Chapter 8
Nematode Pests of Maize and Other Cereal Crops

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8.1 Introduction

The three major cereals in South Africa (SA), in terms of production volume or area planted, are maize (*Zea mays*), wheat (*Triticum aestivum*) and grain sorghum (*Sorghum bicolor*). Of these crops, maize dominates with approximately 9.95 million metric tonnes (MT) being produced from 2.6 million hectares (ha) planted during 2015 (Grain 2016). Half of the produce is used as a primary food source and the remainder as animal feed. Maize production in terms of area harvested shows a steady decline from 1980 (4.6 million ha) to 2015 (2.6 million ha) and fluctuated between 2.0 and 3.6 million ha during this period (FAO 2016; Grain 2016). Despite such fluctuations, mainly due to the periodic droughts, the gross production of maize increased from the 1980s since the productivity of the crop per ha increased markedly. A similar scenario is true for wheat production since the gap between the area under cultivation and total yield also widened substantially since the 1980s (FAO 2016; Grain 2016).

The upward trends in maize and wheat production could most probably be attributed to continuous and significant improvements in crop production

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technology, including the adoption of superior cultivars (cvs). By contrast, the overall trend for grain sorghum production was downwards. In real terms sorghum production was 15 % of the gross annual production of wheat and only 3–4 % of annual maize production at the end of the first decade of the 21st century. Two factors can explain this phenomenon: (i) a decrease in demand for grain sorghum and (ii) reduced research inputs that sorghum received relative to those for the other two crops. Production of other cereals, e.g. oat (*Avena sativa*), barley (*Hordeum vulgare*), pearl millet (*Pennisetum glaucum*), rice (*Oryza sativa*) and rye (*Secale cereale*), is also low in SA. These crops largely serve niche markets, such as bird feed, brewing and traditional foods. Due to limited funding resources and only small and diverse industries to support these commodities, almost all technology and genetic sources for these crops are acquired from abroad.

Since most nematology research related to cereal crops in SA has focused on maize, the major part of this chapter is devoted to this crop. The limited information on nematode research available for barley, grain sorghum, millet, wheat and rice is briefly summarised.

8.2 Maize

8.2.1 Plant-Parasitic Nematodes Associated with Maize

In the 1970s, Walters (1979a, b) reported Hoplolaimidae; *Pratylenchus zeae* Graham, 1951; *Paratrichodorus*; and *Trichodorus* spp. as the most commonly occurring and abundant plant-parasitic nematodes in local maize fields. Before 1995, *Pratylenchus* was generally perceived as the economically most important nematode pest genus that infected maize (Walters 1979a, b; Louw 1982; Zondagh and Van Rensburg 1983; De Waele and Jordaan 1988a; Jordaan et al. 1989). Other plant-parasitic nematodes identified in association with maize crops included Criconematidae; *Ditylenchus*; *Helicotylenchus*; *Hemicycliophora*; *Longidorus*; *Meloidogyne*; *Rotylenchus*; *Scutellonema*; *Telotylenchus*; *Tylenchorhynchus; Quinisulcius; Xiphinema* spp.; *Hoplolaimus pararobustus* (Schuurmans Stekhoven and Teunissen, 1938) Sher, 1963; *Paratrichodorus lobatus* Colbran, 1965; and *Rotylenchulus parvus* (Williams, 1960) Sher, 1961 (Keetch and Buckley 1984; Kleynhans et al. 1996; Riekert 1996a; Riekert and Henshaw 1998; SAPPNS[1]). A concise summary of the most important nematodes of maize is given below.

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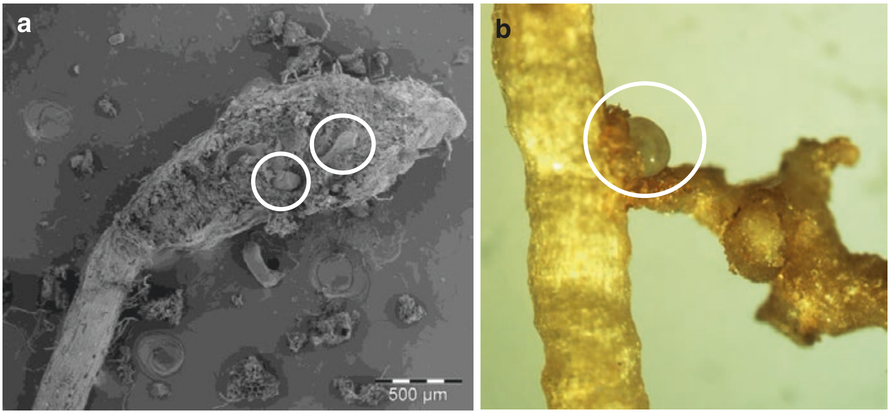

