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GLOBAL KNOWLEDGE AND ITS APPLICATION FOR THE INTEGRATED CONTROL AND MANAGEMENT OF NEMATODES ON WHEAT

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Abstract. Importance of cereals and wheat nematodes in the world is revised. Distribution of cereal nematodes, species and pathotypes includes root lesion, cereal cyst nematodes and other cereal parasitic species. Life cycle, symptoms of damage and yield losses are also revised for root knot, stem and seed gall nematodes. Integrated control of cereal nematodes and some chemical, biological and cultural practices, including grass free rotations and fallowing with cultivation, are discussed. The effects of time of sowing, crop rotations and cultivation of resistant/tolerant varieties are also revised.

1. INTRODUCTION

1.1. Importance of Cereals and Wheat in the World

Cereals constitute the world's most important source of food. Amongst cereals, wheat, maize and rice occupy the most eminent position in terms of production, acreage and source of nutrition, particularly in developing countries. It has been estimated that about 70% of the land cultivated for food crops is devoted to cereal crops. By 2030, world population is expected to increase to 8 billion and world wheat (*Triticum aestivum*) production to increase from 584 million tonnes (1995–1999 average) to 860 million tonnes (Marathee & Gomez-MacPherson, 2001). The world wheat deficit during these three decades is expected to rise by 2.5 times, particularly in the developing world, where 84% of the population increase is expected and where wheat is a staple. To compensate for the additional demand for wheat, methods must be employed to minimise yield production constraints.

Plant parasitic nematodes are recognised as one such constraint, with at least seventeen important species in three major genera (*Heterodera*, *Pratylenchus* and

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Meloidogyne). Although the introduction of new cultivars of wheat has boosted agricultural output, the yield potential of the new cultivars has not been fully expressed and is often far below theoretical maximum yields. This disparity between actual and theoretical yield expression can be attributed to "production constraints". Attention has therefore been focused on minimizing these constraints to increase production. Although insect pests and diseases have long been recognized as important constraints affecting crop production, extensive research on the "weak linkages" in the plant-pest system are lacking.

As most nematodes live in the soil, they represent one of the most difficult pest problems to identify, demonstrate and control. Farmers, agronomists and pest management consultants commonly underestimate their effects but it has been estimated that some 10% of the world crop production is lost as a result of plant nematode damage (Whitehead, 1998). It is also pertinent to consider in many of the cereal systems discussed in this chapter the interaction of nematodes with other plant pathogens, particularly soil borne fungi, and in many cases the synergism which results in more damage than either pathogen alone.

Management of nematodes may be approached by using a complement of methods in an integrated pest management system or may involve only one of these methods. Some of the most commonly practised methods will be discussed, including crop rotation, use of resistant and tolerant cultivars or varieties, cultural practices and chemicals. It is important to stress that the most appropriate control method will be determined by the nematode involved and the economic feasibility of implementing a possible management practice.

The purpose of this chapter is to provide an insight into the economically important nematodes on cereals. Information is presented here on their currently known distribution, damage potential, economic importance and management options that exist for their control. This review will focus on the primary nematodes of global economic importance on wheat and particularly Cereal Cyst Nematode (CCN, *Heterodera*) and Root Lesion Nematode (*Pratylenchus*). Other important genera including Root Knot (*Meloidogyne*), Stem (*Ditylenchus*) and Seed Gall (*Anguina*) will be mentioned, but in much less detail. Efforts have been made in this chapter to capture information from scientists from West Asia, North Africa, India and China which often is not internationally published, however it is of significant importance to the wheat productivity in especially the rainfed or marginal wheat growing regions of this countries. For further references and illustration of many of these nematodes, refer to the reviews of Kort (1972), Griffin (1984), Sikora (1988), Swarup and Sosa Moss (1990), Rivoal and Cook (1993), De Waele and Mc Donald (2000), Kollo (2002), Nicol (2002) and McDonald and Nicol (2005).

2. DISTRIBUTION OF CEREAL NEMATODES, SPECIES AND PATHOTYPES

2.1. Cereal Cyst Nematode

Although the cereal cyst nematode complex is represented by a group of twelve valid and several undescribed species, three main species are documented to be the most economically important: *Heterodera avenae*, *H. filipjevi* and *H. latipons* (Rivoal & Cook, 1993; McDonald & Nicol, 2005). Their common name is due to the fact that grasses (within family Graminearum) are hosts and the nematode adult female structure is a cyst.

The identification of cyst nematodes is complex and has traditionally been based on comparative morphology, through several diagnostic keys (Mulvey, 1972; Wouts, Schoemaker, Sturhan, & Burrows, 1995). However, more recently, techniques based on protein (Rumpenhorst & Sturhan, 1996) or DNA differences have been implemented, with most recently the use of DNA polymorphisms (Bekal, Gauthier, & Rivoal, 1997; Subbotin, Waeyenberge, Molokanova, & Moens, 1999; Subbotin, Waeyenberge, & Moens, 2000) allowing the identification to species level. One of the major obstacles to controlling CCN is the fact that a number of pathotypes occur, and this is further complicated by the presence of ecotypes. The major method to identify pathotype variation is the use of a Host Differential set, using specific barley, oat and wheat varieties, developed by Andersen & Andersen (1982). This was effective at time differentiating pathotypes of the known *H. avenae*, however since then many new pathotypes and additional species have been reported.

Within *H. avenae*, three groups of pathotypes have been distinguished using host reactions of the barley cultivars Drost4, Siri and Morocco with the resistance genes *Rha1*, *Rha2* and *Rha3*, respectively. Pathotypes belonging to groups 1 and 2 are the most numerous and widely distributed in Europe, North Africa and Asia (Andersen & Andersen, 1982; Al-Hazmi, Cook, & Ibrahim, 2001; Mokabli, Valette, Gauthier, & Rivoal, 2002). Pathotypes of group 3 (from Australia and Europe) are virulent to both the *Rha1* and *Rha2* genes (Andersen & Andersen, 1982). However, there appears to be mis-identification with some of these *H. avenae* pathotypes, particularly from Spain and Sweden, where populations previously known as the “Gotland” strain (Bekal et al., 1997) are actually *H. filipjevi*. A new group of pathotypes in *H. avenae* virulent to the *Rha3* gene have been shown to occur in North Africa (Mokabli et al., 2002).

Heterodera avenae is the most widely distributed and damaging species on cereals cultivated on more or less temperate regions. It has been detected in many countries, including Australia, Canada, Israel, South Africa, Japan and most European countries, as well as India (Sharma & Swarup, 1984; Handa, Mathur, Mathur , & Yadav, 1985b; Sikora, 1988), China (Peng et al., 2007) and several countries within North Africa and Western Asia, including Morocco, Tunisia, Libya and Pakistan (Sikora, 1988), Iran (Tanha Maafi, Subbotin, & Moens, 2003), Turkey (Nicol et al., 2002; Abidou et al., 2005), Algeria (Mokabli, Valette, & Rivoal, 2001), Saudi Arabia (Ibrahim, Al-Hazmi, Al-Yahya, & Alderfasi, 1999) and Israel (Mor, Cohn, & Spiegel, 1992).

Heterodera latipons is essentially only Mediterranean in distribution, being found in Syria (Sikora & Oostendorp, 1986; Scholz, 2001), Israel (Kort, 1972; Mor et al., 1992), Cyprus (Sikora, 1988), Turkey (Rumpenhorst, Elekçioglu, Sturhan, Öztürk, & Enneli, 1996), Italy and Libya (Kort, 1972). However, it is also known to occur in northern Europe (Sabova, Valocka, Liskova, & Vargova, 1988) and also in Bulgaria (Stoyanov, 1982). In Iran *H. latipons* is found in Mazandaran, East and West Azarbayejan, Ardabil, Hamadan, Lorestan and Kermanshah provinces (Tanha Maafi, Sturhan, Kheiri, & Geraert, 2007; Talatchian, Akhiani, Grayeli, Shah-Mohammadi, & Teimouri, 1976; Noori, Talatchian, & Teimoori, 1980; Sturhan, unpubl.).

Another species with an increasingly wide distribution is *H. filipjevi*, formerly know as Gotland strain of *H. avenae* (Ferris et al., 1999; Bekal et al., 1997), which appears to be found in more continental climates such as Russia (Balakhnina, 1989; Subbotin, Rumpenhorst, & Sturhan, 1996), Tadzhikistan (Madzhidov, 1981; Subbotin et al., 1996), Sweden (Cook & Noel, 2002; Holgado, Rowe, Andersson, & Magnusson, 2004), Norway (Holgado et al., 2004), Turkey (Rumpenhorst et al., 1996; Nicol et al., 2002), and Greece (Mandani, Vovlas, Castillo, Subbotin, & Moens, 2004). In Iran *H. filipjevi* is widespread, being found in Ardabil, East and West Azarbayejan, Mazandaran, Golestan, Zanjan, Lorestan, Kermanshah, Kordestan, Hamadan, Esfahan, Kerman, Yazd, Fars, Systan and Blouchestan provinces (Tanha Maafi et al., 2007). A relatively new report also finds this species from Himachal Pradesh in India (S. P. Bishnoi, pers. com.)

Other *Heterodera* species known to be of importance to cereals include *H. hordecalis* in Sweden, Germany and Britain (Andersson, 1974; Sturhan, 1982; Cook & York, 1982a) and from the Ardabil province in Iran (Tanha Maafi et al., 2007), *H. zeae*, which is found in India, Pakistan (Sharma & Swarup, 1984; Maqbool, 1988) and Iraq (Stephan, 1988) and various others including *H. mani*, *H. bifenestra* and *H. pakistanensis*, as well as an unrelated species of cyst nematode, *Punctodera punctata* (Sikora, 1988).

Considering China and India which are the two largest wheat producers in the world, *H. avenae* appears to be widespread and damaging in both countries in the bread basket of their wheat production regions. In India *H. avenae* was first reported from Sikar district of Rajasthan in 1958 by Vasudeva, however now it has been reported from north rainfed wheat production region of Rajasthan (Koshy & Swarup, 1971; Mathur, 1969); Haryana (Bhatti, Dahiya, Gupta, & Malhan, 1980); Punjab (Koshy & Swarup, 1971; Chhabra, 1973; Singh, Sharma, & Sakhuja, 1977) and Himachal Pradesh (Koshy & Swarup, 1971). It is speculated that this nematode is continuing its spread slowly and gradually towards the Indo-Gangetic plains of Uttar Pradesh. Bekal, Jahier, and Rivoal (1998) attributed Nazafgarh, Delhi population to Ha 71 pathotype. More recently Bishnoi and Bajaj (2004) concluded on the basis of international host differential, biochemical and morphometric studies of eight geographical populations that the isolates from Jaipur, Udaipur, Narnaul, Sirsa and Delhi belong to pathotype Ha21, whilst Punjab (Ludhiana) and Ambala (Haryana) populations belong to pathotype Ha 41 and the Himachal Pradesh population belongs to *H. filipjevi.*

In China *H. avenae* was first reported from Hubei province in the centre of China in 1987, and now it has been reported in at least eight provinces in high frequencies including Henan, Hebei, Beijing suburb, Inner Mongolia, Shanxi, Qinghai, Anhui and Shandong (Peng et al., 2007). This wheat production area represents about 20 million ha which is around two thirds of China's total wheat production (120Mt). Survey data of more than 500 samples indicate population densities of CCN much higher than reported in other countries where economic damage is reported. Morphological and molecular characterization of the selected populations revealed a close relatedness to species within the *H. avenae* group. Restriction Fragment Length Polymorphism of the ITS regions within the ribosomal DNA classified these populations as "type B" *H. avenae*. Using the host differential pathotypes test developed by Andersen and Andersen (1982), it appears there are at least three pathotypes (CH1, CH2, CH3) which are different from other known pathotypes. In neighbouring Iran molecular studies of specimens already have been reported and supported the presence of *H. avenae* (type B) in Iran (Tanha Maafi et al., 2003).

2.2. Root Lesion Nematodes

The genus *Pratylenchus* contains 63 valid species (Handoo & Golden, 1989), with at least eight species infesting small grains (Rivoal & Cook, 1993). Of these, *P. thornei*, *P. neglectus*, *P. penetrans* and *P. crenatus* are polyphagous and have a worldwide distribution. On cereals, *P. thornei* is the most studied species, being found in Syria, Yugoslavia, Mexico, Australia, Canada, Israel, Morocco, Turkey, Pakistan, India, Algeria, Italy (Nicol, 2002) and the USA (Smiley, Whittaker, Gourlie, Easley, & Ingham, 2005). *P. neglectus* has been reported in Australia (Taylor, Hollaway, & Hunt, 2000; Vanstone, Rathjen, Ware, & Wheeler, 1998), North America (Townshend, Potter, & Willis, 1978; Timper & Brodie 1997), Europe (Lasserre, Rivoal, & Cook, 1994; Hogger, 1990) and Turkey (Nicol et al., 2002). Both *P. neglectus* and *P. thornei* have also been identified in wheat fields in Gilan province of Iran (Tanha Maafi, 1998). *Pratylenchus penetrans* is largely associated with horticultural crops but has been recorded on wheat in Canada (Kimpinski, Anderson, Johnston, & Martin, 1989). *Pratylenchus pratensis* has been identified to be pathogenic on winter wheat in Azerbaijan (Kasimova & Atakishieva, 1981).

As with CCN, the identification of lesion nematodes considers traditional keys relating to morphology (Corbett, 1974; Loof, 1978; Handoo & Golden, 1989) as well as the new DNA based tools (Orui & Mizukubo, 1999). As reviewed by De Waele & Elsen (2002), biological diversity among populations of the same species has been reported in *P. brachyurus*, *P. goodeyi*, *P. loosi*, *P. neglectus*, *P. penetrans* and *P. vulnus*. Unlike CCN, in which many pathotypes exist, to date there is no formal report or evidence to indicate pathotypes in either *P. thornei* or *P. neglectus*. Furthermore, screening of identified resistant accessions in Australia, Mexico and Turkey with local populations reveals the resistance to pertain under greenhouse and field conditions. However, caution should be taken to examine the reproductive fitness between root lesion nematode populations from the field and also in greenhouse studies to be sure about the availability of plant resistance reactions, as nematodes in culture collections for an extended period of time can lose their pathogencity (De Waele & Elsen, 2002).

2.3. Other Cereal Nematodes – Root Knot, Stem and Seed Gall

Root-knot (RK), are the most economically important group of plant parasitic nematodes worldwide, attacking nearly every crop (Sasser & Freckman, 1987). Several species attack *Poaceae* in cool climates, including *Meloidogyne artiellia*, *M. chitwoodi*, *M. naasi*, *M. microtyla* and *M. ottersoni* (Sikora, 1988). In warmer climates, *M. graminicola*, *M. graminis*, *M. kikuyensis* and *M. spartinae* are important (Taylor & Sasser, 1978). In tropical and subtropical areas, *M. incognita*, *M. javanica* and *M. arenaria* are all known to attack cereal crops (Swarup & Sosa Moss, 1990). To date, only *M. naasi* and *M. artiellia* have been shown to cause significant damage to wheat and barley in the winter growing season (Sikora, 1988).

Meloidogyne naasi is reported from Britain, Belgium, the Netherlands, France, Germany, Yugoslavia, Iran, U.S.A. and former U.S.S.R, occurring mostly in temperate climates (Kort, 1972). However, it has also been found in Mediterranean areas, on barley in the Maltese islands (Inserra, Lamberti, Volvas, & Dandria, 1975) and in New Zealand and Chile on small grains (Jepson, 1987). It is probably the most important root-knot nematode affecting grain in most European countries (Kort, 1972). It does not appear to be widespread in temperate, semi-arid regions such as Western Asia and Northern Africa (Sikora, 1988). *Meloidogyne naasi* is a polyphagous nematode, reproducing on at least 100 species of plants (Gooris & D'Herde, 1977) including barley, wheat, rye, sugar beet, onion and several broadleaf and monocot weeds (Kort, 1972). Generally *Poaceae* are considered to be better hosts (Gooris, 1968). In Europe, oat is a poor host compared with other cereals, whereas in the USA oat is an excellent host of *M. naasi* (Kort, 1972). Host races of *M. naasi* have been identified in the USA by using differential hosts (Michel, Malek, Taylor, & Edwards, 1973), which makes control of this nematode more difficult.

Other species of root knot nematodes attacking cereals include *M. artiellia,* which has a wide host range including crucifers, cereals and legumes, especially chickpea (Ritter, 1972; Di Vito, Greco, and Zaccheo, 1985). It is known to reproduce well on cereals and severely damages legumes (Kyrou, 1969; Sikora, 1988). This nematode is chiefly known from Mediterranean Europe in Italy, France, Greece and Spain (Di Vito & Zaccheo, 1987), but also west Asia (Sikora, 1988), Syria (Mamluk, Augustin, & Bellar, 1983) and Israel (Mor & Cohn, 1989).

Meloidogyne chitwoodi is a pest on cereals in the Pacific North West of the USA and is also found in Mexico, South Africa and Australia (Eisenback & Triantaphyllou, 1991). Many cereals, including wheat, oat, barley and maize and a number of dicotiledons are known to be hosts (Santo & O'Bannon, 1981). The three species, *M. incognita, M. javanica* and *M. arenaria* were found to be good hosts on a range of cereal cultivars including wheat, oat, rye and barley under greenhouse conditions (Johnson & Motsinger, 1989). *Meloidogyne graminis* is not known to be widely distributed, being limited to the southern United States, where it is associated with cereals and more often turfgrasses (Eriksson, 1972).

Stem nematodes (SN), belonging to the genus *Ditylenchus* comprise many species which are prevalent in a wide range of climatic conditions from temperate, subtropical to tropical, where moisture regimes enable nematode infection, multiplication and dispersal (Plowright, Caubel, & Mizen, 2002). *Ditylenchus dipsaci* is by far the most common and important species of stem nematode on cereals, particularly on oat, maize and rye and is widespread throughout western and central Europe, USA, Canada, Australia, Brazil, Argentina and North and South Africa (Plowright et al., 2002).

