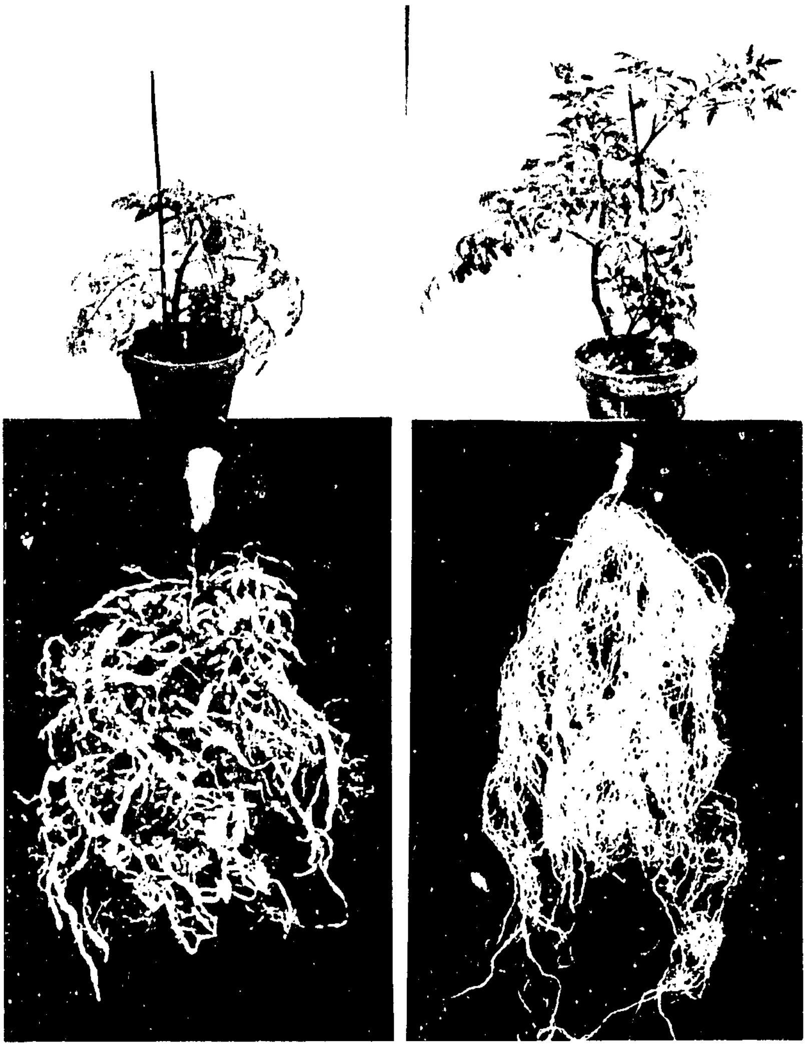


Figure 10. Evaluation for resistance: susceptible tomato variety Rutgers infected with *M. incognita* (left) vs. resistant variety Nemared (right).

Figure 11. Cropping systems research: *Meloidogyne hapla* on peanuts following a nonhost (left) and a host crop (right).

- *Cropping Systems Research (Fig. 11).* Cropping sequences for each region are studied to determine those which most effectively control root-knot nematodes and thereby increase yields.
- *Technology Transfer.* Acquired information is disseminated by several methods. Conferences and advanced laboratory and field training sessions (Fig. 12) allow cooperators to become familiar with new research developments. Particularly useful and important findings are presented in the form of proceedings of conferences, journal articles, brochures, booklets, and posters (See appendix). Training materials also include slide sets, films, and other aids.

A

B

Figure 12. Technology transfer. A) Laboratory training session in Panama, B) Field training at IITA, Ibadan, Nigeria.

