Tribune

REFLECTIONS ON THE PRESENT AND THE FUTURE OF NEMATOLOGY [1]

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Nematodes and nematologists

Nematology, the study of plant parasitic nematodes and the knowledge of their importance to plant protection is a relatively new science. Without misplaced modesty, we must realize that it is a small branch compared to other older fields of research (entomology, mycology, weed science, etc.) that make up plant protection.

Progress in nematode identification has resulted in a considerable increase of the number of known genera and species. Thus, in less than 30 years, we have gone from about 50 genera comprised of roughly 1 000 species to over 120 genera represented by at least 2 500 valid species. Worldwide there are over 100 new species described each year that belong to the ecological group of plant parasitic nematodes. Such an evolution, pleasing in itself, can be of concern to taxonomists and systematicians overwhelmed by the enormity of the work to be done. Moreover, there are an increasing number of new species — often in collections — awaiting description and classification in the existing system. The most conservative of taxonomists estimate that the number of new species to be discovered is double of what is already known.

In a not so distant past, any nematologist worth his name could still risk specific identifications at least in some genera. This time is probably coming to an end and the future of this field will probably belong to the specialized « pure » taxonomists. In effect, it will be more and more difficult to find differentiating simple morphological characters, recognizable with a compound microscope, for the identification of nematodes from genera where the number of species has increased by 800 %.

A modern approach to plant protection demands that pests be precisely identified. The past shows that sibling species can have very different food habits (host ranges) and pathogenicity. There was a time when any *Pratylenchus* was *Pratylenchus pratensis*. Now we know well that *P. penetrans* is much more pathogenic than *P. crenatus* or *P. neglectus*. We now have over 200 species of *Xiphinema* and *Longidorus*. Of that number only 12 species vector viruses, that compel us to use chemical control. What is left to be said, when a given species (e. g. *Ditylenchus dipsaci*) has sympatric biological species that cannot be recognized with the compound microscope. The necessity of an exact identification of the nematodes can also be seen when cultivars with specific resistance (to different pathotypes of *Heterodera* or *Globodera*) are in use. Finally, exact identifications are demanded from civil servants responsible for enforcing quarantine regulations or mandatory control measures (e. g. golden nematode). A misidentification in such cases can lead to serious consequences (lawsuits, fines).

Sophisticated technologies like the scanning electron microscope allows a more detailled study of surfaces. This SEM microscope is obviously an important tool to the taxonomist. There remain however, all the delicate problems related to the morphological variability of nematodes. In that range of ideas, computer analysis of the variability within the genus *Helicotylenchus* have shown the most stable criteria to consider. This type of research is an exemplary illustration. However the future will probably demand of the taxonomist the frequent use of biochemical or cytological methods (especially with parthenogenetic complexes), and even hybridization work.

Enough said about nematodes. Let's examine human problems. How many nematologists are we, spread all over the world? One or two thousand, maybe more? A recent study counted 278 nematologists in 142 research institutions working in tropical nematology alone. A world wide count would probably be helpful to the needs of our profession.

Nematologists belong to several professional societies that can further the goals of the science. One can think of the (American) Society of Nematologists (SON) started in 1960, the European Society of Nematologists (SEN) started in 1954, the Brazilian Society of Nematologists, the Organization of Tropical American Nematologists (OTAN), etc. Several specialized organizations

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like ORSTOM, or international research institutes in Lima, New Delhi, Ibadan, etc., contribute also to nematological research.

Let's move on from professional societies to the question of scientific training of nematologists. In other words, how are we trained and what kind of teaching should we give to the younger scientists? Without hard data we can only attempt to answer. First of all, in Europe because of the lack of formal university programs, most nematologists started as entomologists, mycologists or zoologists. Some of us attended (or perhaps taught) a nematology course in Wageningen, which unfortunately was dicontinued at the death of the late Dr Oostenbrink. So, to my knowledge, the European nematologist is mostly a self learned expert with on the job training.

In the USA, two nematology deparments (Davis and Riverside) are attached to the University of California. These departments give graduate training (Msc and PhD). Other American universities (e. g. Cornell, Purdue, North Carolina State) also give specialized training in nematology. From 1968 to 1978, 80 PhD degrees in nematology were given in the USA. This favorable situation seems to satisfy the demands of the agricultural system of this country and some graduates later go to work in the tropics. Can we foresee what the skills of the future nematologists will be. Right away two schools of thoughts are in conflict : will we provide general basic training with emphasis on nematology in the last semesters or a very specialized training in nematology right at the start? Either of these options have advantages and disadvantages. It has been said tongue in cheek, of American entomologists that there are those specialized in the north side of a tree and those specialized in the south side of the same tree. Is this what we want for nematologists? A survey in the USA (1980) shows research priorities in nematological research and the funds allocated. Moreover, the essential development of new strategies and new control measures, and the prominence of biotechnology in our field, lead us to predict that the future nematologist might also be a molecular biologist, a chemist or a geneticist. With the restraint policies of the public sector in many countries, the labour market at the present time is not very favorable to the young nematology graduates. One can only lament this situation hoping that research administrators will get increased budgets and hire more young scientists. To some extent we may be to blame for not advertising our professional image, and for our non-agressive soliciting of political backing that could create jobs. I leave this an open question.