Another species, *D. radicicola* is distributed throughout the Scandinavian countries, Britain, the Netherlands, Germany, Poland, former USSR, USA and Canada. This nematode also occurs on many grasses of economic importance but is not considered important in subtropical or tropical environments (Plowright et al., 2002). S'Jacob (1962) suggested that biological races of this species occur.

The seed gall (SG) nematode (*Anguina tritici*), is of historical importance since it is the first plant parasitic nematode recorded in the literature. It is commonly known as "ear cockle" in many countries, but in India several names are used, including seed gall, Gegla, Mamni, Sehun and Dhanak. It is frequently found on small grain cereals, and is a problem where farm saved seed is sown without the use of modern cleaning systems. Cereals are infected throughout Western Asia and North Africa (Sikora, 1988; Elmali, 2002) including Iraq (Stephan, 1988), Turkey (Yüksel, Güncan, & Döken, 1980), Pakistan (Maqbool, 1988) and also on winter wheat in Azerbaijan (Kasimova & Atakishieva, 1981).

Iran wheat gall nematode (*Anguina tritici*) was observed in wheat fields of Isfahan and Kerman provinces for the first time in 1949 (Davachi, 1949). Recent surveyed regions of Isfahan province indicated 21.7% of fields were infested with *Anguina tritici*. In addition a closely related species, *A. agrostis*, was found in barley fields causing heavy infection of gum disease in Fars province of Iran for the first time in 2003 (Pakniat & Sahandpour, 2004). In the Indian sub-continent *A. tritici* is widespread in Bihar, Uttar Pradesh, and at a few places in Rajasthan, Haryana and Punjab (Bishnoi, pers. com.). It is also reported from China, parts of Eastern Europe (Tesic, 1969; Swarup, 1986; Urek & Sirca, 2003), Russia, Australia, New Zealand, Egypt, Brazil and several areas in the United States, as reviewed by Swarup and Sosa Moss (1990).

It is important to mention the bacterial related interaction which occurs with "ear cockle" nematode. The disease was first recorded from India by Hutchinson (1917), where the nematode is associated with a bacterium *Corynebacterium michiganense* pv. *tritici*. It has only much later been detected on barley in northern Iraq, where infestations reached 90% (Al-Talib, Al-Taae, Neiner, Stephan, & Al-Baldawi, 1986; Stephan, 1988). The bacterium is frequently present along with juveniles in galls and is responsible for expression of the disease. The bacterium is only capable of producing yellow streaks on leaves on its own, that run parallel to the veins. The nematode carries the bacterium to the growing point as an external body contaminant (Gupta & Swarup, 1972). The bacterium multiplies very quickly under favourable environmental conditions, increasing its concentration in a plant and forming a thick, viscous fluid in which nematode juveniles are not able to survive. Under such conditions, emerging ears are totally sterile and are covered with yellow slime. Economic losses associated with this combination are increased because of the lower price for infected grain (Rivoal & Cook, 1993).

2.4. Other Nematodes

There are other plant parasitic nematodes such as *Longidorus elongatus*, *Merlinius brevidens* and species of *Tylenchorhynchus* and *Paratrichodorus*, which have been found or are implicated to potentially cause yield losses on cereals, although their global distribution and economic importance to date have not been clearly defined. *Tylenchorhynchus nudus*, *T. vulgaris* and *M. brevidens* are responsible for poor growth in limited areas of USA and India (Smolik, 1972; Upadhyaya & Swarup, 1981). *Paratrichodorus anemones* and *P. minor* are two species reported to cause damage to cereal crops in USA, with wheat seeded early in autumn in sandy soils being highly susceptible to *P. minor*. Elekcioglu and Gozel (1997) clearly demonstrated field population dynamics in relation to wheat growth for the nematode complex *P. thornei*, *Paratrophurus acristylus* and *Paratylenhchus* species in the southeast of Turkey, concluding the importance of the two latter genera requires further investigation.

3. LIFE CYCLE, SYMPTOMS OF DAMAGE AND YIELD LOSS

Damage caused by nematodes may be affected by a number of biotic and abiotic factors. In general both cyst and lesion nematodes have a greater damage potential where plant growth is stressed, i.e., with poor soil nutrition or structure, temperature or water stress (Barker & Noe, 1987; Nicol & Ortiz-Monasterio, 2004), or where other pathogen pressure occurs (Taheri, Hollamby, & Vanstone, 1994). Damage caused by nematodes may also be greater where limited rotation or cultivar options exist. The damage threshold of cereal nematodes varies with plant cultivar, soil type, nematodes pathotype and ecotype and climatic conditions within a geographical area (Rivoal & Cook, 1993).

Many abiotic factors, for example fertility, pH, soil type and organic matter content influence nematode population development and damage severity (Duggan, 1961). Moderate nematode population levels, under favourable environmental conditions for plant growth, may not cause as much damage as when plant growth is restricted by moisture stress or low fertility levels (Kornobis, Wolny, & Wilski, 1980). Increased nitrogen application is known to reduce the intensity of nematode damage to the crop, but at high nematode population levels this may no longer hold true (Germershauzen, Kastner, & Schmidt, 1976).

The damage threshold (i.e. the given population of a pathogen to cause a given yield loss) must be determined under many environmental and genotypic factors, such as water and nutrient availability and tolerance and/or resistance reaction of a given cultivar or variety. Furthermore, interpretation of the damage threshold between specific nematological studies should be done with extreme caution, as very few studies are truly comparable, with inherent differences in sampling protocol, extraction procedure and nematodes counting (Duggan, 1961; Stone, 1968; Dixon, 1969; Gill & Swarup, 1971; Meagher & Brown, 1974; Simon & Rovira, 1982; Handa et al., 1985b; Dhawan & Nagesh, 1987, Rivoal & Sarr, 1987; Fisher & Hancock, 1991; Zancada & Althöfer, 1994; Al-Hazmi, Al-Yahya, & Abdul-Razig, 1999; Ibrahim et al., 1999).

3.1. Cereal Cyst Nematode

The life cycle of *H. avenae* involves only one generation during a cropping season, irrespective of geographical region and the host range of this nematode is restricted to gramineaceous plants. There is sexual dimorphism, with males remaining worm-like, whereas females become lemon-shaped and spend their life inside or attached to a root. An adult, white female is clearly visible on roots with a swollen body, about 1 mm across, protruding from the root surface (Fig. 1.). Eggs are retained within the female's body and after the female has died the body wall hardens to a resistant brown cyst, which protects the eggs and juveniles. The eggs within a cyst remain viable for several years (Kort, 1972).

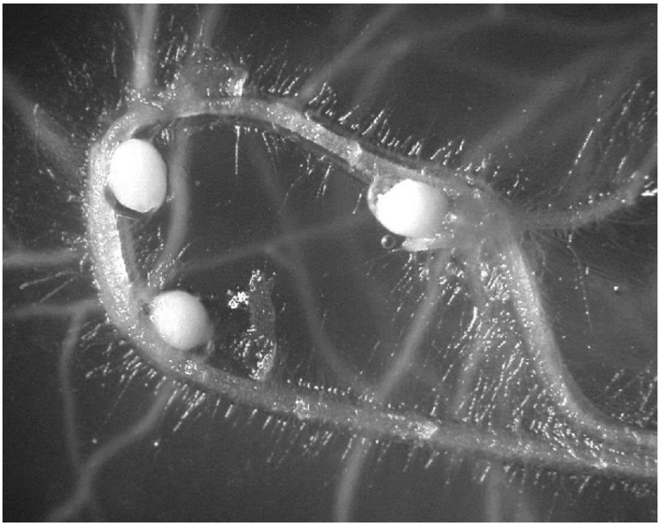

Figure 1. White Heterodera avenae *females clearly visible on roots with a swollen body (1mm) protruding across root surface (photo: R. Rivoal).*

Comparative studies on populations of *H. avenae* from different origins have revealed the existence of ecotypes differing in their hatching cycles, a result of the induction or suppression of dormancy (diapause) by different temperature conditions. Hatch of *H. avenae* in Mediterranean climates is characterized by juvenile emergence from autumn to the beginning of spring, whereas in more or less temperate climates (cooler, usually with snow), the majority of juveniles emerge in spring as the soil temperatures rise (Rivoal, 1982, 1986). The hatching requirements of other species are less understood but are essential to the understand of biology and control of those species.

The above ground symptoms caused by CCN occur early in the season as pale green patches with the lower leaves of the plant being yellow and generally plants with few tillers (Fig. 2). These patches of infestation may vary in size from 1 to 100 m^2 or more. The symptoms can easily be confused with nitrogen deficiency and poor soils and the root damage exacerbates the effect of any other stress, e.g. water and nutrient stress. The below ground symptoms may be slightly different depending on the type of grass host. Wheat attacked by *H. avenae* shows increased root production such that roots have a "bushy-knotted" appearance usually with several females visible at each root (Fig. 3). Oat roots are shortened and thickened, while barley roots appear less affected. The cysts are glistening white-grey initially and dark brown when mature. Attached loosely at their necks, many cysts are dislodged when roots are harvested for examination. Root symptoms are recognisable within one to two months after sowing in Mediterranean environments and often later in more or less temperate climates.

Figure 2. Patches of poor growth caused by Heterodera avenae *on winter wheat in Pacific Northwest of USA (photo: R. Smiley).*

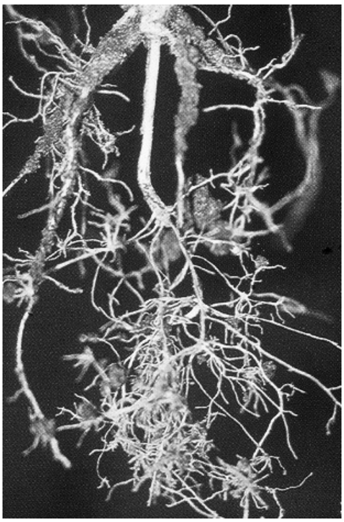

Figure 3. 'Bushy-knotted' roots attacked by Heterodera avenae*, with white female visible (photo: R. Rivoal).*

Heterodera avenae in the northwestern part of India and in southern Australia is considered a major limiting factor of wheat and barley. Figures in India suggest that for every 10 eggs/g soil, there is a loss of 188 kg/ha in wheat and 75 kg/ha in barley (Duggan, 1961; Dixon, 1969). Mathur, Handa, and Swarup (1986) reported avoidable loss in wheat ranging from 32.4 to 66.5% with inoculum varying from 4.6 to 10.6 eggs/ml soil. In China, recent yield loss studies conducted in three provinces including Anhui, Henan and Hebei using aldicarb to provide CCN control, indicated losses of the order 10–40% (Peng et al., 2007).

Yield losses due to this nematode are 15–20% on wheat in Pakistan (Maqbool, 1988), 40–92% on wheat and 17–77% on barley in Saudi Arabia (Ibrahim et al., 1999) and 20% on barley and 23–50% on wheat in Australia (Meagher, 1972). Recent studies in Oregon in Pacific North West have indicated losses on spring wheats of 24% (Smiley et al., 2005). In Tunisia *H. avenae* suppressed grain yields of initial population densities (Pi) on the yield of wheat cultivar Karim by 26–96% and 19–86% on barley cultivar Rihan (Namouchi-Kachouri, B'Chir, & Hajji, 2006). Staggering annual yield losses of 3 million pounds sterling in Europe and 72 million Australian dollars in Australia have been calculated as being caused by *H. avenae* (Wallace, 1965; Brown, 1981). The losses in Australia are now greatly reduced due to their control with resistant and tolerant cultivars.

Little is known about the economic importance of the species *H. latipons* even though it was first described in 1969 (Sikora, 1988). Recent studies by Scholz (2001) implicate yield loss with both barley and durum wheat with *H. latipons*. Field studies in Cyprus indicated a 50% yield loss on barley (Philis, 1988). Because the cysts are similar in size and shape it is possible that previous findings of this recently described nematode species have erroneously been attributed to the economically important *H. avenae* (Kort, 1972). In West Asia and North Africa *H. latipons* has been found on wheat and barley in four countries (Sikora, 1988). It has also recently been confirmed in Turkey (Rumpenhorst, 1996; Nicol et al., 2002) and from several Mediterranean countries, associated with poor growth of wheat (Kort, 1972). Unfortunately this nematode has not been studied in detail and information on its host range, biology and pathogenicity is scarce, but it is suspected to be an important constraint on barley and durum wheat production in temperate, semi-arid regions (Sikora, 1988; Scholz, 2001; Scholz & Sikora, 2004; Ismail, Sikora, & Schuster, 2001).

Similarly *H. filipjevi* is most likely an economically important nematode on cereals due to its widespread distribution and previous misidentifications as *H. avenae* in the former USSR and also Sweden. In Turkey significant yield losses (average 42%) in several rainfed winter wheat locations have been reported (Oztürk, Yildirim, & Kepenekci, 2000; Nicol et al.*,* 2005; Nicol, unpubl.). Natural field trials conducted over several seasons have clearly indicated greater losses under drought conditions (Nicol, unpubl.). Given the increased recognition and incidence, these species are now being identified as a constraint to cereal production (Philis, 1988; Oztürk et al.*,* 2000; Scholz, 2001).

As mentioned water stress is one of the key environmental conditions that can exacerbate damage caused by *H. avenae* and has been demonstrated by the use of radiothermometry technique to detect nematode attacks (Nicolas, Rivoal, Duchesne, & Lili, 1991). At milky dough stage, plant height, total chlorophyll content and light interception by leaves were suppressed but the temperature of plant canopy increased compared to the non-infected controls (Al-Yahya, Alderfasi, Al-Hazmi, Ibrahim, & Abdul-Razig, 1998). Pot experiments in controlled environments revealed a dramatic, negative effect of various populations of CCN on wheat root growth, associated with decreased shoot growth and decreased rates of transpiration (Amir & Sinclair, 1996).

3.2. Root Lesion Nematodes

Pratylenchus species are polycyclic, polyphagous, migratory root endoparasites, which are not confined to fixed places for their development and reproduction. Eggs are laid in the soil or inside plant roots. The nematode invades the tissues of the plant root, migrating and feeding inside a root. Secondary attack by fungi frequently occurs at these lesions. The life cycle is variable between species and environment and ranges from 45 to 65 days (Agrios, 1988).

Pratylenchus feeds on and destroy roots, resulting in characteristic dark brown or black lesions on the root surface, hence their name "lesion" nematodes (Fig. 4). Aboveground symptoms of *Pratylenchus* on cereals, like other cereal root nematodes are non-specific, with infected plants appearing stunted and unthrifty, sometimes with reduced numbers of tillers and yellowed lower leaves (Fig. 5).

The lesion nematode *P. thornei,* causes yield losses in wheat from 38–85% in Australia (Thompson & Clewett, 1986; Doyle, McLeod, Wong, Hetherington, & Southwell, 1987; Nicol, 1996; Nicol, Davies, Hancock, & Fisher, 1999; Taylor et al., 1999), 12–37% in Mexico (Nicol, 2002; Nicol & Ortiz-Monasterio, 2004), 70% in Israel (Orion, Amir, & Krikun, 1984) and most recently in Pacific Northwest USA (Smiley et al., 2005). While *P. thornei* has mainly been reported from regions with a Mediterranean climate, it is possible similar losses may also occur in other countries. *P. neglectus* and *P. penetrans* appear to be less widespread and damaging on cereals compared with *P. thornei.* In southern Australia, losses in wheat caused by *P. neglectus* ranged from 16–23% (Taylor et al., 1999). Vanstone et al. (1998) showed yield loss in wheat of 56–74% in some sites infested with both *P. thornei* and *P. neglectus*. In North America and Germany, *P. neglectus* has been shown to be a weak pathogen to cereals (Heide 1975; Mojtahedi & Santo, 1992). *Pratylenchus penetrans* has been reported to cause losses of 10–19% in wheat in Canada (Kimpinski et al., 1989) indicating that this nematode may be a problem in small grain cereals. Sikora (1988) identified *P. neglectus* and *P. penetrans* in addition to *P. thornei* on wheat and barley in Northern Africa, and all these plus *P. zeae* in western Asia. Further work is necessary to determine the significance of these species in these regions.

Although *Pratylenchus* is capable of multiplying for several generations during a single season, they spread only from plant to plant due to their relative immobility. The impact of plant parasitic nematodes on plant health and crop yield varies with biogeographic location, cropping sequence and intensity, cultivar selection, soil characteristics and nematode community structure (McKenry & Ferris, 1983). As mentioned previously, the economic threshold for plant damage will depend on many such factors and interpretation of the damage threshold between specific nematological studies should be done with extreme caution, as very few studies are truly comparable. There are inherent differences in sampling protocol, extraction procedure and nematode renumerification. It is for this reason the studies conducted are listed, however the reader should interpret these accordingly (Van Gundy, Perez, Stolzy, & Thomason, 1974; Orion et al., 1984; Doyle et al., 1987; Lasserre et al., 1994; Nicol et al., 1999; Taylor et al., 1999; Nicol & Ortiz-Monasterio, 2004).

