Introduction

Reflections on Nematology in Subtropical and Tropical Agriculture

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If the birth of nematology in temperate areas can be dated to 1743 with the observations by Needham of the wheat seed gall nematode or "ear cockle eelworm", nematology in the tropics was initiated at a much later date.

The first tropical nematodes were described from Oceania during the late 19th and beginning of the 20th century. Cobb (1891) reported finding nearly 30 species in banana soil and plant tissues from Fiji; among them, he described (Cobb, 1893) several new species, such as *Radopholus similis* and *Helicotylenchus multicinctus*, now well known, even though their names have changed from the original descriptions. Species now known as *Meloidogyne javanica* and *Hirschmanniella oryzae* were identified at an early date from Java, Indonesia, by Treub (1885) and by van Breda de Haan (1902), respectively. Few records are available for this period from other parts of the tropics, a notable exception being the description of the genus *Meloidogyne*, and its type species *M. exigua*, on coffee trees in Brazil by Göldi (1889, 1892); following an earlier report from Jobert (1880), he made an extensive study of the nematode problem in coffee plantations.

In the following four or five decades, nearly all descriptions of tropical nematode species were done in laboratories in temperate countries, particularly in the USA by Cobb, Steiner and Thorne, in England by T. Goodey and J.B. Goodey and in the Netherlands by Schuurmans Stekhoven. Observations and experiments based on field work were rare in countries outside the temperate regions until the 1950's. Two other exceptions were firstly, the study of red ring disease of coconuts in the Caribbean by Nowell (1919, 1920) who established that a nematode was the cause of the disease and instigated further work in the area; and secondly, some outstanding field work by Butler (1913, 1919) in East Bengal (Bangladesh) who identified ufra disease of rice and described its causal organism, *Ditylenchus angustus*. One other finding in the early part of this century which was to have a profound effect on nematology was the discovery in 1935 of a serious nematode parasite in the pineapple fields of Hawaii, later to be described by Linford and Oliveira (1940) as *Rotylenchulus reniformis*. This led, in the early 1940's, to the discovery of the first effective nematicidal soil fumigant, D-D (1,2-dichloropropane, 1,3-dichloropropene) from work done at the Pineapple Research Institute, Hawaii. Notwithstanding these and other evident successes, the amount of

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nematological work in the tropics was very meagre in the first half of this century. For example, when the first nematology laboratory was established in West Africa (by ORSTOM in the Ivory Coast) in 1955, there were only nine published references relating to plant parasitic nematodes found in the whole of West Africa and Zaire.

Nematology laboratories have now been established in many, but by no means all, subtropical and tropical countries, especially in Africa, South America and India. Up to 1983, 278 scientists working on nematodes in the tropics were recorded (Thomason *et al.*, 1983) not including those in India or Pakistan, nor in the semi-arid regions. We would estimate that there are now at least 400 scientists working full or part-time on the nematode problems and in the areas to which the present book is devoted. Most editions of all the nematological journals now contain a number of articles dealing with nematodes or nematological problems from outside the temperate regions, and some journals (Nematropica, Indian Journal of Nematology, Pakistan Journal of Nematology) deal almost exclusively with such work.

Nematology laboratories established comparatively recently in the tropical regions have had to look afresh at nematode problems. Often they have needed to determine initially which problems exist by basic survey work, and accurately identify which nematodes are present (determination systematics), followed by establishing which nematodes are harmful or economically important by pathogenicity tests and field trials, and finally deciding on which treatments or methods are appropriate for control of nematodes. It has been, and continues to be, a long and difficult task and, if many problems are now rather well known, few of them have been fully solved. This is not surprising if we consider that over the past century, approximately 100 nematologists have worked in temperate countries on the problems caused by the potato and sugarbeet cyst nematodes, and satisfactory results, with the bias on integrated control, have been obtained only recently. It is therefore, safe to predict that the future for subtropical and tropical nematology will be long and full of complex and economically important problems especially with regards to subsistence agriculture.

We have been referring to nematology in "temperate" compared to "subtropical and tropical" regions. It is appropriate here to raise the obvious questions of whether there are fundamental differences or whether they differ only in degrees because of the different species of nematodes and types of crop present?