Before I begin the second part of this talk on nematode control, it is timely to review the importance of agricultural losses caused by nematodes. " Nematodes : the invisible enemies " is the title of a pretty brochure, which brings us to the heart of the subject. To field nematologists, the first difficulty to overcome, is to show growers the harmfulness of the minuscule nematodes. Without characteristic symptoms on the plants the pest can remain unknown to the farmer and the losses attributed to other causes (poor fertilization, unfavorable climatic or edaphic conditions, etc.). In that line, the so called soil fatigue described by agronomists has often been attributed to plant parasitic nematodes. Besides, as everyone knows, the aggregated distribution of nematodes in the soil makes their detection sometimes difficult. Moreover, nematodes can be in synergistic associations with other pathogens (viruses, bacteria, fungi) which makes for even more difficult evaluations of losses.

In that regard we must recognize that for many nematode host-interactions we lack basic knowledge of their mode of distribution, cultivar tolerance or susceptibility, relative pathogenicity and economic thresholds. We also lack essential information on the influence of climatic and edaphic factors on population dynamics. All in all, we only have detailed information on a few cyst nematode species (golden nematode, cereal and sugar beet cyst nematodes) and a few root knot species.

As a general rule, the estimates of losses come from experiments testing nematicides or resistant hosts. It is well known that nematicides that can have secondary effects on other pests or diseases, or even on plant physiology, will exaggerate the economic importance of nematodes. A survey published in 1971 in the Journal of Nematology mentioned nematode related losses in the USA of 5 to 20 %, depending on the crops. In that country *Meloidogyne incognita*, *M. arenaria* and *Heterodera glycines* share the title of most damaging nematode. In Europe, the most damaging species are in the genera *Globodera* and *Heterodera.*

In the tropics, nematode damage can be of a degree rarely seen in temperate regions. There, the parasitic pressure is very high all year round. The lack of winter with its moderating effect, and the very long growing season (12 out of 12 months in certain regions) enable pests to reach extremely high densities. In regions with a dry season, plant parasitic nematodes are well adapted to extreme conditions (anhydrobiosis), but the reprieve is of short duration. This grave situation is found in countries without agricultural surpluses and where agriculture is the essential means of living, providing food or hard currencies for imports. As the population increases in these countries (about + 70 % at year 2 000) the demand for food is going to be greater. The inevitable decrease of agricultural production *per capita* is aggravated by frightening processes such as desertification, salinization, and soil erosion. These developing countries must feed more people as well as earn hard currencies to import the fuel, equipment, and the chemicals essential to their agriculture. For such an aim, the solidarity of the developed countries is essential. One can feel the predicament of populations held in such a vicious circle and the increasing restrictions placed on their leaders to find acceptable solutions and avoid catastrophy. We now have a better perspective of the responsibility of tropical nematologists and the work that needs to be done in the near future.

The management of nematodes

CHEMICAL METHODS

The first generation of fumigant nematicides goes back to 1943, when the mixture of dichloropropane-dichloropropene was introduced on the market. For preplanting treatments these fumigants proved efficient and safe. Most will agree that they have been an immense service and greatly contributed to the blooming of our discipline by stimulating research on nematodes. However, because of their cost, the use of liquid fumigant is still reserved to high value cash crops.

In developing countries, the use of fumigants is not always economically or technically attainable for the grower. It is however, in the tropics that we find the most spectacular results (30 to 200 % increases in yields depending on the crops, reports from ORSTOM).

In the last twenty years, there has been no significant development of new soil fumigants, apart from attempts to better the traditional fumigants. During that time however, the application techniques have improved considerably. One can, nowadays, treat with precision at doses of 300 to 400 litres per hectare. Refined techniques have resulted in the development of low volume applicators. Thus in Australia, ethylene dibromide (EDB) which is normally phytotoxic, is applied at seeding to cereals at a dose of 3.7 l/ha (Jectarow applicator). In these conditions treatments with EDB can be profitable even with a low value crop, and easily paid for with a few extra hundred pounds of grain per hectare.

The problems of treating perenials are not solved yet. Pre-planting treatments (fumigations) or at-planting time treatments are still recommended for sugarcane, banana, pineapple, etc.

In spite of improved techniques (better dosages), the future of fumigant nematicides is uncertain. The use of nematicides in massive quantities has given them a bad name, because of their possible role in the pollution of the land. For proof, one can remember the recent bans on the use of DBCP (dibromochloropropane), EDB (ethylene dibromide), and aldicarb (in some states of the USA).