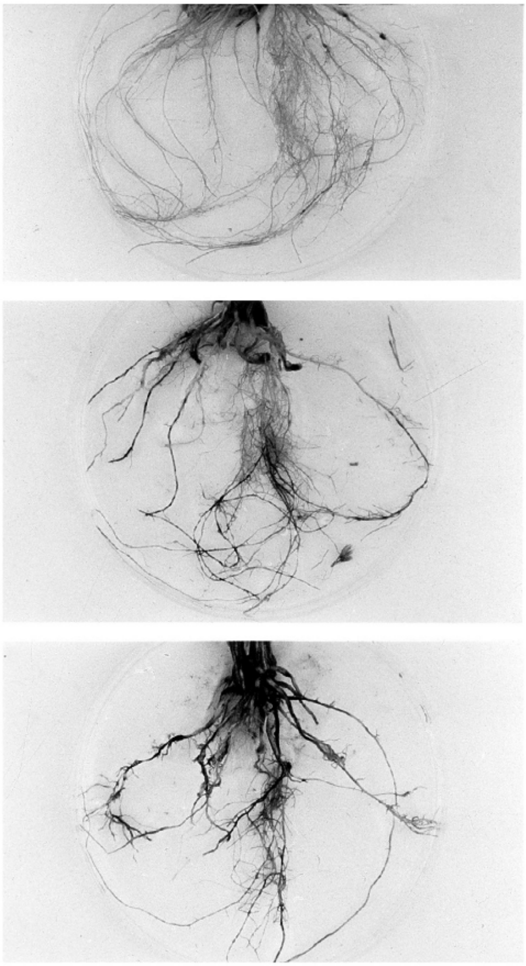

Figure 4. Symptoms of root lesion nematode, Pratylenchus thornei*, on susceptible wheat, showing extensive lesions, cortical degradation and reduction in both seminal and lateral root systems with increasing nematode density from top to bottom under natural field infestation (photo: J. M. Nicol, CIMMYT).*

Figure 5. Winter wheat attacked by root lesion nematode, Pratylenchus neglectus*, showing patchy distribution, reduced tillering and emergence of infected plants (photo: R Rivoal & R. Cook).*

3.3. Other Cereal Nematodes – Root Knot, Stem and Seed Gall

3.3.1. Root Knot Nematodes

Root knot nematodes cause typical small sized root galls on roots. Egg masses attached to the posterior end of protruding females are normally transparent, but darken on exposure to air and can resemble cysts of *H. avenae*. Young juveniles of *M. naasi* invade roots of cereals within 30–45 days of germination, after which small galls on root tips can be observed. *M. naasi* generally has one generation per season (Rivoal & Cook, 1993). Egg masses in galls survive in the soil. Eggs have a diapause, broken by increasing temperature after a cool period (Antoniou, 1989). In warmer regions on perennial or volunteer grass hosts more than one generation per season is possible (Kort, 1972). Juveniles develop and females become almost spherical in shape. Females deposit eggs in an egg sac and usually appear 8–10 weeks after sowing and are found embedded in the gall tissue (Kort, 1972). Large galls may contain 100 or more egg-laying females (Rivoal & Cook, 1993).

Towards the end of a growing season galling of the roots, especially the root tips, is common. Galls are typically curved, horseshoe or spiral shaped (Kort, 1972; Fig. 6). Symptoms of *M. naasi* attack closely resemble those caused by *H. avenae*, with patches of poorly growing, yellowing plants that may vary in size from a few square metres to larger areas. Other root knot nematodes attacking cereals are suspected to produce similar symptoms, but most are much less studied than *M. naasi.*

Information on the economic importance of root knot nematodes on cereals is limited to a few studied species. *M. naasi* can seriously affect wheat yield in Chile (Kilpatrick, Gilchrist, & Golden, 1976) and Europe (Person-Dedryver, 1986). On barley it has been known to cause up to 75% yield loss in California, USA (Allen, Hart, & Baghott, 1970). It is also associated with yield loss in barley in France (Caubel, Ritter, & Rivoal, 1972), Belgium (Gooris & D'Herde, 1977) and Great Britain (York, 1980). Severe losses can occur, with entire crops of spring barley lost in the Netherlands and France (Schneider, 1967). *M. naasi* damage is not known to be widespread in temperate semi-arid regions (Sikora, 1988).

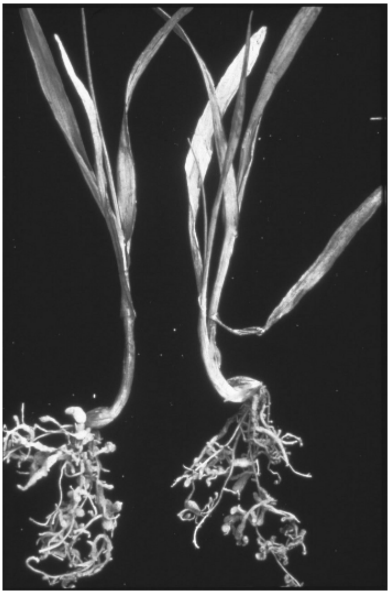

Figure 6. Typical galling of barley roots caused by Meloidogyne naasi *(photo: R. Rivoal).*

Damage to wheat by *M. artiellia* is known from Greece, southern Israel and Italy (Kyrou, 1969; Mor & Cohn, 1989). In Italy 90% yield losses on wheat have been recorded (Di Vito & Greco, 1988). *M. chitwoodi*, an important pathogen of potato also damages cereals in Utah, USA (Inserra, Vovlas, O'Bannon, & Griffin, 1985) and Mexico (Cuevas & Sosa Moss, 1990). In controlled laboratory studies, *M. incognita* and *M. javanica* have been shown to reduce plant growth of wheat (Abdel Hamid, Ramadan, Salem, & Osman, 1981; Roberts, Van Gundy, & McKinney, 1981; Sharma, 1981) and similarly *M. chitwoodi* (Nyczepir, Inserra, O'Bannon, & Santo, 1984). *M. incognita* is a known field problem on wheat in northwestern India (Swarup & Sosa Moss, 1990).

3.3.2. Stem Nematode

Ditylenchus dipsaci is a migratory endoparasite and invades foliage at the base of stems of cereal plants, where it migrates through tissues and feeds on adjacent cells. Reproduction continues inside a plant almost all year round but is minimal at low temperatures. When an infected plant dies, nematodes return to the soil from where they infect neighbouring plants. Typical symptoms of stem nematode attack include basal swellings, dwarfing and twisting of stalks and leaves, shortening of internodes and many axillary buds, producing an abnormal number of tillers to give a plant a bushy appearance (Fig. 7). Heavily infected plants may die in the seedling stage, resulting in bare patches in a field, while other attacked plants fail to produce flower spikes (Kort, 1972).

Figure 7. Close up of stem nematode, Ditylenchus dipsaci*, damage on susceptible oats indicating severe dwarfing, twisting of leaves, an abnormal number of tillers giving the plant a bushy stunted appearance (photo: S. Taylor).*

The nematodes are highly motile in soil and can cover a distance of 10 cm within two hours (Kort, 1972), hence their ability to spread from one plant to another is rapid. There are a number of biological races or strains of *D. dipsaci*, which are morphologically indistinguishable but differ in host range. Kort (1972) stated that the rye strain is more common in Europe and the oat strain is more common in Britain. Rye strains attack rye and oats as well as several other crops, including bean, maize, onion, tobacco, clover and also a number of weed species commonly associated with the growth of cereals in many countries (Kort, 1972). The oat strain attacks oats, onion, pea, bean and several weed species but not rye (Kort, 1972). Wheat is also attacked by *D. dipsaci* in central and eastern Europe (Rivoal & Cook, 1993), and central Asia in Azerbaijan (Kasimova & Atakishieva, 1981). The giant race of *D. dipsaci* is widely distributed throughout North Africa and the Near East on many crops and needs to be monitored for effects on cereals.

Economic damage by *D. dipsaci* depends on a combination of factors such as host plant susceptibility, infection level of soil, soil type and weather conditions. This is further complicated by the extensive intraspecific variation which is known in this species (Janssen, 1994). Furthermore, environmental conditions such as extended soil moisture content in the surface layer of soil provide optimum nematode activity, hence increasing the chance of a heavy attack. It is a problem with cereal crops growing on heavy soils in high rainfall areas (Griffin, 1984). The nematode is economically important on rye and oat but not on wheat and barley (Sikora, 1988). Although few studies have looked at the economic importance of this nematode, work on oats in England attributed a 37% yield loss to *D. dipsaci* (Whitehead, Tite, & Fraser, 1983) and in Italy was considered an important factor in poor wheat yields, where damage caused by *D. dipsaci* was associated with the presence of *Fusarium* (Belloni, 1954). In the seventies of the last Century, *D. dipsaci* had severely affected the maize crop in northen Europe when this culture has replaced oat production (Caubel, Person, & Rivoal, 1980).

3.3.3. Gall Nematode

This nematode disease is generally associated with situations where agricultural practices are not advanced. Within the infected cereal heads (florets), the nematode galls replace the grains. These galls are brown or black in colour and contain large numbers of second stage juveniles whose population ranges between 3000 and 12000, with an average of approximately 6000 juveniles per gall. These galls and their contents (second stage juveniles) are resistant to dry weather (anhydrobiosis) and it has been reported that they do not lose viability even up to 30 years. On getting favourable weather, like soil temperature ($15^{o}C \pm 2$), soil depth (2 cms), 20% soil moisture and 51% soil pore spaces, these galls rupture and discharge juveniles which in turn search the host and attack the plants.

Nematode-infected seed galls, which may be present already in the soil or sown into the soil at planting with contaminated seed, become moist and soft, with soil moisture facilitating the release of juveniles. Approximately one week after seed galls infected with nematode are placed in the soil, juveniles can be traced in the growing point of a germinating plant. These juveniles move upward passively on the growing point as the plant grows. They do not exhibit any morphological change until approximately two months. Nematode morphological changes take place only when the juveniles penetrate a flower primordial after two to three months and then turn into adults. As a result, ovules and other flowering parts of a plant are transmuted into galls or ‘cockles’ (Fig. 8). Nematodes mature inside galls and females lay thousands of eggs from which juveniles hatch and remain dormant in seed. The total life cycle is completed in around four months (Swarup & Sosa Moss, 1990). Temperature, humidity, planting depth and the source of galls are the major determinants in symptom expression. The nematode favours wet and cool weather (Kort, 1972). These environmental conditions and the source of galls are particularly important for development of yellow ear rot. This nematode-vectored bacterial disease, vernacularly known as “tundu” or “tannan” in India, is also commonly found associated with the ear-cockle nematode problem. The disease was first recorded from India by Hutchinson (1917), where the nematode is associated with *Corynebacterium michiganense* pv. *tritici*. This bacterium is frequently present along with juveniles in galls and is responsible for expression of the disease. The bacterium is only capable of producing yellow streaks on leaves on its own that run parallel to the veins. The nematode carries the bacterium to the growing point as an external body contaminant (Gupta & Swarup, 1972). Atmospheric temperatures between 5–10°C and a relative humidity of 95–100% favour multiplication of the bacterium in plants.

Figure 8. A healthy wheat ear (left), moderate infestation of gall nematode Anguina tritici, *and severe infestation of galls into ‘cockles’ (right) (photo: M. Ritter).*

Symptoms of *A. tritici* attack may be indicated by small and dying plants with leaves generally twisted due to nematode infection (Swarup & Sosa Moss, 1990). Infected ears are easily recognized by their smaller size and darkened colour compared with normal seeds, but infected seeds may be easily confused with bunt (*Tilletia tritici*). Under dry conditions juveniles may survive for decades (Kort, 1972).

In both ear-cockle and yellow ear-rot, the first observable symptom is an enlargement of the basal stem portion near the soil base, visible in three week old wheat seedlings. The emerging leaves are twisted and crinkled. Frequently, some leaves remain folded with their tips held near the growing point. These leaves, after about 30–45 days straighten out and many appear normal, with faint ridges on the surface. In comparison to healthy seedlings, the affected plants are dwarfed, with a spreading habit. These symptoms are more clearly discernible on young seedlings and decrease with plant age. Under very low infestation levels plants may not exhibit any visible symptoms, even though a few seed galls are produced in the ears, whereas severely infested plants may die without heading. Infested seedlings produce more tillers and grow faster than normal plants but not necessarily with an increase in the number of ears (Swarup & Sosa Moss, 1990).

Furthermore, ears emerge roughly a month earlier in diseased plants. Such ears are short and broad, with very small or no awns on the glumes. Nematode galls replace either all or some of the grains. In the yellow ear-rot disease, the characteristic feature is the production of a bright yellow slime- or gum-like substance on the abortive ears as well as leaves, which remains in contact with such ears while still in the boot leaf stage. Under humid conditions the bacterial slime trickles down tissues (Swarup & Sosa Moss, 1990) and upon drying it appears brown in colour. An infected spike is narrow and short, with wheat grains partially or completely replaced by slime. In the latter event an emerging spike remains sterile. The stalk of an infected spike is always distorted.

Worldwide, wheat, barley and rye are commonly attacked, but barley is less attacked in India (Paruthi & Gupta, 1987). Severely affected areas in India may suffer crop loss up to 80% (Bishnoi, pers. comm.), particularly in some regions and years such as in 1992 and 1997 several districts in Bihar and similar 1999 in Pawai Tehsil in Panna district of M. P. Significant losses of 20% in Ardestan wheat fields have also been reported (Behdad, 1982). Further studies of *A. tritici* on Roshan cultivar was studied under field conditions with different galled treatment of 0, 1, 2 and 4% infested with galls leading to damage of 0, 11, 21 and 35% respectively (Ahmadi & Akhiyani, 2001).

In Iraq, ear cockle is an important pest on wheat, with infection ranging from 0.03 to 22.9% and causing yield losses up to 30% (Stephan, 1988). Barley is also attacked in Iraq and Turkey (Yüksel et al., 1980; Al-Talib et al., 1986). In Pakistan, ear cockle is a known pest on wheat and barley and is found in nearly all parts of the country, causing losses of 2–3%. However, in association with the yellow ear-rot bacterium it produces serious yield losses on wheat (Maqbool, 1988). In China, Chu (1945) found yield losses between 10 and 30% on wheat.

4. INTEGRATED CONTROL OF CEREAL NEMATODES

In many of the countries where these nematodes occur wheat is often one of the major food staple, and the control of the nematode is of considerable importance to improve the production and livelihood of the farming communities. Furthermore much of West Asia and North Africa is characterised by wheat monoculture systems, where rainfall or irrigation is limited and options for crops rotation are not used or restricted. Such cropping systems frequently suffer moisture or drought stress and in these environments the effects of the nematode damage can be increased, and hence control of nematodes in these cropping systems is of paramount importance (Yadav, Bishnoi, & Chand, 2002)

Many different control options such as chemical, cultural, genetic (resistance/tolerance) and biological control are available and their need effect should be aimed at decreasing and maintain population densities under damage thresholds, so as to maintain or reach the attainable yield. However in order to this a clear understanding of nematode threshold densities that result in yield loss and the interaction of these thresholds with biotic and abiotic factors is required (Rivoal & Sarr, 1987).

Cultural practices represent efficient methods based on rotational combinations of non-hosts crops or cultivars and clean fallows. Frequencies of such combinations should be calculated upon data inferring from specific studies of population dynamics according to the targeted inputs. Application of fertilizers and soil amendments may compensate the reducing effect of nematodes on wheat yields but their use is frequently limited by financial constraints. Adjustment of sowing dates to escape synchrony of peak emergence with the more sensitive stage of the crop could maximise the final yield. Trap cropping could constitute efficient measures to decrease nematode densities. Allelopathy techniques based on toxic plant root exudates and microbial secretions offer also some alternative controlling measures. Control of stem and foliages nematodes could be effective by sanitation based on grain sieving or other discarding process.

Even if in the past low rates of nematicides applied to both soil and seed provided effective and economical control (e.g. in Australia, India and Israel), however, the present day cost and environmental concerns associated with these chemicals do not make them a viable economic alternative for almost all farmers. However, their use in scientific experiments to understand the importance of these nematodes will remain vital. For this reason we will not provide them as an option in this section and again refer to previous reviews cited at the start of this section which mention this work.

The use of resistant/tolerant varieties which ensure both reduction/inhibition of nematode multiplication within the plants and stable crop production offer the best control capabilities. In addition it requires no additional equipment or cost. However, the use of resistant cultivars requires a sound knowledge of the virulence spectrum of the targeted species and pathotypes. Engineering of transformed plants with inhibitors to the development of nematodes may be part of the future options for some countries.

The prospects for using biological antagonists within an IPM strategy for wheat nematodes is still considered promising with the development of natural populations of enemies (e.g. *Pochonia, Nematophtora*) or application of exogenic pathogens i.e. *Trichoderma viride* (Indra-Rajvanshi, 2003), however their ultimate use relies greatly on the agroecology of the cropping systems for persistence and effectiveness.

This section will focus particularly on CCN and RLN, but also consider the other three nematodes and what limited published information is available about their control and the options to combine these in an integrated manner. However, as found with many nematodes there are only a few well published studies which allow a good understanding of population dynamics to establish the most effective integrated management combinations to control a given nematode (Caubel et al., 1980; Dowe & Decker, 1977). More targeted research is needed to consider the holistic system of nematode control in balance with the cropping system options, the agro-ecological conditions and especially the use of resistance, which still offers one of the best cost effective means of control.

4.1. Cereal Cyst Nematode

4.1.1. Chemical

The present day cost and environmental concerns associated with these chemicals do not make them a viable economic alternative for almost all farmers. However, their use in scientific experiments to understand the importance of these nematodes will remain vital. For this reason we will not provide them as an option in this section and again refer to previous reviews mentioned at the start of this section.

4.1.2. Cultural Practices

4.1.2.1. Grass Free Rotations and Fallowing with Cultivation

One of the most efficient methods of controlling *H. avenae* is with the use of grass-free rotations using non-host crops. In long term experiments, non-host or resistant cereal frequencies of 50% (80% in lighter soils) keep populations below damaging thresholds (Rivoal & Besse, 1982; Fisher & Hancock, 1991). Similarly, in India, it was found that nematode population decreased by 70% with continued rotation of non host crops like mustard, carrot, fenugreek and gram or by fallowing, and this resulted in a corresponding 56% increase in barley yields with two year rotation of non host crops (Handa, Mathur, & Mathur, 1975a). Using natural *H. avenae* field infested soil in Hubei province in China, small grained cereals (wheat, barley, oats and grass weeds) were susceptible, whilst maize was infected but the life cycle not completed, and pastures (*Trifolium and Medicago*) were non-hosts (MingZhu, Zhi Feng, & YanNong, 1996). In Spain under natural field conditions the use of vetch in rotation and use of fallow with cereals was effective (Nombela, Navas, & Bello, 1998). Monitoring a 30 year rotation trial over several seasons under rainfed wheat cropping systems in Turkey clearly demonstrated the use of legumes (vetch, lentil), sunflower or safflower in wheat rotation system provided a significant reduction in cyst population, whereas fallowing had little effect and cereal rotation increased significantly cyst populations (Elekçioğlu et al., 2004). In Europe a four-year rotation can be practiced for nematode control, but economic factors do not permit such long rotations in most subtropical and tropical countries.

