*Proc. Indian natn. Sci. Acad.* **B52** No. 1 pp 66-76 (1986)

# Nematode Diseases and their Control in 2000 AD

K S VARAPRASAD and GOPAL SWARUP
*Division of Nematology, Indian Agricultural Research Institute, New Delhi 110012*

Biology and etiology of several of the important nematode diseases have been studied comprehensively in the present century and some headway has been made in successfully controlling these diseases mainly through chemical and partly through non-chemical approaches. Fumigants such as DD, Telone and Methyl bromide, which were initially responsible for focussing the nematode damage and are being used even today for controlling several important nematode diseases such as spreading decline of citrus, root-knot disease, are prohibitive in cost and can be used only in high value commercial crops. Recent introductions of oxime carbamates such as aldicarb and oxamyl, organophosphates such as phenamiphos and ethoprop have simplified the application methods as also somewhat reduced the cost. However, there is still a need for a breakthrough in the management of these organisms. The non-chemical approaches of pest management are summer fallow and ploughing, as has been employed for the cereal cyst nematode in India, crop rotations, hot-water treatment of planting material, regulatory measures, etc.

Some headway has been made in developing resistant varieties. The identification of single dominant resistant gene $H_1$ from *Solanum tuberosum* s.sp. *andigena* has led already to successful manag ment of potato cyst nematode population through use of resistant cultivars. Commercially viable resistant varieties are available now in crops like potato, soybean, cotton, sugarbeet etc.

A great potential is present in the application of computer science for developing programmes for forecasting and prevention of diseases, and for controlling them. The nematode distribution is not static and they can not move long distances like insects, fungal and bacterial spores. It is, therefore, almost impossible to eradicate them once they have stabilised themselves at particular points. In such cases, monitoring of nematode population levels and development of advisory programmes for help in decision making for specific farmer areas, can be programmed effectively, in the years to come through computer science. Further, role of the nematodes in blocking and or draining energy harvest through crop plants can be also assessed accurately with the application of computer science.

The use of remote sensing to detect nematode infestations, particularly in large areas of orchards or annual crops or plantation crops also seems quite prom sing. Such an attempt has been made already with the reniform nematode, infesting cotton, by correlating the presence of the nematode to leaf reflectivity which can be detected by remote sensing techniques.

**Key Words: Nematode infestations, Remote sensing, computer application in nematode Control**

**Introduction**

Plant parasitic nematodes, as an important biotic constituent of soil environment, limiting or contributing largely to low yields of economically important agricultural crops, have gained recognition only recently in comparison to allied disciplines of plant protection. Eventhough a very large number of plant parasitic species have been recorded and documented, only 15 have been identified so far as world problems (table 1). Of these, only three nematode species namely *Ditylenchus dipsaci*, *Heterodera schachtii* and *Radopholus similis* — citrus race (? *citrophilus*) are not reported, as yet, from our country. It may, however, be noted that these nematodes alongwith many others have been intercepted more than once with introduced plant material (Sethi et al. 1972). As a result of large scale as well as continuing import of planting materials, we run a high risk of getting new nematode problems and or new races of existing nematode species in the near future.

Besides the major nematode problems listed above, there are several other important nematode diseases which cause heavy losses in certain areas under specific situations. For example, the earcockle (*Anguina tritici*) disease of wheat could lead to as high as 80% or more crop loss in certain pockets of the country, if contaminated seed is regularly used for sowing. The maize cyst nematode (*Heterodera zeae*) is another nematode problem which has gained economic importance recently in India as well as USA. The 'ufra' and white tip diseases of rice caused by *Ditylenchus angustus* and *Aphelenchoides besseyi* respectively, often cause serious damage in some south-east Asian countries. The soybean cyst nematode, *H. glycines* is responsible for serious economic losses in USA, necessitating intensive nematode management programmes. The lesion nematodes, in general and particularly *Pratylenchus coffeae*, causes heavy losses to coffee in south India and *P. loosi* is a serious pest of tea in Ceylon. The red ring disease of coconut caused by *Rhadinaphelenchus cocophilus* in Surinam and British Guiana and on oil palm in Venezuela is rated as one of the most devastating diseases throughout the world. The ring nematode, *Criconemella onoensis* is responsible for yield reductions in rice in USA. Similarly, the mushroom cultivation is beset with nematode disease caused by *Aphelenchoides compositicola* and *Ditylenchus myceliophagus*.