We can state with some certainty and without too many dissenting voices that nearly all the major problems that can be directly caused by nematodes have been detected in temperate countries. This is not to say that a problem new to a particular country could not arise through the introduction and subsequent spread of a known nematode parasite from another temperate country. It is, therefore, the case in temperate countries that surveys are designed to determine the distribution of known nematodes causing known damage. In contrast, in the subtropical and tropical areas, new problems are being, and have yet to be, discovered involving new nematodes species and even genera, or species not previously recorded as harmful to a crop. Examples we can cite from comparatively recent publications are the "legume Voltaic chlorosis" of leguminous crops, discovered in Burkina Faso, associated with a new species, *Aphasmatylenchus straturatus*, and a genus not previously known to be a harmful parasite (Germani & Luc, 1982); "mitimiti" disease of taro (*Colocasia esculenta*) in the Pacific caused by a new species, *Hirschmanniella miticausa* (Bridge *et al.*, 1983); and, in the semi-arid areas, the new cyst species *Heterodera ciceri* causing damage to chickpeas and lentils (Greco *et al.*, 1984; Vovlas *et al.*, 1985). Also the lack of trained nematologists in the past has often meant a lack of awareness of the importance of nematology in the development of quarantine guidelines. This has led to the movement of both tropical and temperate plant parasitic species into new uninfested areas. Good examples in the past are the dissemination of the banana burrowing and root lesion nematodes (*Radopholus similis, Pratylenchus* spp.) and of the citrus slow decline nematode (*Tylenchulus semipenetrans*) to nearly all areas where these crops are grown. As a more recent case, we may cite the movement of *Globodera rostochiensis* into the high altitude tropical growing areas of the Philippines (Sikora, 1982).

There is a greater diversity of nematode genera and species in subtropical and tropical countries than in temperate ones. As many of these nematodes are new taxa, it is evident that there is a great deal of work for nematode taxonomists in the tropics. This indeed is happening but a big disadvantage of concentrating on this aspect is that surveys are designed to collect nematodes and not to determine problems caused by nematodes. This is often the only possible means of establishing new nematology laboratories with limited staff and financial means. The danger is that such laboratories can limit their activities to systematics and so become production lines for new species and genera, to the exclusion of determining the importance of the nematode being described.

Knowing which nematode genera and species occur is the necessary first step, but establishing the pathogenicity of the nematodes involved in subtropical and tropical agriculture has to be made a main priority. Many nematodes are now recognized as serious or potentially serious pests of tropical crops, as detailed in the following chapters, but information on the *actual* yield losses caused by the nematodes in different situations and on different crops is still sadly lacking for a large proportion of these nematodes. This knowledge is essential to provide agricultural scientists, extension officers and administrators with the information needed to recommend practical and economic means of controlling the harmful nematodes in the face of all the other constraints on crop production. The chapters in this book contain pertinent information on nematodes of the most widely grown crops in subtropical and tropical agriculture but there are still gaps in our knowledge. The chapters show the extent of damage that can be caused by nematodes which is recognised by the nematologists concerned but generally not by other agriculturists. This crop damage by nematodes invariably remains hidden by the many other limiting factors operating in subtropical and tropical agriculture. Nematodes have rarely been considered or recognized as major limiting factors until all other constraints on yield increase have been removed (Bridge, 1978).

The practical problems of determining nematode pathogenicity in the tropics can often be far more difficult than in temperate countries. Problems such as maintaining controlled conditions in glasshouses or screenhouses with air-conditioning or cooling tanks because of the excessive heat can be a daunting and expensive task. The stories behind failure of field experiments are legendary in the tropical countries with everything from lizards to elephants and hurricanes to volcanoes doing their utmost to frustrate the attempts of nematologists to obtain accurate and replicated results. Isolated, irrigated field trials during the dry season tend to result in every hungry pest and predator for some distance around descending in droves on the plots with thanks to the irate research worker. It does mean that nematologists in the tropical countries have to be more resourceful and patient than their counterparts in the temperate countries.

There are more intrinsic differences between temperate and tropical areas based mainly on the wide diversity of nematode crops and agricultural systems.