Clean fallow can reduce population densities of the nematode and one to five deep ploughings during hot summer months can cause reductions in nematode populations between 9.3 and 42.4%, with a corresponding yield increase of 4.4–97.5% (Mathur, Handa, & Swarup, 1987), but are not always economically and environmentally sound. In arid climates, the decrease in population is attributable to killing of cyst contents by intense solar heat and to desiccation of eggs and juveniles by hot winds. In contrast, reducing effect of fallow on population densities could be increased by maintaining humidity of soil which favours emergence of juveniles during the hatching period. Soil sanitation could be achieved by a straw mulch management which was demonstrated to decrease soil evaporation and this resulted in higher levels of soil water and decreased nematode inhibition of rooting (Amir & Sinclair, 1996; Sinclair & Amir, 1996). Studies in rainfed wheat system in Australia under natural CCN populations found no significant differences in the number of cysts produced with normal cultivation versus direct drill, or the timing and number of cultivations with rotary hoe (Boer, Kollmorgen, Macauley, & Franz, 1991), however similar studies by Roget and Rovira (1985) indicated early damage in wheat was reduced with direct drill than normal cultivation inferring these agronomic studies are to some degree site and location specific.

Recent research in India has focused on the identification of new chemicals from botanicals (Kanwar & Walia, 2004). The compositae *Chrysanthemum coronarium* has demonstrated efficient nematostatic activity to *H. avenae* (Bar-Eyal, Sharon, & Spiegel, 2006).

4.1.2.2. Irrigation

Mathur, Arya, Handa, and Mathur (1981) reported higher multiplication of nematodes in well irrigated fields in wheat and barley as compared to soil with low moisture. They found that sandy loam soil resulted in more yield of barley with reducing the irrigation gap i.e. 20 days with maximum post harvest population build up of nematode in question.

4.1.2.3. Time of Sowing

Mathur (1969) tried sowing wheat and barley from 18th October to 26th December at weekly intervals in pots and concluded that change in the date of sowing did not influence the incidence of CCN and their multiplication. Conflicting studies however demonstrated delay in sowing time could escape synchrony between peak emergence of juveniles and the more sensitive stages of the hosting crop, which permitted to maximize the production of wheat (Brigbhan & Kanwar, 2003; Singh & Singh, 2005).

4.1.2.4. Trap and Mixed Cropping

Natural trap cropping was observed when maize replaced oat production in northern Europe. Hypersensitive to *H. avenae* attacks, maize was nevertheless a poor host and provoked sound decreases of soil densities of this nematode (Caubel et al., 1980; Rivoal & Sarr, 1987). It has been also demonstrated that winter maize is also a poor host in India and can be similarly exploited as a trap crop of *H. avenae* and *H. filipjevi* (Bajaj & Kanwar, 2005). Resistant Italian ryegrass has been bred to be introduced in areas where *H. avenae* has a high intrinsic capacity to develop and when the crop season corresponds to the hatching period of the nematode (winter in southern France). As a forage crop and catch crop for nematodes and nitrate excesses, this ryegrass will contribute to control the nematode thus protecting subsequent cereal crops as bread and durum wheats (Rivoal & Bourdon, 2005).

Mixed cropping of wheat and barley as "Gojra" is common practice in the northern region of Rajasthan. Handa, Mathur, Mathur, Sharma, and Yadav (1985a) reported the beneficial effect of resistant variety of barley (Rajkiran) with susceptible variety of wheat (Kalyansona) for increase in grain yield and decrease in nematode population as compared to susceptible crop of wheat/barley. They further indicated the possibility of use a combination of different crops with varying nematode susceptibility to decrease the population and obtaining optimum yield. Similar studies in Rajasthan intercropping wheat and barley with Indian mustard indicated maximum grain yield in addition to highest reduction in cyst populations (Rajvanshi, Mathur, & Sharma, 2002).

4.1.2.5. Organic Amendments and Inorganic Fertilizers

Mathur (1969) in India reported that oil cakes, farm yard manure, compost and saw dust applications improved plant growth and subdued multiplication of CCN. Nitrogenous fertilizer resulted in better plant growth and more nematode multiplication, however no change was found with phosphorus and potash (Mathur, 1969).

4.1.3. Resistance (and Tolerance)

Plant resistance is defined as a reduction/inhibition of nematode multiplication within plants (Trudgill, Kerry, & Phillips, 1992), and is one of the best control methods for CCN due to its wide application as it usually requires no additional equipment or cost. Ideally the resistance should be combined with tolerance (plants which have the ability to yield despite the attack of the nematode). The effectiveness of CCN resistance however will depend on the effectiveness and durability of the resistance source and on correct identification of the nematode species and/or pathotype(s). In addition, an understanding of nematode threshold densities that result in yield loss and the interaction of these thresholds with biotic and abiotic factors is required (Rivoal & Sarr, 1987; Rivoal, Person-Dedryver, Doussinault, & Morlet, 1986).

As mentioned above in order to classify the pathotype variation for *H. avenae*, an International Test Assortment of barley, oat and wheat was developed by Andersen and Andersen (1982). *H. avenae* pathotypes have usually been characterised by virulence on barley genotypes, but geographically different populations can also be differentiated by virulence on wheat (Bekal et al., 1998; Cook & Rivoal, 1998; Rivoal et al., 2001). However, as mentioned this test is more than thirty years old and does not cater for the wider variation of species and pathotypes which are presently reported. Very few studies have been achieved on the two other species *H. filipjevi* and *H. latipons* but preliminary researches indicated heterogeneous responses between populations to different resistant germplasm. It was also demonstrated that populations of *H. avenae* differed in the capacity of juveniles to produce females (part of the fitness component) which was important for designing virulence/resistance investigations and for the management of nematode densities (Rivoal et al., 2001).

A summary of the CCN cereal resistance sources and their genetic control of cyst and lesion nematodes is provided in Table 1. The progress in understanding and locating resistance sources in cereals is more advanced for cyst (*H. avenae*) than lesion (*Pratylenchus* spp.) nematodes, in part due to the specific host-parasite relationship that cyst nematodes form with their hosts (Cook & Evans, 1987), whereby all published sources are controlled by a single gene. In contrast, the relationship of migratory lesion nematodes with their hosts is less specialized and therefore less likely to follow a gene for gene model. The identified sources of resistance to *H. avenae* have been found predominantly in wild relatives of wheat in the *Aegilops* genus (Dosba & Rivoal, 1982; Eastwood, Lagudah, Appels, Hannah, & Kollmorgen, 1991; Dhaliwal, Singh, Gill, & Randhawa, 1993; Delibes et al., 1993; Rivoal & Cook, 1993; Bekal et al., 1998; Jahier et al., 1998, 2001; Romero et al., 1998; Ogbonnaya et al., 2001a; Zaharieva et al., 2001; Barloy et al., 2007). Six out of the seven named *Cre* genes for *H. avenae* resistance in wheat as well as *Rkn2* for resistance to both *M. naasi* and *H. avenae* came from four *Aegilops* species (Table 1) and have already been introgressed into hexaploid wheat backgrounds for breeding purposes. The effectiveness of these designated *Cre* genes is depending on both the species of CCN and pathotype. It has been clearly demonstrated in Australia that *Cre3* has the greatest impact on reducing the Ha13 population followed by *Cre1* and *Cre8* (Safari et al., 2005). In order to understand the effectiveness of resistance to a given population such tests are necessary.

Molecular technologies have been applied to identify markers for various CCN plant resistance genes using techniques such as RAPD and RFLP, in both barley (Kretschemer et al., 1997; Barr et al., 1998) and wheat (Eagles et al., 2001; Ogbonnaya et al., 2001a, 2001b). McIntosh, Devos, Dubcovsky, and Rogers (2001) presented information about introgression, substitution and molecular characterisation of these resistance sources in cereals. In some Australian cereal breeding programmes, markers for both wheat and barley are being implemented using marker assisted selection (MAS) to pyramid resistance genes against *H. avenae*, pathotype Ha13 (Eagles et al., 2001; Ogbonnaya et al., 2001b). Identification and implementation of markers in this way requires sufficient understanding of the biology of the pathogen and genetic control of the resistance. In the future, it may be possible to transform wheat using resistance genes as a method to produce nematode resistant wheat cultivars (Lagudah et al., 1998).

4.1.4. Biological Control

Since a long time in several countries, it is known that populations of *H. avenae* could be naturally controlled by antagonistic fungi such as *Pochonia chlamydosporia* and *Nematophtora gynophila*. This control has been observed in long term experiments with monocultures of host cereals, however there have been marked contrasts in the results between areas which developed suppressive soils and the dryland areas (Kerry, 1981). Unfortunately the biocontrol treatments by these antagonists have never been commercially feasible. In Syria and Germany cereal soils were found to have high levels of natural suppressiveness against *H. latipons* with the pathogenic fungi *Fusarium* and *Acremonium*, with the level being higher in the Syrian semiarid soils (Ismail et al., 2001). Similarly in rainfed wheat soils of cereal crops in Turkey species of *Fusarium* have been isolated from *H. filipjevi* eggs which appear to be colonized and may play some role in suppressiveness (Nicol, unpubl.).

The use of parasites as the nematophagous fungus *Paecilomyces lilacinus*, predators as the trapping fungus *Monacrosporium lysipagum*, and the nematode *Seinura paratenuicaudata* which act on living and mobile stages provided, in laboratory experiments, offer some promise to control *H. avenae* and other nematodes as *Anguina* and *Meloidogyne* (Vats, Kanwar, & Bajaj, 2004; Khan, Williams, & Nevalainen, 2006).

Table 1. Principal sources of genes[a] used for wheat breeding resistance to Cereal Cyst Nematode (Heterodera avenae) *and Root Lesion Nematode* (Pratylenchus thornei *and* P. neglectus).

Species	Cultivar or line	Genetic information	References
		Cereal Cyst Nematode	
T. aestivum	Loros, AUS10894	*Cre1*[a] (formerly *Ccn1*), on chromosome 2BL.	Slootmaker, Lange, Jochemsen, and Schepers, 1974; Bekal et al., 1998.
	Festiguay	*Cre8 (formerly CreF)*, on chromosome 7L. Recent analysis suggests 6B.	Paull, Chalmers, and Karakousis, 1998; Williams et al., (unpub).
	AUS4930=Iraq 48	Possible identical genetic location as *Cre1*. Resistance to Pt.	Bekal et al., 1998; Nicol, Davies, and Eastwood, 1998, 2001; Green (pers. comm); Lagudah (pers. comm).
T. durum	Psathias 7654, 7655, Sansome, Khapli		Rivoal et al., 1986.
Triticosecale	T701-4-6	*CreR,* on chromosome 6RL.	Dundas, Frappell, Crack, and Fisher, 2001; Asiedu, Fisher, and Driscol, 1990.
Secale cereale	R173 Family	*CreR,* on chromosome 6RL	Taylor, Shepherd, and Langridge, 1998.

(continued)

Table 1. (continued)

Species	Cultivar or line	Genetic information	References
Ae. tauschii	CPI 110813	*Cre4,* deduced to be on chromosome 2D.	Eastwood et al., 1991; Rivoal et al., 2001.
Ae. tauschii	AUS18913	*Cre3,* on chromosome 2DL	Eastwood et al., 1991; Rivoal et al., 2001.
Ae. peregrina (Ae. variabilis)	1	*Cre(3S) with (Rkn2)* on chromosome 3S; *CreX* not yet located, *CreY*	Barloy, Martin, Rivoal, and Jahier, 1996; Jahier et al., 1998; Rivoal et al., 2001; Barloy et al., 2007; Lagudah (pers. comm).
Ae. longissima	18		Bekal et al., 1998.
Ae. geniculata	79 MZ1, MZ61, MZ77, MZ124		Bekal et al., 1998; Zaharieva et al., 2001.
Ae. triuncialis	TR-353	*Cre7 (*formerly *CreAet).*	Romero et al., 1998.
Ae. ventricosa	VPM 1	*Cre5* (formerly *CreX*), on chromosome 2AS.	Jahier et al., 2001; Ogbonnaya et al., 2001b.
	11, AP-1, H-93-8	*Cre2* (formerly *CreX*) on genome N^v.	Delibes et al., 1993; Andrés, Romero, Montes, and Delibes, 2001; Rivoal et al., 2001.
	11, AP-1, H-93-8, H-93-35	*Cre6,* on chromosome $5N^v$.	Ogbonnaya et al., 2001b; Rivoal et al., 2001.
		Root Lesion Nematode	
T. aestivum	GS50a	Resistance to Pt .	Thompson and Clewett, 1986.
	AUS4930=Iraq 48	Resistance to Pt but also portrays resistance to CCN.	Nicol et al. 1998.
	Excalibur	Resistance to Pn (*Rlnn1*), on chromosome 7AL.	Williams et al., 2002.
	Croc_1/*Ae. tausch.* (224)//Opata	Resistance to Pt. Unknown where resistance is derived from.	Nicol et al., 2001.
Ae tauschii	CPI 110872	Resistance to Pt and Pn.	Thompson (pers. comm).
Ae. geniculata	MZ10, MZ61, MZ96, MZ144	Moderate resistance to Pt. Several also portray resistance to CCN	Zaharieva et al., 2001.

Pt: *Pratylenchus thornei*, Pn: *Pratylenchus neglectus*; [a]: characterized single gene; for marker implemented in commercial breeding program refer to Ogbonnaya et al., 2001b; *Aegilops* classification used according to Van Slageren (1994). Information for other cereal species can be found in Nicol (2002).

4.1.5. True IPM Investigations

As previously applied with the SIRONEM bioassay in Australia (Brown, 1987), investigations to validate the resulting damage model and the correlation between the forecast damage and field rating of CCN were relatively frequent, both in northern Europe (Rivoal & Besse, 1982) and more recently in West Asia (Bonfil, Dolgin, Mufradi, & Asido, 2004). Long term experiments were initiated on the effects of resistance on the targeted nematode densities, the community of other nematodes and biological antagonists, recolonization by susceptible varieties and based on a population genetics approach for the first time using CCN (Lasserre et al., 1994; Rivoal, Lasserre, & Cook, 1995; Lasserre et al., 1996). However, the true integration of different controlling measures as nematicide, farm-yard manure, biological antagonist and resistant cultivar are rare and began in Asia (Pankaj Mishra & Sharma, 2002).

In India studies on integrated management of CCN on wheat and barley have been undertaken by integrating several methods, for example summer ploughing + irrigation, summer ploughing + nitrogenous fertilizers + seed treatment or soil application of nematicides (Handa et al., 1975a; Handa, Mathur, & Mathur, 1975b; Mangat, Gupta, & Ram, 1988). Integration of some of these methods has given encouraging results for increasing the crop yield and reducing nematode population.

4.2. Root Lesion Nematode

4.2.1. Chemical

The present day cost and environmental concerns associated with these chemicals do not make them a viable economic alternative for almost all farmers. However, their use in scientific experiments to understand the importance of these nematodes will remain vital. For this reason we will not provide them as an option in this section and again refer to previous reviews mentioned.

4.2.2. Cultural Practices

Cultural methods offer some control options, but are of limited effectiveness. To be of major significance these need to be integrated with other control measures.

4.2.2.1. Crop Rotation and Cultivation

The use of crop rotation is a limited option for root lesion nematodes, due to their polyphagous nature. Little is understood about the potential role of crop rotation in controlling these nematodes, although some field and laboratory work has been undertaken to better understand the hosting ability of both *P. thornei* (Van Gundy et al., 1974; O'Brien, 1983; Clewett, Thompson, & Fiske, 1993; Hollaway, Taylor, Eastwood, & Hunt, 2000) and *P. neglectus* (Vanstone, Nicol, & Taylor, 1993; Lasserre et al., 1994; Taylor et al., 1999, 2000) to utilise cereals and leguminous crops as hosts. Results from these studies indicate hosting ability is both species and cultivar specific, both with legumes and cereals. Therefore it is essential that hosting-ability studies are conducted with local/regional cultivars. It is possible, depending on crop rotation patterns and the population dynamics of nematodes, that resistant cultivars of cereals alone may not be sufficient to maintain nematode populations below economic levels of damage.

In Australia, cultivation reduced populations of *P. thornei* (Thompson, Mackenzie, & McCulloch, 1983) and in Israel Orion et al. (1984) found that biannual fallowing reduced *P. mediterraneus* populations by 90% and increased grain yields by 40–90%. Nombela et al. (1998) also found fallowing to be effective. An eleven-year management trial conducted in Queensland revealed that the topsoil of zero tillage fallow systems had higher *P. thornei* populations than mechanically cultivated treatments (Thompson et al., 1983).

Monitoring a 30 year rotation trial over several seasons under rainfed wheat cropping systems in Turkey with natural *P. thornei* populations clearly demonstrated the use of legumes (vetch, lentil) should be avoided due to increased populations, whilst sunflower or safflower and fallowing provided the best reduction of *P. thornei* in the wheat rotation system (Elekçioğlu et al*.,* 2004). As with cereal cyst nematode, some triticale varieties such as Abacus and Muir in Australia are known to host fewer nematodes than with bread or durum wheats and hence may offer some useful rotational options (Farsi, Vanstone, Fisher, & Rathjen, 1995).

4.2.2.2. Time of Sowing

Van Gundy et al. (1974) found that delaying sowing of irrigated wheat by one month in Mexico gave maximum yields.

4.2.2.3. Other Cultural Practices

Di Vito, Greco, and Saxena (1991) found that mulching fields with polyethylene film for 6–8 weeks suppressed *P. thornei* populations by 50%.