Apart from direct damage to plants by nematode infestations, there are some nematode species which act as virus vectors. So far, there are 20 virus diseases which are known to be transmitted by several species of dorylaimid nematodes. In addition, there are several nematode species which have been demonstrated to be important or dominant factors in contributing to disease complexes with fungi, bacteria or other micro-organisms.

**Nematode Population Management—Computer Phase**

It is now fairly well recognised that we cannot totally dispense with any pest/pathogen in any Agricultural Production System (APS). The only alternative as suggested by Wallace (1973) is to "live with the disease". In the modern terminology "Nematode Control" is a jargon which is being rapidly replaced with nematode population management. Thus, the attention now is rightly focussed to control crop losses rather than eradication of nematodes. For scientific management of nematode populations, understanding of nematode, host and their environment is essential.

Unlike insect pests and many fungal and bacterial diseases, diagnosis of nematode problems is relatively an elaborate procedure. This is largely due to their less understood

**Table 1** *World nematode problems of high economic importance*

| Nematode | Year of first discovery | Distribution | Crops attacked | Economic Damage (Reference) |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| ROOT KNOT NEMATODES (*Meloidogyne* spp.) | | | | |
| 1. *M. incognita*<br>2. *M. javanica*<br>3. *M. hapla*<br>4. *M. arenaria* | 1855 | Throughout world (England*) | Vegetables, pulses, oilseeds, fruits, fibre, plantation and few cereal crops. | 4% — tomato (Valdez 1978) |
| 5. *Rotylenchulus reniformis* (Reniform nematode) | 1940 | Tropical and Semi-tropical areas of world (USA*) | Vegetables, Pulses, oilseeds, some fruits and fibre crops | USA—cotton, soybean<br>Peurto Rico—vegetables<br>India—pulses |
| POTATO CYST NEMATODES (*Globodera* spp.) | | | | |
| 6. *G. rostochiensis*<br>7. *G. pallida* | 1881 | 48 potato growing (European, American and Asian) countries (Germany*) | Potato, tomato brinjal | 10% — USA (Brodie 1984)<br>9% — UK (Evans & Stone 1977) |
| 8. *Ditylenchus dipsaci*+ (Stem and bulbnematode) | 1857 | Germany*, USA, England, France, Russia, The Netherlands | 300 plants including vegetables, cereals and ornamental plants | 60% onion in garlic, Russia (Kirjanova & Krall 1980)<br>18%— Corn in France (Caubel 1973) |
| 9. *Heterodera avenae* | 1874 | 31 wheat growing countries (Germany*) | Wheat, oat, Barley, Rye and Maize | Rs. 40 million on wheat, Rs. 30 million on barley in India<br>73-89% of wheat yield in parts of Australia (Meagher 1972) |
| 10. *Heterodera schachtii* (Sugarbeet cyst nematode) | 1859 | 40 countries including European (Germany*), American, African and Middle East | 218 species belonging to 23 plant families including sugarbeet | 10% on sugarbeet in USA (Anon. 1970)<br>25% in Central Europe (Weischer & Steudal 1972) |
| BURROWING NEMATODES (*Radopholus* spp.) | | | | |
| 11. *R. citrophilus*+ | 1928 | USA* (Florida) | 1275 species and relatives of citrus | 40–80% on Grape fruit and oranges (Suit & Ducharme 1967) |
| 12. *R. similis* | 1891 | Tropical and Sub-tropical parts of world (Fiji*, New South Wales) | 250 plants including banana, pepper and coconut | — |