The range and severity of parasitism on all living organisms, humans, animals and plants, is greater in the subtropical and tropical countries. Plant parasitic nematodes generally have shorter life cycles resulting in a more rapid population explosion than in temperate areas. For example, in temperate areas *Heterodera* spp. produce generally one or two generations per year, whereas *H. oryzae,* in West Africa, produces one generation every 25 days (Merny, 1966). More often than not a crop is attacked by a number of damaging nematodes. In temperate areas, there are also "secondary species" but most often there is only one main nematode parasite of a crop which is easily recognizable and upon which control efforts can be focussed. This is not the case for many tropical crops where a number of species of several different genera may be major parasites of a crop. For instance, sugar cane can be damaged by 10–20 different species of genera such as *Meloidogyne, Heterodera, Pratylenchus, Xiphinema* and *Paratrichodorus*. The component species of a nematode population do differ from country to country, making predictions of damage that much more difficult. Such types of multi-species populations have a number of consequences concerning control of the nematodes. Firstly, it can seriously hinder the establishment of an effective crop rotation as the host status of each crop will differ depending on the nematode species present. We have an example of such a phenomenon in Ivory Coast where *Crotalaria* was recommended as an intercrop to control *Meloidogyne* spp. on pineapple. The intercrop produced an effective control of the root-knot nematodes but increased the populations of *Pratylenchus brachyurus* to levels which were at least as harmful to the crop as *Meloidogyne* spp. A second consequence is that multispecies populations increase the complexity of the search for crop resistance to nematodes; targeting one nematode species for resistance is normally not sufficient. The lesson of breeding for resistance to one species of nematode should have been learned with the emergence of the potato cyst nematode *Globodera pallida* following extensive planting of *G. rostochiensis* resistant cultivars.

The most fundamental facts of subtropical and tropical agriculture that differ from the temperate regions and markedly affect the study and control of plant nematodes are the crops grown, the cultural practices and the farming systems. Commercial, plantation crops are a common feature of subtropical and tropical agriculture but by far the largest proportion of cultivated land in most of the tropical countries is farmed by farmers with small-holdings, using traditional cropping practices. The crops grown cover a very wide range of grain, root and vegetable food crops, also many different cash and utility crops. Monocropping is practised but multiple or intercropping is more common. Much of the traditional agriculture in the tropics is based on the reproduction of crops by vegetative propagation, in contrast to the dependence upon seed-reproduced plants in the temperate countries. This can increase the dissemination of nematodes. The outstanding feature of traditional agriculture, and one that makes life difficult for nematologists, is the complexity of the methods involved (Bridge, 1987). In contrast, modern farming in temperate countries is comparatively simple and the study and control of the nematodes is also, in comparison, relatively straightforward. The many different farming systems operating in the tropics fall into four main categories: 1. shifting cultivation; 2. fallow farming; 3. permanent upland cultivation, and 4. systems with arable irrigation (Ruthenberg, 1983). In some of these farming systems, nematodes are less likely to be causing damage, in others the cultivation practices will greatly increase the risk of nematodes causing serious yield losses (Bridge, 1987).

The nematode control methods that can theoretically be employed in the subtropical and tropical countries differ little from those used in temperate countries but in practice they are more difficult to implement and need to be considerably modified in many circumstances. There will be obvious differences in the methods to control nematodes in developed countries compared to developing countries and in large, modern farms or plantations compared to small rural farms with more traditional cultivation systems.

Chemical soil treatment is recognized as an essential means of controlling nematodes on a number of cash crops in the tropics. In many instances these crops cannot be grown economically without the use of nematicides. The use of nematicides and pesticides to control nematodes is of limited or no importance on most field crops especially at the subsistence level in developing countries. Nematicide usuage in the past has been strongly limited by their high price. The choice and availability of many nematicides is now even more limited with the banning on most of the world markets of the fumigants D-D, EDB and DBCP. Some of the more easily applied granular, non-volatile nematicides are effective and are used extensively on a number of crops. They have disadvantages in being expensive and extremely toxic to man and animals when used improperly. Their availability may be further curtailed because of their recent detection in groundwater. The future of nematicides for the control of nematodes will depend on the formulation of new compounds that are effective and environmentally safe. The development of new application technology, for example, treatment by seedcoating or chemicals applied to irrigation water as well as development of systemic nematicides that move basipetally, is urgently needed (Thomason, 1987).

The modification of existing agricultural practices in order to control nematode populations is one of the most acceptable alternatives to chemical control for both the small and large scale farmers in the tropics. Crop rotation can vary from non-existent, where there is continuous cultivation of a susceptible crop or crops, through what can be termed random rotation, to a relatively sophisticated form of rotation. However, most of the rotation schemes in operation have been designed to prevent disease outbreaks or increase available nutrients, and are not always compatible with nematode control. With an understanding of the nematodes involved and the accepted cropping systems, modifications can be made to produce effective control by rotation of crops. Many other cultural methods, apart from rotation, can be used and are outlined in the following chapters.