4.2.3. Resistance (and Tolerance)

Unlike cereal cyst nematode, no commercially available sources of cereal resistance are available to *P. thornei*, although sources of tolerance have been used by cereal farmers in northern Australia for several years (Thompson, Brennan, Clewett, & Sheedy, 1997). As illustrated in Table 1, Thompson and Clewett (1986), Nicol, 1996; Nicol et al. (1999), and Nicol (2002) identified wheat lines that have proven field resistance and work is continuing to breed this resistance into suitable backgrounds. Recent work by Thompson and Haak (1997) identified twenty-nine accessions from the D-genome donor to wheat, *Aegilops tauschii*, suggesting there is future potential for gene introgression. Some of this material also contained the *Cre 3* and other different, unidentified sources of cereal cyst nematode resistance gene conferring resistance to some cereal cyst nematode pathotypes.

As with the cereal cyst nematode, molecular biology is being used to determine the genetic control, location and the subsequent identification of markers for resistance to both *P. thornei* and *P. neglectus*. Table 1 indicates that the significant gains in knowledge have been made with several sources of resistance in bread wheat against RLN. However, unlike CCN the genetic of resistance is quantitative, so that development of QTL markers is required to use these in a marker assisted selection approach, which however will only explain part of the variation of resistance.

As with CCN, marker assisted selection is being used routinely with PCR based markers for *P. neglectus* (*rln1*), both in Australia and with CIMMYT International. Commercial cultivars with resistance and tolerance to RLN are now commercially available in Australia and soon within the international breeding programs at CIMMYT.

4.2.4. Biological Control

Successful biological control of *Pratylenchus* species is likely to be difficult due to their migratory behaviour. *Pratylenchus* species spend much of their lives in roots and tend to be found only in soil when their host plants are stressed, senescing or diseased, or when their hosts have been ploughed out after harvest (Stirling, 1991).

Currently, several commercial biological control products are available for the control of nematodes but their use for controlling lesion nematode on cereals is not reported in literature. However, as mentioned previously their application and use is more common on higher value, more intensive agricultural crops such as tomato. Trudgill et al. (1992) reinforces that the greatest value of biocontrol agents will be in combination with other control options.

4.2.5. True IPM Investigations

Unfortunately with RLN very few studies have looked at combining options for control, however it is common practice now in Australia to use resistant and/or tolerant cultivars in combination with rotation crops which are poor or non-hosts of RLN.

4.3. Other Cereal Nematodes – Root Knot, Stem and Seed Gall

Within the individual sections the known control methods for each nematode will be reported.

4.3.1. Chemical

The present day cost and environmental concerns associated with these chemicals do not make them a viable economic alternative for almost all farmers. However, their use in scientific experiments to understand the importance of these nematodes will remain vital. For this reason we will not provide them as an option in this section and again refer to previous reviews mentioned at the start of this section which mention this work.

Sulphur dioxide (SO_2) has been demonstrated to provoke an antagonistic action on the *A. tritici* which resulted in a significant decreasing of number of cockles on different wheat cultivars (Kausar, Khan, & Raghav, 2005).

4.3.2. Cultural Practices

4.3.2.1. Grass Free Rotations and Fallowing with Cultivation

Use of poor or non-host crops is an option to control *M. naasi* (Cook, York, & Guile, 1986). Also the use of fallow during the hatching period (Allen et al., 1970; Gooris & D'Herde, 1972) has been found effective. Rotations also offer some options for *M. artiellia*. Di Vito et al. (1985) were able to demonstrate that, although most legumes and Graminanceae are hosts, cowpea, lupin, sainfoin and maize could be considered non-hosts.

For seed gall nematode oat, maize and sorghum are considered to be non-hosts (Limber, 1976; Paruthi & Gupta, 1987) and while they may offer some option for reducing populations by rotation, the diseases is not completely controlled.

Due to the polyphagous nature of stem nematode and the fact that *D. dipsaci* being a pest on lucerne (alfalfa), red and white clover, pea, bean and bulbous species of the Liliaceae, including garlic, onion, tulip and narcissus, the use of crop rotation in some cropping systems is limited. However, within lucerne, red and white clover, oat, garlic, strawberry and sweet potato resistant cultivars have been developed, as reviewed by Plowright et al. (2002). Rotational combinations of non-hosts including barley and wheat offer some control method for the rye and oat races of *D. dipsaci*. However, once susceptible oat crops have been damaged, rotations are largely ineffective (Rivoal & Cook, 1993).

4.3.2.2. Seed Hygiene

Since ear-cockles (seed galls) are the only source for perpetuation of seed gall therefore their removal from contaminated seed lots can completely eliminate this problem. *A. tritici* can most easily be controlled by seed hygiene. Clean, uninfected seed can be obtained either through use of certified seed or by cleaning infected seed by using modern seed cleaning techniques or by sieving and freshwater flotation (Singh & Agrawal, 1987). Although it has been eradicated from the Western Hemisphere through adoption of this approach, it remains a problem on the Indian sub-continent, in Western Asia and to some extent China (Swarup & Sosa Moss, 1990). Galls are lighter in weight than wheat seed and can be easily discarded through a winnowing process or by flotation of contaminated seeds in 20% brine solution. It is important, however, to wash wheat seed after brine treatment two or three times in water to remove adhering salt particles, otherwise seed germination is impaired.

To dispense with salt treatment, Byars (1920) suggested presoaking contaminated seeds in water, then soaking them at either 50°C for 30 min, 52°C for 20 min, 54°C for 10 min or at 56°C for 5 min. The principle is to reactivate quiescent juveniles before killing them with hot water. Leukel (1957) suggested presoaking galls for 4–6 hours in water and then expose them to hot water at 54°C for 10 min.

4.3.3. Resistance and Tolerance

Work with the most economically important RKN species *M. naasi* has reported partial resistance found in barley and also in *Triticum squarrosa* and *T. monococcum*, while full resistance was identified with *Hordeum chilense*, *H. jabatum, T. umbellulatum* and *T. variabile* (bread wheat) (Cook & York, 1982b; Roberts et al., 1982; Person-Dedryver & Jahier, 1985). Resistance has also been expressed in *H. chilense* (Person-Dedryver, Jahier, & Miller, 1990; Yu, Person-Dedryver, & Jahier, 1990).

For countries where hygiene practices are difficult to implement to seed gall nematode, host resistance and rotation offer some hope. The earliest record of a resistance source is the cultivar Kanred (Leukel, 1924) used in a breeding programme initiated by Shen, Tai, and Chia (1934). Crosses between Kanred and a highly susceptible wheat cultivar resulted in a few lines in the F_2 and F_3 free from nematode attack. Unfortunately, this work was not continued. However, since then, resistance to *A. tritici* has been identified in Iraq in both wheat and barley (Saleh & Fattah, 1990) and Pakistan (Shahina, Abid, & Maqbool, 1989) and was sought in India (Swarup & Sosa Moss, 1990). In Iraq, laboratory screening has identified sources of resistance in both wheat and barley (Stephan, 1988). In Iran the reaction of some bread and durum wheat and barley cultivars were evaluated to wheat gall nematode (*Anguina tritici*): among bread wheat cultivars Atrak was more resistant than Darab2 cultivar and among durum wheat cultivars Showa was infected less than Yavarus cultivar.

Occurrence of different biological races or strains of *D. dipsaci* makes it a difficult nematode to control and as a result the only economic and highly effective method is use of host resistance as reviewed by Rivoal et al. (1986). In Britain the most successful oat crop has resistance derived by the landrace cv. Grey Winter, which is controlled by a single dominant gene that is now bred into several commercial cultivars (Plowright et al., 2002). In other oat, resistance may be derived from Uruguayan land races. The wild oat, *Avena ludoviciana* has more than one gene for resistance (Plowright et al., 2002), whilst a number of other oat cultivars have been reported resistant (Whitehead, 1998) but many of these offer only partial resistance or tolerance.

4.3.4. Biological Control

Meloidogyne species have been demonstrated to be controlled by the bacterium *Pasteuria penetrans* although difficulties are perceived with its mass-production and specificity of populations (Gowen & Pembroke, 2004). Success of such control could be connected to the intraspecific variability in attachment of *P. penetrans* to juveniles as for *M. chitwoodi* (Wishart, Blok, Phillips, & Davies, 2004). Disturbancy of biological control could be caused by a distinct microbial community in the egg mass that may have a function in protecting the eggs from antagonists as *P. chlamydosporia* (Kok & Papert, 2001). To date however, there are no published report of its effectiveness on control RKN on wheat.

For both Seed Gall and Stem Nematode there are no published reports of successful control with biologicals on wheat.

4.3.5. True IPM Investigations

It would appear as these three nematodes are considered less important on wheat, that the overall global research in their control is much more limited, hence studies that apply the integration of different methods are not reported.

5. CONCLUSIONS

This chapter has clearly identified CCN and RLN are major biotic constraints to wheat production systems worldwide, especially where the plants suffer other biotic and abiotic stress, particularly drought. In particular the widespread global importance of complex of CCN species and pathotypes is of major economic constraint to wheat production, particularly throughout the region of West Asia, North Africa, China and India. The other three nematodes RK, SG and SN have local reports of economic importance.

Control of any of these cereal nematodes requires a very clear understanding of the biology and population dynamics of each nematode, and in the case of CCN and SN the pathotype and even ecotype. Without this very basic information it is hard to fully understand the value of components of control.

It is clear with CCN and RLN most of the global efforts of research have focussed on the use of non-hosts, and the identification of resistance within bread wheat and associated relatives of wheat. This is the most logical method as it is cost effective, environmentally sound, and particularly in developing countries does not require additional facilities. International breeding programs such as CIMMYT (International Wheat and Maize Improvement Center cimmyt.cgiar.org) and ICARDA (International Centre for Agricultural Research in Dryland Areas icarda.cgiar.org) have a key and integral role to play in providing the appropriate germplasm to National Program partners in developing countries, in addition to technical backup. In several countries with long standing research this is being combined with the use of crop rotation. Other integrated methods at this time do now seem be used, however it is clear that molecular tools both for nematode diagnostics and the identification of resistance are playing a catalytic role in fast tracking efforts in this area. Futuristically the use of plant transformation with genes of interest with resistance to target nematodes may offer tremendous potential where they are accepted. With respect to RK and SN most efforts have similarly focussed on host resistance and rotation. However, for SG seed hygiene is the major method of control, which can easily been implemented by farmers.

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REFERENCES

Abdel Hamid, M. E., Ramadan, H. H., Salem, F. M., & Osman, G. Y. (1981). The susceptibility of different field crops to infestation by *Meloidogyne javanica* and *M. incognita acrita*. *Anzeiger für schädlingskunde, Pflanzenschutz, Umweltschutz, 54*, 81–82.

Abidou, H., El-Ahmed, A., Nicol, J. M., Bolat, N., Rivoal, R., & Yahyaoui, A. (2005). The occurrence and distribution of species of the *Heterodera avenae* group in Syria and Turkey. *Nematologia Mediterranea, 33*,197–203.

Agrios, G. N. (1988). *Plant Pathology* (3rd ed.). London, UK: Academic Press.

Ahmadi, A. R., & Akhiyani, A. (2001). Status of wheat seed gall nematode (*Anguina tritici*) in irrigated wheat fields of Esfahan province. *Applied Entomology and Phytopathology,* 69, 1–13.

Al-Hazmi, A. S., Al-Yahya, F. A., & Abdul-Razig, A. T. (1999). Damage and reproduction potentials of *Heterodera avenae* under outdoor conditions. *Journal of Nematology, 31*(Suppl.), 662–666.

Al-Hazmi, A. S., Cook, R., & Ibrahim, A. A. M. (2001). Pathotype characterisation of the cereal cyst nematode, *Heterodera avenae*, in Saudi Arabia. *Nematology, 3*, 379–382.

Allen, M. W., Hart, W. H., & Baghott, K.V. (1970). Crop rotation controls the barley root-knot nematode at Tulelake. *California Agriculture, 24*, 4–5.

Al-Talib, N. Y., Al-Taae, A. K. M., Neiner, S. M., Stephan, Z. A., & Al-Baldawi, A. S. (1986). New record of *Anguina tritici* on barley from Iraq. *International Nematology Network Newsletter, 3*, 25–27.

Al-Yahya, F. A, Alderfasi, A. A., Al-Hazmi, A. S., Ibrahim, A. A. M., & Abdul-Razig, A. T. (1998). Effects of cereal cyst nematode on growth and physiological aspects of wheat under field conditions. *Pakistan Journal of Nematology, 16*, 55–62.

Amir, J., & Sinclair, T. R. (1996). Cereal cyst nematode effects on wheat water use and on root and shoot growth. *Field Crop Research, 47*, 13–19.

Andersen, S., & Andersen, K. (1982). Suggestions for determination and terminologyof pathotypes and genes for resistance in cyst-forming nematodes, especially *Heterodera avenae*. *EPPO/OEPP Bulletin, 12*, 379–386.

Andersson, S. (1974). *Heterodera hordecalis* n.sp. (Nematoda: Heteroderidae) a cyst nematode of cereals and grasses in southern Sweden. *Nematologica, 20*, 445–454.

Andrés, M. F., Romero, M. D., Montes, M. J., & Delibes, A. (2001). Genetic relationships and isozyme variability in the *Heterodera avenae* complex determined by isoelectric focusing. *Plant Pathology, 50*, 270–279.

Antoniou, M. (1989). Arrested development in plant parasitic nematodes. *Helminthological Abstracts Series B, 58*, 1–9.

Asiedu, R., Fisher, J. M., & Driscol, C. J. (1990). Resistance to *Heterodera avenae* in the rye genome of triticale. *Theoretical and Applied Genetics, 79*, 331–336.

Bajaj, H. K., & Kanwar, R. S. (2005). Parasitization of maize by *Heterodera avenae* and *H. filipjevi*. *Nematologia Mediterranea, 33*, 203–207.

Balakhnina, V. P. (1989). Resistance of varieties of *Triticum durum* desf. and *Triticum aestivum* L. to the oat cyst nematode. In *Gel'mintologiya segodnya: Problemy i perspektivy*. Tezisy dokladov nauchnoi konferentsii, Moskva, 4–6 Aprelya 1989. Tom 2. Moscow, USSR, pp. 36–37.

Bar-Eyal, M., Sharon, E., & Spiegel, Y. (2006). Nematicidal activity of *Chrysanthemum coronarium*. *European Journal of Plant Pathology, 114*, 427–433.

Barker, K. R., & Noe, J. P. (1987). Establishing and using threshold populations levels. In J. A. Veech & S. W. Dickson (Eds.), *Vistas on Nematology* (pp. 75–81). Maryland, USA: Society of Nematologists.

Barloy, D., Lemoine, J., Abelard, P., Tanguy, A.M., Rivoal, R., & Jahier, J. (2007). Marker-assisted pyramiding of two cereal cyst nematode resistance genes from *Aegilops variabilis* in wheat. *Molecular Breeding, 20*, 31–40.

Barloy, D., Martin, J., Rivoal, R., & Jahier, J. (1996, July 7–12). Genetic and molecular characterization of lines of wheat resistant to the cereal cyst nematode *Heterodera avenae*. In *Proceeding 3rd International Nematology Congress*, Gosier, Guadeloupe, 164.

Barr, A. R., Chalmers, K. J., Karakousis, A., Manning, S., Lance, R. C. M., & Lewis, J. (1998). RFLP mapping of a new cereal cyst nematode resistance locus in barley. *Plant Breeding, 117*, 185–187.

Behdad, E. (1982). Disease of field crops in Iran (424pp.). Isfahan, Iran: Neshat publishing Co. (in Farsi).

Bekal, S., Gauthier, J. P., & Rivoal, R. (1997). Genetic diversity among a complex of cereal cyst nematodes inferred from RFLP analysis of the ribosomal internal transcribed spacer region. *Genome, 40*, 479–486.

Bekal, S., Jahier, J., & Rivoal, R. (1998). Host response of different triticeae to species of the cereal cyst nematode complex in relation to breeding resistant durum wheat. *Fundamental and Applied Nematology, 21*, 359–370.

Belloni, V. (1954). Comparsa in Italia di una anguillulosi del frumento e prove de lotta. *Notiziario sulle Malattie delle Piante, 27*, 3–6.

Bhatti, D. S., Dahiya, R. S., Gupta, D. C., & Malhan, I. (1980). Plant parasitic nematodes associated with various crops in Haryana. *Haryana Agricultural University Journal of Research, 10*, 413–414.

Bishnoi, S. P., & Bajaj, H. K. (2004). On the species and pathotypes of *Heterodera avenae* complex of India. *Indian Journal of Nematology, 34*, 147–152.

Boer, R. F. de, Kollmorgen, J. F., Macauley, B. J., & Franz, P. R. (1991). Effects of cultivation on *Rhizoctonia* root rot, cereal cyst nematode, common root rot and yield of wheat in the Victorian Mallee. *Australian Journal of Experimental Agriculture, 31*, 367–372.

Bonfil, D. J., Dolgin, B., Mufradi, I., & Asido, S. (2004). Bioassay to forecast cereal cyst nematode damage to wheat in fields. *Precision Agriculture, 5*, 329–344.

Brig, B. & Kanwar, R. S. (2003). Effect of sowing time on multiplication of *Heterodera avenae* and performance of wheat crop. *Indian Journal of Nematology, 33*, 172–174.

Brown, R. H. (1981). Nematode diseases. In *Economic Importance and Biology of Cereal Root Diseases in Australia.* Australia: Report to Plant Pathology Subcommittee of Standing Committee on Agriculture.

Brown, R. H. (1987). Control strategies of low value crops. In Brown, R. H. and Kerry, B. R. (Eds.), *Principles and Practice of Nematode Control in Crops* (pp. 351–387). Sydney, Australia: Hartcourt Brace Jovanovic.