**Table 1** (*contd.*)

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| 13. *Tylenchulus semipenetrans* (Citrus nematode) | 1889 | Throughout world (USA*) | 75 rutaceous and, 9 non-ru aceous plants, including citrus | 8.7 to 12.2% (Cohn 1972) |
| 14. *Hirschmanniella* spp. (Rice rootnematodes) | 1952 1902(?) | 46 rice-growing countries (Indonesia*) | Rice | 25 % (Hollis & Keoboonrueng 1984) |
| 15. *Bursaphelenchus xylophilus*+ (Pine woodnematode) | 1971 1913(?) | Japan*, USA and France | Pines | 2,400,000m³ of timber annually (Mamiya 1984) |

* Country from where first discovered
\+ Not yet reported from India

distribution patterns in soil, non-specific symptoms they cause and cumbersome procedure involved in their extraction. Decisions in nematode population management, particularly in Integrated Nematode Management (INM) systems often depend upon the accuracy of prediction about damage caused by pre-plant nematode densities. Some models have been developed by plant-nematologists for predicting damage by correlating initial populations with plant growth.

**Damage Predicting Models**

These models are useful for taking management decisions such as, which variety of crop should be grown, which method of control to be adopted, etc. Secondly, they are necessary for evaluating crop losses on a wider scale which in turn determines research objective and priorities. Moreover, the policy-makers at governmental level and other administrators need crop loss data for policy decisions.

The relationship between pre-plant nematode densities and crop growth/yield is classically described by two equations given by Seinhorst (1965) and Oostenbrink (1966). According to Oostenbrink (1966), the empirical relationship between log transformed nematode densities and crop yield are mostly linear. However, the damage function model developed by Seinhorst (1965), $y=m+(1\text{-}m)z^{P-T}$ (where $y$ is the crop yield; $m$, minimum yield; $p$, initial nematode density; $T$, tolerance level and z, a constant), has strong biological foundation. It is possible to calculate $m$, $z$ and $T$ values for any given data set by a computer programme developed by Ferris et al. (1981). A similar programme has been recently developed on Burrough's 4700 computer installed at IASRI for calculating tolerance levels of *R. reniformis* infesting cotton (Sud et al. 1984a) and several other crops (Sud et al. 1984b). However, Seinhorst's model describes a relationship between one nematode species and a crop at a time, while in nature, polyspecific nematode communities are common. This problem can be solved by developing a critical species model and the pathogenicity of other nematode species weighted relative to the critical species (Ferris 1980). The relative weightage given can take into account not only pathogenic ability of other species but also the suitability of soil texture to their movement, survival and infectivity (Ferris & Duncan 1980). Seinhorst's model is mainly based on the data collected at one critical stage (pre-plant densities). Fortunately, this is a convenient stage because most of the important management decisions such as crop and variety selection and soil fumigation etc. are pre-plant decisions. However, this model is of limited value in case of perennial crops where population fluctuations during the plant growth are highly important for management decisions. There is ample scope for development of multiple point models, where data are collected at several stages during the crop growth instead of one critical stage and simulation models including nematode as a component in APS. In simulation models, the rationale is that the rate of photosynthesis is proportional to the undamaged part of root and its efficiency. The plant is considered an energy supply/demand system from which nematode partitions out energy in several ways. Advanced parasites such as root-knot nematodes and reniform nematode are known to interfere the vital process of plants photosynthesis (Loveyh & Bird 1973, Varaprasad 1982). However, real time simulation models necessitates the use of computers because of large number of computations involved in the process, unlike Seinhorst's critical point model, which can be used with or without computers.

Computers are also being used now-a-days for developing sampling strategies (Barker & Campbell 1981). Nematode distribution can be uniform, random or in clusters. However, negative binomial distribution is common for many important pathogenic nematodes. Negative biomial distribution is normally described by two parameters, mean and the exponent K, which is an index of aggregation of population. Estimation of K can be computed on the principle of maximum likelihood techniques. Computer programmes have recently been developed to simulate sampling strategies for nematode distribution (Mcsorley 1982) and it is realised that sampling plans must be separately made for different situations.