- *Collection.* Root-knot nematode populations are collected from diverse habitats, hosts, and types of agriculture.
- *Identification.* Field populations are identified to species and race primarily on the basis of differential host tests and perineal pattern morphology.
- *Differential Host Studies.* These tests are conducted regularly for preliminary identification of species and for detection of pathogenic variation among populations of the same species.
- *Ecological Studies.* For each sample and location, cooperators record extensive ecological data: crop host, extent of damage, names of plant pathogens found in association with infected plants, cropping history of the field sampled, as well as monthly and annual averages for air temperature and precipitation. This information, plus a soil sample, accompanies most egg mass samples sent to the IMP headquarters. There, all pertinent ecological factors are analyzed for correlation with nematode survival and pathogenicity.
- *Search for Resistant Host Plants.* Economic crops of the region are tested for degree of resistance to the root-knot nematode species present. A search is maintained for new sources of resistant germ plasm in crop varieties, plant introductions, and breeding lines.
- *Development of Effective Rotation Schemes.* Information on the response of local crops to root-knot nematode infestations makes the development of effective rotation schemes for control possible.
- *Evaluation of Nematicides.* Effectiveness and economic justification are taken into consideration when the feasibility of chemical control is determined (Fig. 13).

Figure 13. Nematicide-treated peanut plots (center) vs. untreated plots (sides).

PRACTICAL APPLICATION OF IMP RESEARCH

Evaluation for resistance, cropping systems research, and technology transfer form the groundwork for development of integrated crop protection systems which are aimed at root-knot nematode control. These systems utilize the best combination of available control measures, including resistant cultivars, crop rotation, nematicides, and sanitary and cultural practices. Use of a wide variety of control strategies prevents the buildup of any single nematode population and minimizes the development of resistance in root-knot nematodes to any single practice.

Integrated crop protection systems require flexibility in management approaches depending upon the specific pest problem and locally available management options. A fixed set of recommendations may not adequately solve a given problem. System development takes into account many factors including the species and race(s) of nematodes present, the availability of resistant host plants, the longevity of the pest, and the crops and climate of the geographical region. With the wealth of information already available plus that now being acquired by the IMP, growers and researchers can work together to develop crop protection systems uniquely effective in each region. Although eradication of nematodes from the soil may be impossible, population densities can be lowered to levels at which damage to the crop is negligible. Steps and appropriate considerations in the development of an integrated crop protection system (ICPS) for a *hypothetical* situation are outlined on the following pages.

I. Recognition of a Problem (Fig. 14).

Figure 14. Root-knot nematode-infested soybean field in eastern North Carolina.

II. Diagnosis of Problem: Soil assay of the above field reveals it to be heavily infested with *Meloidogyne incognita* race 1.

III. Considerations for ICPS Development*

A. Prerequisite information

1. Knowledge of some pertinent aspects of pest biology, for example:

   a. In the absence of a host, *Meloidogyne* spp. can survive in the soil for as long as 2 years, depending on the environment.

   b. Temperatures of at least 18°C are necessary for *M. incognita* juveniles to migrate through the soil and penetrate roots. Maximum migration occurs at about 22°C. Juveniles of some species have been known to migrate as far as 75 cm over a period of only 9 days.

   c. *M. incognita* continues to develop at temperatures below 18°C, but cannot survive for long periods at -1.1°C or lower.

   d. Fields very often have more than one species or race of root-knot nematodes, with one species usually occurring in much larger numbers than the other(s). A rotation designed to reduce populations of the dominant species may cause other root-knot populations to increase.

* This information is available through IMP research, agricultural extension, and other sources.

2. List of available crop cultivars resistant to *M. incognita* race 1
   a. Soybean: Bragg, Brysoy-9, Centennial, Cobb, Coker 136, Coker 338, Dare, Forrest, Govan, Hutton, Lee 74
   b. Peanut: all varieties are highly resistant
   c. Cotton: all varieties are highly resistant
   d. Tobacco: Coker 51, 86, 254, 347; NC 89, 95, 98, 628; SC72; Speight G-23, G-28, G-33, G-58, G-70; McNair 373, 3199
   e. Corn: Carmel Cross, Span Cross
   f. Sweet Potato: Carver, Gold Rush
3. List of approved and available nematicides
   a. Fumigants: chloropicrin, DD, dichloropropene, EDB, methyl bromide
   b. Non-fumigants: aldicarb, carbofuran, ethoprop, fenamiphos, fensulfothion, oxamyl