Byars, L. P. (1920). *The Nematode Disease of Wheat Caused by Tylenchus tritici*. United States Department of Agriculture Bulletin 842 Washington, D.C.

Caubel, G., Person, F., & Rivoal, R. (1980). Les nématodes dans les rotations céréalières. *Perspectives Agricoles, 36*, 34–48.

Caubel, G., Ritter, M., & Rivoal, R. (1972). Observations relatives à des attaques du nématode *Meloidogyne naasi* Franklin sur céréales et graminées fourragères dans l'Ouest de la France en 1970. *Comptes Rendus des Séances de l'Académie d'Agriculture de France, 58*, 351–356.

Chhabra, H. K. (1973). Distribution of *Heterodera avenae* Wollenweber, cereal cyst nematode in the Punjab. *Current Science, 42*, 441.

Chu, V. M. (1945). The prevalence of the wheat nematode in China and its control. *Phytopathology, 35*, 288–295.

Clewett, T. G., Thompson, J. P., & Fiske, M. L. (1993). Crop rotation to control *Pratylenchus thornei*. In V. A. Vanstone, S. P. Taylor, & J. M. Nicol (Eds.), In *Proceedings of the Pratylenchus Workshop*. Hobart, Tasmania, Australia: Ninth Biennial Australasian Plant Pathology Conference.

Cook, R., & Evans, K. (1987). Resistance and tolerance. In R. H. Brown & B. R. Kerry (Eds.), *Principles and Practice of Nematode Control in Crops* (pp. 179–231). Orlando, FL: Academic Press.

Cook, R., & Noel, G. R. (2002). Cyst nematodes: *Globodera* and species. In J. L. Starr, R. Cook, & J. Bridge (Eds.), *Plant Resistance to Parasitic Nematodes* (pp. 71–106). Wallingford, UK: CABI Publishing.

Cook, R., & Rivoal, R. (1998). Genetics of resistance and parasitism. In S. B. Sharma (Ed.), *The Cyst Nematodes* (pp. 322–352). London, UK: Chapman & Hall.

Cook, R., & York, P. A. (1982a). Resistance of cereals to *Heterodera avenae*: Methods of investigation, sources and inheritance of resistance. *EPPO Bulletin, 12*, 423–434.

Cook, R., & York, P. A. (1982b). Genetics of resistance to *Heterodera avenae* and *Meloidogyne naasi.* In *Proceedings of the 4th International Barley Genetics Symposium*, Edinburgh, Scotland.

Cook, R., York, P. A., & Guile, C.T. (1986). Effects and control of cereal root-knot nematode in barley/grass rotations. In *Proceedings of the 1986 British Crop Protection Conference – Pests and Diseases,* 433–440 Brighton, England.

Corbett, D. C. M. (1974). *Pratylenchus pinguicaudatus* n. sp. (Pratylenchidae: Nematoda) with a key to the genus *Pratylenchus*. *Nematologica, 15*, 550–556.

Cuevas, O. Y. J., & Sosa Moss, C. (1990). Host plants of *Meloidogyne chitwoodi* in the states of Tlaxcala and Puebla, Mexico. *Current Nematology, 1*, 69–70.

Davachi, A. (1949). Important pests of agricultural crops and their control methods. Bureau of Agric. Chem. Ministry of Agric. 205 pp. (in Farsi).

Delibes, A., Romero, D., Aguaded, S., Duce, A., Mena, M., Lopez-Brana, I., et al. (1993). Resistance to the cereal cyst nematode (*Heterodera avenae* Woll.) transferred from the wild grass *Aegilops ventricosa* to hexpaloid wheat by a stepping-stone procedure. *Theoretical and Applied Genetics, 87*, 402–408.

De Waele, D., & Elsen, A (2002). Migratory endoparasites: *Pratlylenchus* and *Radopholus* species. In J. L. Starr, R. Cook & J. Bridge (Eds.), *Plant Resistance to Parasitic Nematodes* (pp. 175–206). Wallingford, UK: CABI Publishing.

De Waele, D., & Mc Donald, A. H. (2000). Diseases caused by nematodes. In R. A. Frederiksen & G. N. Odvody (Eds.), *Compendium of Sorghum Diseases* (2nd ed., pp. 50–53). Minnesota, USA: American Phytopathological Society.

Dhaliwal, H. W., Singh, H., Gill, K. S., & Randhawa, H. S. (1993). Evaluation and cataloguing of wheat germplasm for disease resistance and quality. In A. B. Damania (Ed.), *Biodiversity and Wheat Improvement* (pp. 123–140). Chichester, UK: John Wiley and Sons.

Dhawan, S. C., & Nagesh, M. (1987). On the relationship between population densities of *Heterodera avenae*, growth of wheat and nematode multiplication. *Indian Journal of Nematology, 17*, 231–236.

Di Vito, M., & Greco, N. (1988). Investigation on the biology of *Meloidogyne artiella*. *Revue de Nématologie, 11*, 221–225.

Di Vito, M., Greco, N., & Saxena, M.C. (1991). Effectiveness of soil solarization for control of *Heterodera ciceri* and *Pratylenchus thornei* on chickpeas in Syria. *Nematologia Mediterranea, 19*, 109–111.

Di Vito, M., Greco, N., & Zaccheo, G. (1985). On the host range of *Meloidogyne artiellia*. *Nematologia Mediterranea, 13*, 207–212.

Di Vito, M., & Zaccheo, G. (1987). Responses of cultivars of wheat to *Meloidogyne artiellia*. *Nematologia Mediterranea, 15*, 405–408.

Dixon, G. M. (1969). The effect of cereal cyst eelworm on spring sown cereals. *Plant Pathology, 18*, 109–112.

Dosba, F., & Rivoal, R. (1982). Estimation des niveaux de resistance au development d'*Heterodera avenae* chez les triticinées. *EPPO Bulletin, 12*, 451–456.

Dowe, A., & Decker, H. (1977). Importance of plant parasitic nematodes in intensive cereal growing and ways of preventing losses due to nematodes. *Nachrichtenblatt fur den Pflanzenschutz in der DDR, 31*, 159–162.

Doyle, A. D., McLeod, R. W., Wong, P. T. W., Hetherington, S. E., & Southwell, R. J. (1987). Evidence for the involvement of the root lesion nematode *Pratylenchus thornei* in wheat yield decline in northern New South Wales. *Ausralian Journal Experimental Agriculture, 27*, 563–570.

Duggan, J. J. (1961). The effect of cereal root eelworm on its hosts. *Irish Journal of Agriculture Research, 1*, 7–16.

Dundas, I. S., Frappell, D. E., Crack, D. M., & Fisher, J. M. (2001). Deletion mapping of a nematode resistance gene on rye chromosome 6R in Wheat. *Crop Science, 41*, 1771–1778.

Eagles, H. A., Bariana, H. S., Ogbonnaya, F. C., Rebetzke, G. J., Hollamby, G. L., Henry, R. J. et al., (2001). Implementation of markers in Australian wheat breeding. *Australian Journal of Agricultural Research, 52*, 1349–1356.

Eastwood, R. F., Lagudah, E. S., Appels, R., Hannah, M., & Kollmorgen, J. F. (1991). *Triticum tauschii*: a novel source of resistance to cereal cyst nematode (*Heterodera avenae*). *Australian Journal of Agricultural Research, 42*, 69–77.

Eisenback, J. D., & Triantaphyllou, H. H. (1991). Root-knot nematode: *Meloidogyne* species and races. In W. R. Nickle (Ed.), *Manual of agricultural nematology* (pp. 191–274). New York, USA: Marcel Dekker Inc.

Elekcioglu, I. H, & Gozel, U. (1997). Effect of mixed population of *Paratrophurus acristylus*, *Pratylenchus thornei* and *Pratylenchus* sp. (Nematoda: Tylenchida) on yield parameters of wheat in Turkey. *Journal of Nematology, 7*, 217–220.

Elekçioğlu, İ. H., Avcı, M., Nicol, J., Meyveci, K., Bolat, N., Yorgancılar, A., et al. (2004, September 8–10). The use of crop rotation as a means to control the cyst and lesion nematode under rainfed wheat production systems. 1st National Pathology Congress, Samsun, Turkey.

Elmali, M. (2002). The distribution and damage of wheat gall nematode *Anguina tritici* (Steinbuch) (Tylenchida: Tylenchidae) in western part of Anatolia. *Turkyie Entomoloji Dergisi, 26*, 105–114.

Eriksson, K. B. (1972). Nematode diseases of pasture legumes and turf grasses. In J. M. Webster (Ed.), *Economic Nematology* (pp. 66–96). Academic Press, New York, USA,

Farsi, M, Vanstone, V. A., Fisher, J. M., & Rathjen, A. J. (1995). Genetic variation in resistance to *Pratylenchus neglectus* in wheat and triticales. *Australian Journal of Experimental Agriculture, 35*, 597–602.

Ferris, V. R., Subbotin, S. A., Ireholm, A., Spiegel, Y., Faghihi, J., & Ferris, J. M. (1999). Ribosomal DNA sequence analysis of *Heterodera filipjevi* and *H. latipons* isolates from Russia and comparisons with other nematode isolates. *Russian Journal of Nematology, 7*, 121–125.

Fisher, J. M., & Hancock, T. W. (1991). Population dynamics of *Heterodera avenae* Woll in South Australia. *Australian Journal of Agricultural Research, 42*, 53–68.

Germershauzen, K., Kastner, A., & Schmidt, W. (1976). Observations on the threshold of damage by *Heterodera avenae* on cereals under different rates of nitrogen fertilization. *Vortragstagung zu Aktuellen Problemen der Phytonematologie, 11*, 30.

Gill, J. S., & Swarup, G. (1971). On the host range of cereal cyst nematode, *Heterodera avenae*, the casual organism of ‘molya’ disease of wheat and barley in Rajasthan, India. *Indian Journal of Nematology, 1*, 63–67.

Gooris, J. (1968). Host plants and non-host plants of the Gramineae root-knot nematode *Meloidogyne naasi* Franklin. *Mededelingen van de Rijksfaculteit Landbouwwetenschappen te Gent, 33*, 85–100.

Gooris, J., & D’Herde, C. J. (1972). Mode d’hivernage de *Meloidogyne naasi* Franklin dans le sol et lutte par rotation culturale. *Revue de l’Agriculture* (Bruxelles), 25, 659–664.

Gooris, J., & D’Herde, C. J. (1977). Study on the biology of *Meloidogyne naasi* Franklin, 1965. Ministry of Agriculture, Agriculture Research Centre, Ghent, Belgium, 165p.

Gowen, S. R., & Pembroke, B. (2004). *Pasteuria penetrans* and the integrated control of root-knot nematodes. *Bulletin OILB/SROP, 27*, 75–77.

Griffin, G. D. (1984). Nematode parasites of alfalfa, cereals, and grasses. In W. E. Nickle (Ed.), *Plant and Insect Nematodes* (pp. 243–321). New York, USA: Marcel Dekker Inc.

Gupta, P., & Swarup, G. (1972). Ear-cockle and yellow rot disease of wheat. II. Nematode-bacterial association. *Nematologica, 18*, 320–324.

Handa, D. K., Mathur, R. L., & Mathur, B. N. (1975a, publ. 1976). The effect of crop rotation and nematicides on the cereal cyst nematode *Heterodera avenae* and yield of wheat and barley. *Indian Journal of Mycology and Plant Pathology, 5*, 20–21.

Handa, D. K., Mathur, R. L., & Mathur, B. N. (1975b, publ. 1976). Studies on the effect of deep summer ploughings on the cereal cyst nematode (*Heterodera avenae)* and yield of wheat and barley [Abstract]. *Indian Journal of Mycology and Plant Pathology, 5*, 18.

Handa, D. K., Mathur, R. L., Mathur, B. N., Sharma, G. L., & Yadav, B. D. (1985a). Host efficiency of tall and dwarf wheat and barley cops to cereal cyst nematode (*Heterodera avenae*). *Indian Journal of Nematology, 15*, 36–42.

Handa, D. K., Mathur, R. L., Mathur B. N., & Yadav, B. D. (1985b). Estimation of losses in barley due to cereal cyst nematode in sandy and sandy loamy soils. *Indian Journal of Nematology, 15*, 163–166.

Handoo, Z. A., & Golden, A. M. (1989). A key and diagnostic compendium to the species of the genus *Pratylenchus* Filpjev, 1936 (Lesion nematodes). *Journal of Nematology, 21*, 202–218.

Heide, A. (1975). Studies on the population dynamics of migratory root nematodes in cereal monocultures as well as in rotational cereal growing. *Archiv fur Phytopathologie und Pflanzenschutz, 11*, 225–232.

Hogger, C. H. (1990). Distribution of plant-parasitic nematodes on winter wheat in Switzerland. *Landwirtschaft Schweiz, 9*, 477–483.

Holgado, R., Rowe, J., Andersson, S., & Magnusson, C. (2004). Electrophoresis and biotest studies on some populations of cereal cyst nematode, *Heterodera* spp. (Tylenchida: Heteroderidae). *Nematology, 6*, 857–865.

Hollaway, C. J., Taylor, S. P., Eastwood, R. F., & Hunt, C. H. (2000). Effect of field crops on density of *Pratylenchus* in southeastern Australia, Part 2: *P. thornei*. *Journal of Nematology, 32*, 600–608.

Hutchinson, C. M. (1917). A bacterial disease of wheat in Punjab. Memoirs of Department of Agriculture, India, Bacteriological Series 1.

Ibrahim, A. A. M., Al-Hazmi, A. S., Al-Yahya, F. A., & Alderfasi, A. A. (1999). Damage potential and reproduction of *Heterodera avenae* on wheat and barley under Saudi field conditions. *Nematology, 1*, 625–630.

Indra-Rajvanshi (2003). Integrated management of cereal cyst nematode, *Heterodera avenae* in barley. *Current Nematology, 14*, 99–101.

Inserra, R. N., Lamberti, F., Volvas, N., & Dandria, D. (1975). *Meloidogyne naasi* nell'Italia meridionale e a Malta. *Nematologia Mediterranea, 3*, 163–166.

Inserra, R. N., Vovlas, N., O'Bannon, J. H., & Griffin, G. D. (1985). Development of *Meloidogyne chitwoodi* on wheat. *Journal of Nematology, 17*, 322–326.

Ismail, S., Sikora, R. A., & Schuster, R. P. (2001). Occurrence and biodiversity of egg pathogenic fungi of Mediterranean cereal cyst nematode *Heterodera latipons*. *Mededelingen-Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen, Universiteit Gent, 66*, 645–653.

Jahier, J., Abelard, P., Tanguy, A. M., Dedryver, F., Rivoal, R., Khatar, S., et al. (2001). The *Aegilops ventricosa* segment on chromsome 2AS of the wheat cultivar VPM1 carries the cereal cyst nematode resistance gene Cre5. *Plant Breeding, 120*, 125–128.

Jahier, J., Rivoal, R., Yu, M. Q., Abelard, P., Tanguy, A. M. & Barloy, D. (1998). Transfer of genes for resistance to cereal cyst nematode from *Aegilops variabilis* Eig to wheat. *Journal of Genetics and Breeding, 52*, 253–257.

Janssen, G. J. W. (1994). The relevance of races in *Ditylenchus dipsaci* (Kühn) Filipjev, the stem nematode. *Fundamental and Applied Nematology, 17*, 469–473.

Jepson, S. B. (1987). Identification of root-knot nematodes (*Meloidogyne* species). Wallingford, U.K.: C.A.B. International.

Johnson, A. W., & Motsinger, R. E. (1989). Suitability of small grains as hosts of *Meloidogyne* species. *Journal of Nematology, 21*(Suppl.), 650–653.

Kanwar, R. S., & Walia, R. K. (2004). Applied allelopathy techniques. In S. S. Narwal, R. Singh, & R. K. Walia (Eds.), *Research methods in plant sciences: allelopathy*. (Vol. 2, pp. 188–204). Plant Protection. Jodhpur, India: Scientific Publishers.

Kasimova, G. A, & Atakishieva, Y. Y. (1981). Nematode fauna and nematode dynamics on winter wheat in Apsheron. *Parazitologicheskie Issledovaniya v Azerbaidzhane*, 119–134.

Kausar, S., Khan, A. A., & Raghav, D. (2005). Interaction of sulphur and seed gall nematode, *Anguina tritici* on wheat. *Journal of Food, Agriculture and Environment, 3*, 130–132.

Kerry, B. R. (1981). Fungal parasites, a weapon against cyst nematodes. *Plant Disease, 65*, 390–393.

Khan, A., Williams, K. L., & Nevalainen, H. K. M. (2006). Control pf plant-parasitic nematodes by *Paecilomyces lilacinus* and *Monacrosporium lysipagum* in pot trials. *Biocontrol, 51*, 643–658.

Kilpatrick R. A., Gilchrist, L., & Golden A. M. (1976). Root knot on wheat in Chile. *Plant Disease Reporter, 60*, 135.

Kimpinski, J., Anderson, R. V., Johnston, H. W., & Martin, R. A. (1989). Nematodes and fungal diseases in barley and wheat on Prince Edward Island. *Crop Protection, 8*, 412–416.

Kok, C. J., & Papert, A. (2001). Microbial community of *Meloidogyne* egg masses. In R. J. Sikora (Ed.), *Proceedings of the IOBC/WPRS Study group "Integrated Control of Soil Pests". Tri-trophic interactions in the rhizosphere and root health nematode-fungal-bacterial interrelationships*, Bad Honnef, Germany, 3–5 November, (1999). *Bulletin OILB/SROP, 24*, 91–95.

Kollo, I. A. (2002). Plant-parasitic nematodes of sorghum and pearl millet: Emphasis on Africa. In J. F. Leslie (Ed.), *Sorghum and Millets Diseases* (pp. 259–266). Iowa, USA: Iowa State Press.

Kornobis, S., Wolny, S., & Wilski, A. (1980). The effect of *Heterodera avenae* population density in the soil on the yield and plant weight of oats. *Zeszyty Problemowe Postetow Nauk Rolniczych, 232*, 9–17.