Integrated nematode management includes research, development, technology transfer and implementation needed to integrate two or more control procedures, to manage one or more nematode species (Bird 1981). Pest crop eco-system models, biological and environmental monitoring, system design and implementation are major components of an INM system. These INM systems have been found to be very useful in certain cases e.g. cyst nematode problem of sugarbeet, and root-knot nematode problem of several crops including carrots and tomato.

## Chemical Methods of Nematode Management

Eventhough, the nematicidal properties of chloropicrin and methylbromide were recognised much earlier than that of DD, both were largely used as soil sterilants rather than nematicides, particularly at higher doses, because of their wide spectrum efficacy. The discovery of DD, as a nematicide by Carter in 1943, after its initial application in pineapple fields, is a landmark in the history of nematology. Thereafter, several other fumigant nematicides such as EDB (Dowfume W-85, Nematox 100), 1-3D (Telone), CPB and DBCP (Nemagon, Nemabrom, Fumazone, Nemapaz, Lirofume) were discovered and were initially responsible for focussing nematode damage.

In the second phase, certain mixtures of fumigant nematicides in different proportions such as Trapex (MIT+DD), Vorlex (MIT+ Chlorinated → hydrocarbons + chloropicrin) Telone C (1, 3D+chloropicrin), Dorlone (1, 3D+EDB), Larvacide (chloropicrin+ EDB) and certain other mixtures of methyl bromide and EDB were introduced into the market with limited success. In the next phase, certain methylisothiocyanate (MIT) liberations became popular as nematicides. Among these MIT liberators, Dazomet (N 521, Mylone, Basamid, Forgosian) is available in dust formulation while Terracur is available in granular formulation. Thus, with the introduction of these nematicides, all conventional problems in handling and application as injection into soil were surmounted. However, metham sodium (Vapam, VPM, Nematin, Vitafume), which is also MIT liberator, is available in compressed liquid form and needs to be injected into soil.

Following the discovery that some of these effective fumigant nematicides were carcinogenic and have residue problems, a need was felt for discovery of new nematicides. This need was all the more accentuated with the finding that DBCP which was one of the most popular nematicides, applied with irrigation water, was responsible for contamination of groundwater resources and therefore its production had to be stopped. Now several organophosphate and oxime carbamate nematicides are available in different convenient formulations such as wettable powders, granules, emulsifiable concentrates and flowable powders. Fensulfothion (Terracur P, Dasanit) an organophosphate, has been successfully used in the Nilgiris (Tamil Nadu) to contain the golden cyst nematode population in potato. Several other effective organophosphates are available such as Diazinon (Basudin, Diazitol, Neocid, Neocidol) @0.5 to 3 kg a.i./ha; thionazin (Zinophos Nematos, cynem, Nemaphos, Nemasol) @2–10 kg a.i./ha, Fenamiphos (Nemacur) @5–20 kg a.i./ha, Prophos (Mocap, Ethoprophos) @2-10 kg a.i./ha. Besides these organophosphates, the recent introduction of certain oxime carbamates such as aldicarb (Temik), aldicarb sulfone (U.C. - 21865), Carbofuran (Curatterr, Furadan, NTA 10242), Oxamyl (Vydate, Dupont 1410) and methomyl (Lannate) have made the nematicidal application as an economically viable proposition, and these nematicides are becoming increasingly popular particularly with reference to cash crops.

However, the nematicides listed so far and belonging to halongenated hydrocarbons, organophosphates and oxime carbamates are ineffective against nematode eggs particularly at the prescribed doses. Moje and Thomason (1963) have demonstrated that DBCP dosage required to kill the eggs of *M. javanica* is 200 times that of needed for killing hatched second stage juveniles. The egg is only stage in the nematode life-cycle containing chitin and therefore, highly resistant to these nematicides. Consequently, the recent researchers have chosen 'egg' as the target stage of nematode life-cycle. Diflubenzuron (DFB), a potent inhibitor of chitinsynthesis in insects, has been observed to reduce number of egg masses and eggs produced by *M. incognita*. However, DFB did not appear to be toxic to juveniles (Veech 1978). Similarly, PCNB, a soil fungicide, has been reported to weaken the egg shell of *A. avenae*. Another target area for research is chemicals affecting fecundity or development of females. For example, some benziamidazole compounds (Thiabendazole, benomyl) have been found to increase the proportion of males and impede the development of females (Wright 1981).