Resistant cultivars can produce the most dramatic increases in the yields of many crops and appear to hold the solution to most nematode problems, particularly with the recent increase in research on gene transfer. Unfortunately, this solution is more apparent than real as it is now clear that such cultivars mainly show resistance to only a limited number of nematode genera. These nematodes tend to belong to the groups of parasites, such as the Heteroderidae, which have a highly developed host-parasite relationship where cell modification occurs and is required for successful reproduction of the nematodes (Luc & Reversat, 1985). Many of the major subtropical and tropical plant parasitic nematodes belong to the group of migratory endoparasites which cause cell destruction without modifying the host tissues. Examples are to be found in the genera *Radopholus, Pratylenchus, Hirschmanniella, Scutellonema, Helicotylenchus* and *Hoplolaimus.* At the present time, no true resistance has been found for this group of nematodes. Even when the possibility does exist, for nematodes such as *Heterodera, Meloidogyne* and *Rotylenchulus*, such research nevertheless remains aleatory and very costly: many years and several millions of US dollars were necessary to obtain a cultivar of soybean resistant to *Heterodera glycines* (Miller, pers. comm.). A major limiting factor affecting the effectiveness of newly introduced resistant cultivars is the selection of pathotypes or races that are able to breakdown the resistance. The existence of resistant breaking pathotypes are major problems in breeding programmes in temperate crops. Similar complications must be expected when resistant cultivars are bred for tropical crops. Another difficulty which applies more to subtropical and tropical countries is in the practical introduction of these resistant cultivars. Where resistant cultivars are available and suited to the conditions prevailing in a country, many other factors have to be taken into account before their successful introduction. There will be again a marked contrast in what can be achieved with the big producer compared to the rural farmer, but consideration has to be given to local needs. A good illustration of this difficulty was when dwarf rice cultivars were introduced to prevent lodging (Mydral, 1974): people in South East Asia were deprived of their normal source of rice straw for animal feed, bedding, and thatching material. Because of economic constraints, research in nematode management in the tropics often focuses on low-input methods involving crop rotations, multicropping, adjustment of planting and harvest dates, use of various soil amendments and mulches, trap and antagonistic crops, fallow, flooding, etc. Emphasis on these forms of control strategies by agricultural scientists working in the tropics and subtropics reflects increased awareness of the need for nematode management systems that rely less on use of nematicides.

We have outlined some of the differences and difficulties facing nematology in the tropics but wish to emphasize that none of the problems are insurmountable with the appropriate effort, expertise and backing. You will see, reading through the chapters, that there is a great deal of accumulated knowledge on the importance of nematodes as plant parasites and, more relevantly, there are successes in their control. However, nematology in the tropics is underfunded and there is a shortage of nematologists to work on the problems. Sasser and Freckman (1987) have estimated that less than 0.2% of the crop value lost to nematodes worldwide is used to fund nematological research to combat these losses which probably exceed $100 billion annually. The percentage funding for nematological research in the tropics is considerably less than it is in most of the temperate countries, which makes the amount infinitesimal. But the need for such research in subtropical and tropical agriculture is greater than in temperate agriculture. Many temperate countries are suffering the embarassment of massive surpluses in food production which are not transferable. In contrast, the majority of countries in the tropics have shortfalls in the production of most crops. An increase is needed in food crops, to improve the nutritional level of the populations, and in export cash crops, to obtain essential foreign currency. Solving nematode problems can play an important part in improving crop yields to the benefit of commercial and subsistence farms, the consumers and governments.

This book details our present knowledge on plant parasitic nematodes associated with the main crops grown in subtropical and tropical agricultural systems. It also includes nematodes of warm temperate crops growing in semi-arid regions and those of crops growing in high altitude, temperate regions of the tropics. The presentations are by some of the most experienced nematologists from both the developed and developing countries who have worked in full cooperation to present a practical and informative guide to the nematodes found in these areas. The book is by no means aimed solely at nematologists but is designed to provide up-to-date information on the nematodes for all people working in agriculture, whether they be crop protection specialists, agronomists, economists or administrators.

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