Kort, J. (1972). Nematode diseases of cereals of temperate climates. In J. M. Webster (Ed.), *Economic Nematology* (pp. 97–126). London, UK: Academic Press.

Koshy, P. K., & Swarup, G. (1971). Distribution of *Heterodera avenae, H. zeae*, *H. cajani* and *Anguina tritici* in India. *Indian Journal of Nematology, 1*, 106–111.

Kretschemer, J. M., Chalmers, K. J., Manning, S., Karakousis, A., Barr, A. R., Islam, A. K. M. R., et al. (1997). RFLP mapping of the Ha2 cereal cyst nematode resistance gene in barley. *Theoretical and Applied Genetics, 94*, 1060–1064.

Kyrou, N. C. (1969). First record of occurrence of *Meloidogyne artiellia* on wheat in Greece. *Nematologica, 15*, 432–433.

Lagudah, E. S., Moullet, O., Ogbonnaya, F., Eastwood, R., Appels, R., Jahier, J., et al. (1998). Cyst nematode resistance genes in wheat. In *Proceedings from the 7th International Congress of Plant Pathology*, Edinburgh, Scotland.

Lasserre, F., Gigault, F., Gauthier, J. P., Henry, J. P. Sandmeier, M., & Rivoal, R. (1996). Genetic variation in natural populations of the cereal cyst nematode (*Heterodera avenae* Woll.) submitted to resistant and susceptible cultivars of cereals. *Theoretical and Applied Genetics, 93*, 1–8.

Lasserre, F., Rivoal, R., & Cook, R. (1994). Interactions between *Heterodera avenae* and *Pratylenchus neglectus* on wheat. *Journal of Nematology, 26*, 336–344.

Leukel, R.W. (1924). Investigations on the nematode disease of cereals caused by *Tylenchus tritici*. *Journal of Agricultural Research, 27*, 928–956.

Leukel, R. W. (1957). Nematode disease of wheat and rye. Farmers' Bulletin, USDA No. 1607.

Limber, D. (1976). Artificial infection of sweet corn seedlings with *Anguina tritici* Steinbuch (1799) Chitwood, 1935. *Proceedings of the Helminthological Society of Washington, 43*, 201–203.

Loof, P. A. A. (1978). The genus *Pratylenchus* Filipjev, 1936 (Nematoda: Pratylenchidae): a review of its anatomy, morphology, distribution, systematics and identification. Swedish University of Agricultural Sciences, Research Information Centre, Uppsala, Sweden, 50 pp.

Madzhidov, A. R. (1981). [*Bidera flipjevi* n.sp. (Heteroderina: Tylenchida) in Tadzhikistan]. *Izvestiya Akademii Nauk Tadzhikskoï SSR, Biologicheskie Nauki, 2*, 40–44.

Mamluk, O. F., Augustin, B., & Bellar, M. (1983). New record of cyst and root-knot nematodes on legume crops in the dry areas of Syria. *Phytopathologia Mediterranea, 22*, 80.

Mandani, M., Vovlas, N., Castillo, P., Subbotin, S. A., & Moens, M. (2004). Molecular characterization of cyst nematode species (*Heterodera* spp.) from the Mediterranean basin using RFLPs and sequences of ITS-rDNA. *Journal of Phytopathology, 152*, 229–234.

Mangat, B. P. S., Gupta, D. C., & Ram, K. (1988). Effect of deep summer ploughing and in combination with aldicarb and time of application of aldicarb on cyst population of *Heterodera avenae* and subsequent effect on wheat yield. *Indian Journal of Nematology, 18*, 345–346.

Maqbool, M. A. (1988). Present status of research on plant parasitic nematodes in cereals and food and forage legumes in Pakistan. In M. C. Saxena, R. A. Sikora, & J. P. Srivastava (Eds.), *Nematodes parasitic to cereals and legumes in temperate remi-arid regions* (pp. 173–180). Aleppo, Syria: ICARDA.

Marathee, J.-P., & Gomez-MacPherson, H. (2001). Future world supply and demand. In A. P. Bonjean & W. J. Angus (Eds.), *The world wheat book: A history of wheat breeding* (pp. 1107–1116). Paris: Lavoisier Publishing.

Mathur, B. N. (1969). Studies on cereal cyst nematode (*Heterodera avenae* Woll.) with special reference to 'molya' diseases of weath and barley in Rajesthan. Ph.D. thesis, University of Rajesthan, 233 pp.

Mathur, B. N., Arya, H. C., Handa, D. K., & Mathur, R. L. (1981). The biology of cereal-cyst nematode, *Heterodera avenae* in India. III. Factors affecting population level and damage to host crops. *Indian Journal of Mycology and Plant Pathology, 11*, 5–13.

Mathur, B. N., Handa, D. K., & Swarup, G. (1986). On the loss estimation and chemical control of 'Molya' disease of wheat caused by *Heterodera avenae* in India. *Indian Journal of Nematology, 16*, 152–159.

Mathur, B. N., Handa, D. K., & Swarup, G. (1987). Effect of deep summer ploughings on the cereal cyst nematode, *Heterodera avenae* and yield of wheat in Rajasthan, India. *Indian Journal of Nematology, 17*, 292–295.

McDonald, A., & Nicol, J. M. (2005). Nematode Parasites of Cereals. In J. Bridge, R. Sikora & M. Luc (Eds.), *Plant parasitic nematodes in tropical and subtropical agriculture* (pp. 131–191). CABI Publishing, Wallingford, Oxon, United Kingdom.

McIntosh, R. A., Devos, K. M., Dubcovsky, D., & Rogers, W. J. (2001). Catalogue of gene symbols for wheat. In A. E. Slinkard (Ed.), *Proceedings of the 9th Wheat Genetics Symposium.* Vol. 5, Saskatoon, Canada: University Extension Press, University of Saskatchewan.

McKenry, M. V., & Ferris, H. (1983). Nematodes. In: Challenging problems in plant health. T. Kommendahl (Ed.), (pp. 267–279). St Paul, USA: American Phytopathological Society Press.

Meagher, J. W. (1972). Cereal cyst nematode (*Heterodera avenae* Woll). Studies on ecology and content in Victoria. Technical Bulletin 24, Department of Agriculture, Victoria, Australia, 50p.

Meagher, J. W., & Brown, R. H. (1974). Microplot experiments on the effect of plant hosts on populations of cereal cyst nematode (*Heterodera aveane*) and its potential as a pathogen of wheat. *Nematologica, 20*, 337–346.

Michel, R. E., Malek, R. B., Taylor, D. P., & Edwards, D. I. (1973). Races of the barley root-knot nematode, *Meloidogyne naasi* I. Characterisation by host preference. *Journal of Nematology, 5*, 41–44.

MingZhu, W., Zhi Feng, L., & YanNong, X. (1996). Host range of wheat cereal cyst nematode in some plants. *Plant Protection, 22*, 3–5.

Mojtahedi, H., & Santo, G. S. (1992). *Pratylenchus neglectus* on dryland wheat in Washington. *Plant Disease, 76*, 323.

Mokabli, A., Valette, S., & Rivoal, R. (2001). Différenciation de quelques espèces de nématodes à kystes des céréales et des graminées par électrophorèse sur gel d'acétate de cellulose. *Nematologia Mediterranea, 29*, 103–108.

Mokabli, A., Valette, S., Gauthier, J. P., & Rivoal, R. (2002). Variation in virulence of cereal cyst nematode populations from North Africa and Asia. *Nematology, 4*, 521–525.

Mor, M., & Cohn, E. (1989). New nematode pathogens in Israel: *Meloidogyne* on wheat and *Hoplolaimus* on cotton. *Phytoparasitica, 17*, 221.

Mor, M., Cohn, E., & Spiegel, Y. (1992). Phenology, pathogenicity and pathotypes of cereal cyst nematodes, *Heterodera avenae* Woll. and *H. latipons* (Nematoda: Heteroderidae) in Israel. *Nematologica, 38*, 444–501.

Mulvey, R. H. (1972). Identification of *Heterodera* cysts by terminal and cone structures. *Canadian Journal of Zoology, 50*, 1277–1292.

Namouchi-Kachouri, N., B'Chir, M. M., & Hajji, A. (2006, 19–23 November). Damage potential and reproduction of *Heterodera avenae* on wheat and barley under Tunisian field conditions. 9th Arab Congress of Plant Protection Damascus- Syria, Abstract E, 114.

Nicol, J. M. (1996). The distribution, pathogenicity and population dynamics of *Pratylencus thornei* (Sher and Allen, 1954) on wheat in South Australia. Ph.D Thesis, The University of Adelaide, Adelaide, Australia, 236 pp.

Nicol, J. M. (2002). Important Nematode Pests of Cereals. In: B. C. Curtis (Ed.), *Wheat Production and Improvement* (pp. 345–366). Rome, Italy: FAO Plant Production and Protection Series, FAO.

Nicol, J. M., Bolat, N., Sahin, E., Tulek, A., Yildirim, A. F., Yorgancilar, A., et al. (2005). The Cereal Cyst Nematode is causing economic damage on rainfed wheat production systems of Turkey. Joint Meeting of the Annual Western Soil Fungus Conference and the American Phytopathology Society Pacific Division, Portland, United States of America, 28 June – 1st July. [Abstract].

Nicol, J. M., Davies, K. A., & Eastwood, R. (1998). AUS4930: A new source of resistance to *Pratylenchus thornei* in wheat. 24th International Symposium of the European Society of Nematologists, St. Andrews, Scotland, UK [Abstract].

Nicol, J. M., Davies, K. A., Hancock, T. W., & Fisher, J. M. (1999). Yield loss caused by *Pratylenchus thornei* on wheat in South Australia. *Journal of Nematology, 31*, 367–376.

Nicol, J. M., Rivoal, R., Trethowan, R. M., Van Ginkel, M., Mergoum, M., & Singh, R. P. (2001). CIMMYT's Approach to identity and use resistance to nematodes and soil-borne fungi, in developing superior wheat germplasm. In Z. Bedö & L. Langö (Eds.), *Wheat in a global environment* (pp. 381–389). The Netherlands: Kluwer Academic Publishers.

Nicol, J., & Ortiz-Monasterio, I. (2004). Effects of the root lesion nematode, *Pratylenchus thornei,* on wheat yields in Mexico. *Journal of Nematology, 6*, 485–493.

Nicol, J., Rivoal, R., Valette, S., Bolat, N., Aktas, H., Braun, H. J., et al. (2002). The frequency and diversity of the cyst and lesion nematode on wheat in the Turkish Central Anatolian Plateau. *Journal of Nematology, 4*, 272. [Abstract].

Nicolas, H., Rivoal, R., Duchesne, J., & Lili, Z. (1991). Detection of *Heterodera avenae* infestations on winter wheat by radiothermometry. *Revue de Nématologie, 14*, 285–290.

Nombela, G., Navas, A., & Bello, A. (1998). Effects of crop rotations of cereal with vetch and fallow on soil nematofauna in Central Spain. *Nematologica, 44*, 63–80.

Noori, P., Talatchian, P., & Teimoori, F. (1980). Survey on sugar beet fields' harmful nematodes in the west of Iran from 1975 to 1978. *Iranian Journal d'Entomologie et Phytopathologie Appliquées, 48*, 39–41.

Nyczepir, A. P., Inserra, R. N., O'Bannon, J. H., & Santo, G. S. (1984). Influence of *Meloidogyne chitwoodi* and *M. hapla* on wheat growth. *Journal of Nematology, 16*, 162–165.

O'Brien, P. C. (1983). A further study on host range of *Pratylenchus thornei*. *Australian Plant Pathology, 12*, 1–3.

Ogbonnaya, F. C., Seah, S., Delibes, A., Jahier, J., Lopez-Brana, I., Eastwood, R. F, et al. (2001a). Molecular-genetic characterisation of a new nematode resistance gene in wheat. *Theoretical and Applied Genetics, 102*, 623–629.

Ogbonnaya, F. C., Subrahmanyam, N. C., Moullet, O., de Majnik, J., Eagles, H. A., Brown, J. S., et al. (2001b). Diagnostic DNA markers for cereal cyst nematode resistance in bread wheat. *Australian Journal of Agricultural Research, 52*, 1367–1374.

Orion, D., Amir, J., & Krikun, J. (1984). Field observations on *Pratylenchus thornei* and its effects on wheat under arid conditions. *Revue de Nématologie, 7*, 341–345.

Orui, Y., & Mizukubo, T. (1999). Discrimination of seven *Pratylenchus* species (Nematoda: Pratylenchidae) in Japan by PCR-RFLP analysis. *Applied Entomology and Zoology, 34*, 205–211.

Oztürk, G., Yildirim, A. F., & Kepenekci, I. (2000). [Investigation on the effect of *Heterodera filipjevi* Madzhidov on cereal yields which is one of the important cyst nematodes in cereal planted areas in Konya province]. In H. Ekiz (Ed.), Orta Anadolu'da hububat tardotless imdotless indotless in sorunlardotless i ve cözüm yollardotless i Sempozyumu, Konya, Turkey, 8–11 Haziran, 477–482.

Pakniat, M., & Sahandpour, A. (2004). Occurrence of *Anguina agrostis* (Steinbuch, 1799) Filipjev, 1936 on Barley in Fars province. 16th Iranian Plant Protection Congress, Karaj, 77 [Abstract].

Pankaj Mishra, S. D., & Sharma, G. L. (2002, 11–13 November). Integrated management of *Heterodera avenae* infecting wheat. In R. V. Singh, S. C. Pankaj Dhawan, & H. S. Gaur (Eds.), *Proceedings of National Symposium on Biodiversity and Management of Nematodes in Cropping Systems for Sustainable Agriculture* (pp. 265–266). Jaipur, India.

Paruthi, I. J., & Gupta, D. C. (1987). Incidence of tundu in barley and kanki in wheat field infested with *Anguina tritici*. *Harayana Agricultural University Journal of Research, 17*, 78–79.

Paull, J. G., Chalmers, K. J., & Karakousis, A. (1998). Genetic diversity in Australian wheat varieties and breeding material based on RFLP data. *Theoretical and Applied Genetics, 96*, 435–446.

Peng, D., Nicol, J. M., Zhang, D., Chen, S., Waeyenberge, L., Moens, M., et al. (2007). Occurrence, distribution and research situation of cereal cyst nematode in China. International Plant Protection Conference, Scotland, Glasgow, Sept. 07 [Abstract].

Person-Dedryver, F. (1986). Incidence du nématode à galle *Meloidogyne naasi* en cultures céréalières intensives. Dix années d'études concertées INRA-ONIC-ITCF, 1973-1983. INRA, Paris, 175–187.

Person-Dedryver, F., & Jahier, J. (1985). Les céréales à paille hôtes de *Meloidogyne naasi* Franklin II. Variabilité du comportement multiplicateur ou résistant de variétés cultivées en France. *Agronomie, 5*, 573–578.

Person-Dedryver, F., Jahier, J., & Miller, T. E. (1990). Assessing the resistance to cereal root-knot nematode, *Meloidogyne naasi*, in a wheat line with the added chromosome arm 1HchS of *Hordeum chilense*. *Journal of Genetics and Breeding, 44*, 291–295.

Philis, I. (1988). Occurrence of *Heterodera latipons* on barley in Cyprus. *Nematologia Mediterranea, 16*, 223.

Plowright, R. A., Caubel, G., & Mizen, K. A. (2002). *Ditylenchus* Species. In J. L. Starr, R. Cook & J. Bridge (Eds.), *Plant Resistance to Parasitic Nematodes* (pp. 107–139). Wallingford, UK: CAB International.

Rajvanshi, I., Mathur, B. N., & Sharma, G. L. (2002). Effect of inter-cropping on indicidence of *Heterodera avenae* in wheat and barley crops. *Annals of Plant Protection Sciences, 10*, 406–407.

Ritter, M. (1972). Rôle économique et importance des *Meloidogyne* en Europe et dans le bassin Méditerranéen. *OEPP/EPPO Bulletin, 2*, 17–22.

Rivoal, R. (1982). Caractérisation de deux écotypes d'*Heterodera avenae* en France par leurs cycles et conditions thermiques d'éclosion. *Bulletin EPPO/OEPP, 12*, 353–359.

Rivoal, R. (1986). Biology of *Heterodera avenae* Wollenweber in France. IV. Comparative study of the hatching cycles of two ecotypes after their transfer to different climatic conditions. *Revue de Nématologie, 9*, 405–410.

Rivoal, R., Bekal, S., Valette, S., Gauthier, J. P., Bel Hadj Fradj, M., Mokabli, A., et al. (2001). Variation in reproductive capacity and virulence on different genotypes and resistance genes of Triticeae, in the cereal cyst nematode species complex. *Nematology, 3*, 581–592.

Rivoal, R., & Besse, T. (1982). Le nématode à kyste des céréales. *Perspectives Agricoles, 63*, 38–43.

Rivoal, R., & Bourdon P. (2005). Sélection du ray-grass d'Italie pour la résistance au nématode à kyste des céréales (*Heterodera avenae*). *Fourrages, 184*, 557–566.

Rivoal, R., & Cook, R. (1993). Nematode pests of cereals. In K. Evans, D. L. Trudgill & J. M. Webster (Eds.), *Plant parasitic nematodes in temperate agriculture* (pp. 259–303). U.K.: CAB International.

Rivoal, R., Lasserre, F., & Cook, R. (1995). Consequences of long-term cropping with resistant cultivars on the population dynamics of the endoparasitic nematodes *Heterodera aveanae* and *Pratylenchus neglectus* in a cereal production ecosystem. *Nematologica, 4*, 516–529**.**

Rivoal, R., Person-Dedryver, F., Doussinault, G., & Morlet, G. (1986). Significance and application of cereal resistance to nematodes. In F. Rapilly & G. Doussinault (Eds.), Les résistances génétiques dans le systèmes de protection des cultures céréalières contre les champignons, virus et nématodes. *Les Colloques de l'INRA*, 35, Paris, France, 57–64.