Nematicides are not known, generally, to have specificity in their actions against nematode species. Most of the fumigant nematicides intoxicate nematodes either by oxidation of $Fe^{2+}$ centres in the cytochrome chain, thus blocking respiration, or by an alkylation reaction at the active sites of esterase and/or protease enzymes. Both organophosphates and carbamates act on nematodes by inhibiting the acetylcholine esterase (ACh E) at cholinergic synapses in nematode nervous system. There appears to be a great scope for development of new nematicides as suggested by Wright (1981) by selecting and studying intensively alternative target sites. ACh E is a general neuro-transmitter common to vertebrates and arthropods. Research efforts in identifying and mimicking neurotransmittors that are specific to nematodes may lead to the discovery of selective nematicides eliminating mammalian toxicity and other pollution hazards.

The intensive study of virgin areas on nematode biology such as energy metabolism, hormonal systems and nutrient transport process is likely to reveal the new targets for managing the populations of these tiny animals. The recent formulations of nematicides and their methods of applications such as bare root dip treatments, seed treatments, row applications, spot treatments and foliar applications have considerably increased the effectiveness and made them relatively economical. However, a large amount of chemical is wasted in the process of reaching the target animal and actual amounts required to kill them are relatively very small. By improving the existing formulations by use of adjuvants and inventing controlled release formulations would certainly economise nematicides to a great extent.

## Nematode Management through Host Resistance

Plant nematologists have devoted considerable time and energy to understand and explore the use of host-resistance against nematode populations. Availability of resistance and type of nematode parasitism are inter-related (Roberts 1982). Thus, the sedentary endoparasites are specialized parasites having relatively narrow host range where resistant source is easily available. On the other hand ectoparasites have a wider host range, less specialised interaction with host and the availability of resistant sources is meagre. Nevertheless, resistant sources are known in several crops against some important nematode problems (table 2). As a result of intensive studies on plant-nematode interaction, nematologists have been able to identify some allelochemicals, allelopathics and phytoalexins having implications in nematode population management (tables 3 and 4). Of the two allelochemicals identified

**Table 2** *Resistant sources known against nematodes*

| Nematode | Crop |
|---|---|
| 1. Root-knot nematodes | Beans, cowpea, cotton, soybean, tomato, sweet-potato, alfalfa, pepper, apricot, grape, walnut, peach, plum, almond |
| 2. Potato cyst nematodes | *Solanum tuberosum* sub. sp. *andigena*, *S. vernei*, *S. multidissectum*, *S. chacoense*, *S. spegazzinii* |
| 3. Cereal cyst nematode | Wheat (?), barley, oats |
| 4. Stem and bulb nematode | Alfalfa, red clover |
| 5. Citrus nematode | Citrus |
| 6. Soybean cyst nematode | Soybean |
| 7. Reniform nematode | Soybean, tomato |
| 8. Burrowing nematode | Banana |
| 9. Sugarbeet cyst nematode | Beet, tomato |

**Table 3** *Allelopathics toxic to nematodes*

| Plants | Allelopathics | Target species |
|---|---|---|
| Marigolds | Terthienyl 5-(3-Buten-1-ynyl)-2-2'-Bithienyl | *Pratylenchus penetrans*, *Meloidogyne javanica* |
| Cucumbers | Glycosides/Aglycones (Triterpenoids) | *M. incognita* |
| *Carthamus tinctorius* | Isomeric polyacetylene compounds | *Aphelenchoides besseyi* |
| Neem | Nimbidin | *M. incognita*, *Rotylenchulus reniformis*, *Tylenchorhynchus brassicae* |
| Potato | Chaconine | Potato cyst nematodes |