Thus, there are potential threats to other nematicides that could disappear from the shelves (Shell DD for example) under the pressure from various (mostly political) interest groups. This situation with all its uncertainties should be an incitation to discover new products, but industrial chemical research is stagnating.

As early as 1960, non phytotoxic nematicides became available (aldicarb, carbofuran, oxamyl, ethoprophos, phenamiphos, etc.). The well known insecticidal properties of these molecules contributed greatly to their success.

More recent trials are opening new possibilities for the use of granular nematicides. They can also be used in liquid formulations. However, only those molecules with systemic properties, going downwards and protecting the roots, like oxamyl, can be used in this manner. There has been no new granular nematicides developed in many years. This may be explained by the fact that the pesticide market share of nematicides in the USA is 3 % (herbicides 60 % and insecticides 21 %). To invest 15 to 20 million dollars and nine to ten years for research and development of a new nematicide for such a reduced market becomes a shaky proposition. Another constraint is the increasing restrictions legislating pesticide uses (for registration). In the past (1959), five to seven experimental tests were enough to obtain registration and market a product. Nowadays, over 40 differents tests (biological, analytical, toxicological assays) are necessary to patent and market a chemical. The consequence is that the benefit (profitability) is more uncertain and the risks of failure increased, so that industries cut down on the development of new molecules.

Even if the intentions of the legislators are honorable (to protect people and the environment), it seems that the state is not playing the role it should by seconding industries in the long term search of new products. Finally, we have not found chemicals more efficient than the organo-phosphates, oxime-carbamates, and carbamates now available.

Is this to say that the development of third generation nematicides is not justified? Certainly not. However, the development of such nematicides entails a more sophisticated knowledge of nematode physiology and biology. Thus to improve the effectiveness of future nematicides we need to know which biological stages are more affected by them (eggs, motile juveniles, at molt, resting stages, etc.). Furthermore, the nematicides of the future will be more specific. One can attempt to draw a portrait of these products :

— non phytotoxic, in granulated or liquid form, easily degradable;

— systemic (going down to the roots);

— slow release of active ingredient, therefore less susceptible to washing out and drainage (lethal concentration maintained longer);

— more specific sites of action : nervous, hormonal or respiratory systems, general metabolism, synthesis of nucleic acids, etc.

New substances from the group of the « avermectins » or from the group of the « lectins » (concavalit) seen to fit several of the characteristics set in the « portrait ». So there is light around the corner.

The intensification of chemical control has led several pests (insects, mites, fungi) to develop resistance by adaptive mutations. It is apparent that the probability for the development of resistance mechanisms is low in nematodes. The selective pressures are weak in temperate zones, since nematodes have only a few generations per year, and nematicide applications, because they are expensive, are infrequent.

Use of resistant plants

Resistant plants are most useful with specialized parasites such as species of *Heterodera* or *Globodera.* Also, most achievements with selection for resistance have been against nematodes from temperate regions. In agriculture, the use of resistant cultivars is an inexpensive, non polluting management tool. Moreover, it is a practice that does not need to alter the sequence of farming activities. The selection of resistant plants has been done essentially against *Meloidogyne* and *Heterodera s. lato* species. Although there is an urgent need for them, no resistant cultivars have been developed against the migratory endoparasitic nematodes (*Pratylenchus, Hirschmanniella,* etc.) or against ectoparasites *(Trichodorus).*

Resistant cultivars have great advantages of essential interest to tropical nematologists. Unfortunately, multiple infestations that are often the rule in tropical zones reduce greatly the effectiveness of resistant cultivars. When a resistant cultivar, without the necessary multiple resistance is used, the dominant nematode species suppressed by the resistant cultivar are replaced by others that are part of the pathogen complex (up to ten different genera in sugar cane). This substitution of species has been well studied in crops such a pineapple where there is a substantial competition between species or group of species. This crop offers a striking example : the use of *Crotalaria* (a toxic legume) eliminated species of *Meloidogyne* that were then replaced by *Pratylenchus brachyurus* which was even more damaging. So in the tropics resistant cultivars give only a temporary reprieve from nematode attacks. Moreover, experience has shown that plant resistance is often broken at soil temperatures above 30°, a common condition in the tropics. The uninterrupted use of resistant cultivars has led to adaptive mutations and created new « B » races of *Meloidogyne* that can attack normally resistant cultivars. With this situation, tropical nematologists can only hope for an increased contribution from breeders to create cultivars with multiple resistance.

In this light, we should hope for, and encourage the formation of a repository for resistant genes providing the means to create resistant varieties responding to the needs of every region. The accomplishments of the « International *Meloidogyne* Project » (supervised by Dr Sasser) have given the elements necessary to foresee the making of such a gene bank, which will serve the tropical regions immensely.