B. Consideration of other nematode species present as well as insect, disease, and weed problems

C. Commitment to use of cultural and sanitary control practices
   1. Clean planting stock
   2. Weed control
   3. Adequate fertilization
   4. Control of indiscriminate movement of farm machinery between clean and infested fields
   5. Crop residue destruction

IV. Development of alternative 3-year system outlines

	1st year	2nd year	3rd year
A.	Corn: susceptible host, but often economically undamaged	Soybean: resistant variety	Soybean: resistant or susceptible variety, depending on results of soil assay
B.	Cotton: non-host	Soybean: resistant variety	Winter Wheat: susceptible host, but usually economically undamaged Soybean: susceptible variety
C.	Soybean: resistant variety	Nematicide Sweet potato: insect- or nematode-resistant variety	Soybean: susceptible variety
D.	Nematicide Tobacco: resistant variety	Soybean: resistant variety	Soybean: susceptible variety
E.	Soybean: resistant variety	Peanut: non-host	Soybean: susceptible variety

V. Analysis of alternative system B: Cotton-Soybean-Winter Wheat/Soybean

1st year: Meloidogyne incognita races 1 and 2 do not infect or reproduce on cotton, but races 3 and 4 do. However, all four races can infect soybean. A year of cotton significantly reduces the race-1 population; however, close monitoring is necessary to prevent an increase among race-3 or race-4 populations which would pose a threat to soybean. The cost of disease and insect control for cotton affects the economic feasibility of this rotation.

2nd year: A soybean variety is chosen which is resistant to *M. incognita*; so far, such resistant varieties are believed to be effective against all four races. Other desirable characteristics such as high yield, minimum lodging, and shatter resistance also demand consideration during variety selection.

3rd year: The pest population is sufficiently low to allow the growth of susceptible crops. Although wheat is susceptible to all races of *M. incognita*, this nematode poses little threat to winter crops. A delay in planting until the soil is below 18°C helps reduce the chances that root-knot juveniles will migrate to the newly planted crop. Use of an early-maturing winter-wheat variety allows timely harvest in the spring and sufficient time to plant soybeans in accordance with favorable moisture conditions. A susceptible soybean variety is safely grown at this time unless sizeable populations of other root-knot nematode species or races have developed.

Figure 15. Properly-managed soybean field.

SUMMARY

Survey of the root-knot nematode problem has produced the first reliable international estimate of crop loss due to root-knot: 15% on the average, with losses two or three times that high in some localities. This estimate provides a strong incentive for development and dissemination of control methods—something that has been lacking previously. Through the concerted efforts of scientists around the world, development of integrated crop protection systems based on control methods uniquely effective in each region is currently underway.

To date, about 1,300 live populations of *Meloidogyne* species from over 70 countries have been studied. This worldwide effort has had the effect of increasing the knowledge base for root-knot biology and of facilitating greater communication among scientists working on the program around the world. Additional benefits include improvement of nematode research capabilities in developing countries and enhancement of nematode research efforts at the various cooperating International Agriculture Research Centers.

Important biological information obtained by IMP personnel during the past five years can now be of immediate value to others. Important findings include:

1) Root-knot nematodes over a large part of the world are remarkably uniform in morphology, cytology, and reactions to the crop cultivars used in the differential host test.

2) More than 95% of the root-knot nematodes in the agricultural soils of the countries surveyed belong to only four species: *M. incognita*, *M. javanica*, *M. arenaria* and *M. hapla*.

3) Two of the common species of *Meloidogyne* have more than a single pathogenic race. *M. incognita* has four, and *M. arenaria* has two.

4) Distribution of species is correlated with climatic factors: average yearly temperature, average temperatures of the coldest and warmest months of the year, total annual precipitation, and distribution of precipitation by months. By study of climatic records, prediction of which of the four common species will be found in an unexplored country is possible with about 95% accuracy.

5) Resistance of agricultural crops to species or races of root-knot nematodes has been documented for several hundred cultivars from around the world.