**Table 4** *Phytoalexins toxic nematodes*

| *Plants* | *Phytoalexins* | *Elicitors* |
|---|---|---|
| Limabean | Coumestrol | *Pratylenchus scribneri* |
| Soybean | Glyceollin | *Meloidogyne incognita* |
| Cotton | Terpenoids (Gossypol/ hemigossypol methoxygossypol/ dimethoxygossypol) | *M. incognita* |

from marigolds, terthienyl was found to be highly nematicidal, particularly after its activation by ultra-violet radiation (350 nm). Another allelopathic (?) group identified from bitter cucumbers, called cucurbitacins, though reported to have variable effect on nematode attraction, was found to adversely affect nematode reproduction under green house conditions. Though several other allelochemicals such as nimibidin, thionemone, L-chaconine and some isometric polyacetylene compounds were discovered, none of them could be brought so far to commercial status for application on field scale. Among the different phytoalexins discovered, coumestrol, psoralidin, glyceollin and some terpenoides such as gossypol, hemigossypol, etc. are important. These phytoalexins are toxic to only their respective elicitors and not to other nematode species. The potential of these phytoalexins and allelopathics is yet to be exploited for nematode population management.

The mechanism of resistance in potato against *G. rostochiensis* and *G. pallida* is better understood than any other host-resistant mechanisms involved against nematodes. Genes responsible for resistance against potato cyst nematodes such as $H_1$ $H_2$ $H_3$, h and K were identified from potato cultivars, plant breeders' hybrids and wild species of potato. The source-sink relationship established between female nematode and potato-susceptible cultivar can be upset by single major gene change in the host. The host resistance is against female nematodes as males do not have any critical role in the disease syndrome. The gene forgenes relationship similar to that of rust fungi attacking wheat has been proposed in this case also (Jones, 1979) with 'H' and 'h' as host genes for resistance and N and 'n' as corresponding genes in nematodes.

Resistant genes (R-genes) have been identified in several other economically important crops. However, the studies on resistance in barley and oat against cereal cyst nematode, in soybean against soybean cyst nematode and in tomato and tobacco against root-knot nematodes have received greater attention than other plant-nematode interactions. Resistant varieties against many of the important nematode problems have been developed and released on commercial scale. Development of resistance breaking new races has so far not been a problem atleast in potato where potato cyst nematode resistant cultivars are continuously grown. However, to avoid such risks 'dirty vs clean' crop practice has been advocated (Sidhu & Webster 1981). Each component line of 'clean crop' carried a different resistant gene against all the prevalent races of pathogen while the resistant genes in 'dirty crop' are semi-resistant to all the races.

Use of host resistance in nematode management can be tapped better with sophisticated techniques like protoplast fusion methods cytoplasmic techniques and tissue culture techniques. Further, the reasons for epidemics of pests and pathogens can be understood by concentrating future studies on natural parasite systems versus agricultural parasite systems.

## Nematode as Biological Models

Study of nematodes led to the discovery of certain classical cytological and biological phenomena, which were considered incomprehensible until that time. They are role of fertilisation in reproduction, the process of meiosis discovered in eggs of *Parascaris equorum* (*Acsaris megalocephala*), the process of chromosome fragmentation and chromatin diminution and gynogenesis which is (pseudogamy or pseudo fertilisation) first discovered in *Rhabditis aberrans* (Triantaphyllou 1971).

Though several nematodes were chosen for developing biological models as *Caenorhabidits elegans, C. briggsae, Pangrellus redivivus, Turbatrix aceti, Ascaris lumbricoides A. suμm, Aphelenchus avenae* etc., the most favoured species is *C. elegans*. *C. elegans* has been used as a model for investigating many phases of biology (table 5). This nematode species has a unique combination of characters which made it possible to be an ideal biological model (table 6). The potential uses of this biological model were well recognised and David Hirsh of University of Colorado was the first American investigator to establish in 1974 an independent laboratory aimed at the analysis of *C. elegans* embryogensis and gonadal development. Genetic map of *C. elegans*, including 350 genes and numerous chromosome re-arrangements, has been prepared (Riddle 1982) and is considered as one of the most sophisticated genetic maps available so far. The motility of spermatozea in *C. elegans* has been investigated, which opens up new avenue of nematode control in amphimictic plant parasitic nematodes (Ward et al. 1982). Thus a better understanding of anatomy, development, physiology, genetics and behaviour of free-living nematodes will provide fundamental new insights into nematode control.