Modern techniques (biotechnology) envision resistance gene transfers, or the transfer of increased capacity to form inhibitory substances such as phytoalexins, from parent plants (from different genera or even from different families). The new techniques of somatic hybridization cloning, meristem tissue culture, etc., give us confidence that we shall be able to increase the resistance of our crops.

Biological control against nematodes

Nematodes have numerous natural enemies (mites, insects, fungi,...). Some of these antagonists are probably more effective than is generally believed. Very few antagonistic agents have actually been utilized in specific biological control program.

In the future, basic research should elucidate the very specific relations between hosts and parasites. In that light, we now see that the affinity reactions between the fungal lectins and the cuticle of some nematodes is all important to successful trapping. Nematode egg parasitic fungi are quite specific (cyst nematodes) and also have a good potential. However, commercial production of these fungi seems remote because they are obligate parasites and they sporulate only in live hosts; anyway products as Royal 300 and Royal 350 are commercialy producted in France.

Moreover, future research must attempt to improve the performance of biocontrol agents by finding more beneficial agricultural methods, better techniques to inoculate soils, etc. There is also room for more involved studies of soils suppressive to nematodes themselves or to the diseases they cause. Several aspects of biological control can advance with biotechnology (Symposium of Atlantic City, USA, 1985). This modern technology contemplates genetic manipulations of biological agents to increase their virulence or change their host range. Natural toxins from these biological agents could be isolated and identified. These advanced technologies are of high interest to industries, and so they may well finance part of the basic research in that field.

Crop rotation

Crop rotations are the oldest control method against nematodes. Unfortunately, often because of the economics, it is not practiced. In fact the trend of modern intensive agriculture is to do away with rotation and instead make generous use of inorganic fertilizers and pesticides. In consequence, the agricultural ecosystems are simplified. This monotony of cultures is favorable to the multiplication, and even a form of selection of some genera of nematodes. Such perturbations of ecosystems with its predominant pests are at the core of many problems. Perhaps, and I must insist on this, a complex rotation system maintaining a diverse and stable nematode fauna, could be as economically feasible as a simple or nonexistent rotation system with its necessary use of pesticides. These considerations are also valid for tropical agriculture where monoculture leads to even more unstable situations.

In the tropical milieu, there is also the real possibility of continuous reinfestation of crops (through trees, bushes, and their adventitious roots) established in fields freshly cleared. In the temperate zone the same situation, although less extreme, arises from forested environment where numerous nematode species can be found including virus vectors. To include intermediate crops in the rotation scheme can be profitable if some of these are resistant (e. g. *Raphanus* species against *Heterodera schachtii*, *Crotalaria* against species of *Meloidogyne*), or have nematicidal properties (*Tagetes* against species of *Pratylenchus*). For plants that are propagated vegetatively (stolons, rhizomes, tubers, etc.), or by seeds, the risks of propagating soil pathogens through these vegetative organs are real when these crops are established in infected soil (*Heterodera*, *Globodera*, *Radopholus*, etc.). Restricted cropping, quarantine regulations, phytosanitary inspections at borders, come into effect, seeking to stop the spread or the introduction of harmful nematodes. In Europe the efforts and established standards of the EPPO (Lists of pests A1, A2, A3) have the same scope.

Integrated pest management

This modern management strategy is comprised of all biological, chemical, cultural and genetic methods that can decrease pests (including nematodes) below the damage threshold. Integrated pest management (IPM) means a lesser impact on the ecosystem — the non damaging fauna such as predators and parasites are not targeted —, and on the environment by lowering the number of applications of pesticides and eliminating the « no risks » rigid spray programs.

If they are going to be operational, integrated pest management programs must have detailed information on the biology and the ecology of pests, as well as precise and accurate records of population levels (which are a problem to obtain for many nematodes).

Because of its global scope, integrated pest management represents a part of the future of our discipline. IPM allows for the restrained use of nematicides, since we cannot do without for lack of alternatives. These programs are also in opposition against people seeking a future without pesticides. A serious debate can only consider the ways and methods to better utilize pesticides, not their ban. The stakes are too high to let idealists make the decisions for the protection of worldwide agricultural products valued at between 20 and 60 billion dollars. The FAO is well aware of what would mean for mankind a general ban on agricultural chemicals. Finally in IPM, and I believe this is progress, nematologists will work in a team including all disciplines aiming at the control of pests in our crops.

Conclusions

I have tried in this address to take a realistic look at our profession and its future. Many questions remain unanswered and many problems are still without a solution. To conclude, I want to express my hope that all the forces and talents of our profession may unite, for harmony and complementarity between researchers are the keys to progress in Nematology. This 18th Symposium is a perfect setting for everyone to cultivate science, friendship and good humor.

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