Rivoal, R., & Sarr, E. (1987). Field experiments on *Heterodera avenae* in France and implications for winter wheat performance. *Nematologica, 33*, 460–479.

Roberts, P. A., Van Gundy, S. D., & McKinney, H. E. (1981). Effects of soil temperature and planting date of wheat on *Meloidogyne incognita*, reproduction, soil populations and grain yield*. Journal of Nematology, 13*, 338–345.

Roberts, P. A., Van Gundy, S. D. & Waines, J. G. (1982). Reaction of wild and domesticated *Triticum* and *Aegilops* species to root-knot nematodes (*Meloidogyne*). *Nematologica*, 28, 182–191.

Roget, D. K, & Rovira, A. D. (1985). Effect of tillage on *Heterodera avenae* in wheat. In C. A. Parker, A. D. Rovira, K. L. Moore & P. T. W. Wong (Eds.), *Ecology and management of soilborne plant pathogens* (pp. 252–254). The American Phytopathological Society, St. Paul, MN.

Romero, M. D., Montes, M. J., Sin, E., Lopez-Braña, I., Duce, A., Martín-Sanchez, J. A. et al. (1998). A cereal cyst nematode (*Heterodera avenae* Woll.) resistance gene transferred from *Aegilops triuncalis* to hexaploid wheat. *Theoretical and Applied Genetics, 96*, 1135–1140.

Rumpenhorst, H. J., Elekçioglu, I. H., Sturhan, D., Öztürk, G., & Enneli, S. (1996). The cereal cyst nematode *Heterodera filipjevi* (Madzhidov) in Turkey. *Nematologia Mediterranea, 24*, 135–138.

Rumpenhorst, H. J., & Sturhan, D. (1996). Morphological and electrophoretic studies on populations of the *Heterodera avenae* complex from the former USSR. *Russian Journal of Nematology, 49*, 29–38.

Sabova, M., Valocka, B., Liskova, M., & Vargova, V. (1988). The first finding of *Heterodera latipons* Franklin, 1969 on grass stands in Czecholovakia. *Helminthologia, 25*, 201–206.

Safari, E., Gororo, N. N., Eastwood, R. F., Lewis, J., Eagles, H. A., & Ogbonnaya, F. C. (2005). Impact of *Cre1*, *Cre8* and *Cre3* genes on cereal cyst nematode resistance in wheat. *Theoretical and Applied Genetics, 110*, 567–572.

Saleh, H. M., & Fattah, F. A. (1990). Studies on the wheat seed gall nematode. *Nematologia Mediterranea, 18*, 59–62.

Santo, G. S., & O'Bannon, J. H. (1981). Pathogenicity of the Columbia root-knot nematode (*Meloidogyne chitwoodi*) on wheat, corn, oat and barley in the Pacific North West. *Journal of Nematology, 13*, 548–550.

Sasser, J. N., & Freckman, D. W. (1987). A world perspective on nematology: the role of the society. In J. A. Veech & D. W. Dickson (Eds.), *Vistas on Nematology* (pp. 7–14). Maryland: Society of Nematologists, Hyattsville.

Schneider, J. (1967). Un nouveau nématode du genre *Meloidogyne* parasite des céréales en France. *Phytoma, 185*, 21–25.

Scholz, U. (2001). Biology, pathogenicity and control of the cereal cyst nematode *Heterodera latipons* Franklin on wheat and barley under semiarid conditions, and interactions with common root rot *Bipolaris sorokinana* (Sacc.) Shoemaker [teleomorph: *Cochliobolus sativus* (Ito et Kurib.) Drechs. ex Dastur.]. Ph.D Thesis. University of Bonn, Germany, 159 pp.

Scholz, U., & Sikora, R. A. (2004). Hatching behavior of *Heterodera latipons* Franklin under Syrian agro-ecological conditions. *Nematology, 6*, 245–256.

Shahina, F., Abid, M., & Maqbool, M. A. (1989). Screening for resistance in corn cultivars against *Heterodera zeae*. *Pakistan Journal of Nematology, 7*, 75–79.

Sharma, R. D. (1981). Pathogenicity of *Meloidogyne javanica* to wheat. In Trabalhes Apresentados V Reunas Brasileira de Nematologia, 9 B. Publicao No. 5.

Sharma, S. B., & Swarup, G. (1984). Cyst forming nematodes of India. Cosmo Publication 1, New Delhi, India, 150 pp.

Shen, T. H., Tai, S. E., & Chia, W. L. (1934). A preliminary report on the inheritance of nematode resistance and length of beak in a certain wheat cross. *Bulletin College of Agriculture and Forestry*, No. 19, University of Nanking, China.

Sikora, R. A. (1988). Plant parasitic nematodes of wheat and barley in temperate and temperate semi-arid regions – a comparative analysis. In M. C. Saxena, R. A. Sikora & J. P. Srivastava (Eds.), *Nematodes Parasitic to Cereals and Legumes in Temperate Semi-arid Regions* (pp. 46–48). International Centre for Agricultural Research in the Dry Areas (ICARDA), Syria.

Sikora, R. A., & Oostendorp, M. (1986). Report: Occurrence of plant parasitic nematodes in ICARDA experimental fields. ICARDA, Aleppo, Syria, 4 pp.

Simon, A., & Rovira, A.D. (1982). The relation between wheat yield and early damage of root by cereal cyst nematode. *Australian Journal Agriculture and Animal Husbandry, 22*, 201–208.

Sinclair, T. R., & Amir, J. (1996). Model analysis of a mulch system for continuous wheat in an arid climate. *Field Crops Research, 47*, 33–41.

Singh, D., & Agrawal, K. (1987). Ear cockle disease (*Anguina tritici* (Steinbuch) Filipjev) of wheat in Rajasthan, India. *Seed Science and Technology, 15*, 777–784.

Singh, I., Sharma, N. K. & Sakhuja, P. K. (1977). Distribution of the cereal cyst nematode, *Heterodera avenae* Woll., on wheat in Ludhiana (Punjab). *Journal of Research, Punjab Agricultural University, 14*, 314–317.

Singh, D., & Singh, S. (2005). Effect of date of sowing on the pathogenicity of different populations of cereal cyst nematode (*Heterodera avenae*) on dry shoot weight, number of grains/earhead and on the yield of wheat. *Environment and Ecology, 23*, 180–183.

S'Jacob, J. J. (1962). Beobachtungen an *Ditylenchus radicicola* (Greeff). *Nematologica, 7*, 231–234.

Slootmaker, L. A. J., Lange, R., Jochemsen, G., & Schepers, J. (1974). Monosomic analysis in breadwheat of resistance to cereal root eelworm. *Euphytica, 23*, 497–503.

Smiley, R. W., Whittaker, R. G., Gourlie, J. A., Easley, S. A., & Ingham, R. E. (2005). Plant-parasitic nematodes associated with reduced wheat yield in Oregon: *Heterodera avenae*. *Journal of Nematology, 37*, 297–307.

Smolik, J. D. (1972). Reproduction of *Tylenchorhynchus nudus* and *Helicotylenchus leiocephalus* on spring wheat and effect of *T. nudus* on growth of spring wheat. *Proceedings South Dakota Academy of Science, 51*, 153–159.

Stephan, Z. A. (1988). Plant parasitic nematodes on cereals and legumes in Iraq. In M. C. Saxena, R. A. Sikora & J. P. Srivastava (Eds.), *Nematodes parasitic to cereals and legumes in temperate semi-arid regions* (pp. 155–159). ICARDA, Aleppo, Syria.

Stirling, G. R. (1991). Biological control of plant parasitic nematodes. Progress, problems and prospects. Wallingford, Oxon, UK: CAB International. 275 pp.

Stone, L. E. W. (1968). Cereal cyst nematode in spring barley damage assessments 1963–64. *Plant Pathology, 17*, 145–150.

Stoyanov, D. (1982). Cyst-forming nematodes on cereals in Bulgaria. *EPPO/OEPP Bulletin, 12*, 341–344.

Sturhan, D. (1982). Distribution of cereal and grass cyst nematodes in the Federal Republic of Germany. *EPPO/OEPP Bulletin, 12*, 321–324.

Subbotin, S. A., Rumpenhorst, H. J., & Sturhan, D. (1996). Morphological and electrophoretic studies on populations of the *Heterodera avenae* complex from the former USSR. *Russian Journal of Nematology, 49*, 29–38.

Subbotin, S. A., Waeyenberge, L., & Moens, M. (2000). Identification of cyst forming nematodes of the genus *Heterodera* (Nematoda: Heteroderidae) based on the ribosomal DNA-RFLP. *Nematology, 2*, 153–164.

Subbotin, S. A., Waeyenberge, L., Molokanova, I. A., & Moens, M. (1999). Identification of *Heterodera avenae* group species by morphometrics and rDNA-RFLPs. *Nematology, 1*, 195–207.

Swarup, G. (1986). Investigations on wheat nematodes. In J. P. Tandon & A. P. Sethi (Eds.), *Twenty-five years of coordinated wheat research 1961–86* (pp. 189–206). New Delhi: Wheat Project Directorate, Indian Council of Agricultural Research.

Swarup, G., & Sosa Moss, C. (1990). Nematode parasites of cereals. In M. Luc, R. A. Sikora & J. Bridge (Eds.), *Plant parasitic nematodes in subtropical and tropical agriculture* (pp. 109–136). Wallingford, UK: CAB International.

Tanha Maafi, Z. (1998). *Pratylenchus neglectus* and *P. thornei* endoparasitc nematodes associated with wheat in Gilan province. 13th Iranian Plant Protection Congress. p 66. [Abstract].

Tanha Maafi, Z., Sturhan, D., Kheiri, A., & Geraert, E. (2007). Species of the *Heterodera avenae* group (Nematoda: Heteroderidae) from Iran. *Russian Journal of Nematology*, 15, in press.

Tanha Maafi, Z., Subbotin, S. A., & Moens, M. (2003). Molecular identification of cyst-forming nematodes (Heteroderidae) from Iran and a phylogeny based on ITS-rDNA sequences. *Nematology, 5*, 99–111.

Taheri, A., Hollamby, G. J., & Vanstone, V. A. (1994). Interaction between root lesion nematode, *Pratylenchus neglectus* (Rensch 1924) Chitwood and Oteifa 1952, and root rotting fungi of wheat. *New Zealand Journal of Crop and Horticultural Science, 22*, 181–185.

Talatchian, P., Akhiani, A., Grayeli, Z., Shah-Mohammadi, M., & Teimouri, F. (1976). Survey on cyst forming nematodes in Iran in 1975 and their importance. *Iranian Journal of Plant Pathology, 12*, 42–43.

Taylor, S. P., Hollaway, G. J., & Hunt, C. H., (2000). Effect of field crops on population densities of *Pratylenchus neglectus* and *P. thornei* in southeastern Australia; Part 1: *P. neglectus*. *Journal of Nematology, 32*, 591–599.

Taylor, A. L., & Sasser, J. N. (1978). Biology, identification and control of root-knot nematodes (*Meloidogyne* species). North Carolina State University Department of Plant Pathology and USAID, Raleigh, U.S.A.

Taylor, C., Shepherd, K. W., & Langridge, P. (1998). A molecular genetic map on the long arm of chromosome 6R of rye incorporating the cereal cyst nematode resistance gene, *CreR. Theoretical and Applied Genetics, 97*, 1000–1012.

Taylor, S. P., Vanstone, V. A., Ware, A. H., McKay, A. C., Szot, D., & Russ, M. H. (1999). Measuring yield loss in cereals caused by root lesion nematodes (*Pratylenchus neglectus* and *P. thornei*) with and without nematicide. *Australian Journal of Agricultural Research, 50*, 617–622.

Tesic, T. (1969). [A study on the resistance of wheat varieties to wheat eelworm (*Anguina tritici* Stein.)]. *Savrenema Poljoprivreda, 17*, 541–543.

Thompson, J. P., Brennan, P. S., Clewett, T. G., & Sheedy, J. G. (1997). *Disease reactions. Root-lesion nematode*. Northern Region Wheat Variety Trials 1996. Brisbane, Queensland, Australia: Department of Primary Industries Publication.

Thompson, J. P., & Clewett, T. G. (1986). Research on root-lesion nematode. In Queensland Wheat Research Institute Biennial Report 1982–1984. (pp. 32–35). Queensland Dept. Primary Industries, Queensland. Government, Wheat Research Institute, Toowoomba, Queensland.

Thompson, J. P., & Haak, M. I. (1997). Resistance to root-lesion nematode (*Pratylenchus thornei*) in *Aegilops tauschii* Coss., the D-genome donor to wheat. *Australian Journal of Agricultural Research, 48*, 553–559.

Thompson, J. P., Mackenzie, J., & McCulloch, J. (1983). Root lesion nematode (*Pratylenchus thornei*) on Queensland wheat farms. Proceedings of the 46th International Congress of Plant Pathology, Melbourne, Australia, [Abstract].

Timper, P., & Brodie, B. B. (1997). First report of *Pratylenchus neglectus* in New York. *Plant Disease, 81*, 228.

Townshend, J. L., Potter, J. W., & Willis, C. B. (1978). Ranges in distribution of species of *Pratylenchus* in Northeastern North America. *Canadian Plant Disease Survey, 58*, 80–82.

Trudgill, D. L., Kerry, B. R., & Phillips, M. S. (1992). Seminar: Integrated control of nematodes (with particular reference to cyst and root knot nematodes). *Nematologica, 38*, 482–487.

Upadhyaya, K. D., & Swarup, G. (1981). Growth of wheat in the presence of *Merlinius brevidens* singly and in combination with *Tylenchorhynchus vulgaris*. *Indian Journal of Nematology, 11*, 42–46.

Urek, G., & Sirca, S. (2003). Plant parasitic nematode affecting the aboveground plant parts in Slovenia. Zbornik predavanj in referatov 6. Slovenskega Posvetovanje o Varstva Rastlin, Zrece, Slovenije, 4–6 marec, 486–488.

Van Gundy, S. D., Perez, B. J. G., Stolzy, L. H. A., & Thomason, I. J. (1974). A pest management approach to the control of *Pratylenchus thornei* on wheat in Mexico. *Journal of Nematology, 6*, 107–116.

Vanstone, V. A., Nicol, J. M., & Taylor, S. P. (1993). Multiplication of *Pratylenchus neglectus* and *P. thornei* on cereals and rotational crops. In V. A. Vanstone, S. P. Taylor & J. M. Nicol (Eds.), *Proceedings of the Pratylenchus Workshop, 9th Biennial Australasian Plant Pathology Conference*, Hobart, Tasmania, Australia.

Vanstone, V. A., Rathjen, A. J., Ware, A.H., & Wheeler, R. D. (1998). Relationship between root lesion nematodes (*Pratylenchus neglectus* and *P. thornei*) and performance of wheat varieties. *Australian Journal of Experimental Agriculture, 38*, 181–188.

Vats, R., Kanwar, R. S., & Bajaj, H. K. (2004). Biology of *Seinura paratenuicaudata* Geraert. *Nematologia Mediterranea, 32*, 117–121.

Wallace, H. R. (1965). The ecology and control of the cereal root nematode. *Journal of Australian Institute of Agricultural Science, 31*, 178–186.

Whitehead, A. G. (1998). Plant nematode control (384 pp.). Wallingford, U.K.: CAB International.

Whitehead, A. G., Tite, D. J., & Fraser, J. E. (1983). Control of stem nematode *Ditylenchus dipsaci* (oat race) by aldicarb and resistant crop plants. *Annals of Applied Biology, 103*, 291–299.

Williams, K. J., Taylor, S. P., Bogacki, P., Pallotta, M., Bariana, H. S., & Wallwork, H. (2002). Mapping of the root lesion nematode (*Pratylenchus neglectus*) resistance gene *Rlnn1* in wheat. *Theoretical and Applied Genetics, 104*, 874–879.

Wishart, J., Blok, V. C., Phillips, M. S., & Davies, K. G . (2004). *Pasteuria penetrans* and *P. nishizawae* attachment to *Meloidogyne chitwoodi*, *M. fallax* and *M. hapla*. *Nematology, 6*, 507–510.

Wouts, W. W., Schoemaker, A., Sturhan, D., & Burrows, P. R. (1995). *Heterodera spinicauda* sp. n. (Nematoda: Heteroderidae) from mud flats in the Netherlands, with a key to the species of the *H. avenae* group. *Journal of Nematology, 41*, 575–58.

Yadav B. D., Bishnoi, S. P., & Chand, R. (2002). Proceedings of the National Symposium on 'Biodiversity and Management of nematodes in Cropping Systems for Sustainable Agriculture – Nematology in Rajasthan at a glance'. Department of Nematology, Rajasthan Agricultural University, Agricultural Research Station, Durgapura, Jaipur, 51pp.

York, P. A. (1980). Relationship between cereal root-knot nematode *Meloidogyne naasi* and growth and yield of spring barley. *Nematologica, 26*, 220–229.

Yu, M. Q., Person-Dedryver, F., & Jahier, J. (1990). Resistance to root knot nematode, *Meloidogyne naasi* (Franklin) transferred from *Aegilops variabilis* Eig to bread wheat. *Agronomie, 6*, 451–456.

Yüksel, H., Güncan, A., & Döken, M. T. (1980). The distribution and damage of bunts (*Tilletia* spp.) and wheat gall nematode [*Anguina tritici* (Steinbuch) Chitwood] on wheat in the eastern part of Anatolia. *Journal of Turkish Phytopathology, 9*, 77–88.

Zancada, M. C., & Althöfer, M. V. (1994). Effect of *Heterodera avenae* on the yield of winter wheat. *Nematologica, 40*, 244–248.

Zaharieva, M., Monneveux, P., Henry, M., Rivoal, R., Valkoun, J. & Nachit, M. M. (2001). Evaluation of a collection of wild wheat relative *Aegilops geniculata* Roth. and identification of potential sources for useful traits. *Euphytica, 119*, 33–38.