It is possible now, with remote sensing techniques, to detect nematode diseases of orchards and plantation crops as has been demonstrated in the case of reniform nematode infesting cotton by correlating nematode stress to leaf reflectency. Thus, nematode problems in the 2000 A.D. may be easily and accurately diagnosed and consequently the nematode populations would be economically and suitably managed with minimum disturbance to natural ecosystem and energy harvest through crops.

**Table 5** Caenorhabditis elegans *an ideal biological model for investigating*

| | |
|---|---|
| A. | Genetic basis of eukaryotic development and animal behaviour |
| B. | Cell lineage and development |
| C. | Muscle development |
| C. | Gerontological studies |
| E. | Toxicity studies in development and formulation of nematicides |

**Table 6** Caenorhabditis elegans *an ideal biological model because of the following unique combination of characters*

| |
|---|
| 1. Small genome size — 2,500 genes |
| 2. Short generation time — 3 days |
| 3. Small size — 60μM × 1μM |
| 4. Small number of neurons (about 250 in adult) |
| 5. Large number of progeny per parental worm—300 |
| 6. Self reproducing — hermaphrodlite |
| 7. Can be stored in liquid nitrogen (—196°C) permitting maintenance of large number of mutants |
| 8. Cellular simplicity with constant number and arrangement — 1000 non-gonadal cells |
| 9. Easy to culture |
| 10. Devoid of capacity to repair cells — suits for gerontological studies |

## References


Anon. 1970 Estimated crop losses from plant parasitic nematodes in the United States; Report of the Soc. Nem. Comm. on Crop losses

Barker K R and CampBell C L 1981 Sampling nematode populations; in *Plant Parastitic Nematodes* Vol. III ed B M Zuckerman and R A Rhode (New York: Academic Press) pp 451–474

Bird G W 1981 Integrated nematode managment for plant protection; in *Plant Parasitic Nematodes* Vol. III ed B M Zuckerman and R A Rhode (New York: Academic Press) pp 355–375

Brodie B B 1984 Nematode parasites of potato; in *Plant and Insect Nematode* ed W R Nickle (New York: Marcel Dekker, Inc) pp 167–212

Caubel G 1973 Problems poses parle nematode des tiges (*Ditylenchus dipsaci* Kuhn) en culture de mais C.R.; *Sciences Acad Agric* (France) **59** 627–640

Cohn E 1972 Nematode diseases of citrus; in *Economic Nematology* ed J M Webster (New York: Academic Press) pp 215–244

Evans K and Stone A R 1977 A review of the distribution and biology of the potato cyst nematodes *Globodera rostochiensis* and *G. pallida*; *PANS* **23** 178–189

Ferris H 1980 Nematology — status and prospects: Practical implementation of quantitative approaches to Nematology; *J. Nematol.* **12** 164–170

—— and Duncan L 1980 Consideration of edaphic factors in quantifying nematode stress on plant growth; *J. Nematol.* **12** 220

——, Tunner W D and Duncan L W C 1981 An algorithm for fitting Seinhorst curves to the relationship between plant growth and pre-plant nematode densities; *J. Nematol.* **13** 300–304

Hollis J P and Keoboonrueng 1984 in *Nematode Parasites of Rice in Plant and Insect Nematodes* ed W R Nickle (New York: Marcel Dekker Inc) pp 95–146

Jones F G W 1979 *Rep. Rothamsted Exp. Sta.* 1978 Pt pp 178–182

Kirjanova E S and Krall E L in 1980 *Plant Parasitic Nematodes and their Control* (Nauka Publishers Leningrad Section Leningrad transl American Publishing Co. Pvt. Ltd., New Delhi)