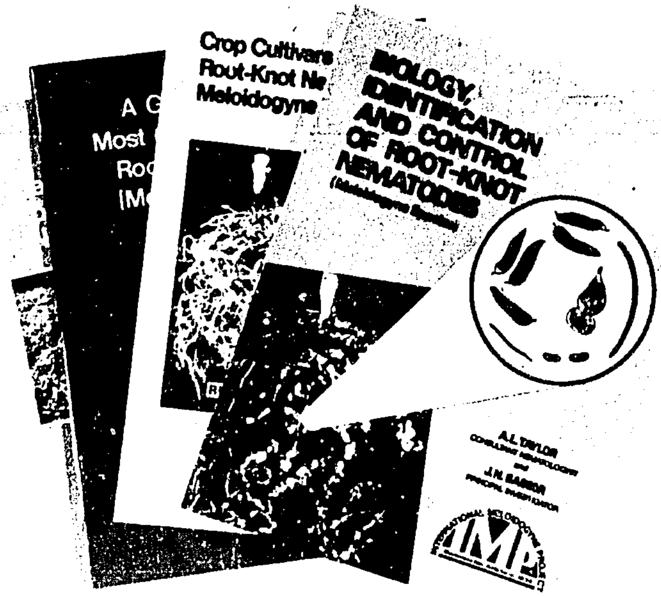
6) The taxonomy of *Meloidogyne* has been placed on a solid base by the development of more positive procedures for identification. Useful morphological characters visible under the light microscope

include perineal patterns, adult male head shape, and adult male stylet morphology. Cytogenetic characters include mode of reproduction, process of maturation of oocytes, and chromosome number. Species can be identified biochemically by determination of soluble proteins and various specific enzymes.

Much biological and ecological data concerning root-knot nematodes have been collected in the past five years. Now the project's emphasis is shifting from acquisition of information to its application and dissemination. Resistant cultivar development and cropping systems research are being encouraged. Cropping systems such as the ones outlined on the previous pages are being developed which are uniquely suited to specific geographic regions. Dissemination of information (technology transfer) is being accomplished through scientific journals, conferences, advanced training sessions, booklets, brochures, posters, slide sets, and other materials.

Although the primary focus of IMP is in developing countries, additional cooperators from developed countries including the USA are welcomed on a non-funded basis. So far, IMP has had over 100 cooperators from 75 nations. Persons interested in obtaining additional information concerning IMP should contact Dr. J. N. Sasser, Department of Plant Pathology, North Carolina State University, P.O. Box 5397, Raleigh, N.C., USA 27650-5397.

Appendix: IMP Publications



GENERAL

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. 48 pp.

Sasser, J. N. and M. F. Kirby. 1979. Crop cultivars resistant to root-knot nematodes, *Meloidogyne* species, with information on seed sources. 24 pp.

Taylor, A. L. and J. N. Sasser. 1978. Experimental and agronomic use of nematicides. 20 pp.

Taylor, A. L. and J. N. Sasser. 1978. Biology, identification and control of root-knot nematodes (*Meloidogyne* species). 111 pp.

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Baldwin, J. G. and J. N. Sasser. 1978. *Meloidogyne megatyla*, n. sp., (Heteroderidae) a root-knot nematode from loblolly pine. J. Nematol. 11:47-56.

Eisenback, J. D. and H. Hirschmann. 1979. Morphological comparison of second-stage juveniles of six populations of *Meloidogyne hapla* by SEM. J. Nematol. 11:5-16.

Eisenback, J. D. and H. Hirschmann. 1979. Morphological comparison of second-stage juveniles of several *Meloidogyne* species (root-knot nematodes) by scanning electron microscopy. Proceedings of SEM, Inc. pp. 223-229.

Eisenback, J. D. and H. Hirschmann. 1980. Morphological comparison of *Meloidogyne* males by scanning electron microscopy. J. Nematol. 12:23-32.

Eisenback, J. D. and H. Hirschmann. 1981. Identification of *Meloidogyne* species on the basis of head shape and stylet morphology of males. J. Nematol. 13:513-521.