Loveys B R and Bird A F 1973 The influence of nematodes on photosynthesis in tomato plants; *Physiol. Plant. Pathol.* **3** 525–529

Mamiyay Y 1984 in *The Pine Wood Nematode in Plant and Insect Nematode* ed. W R Nickle (New York: Marcel Dekker. Inc.) pp 589–626

Meagher J W 1972 Cereal cyst nematode (*Heterodra avenae* Wall) studies on ecology and content in Victoria; *Tech. Bull.* **24** (Dept. Agric Vict.)

McSorley R 1982 Simulated sampling strategies for nematodes distributed according to a negative binomial model; *J. Nematol.* **14** 517–522

Moje W and Thomason I J 1963 Toxicity of mixtures of 1, 2-Dibromo-3-chloropropane and 1,2-Dibromo-ethane to the root-knot nematode, *Meloidogne javanica*; *Phytopathology* **53** 428–431

Oostenbrink M 1966 Major characteristics of the relation between nematodes and plants; *Meded Landb. Hogesch* Wageningen 66–4

Riddle D L 1982 Developmental biology of *Caeoorhabditis elegans:* Symposium introduction; *J. Nematol.* **14** 238–240

Roberts P A 1982 Plant resistance in nematode pest management; *J. Nematol.* **14** 24–32

Seinhorst J W 1965 The relation between nematode desnity and damage to plants; *Nematologica* **11** 137–154

Sethi C L, Nath R P, Mathur V K and Ahuja S 1972 Interceptions of plant parasitic nematodes from imported seed/plant materials; *Indian J. Nematol.* **2** 89–93

Sidhu G S and Webster J M 1981 Genetics of plant-nematode interactions; in *Plant Parasitic Nematodes* Vol. III ed B M Zuckerman and R A Rhode (New York: Academic Press) pp 61–87

Sud U C, Varaprasad K S, Seshadri A R and Kher K K 1984 a Relationship between inital densities of *Rotylenchulus reniformis* and damage to cotton with a fit to Seinhorsts's curves; *Indian J. Nematol.* **14** 148–151

——, —— and Swarup G 1984b Application of Seinhorst's equation for the estimation of host tolerance levels against the reniform nematode *Rotylenchulus reniformis* 30th Annual Conference of Indian Society of Agricultural Statistics, Calcutta

Suit R F and Ducharme E P 1967 Spreading decline of citrus in burrowing nematode in citrus (eds C Poucher, H W Ford, R F Suit and E P Ducharme) *Florida Department of Agriculture Bulletin* pp 1–20

Triantaphyllou A C 1971 Genetics and Cytology; in *Plant Parasitic Nematodes* Vol. II ed. B M Zuckerman, W F Mai and R A Rohde (New York: Academic Press) pp 1–34

Valdez R B 1978 Nematodes attacking tomato and their control; in *First International Symposium on Tropical Tomato* ed. R Cowell 290 pp

Varaprasad K S 1982 Studies on *Rotylenchulus reniformis* linford and Oliveira 1940, with special reference to host nutrition; Ph D Thesis, Indian Agricultural Research Institute, New Delhi 135 pp

Veech J A 1978 The effect of diflubenzuron on egg formation by the root-knot nematode; *J. Nematol.* 10 208-209

Wallace H R 1973 in *Nematode Ecology and Plant Disease* [Edward Arnold (Publishers) Ltd] 215 pp

Ward S, Roberts T M, Nelson G A and Argon Y 1982. The development and motility of *Caenorhabditis elegans* spermatozoa; *J. Nematol.* 14 259-266

Weischer B and Steudel W 1972 *Nematode Diseases of Sugarbeet in Economic Nematology* ed. J M Webster (London: Academic Press) pp 49-65

Wright D J 1981 Nematicides : Mode of action and new approaches to chemical control; in *Plant Parasitic Nematodes* Vol. III eds B M Zuckerman and R A Rhode (New York : Academic Press) pp 421-449