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Goldstein, P. and A. C. Triantaphyllou. 1978. Electron microscopic comparison of oogenesis in a meiotic and mitotic race of *Meloidogyne hapla*. J. Nemtaol. 10:288-289.

Goldstein, P. and A. C. Triantaphyllou. 1980. The ultrastructure of sperm development in *Meloidogyne hapla*. J. Ultrast. Res. 71:143-153.

Goldstein, P. and A. C. Triantaphyllou. 1981. Pachytene karyotype analysis of the synaptonemal complexes of a tetraploid form of *Meloidogyne hapla*. Chromosoma 84:405-412.

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Sasser, J. N. 1980. Root-knot nematodes: a global menace to crop production. Plant Dis. 64:36-41.

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Starr, J. L. 1979. Peroxidase isozymes from *Meloidogyne* spp. and their origin. J. Nematol. 11:1-5.

Triantaphyllou, A. C. 1981. Oogenesis and the chromosomes of the parthenogenetic root-knot nematode *Meloidogyne incognita*. J. Nematol. 13:95-104.

IMP PROCEEDINGS

Proceedings of the Research Planning Conference on Root-Knot Nematodes, *Meloidogyne* spp. January 12-16, 1976. (Raleigh, N.C.) 106 pp

*Proceedings of Asian Regional Planning Conference on Root-Knot Nematode Research, Region VI, February 16-20, 1976. (Los Baños, Philippines).

*Memorias de la Conferencia de Trabajo Sobre el Proyecto Internacional Meloidogyne, Regional II, Marzo 22-26 de 1976. (Palmira, Colombia).

*Proceedings of the Regional Planning Conference of the International *Meloidogyne* Project, Region I, April 26-30, 1976. (Panama).

*Proceedings of the Research Planning Conference on Root-Knot Nematodes, *Meloidogyne* spp., Region IV, June 7-11, 1976. (Ibadan, Nigeria).

*Proceedings of the Research Planning Conference on Root-Knot Nematodes, *Meloidogyne* spp., Region VII, Jan. 29-Feb. 2, 1978. (Giza, Egypt).

Proceedings of the Second Asian Regional Conference on Root-Knot Nematodes, *Meloidogyne* spp., Region VI, February 13-17, 1978. (Bangkok, Thailand).

Proceedings of the Second Research Planning Conference on Root-Knot Nematodes, *Meloidogyne* spp., Region IV, February 20-24, 1978. (Abidjan, Ivory Coast).

Proceedings of the Second Regional Planning Conference of the International *Meloidogyne* Project, Region I, September 4-8, 1978. (San Jose, Costa Rica).

Memorias de la II[a] Conferencia de Trabajo sobre el Proyecto Internacional *Meloidogyne*, Regional II, Septiembre 18-22 de 1978. (Lima, Peru).

Proceedings of the Second Research Planning Conference on Root-Knot Nematodes, *Meloidogyne* spp., Region VII, November 26-30, 1979. (Athens, Greece).

Proceedings of the Third Research Planning Conference on Root-Knot Nematodes, *Meloidogyne* spp., Region VI, July 20-24, 1981. (Jakarta, Indonesia).

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* Out of print/no copies available

Proceedings of the Third Research Planning Conference on Root-Knot Nematodes, *Meloidogyne* spp., Regions IV and V, November 16-20, 1981. (Ibadan, Nigeria).

Proceedings of the Third Research Planning Conference on Root-Knot Nematodes, *Meloidogyne* spp., Region I, January 11-15, 1982. (Panama).

POSTERS (45 x 60 cm)

Perineal Patterns of the Four Most Common Species of Root-Knot Nematodes (*Meloidogyne* Species)

Head Shape and Stylet Morphology of Males of the Four Most Common Species of Root-Knot Nematodes (*Meloidogyne* Species)

Life Cycle of Root-Knot Nematode (color)

Copies of some of these publications may be obtained by writing to Miss Milly Oldham, Secretary, IMP, Department of Plant Pathology, North Carolina State University, P.O. Box 5397, Raleigh, NC 27650-5397.