Fig. 8.1 (**a**, **b**) Root-knot nematode females (indicated by *white circles*) visible in the root tissue of a swollen, infected maize root tip (**a**) and at the junction of the tap and secondary roots (**b**) of a maize plant (**a** Louwrens Tiedt and **b** Driekie Fourie, North-West University, Potchefstroom, South Africa)

8.2.1.1 Root-Knot Nematodes

The predominant root-knot nematode species that parasitise local maize crops are *Meloidogyne javanica* (Treub, 1885) Chitwood, 1949, and *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 (Riekert 1996a; Riekert and Henshaw 1998) (Fig. 8.1a, b).

Meloidogyne arenaria (Neal, 1889) Chitwood, 1949, has also been recorded from maize fields (Kleynhans et al. 1996; Agenbag 2016; SAPPNS). The introduction of a more specialised extraction method (Riekert 1995) resulted in more accurate assessments of root-knot nematode infections in plant roots. The modified sodium hypochlorite (NaOCl) technique hence brought new perspectives to maize nematology. During the earlier work on nematode surveys in maize fields, this technique was not used, and the relative importance of *Meloidogyne* spp. on maize was not appreciated.

8.2.1.2 Lesion Nematodes

Pratylenchus zeae is generally listed as the major lesion nematode species that dominates in terms of abundance in local maize fields (Walters 1979a, b; De Waele and Jordaan 1988a), followed by *Pratylenchus brachyurus* (Godfrey, 1929) Filipjev and Schuurmans Stekhoven, 1941 (Mc Donald and De Waele 1987a, b; De Waele and Jordaan 1988a). Other lesion nematode species identified locally from maize crops are *Pratylenchus crenatus* Loof, 1960; *Pratylenchus delattrei* Luc, 1958; *Pratylenchus neglectus* (Rensch, 1924) Filipjev and Schuurmans Stekhoven, 1941; *Pratylenchus penetrans* (Cobb, 1917) Filipjev and Schuurmans Stekhoven, 1941;

Fig. 8.2 (**a**, **b**) Root-knot nematode damage on roots of a maize plant (**a**) and a close-up of galled and stunted maize roots due to high population densities of this nematode genus (**b**) (**a** Kirk West, Port Elizabeth, South Africa and **b** Suria Bekker, North-West University, Potchefstroom, South Africa)

Pratylenchus pratensis (De Man, 1880) Filipjev, 1936; and *Pratylenchus vulnus* Allen and Jensen, 1951 (Kleynhans et al. 1996; SAPPNS).

8.2.1.3 Other Nematodes

The plant-parasitic nematode genus *Rotylenchulus* is worth mentioning here. Although *R. parvus* has been associated with maize plantings in earlier years (Louw 1982; Zondagh and Van Rensburg 1983; Keetch and Buckley 1984; Kleynhans et al. 1996), the impact and pathogenicity of this genus on the crop remain unknown (De Waele and Jordaan 1988a; Marais et al. 2009). Interestingly, exceptionally high egg and second-stage juvenile (J2) population levels (>10,000 50 g roots^{-1}) of this genus have been recorded during the past few seasons from maize under both conservation and conventional agricultural practices. However, since the identity of plant-parasitic nematode genera/species cannot be determined using morphological/morphometrical techniques, molecular analyses of eggs present in maize root samples (which represented both that of *Meloidogyne* and *Rotylenchulus*) was applied to confirm the identity of *Rotylenchulus* (Bekker et al. 2016). Routine use of the modified NaOCl method revealed that this phenomenon warrants further investigations (e.g. distribution of species involved and their pathogenicity), which are currently underway.

8.2.2 Symptoms

Symptoms of damage caused by plant-parasitic nematodes are usually not visible on below- or above-ground parts of infected maize plants (Mc Donald and Nicol 2005). However, root-knot nematode galling has been increasingly observed during the last decade on roots of maize (Fig. 8.2a, b). This is especially the case where exceptionally high infection levels of this nematode pest occur, e.g. 101,500 eggs and J2 50 g roots^{-1} from a field near Orkney (North-West Province).

Fig. 8.3 (**a**, **b**) Areas of 'poorly growing' maize plants in a root-knot nematode-infested field (**a**) near Viljoenskroon (Free State Province), showing stunting, and (**b**) phosphate deficiency visible as purple discolouration of the leaf edges of infected plants (Kirk West, Port Elizabeth, South Africa)

Anhydrobiotic *P. zeae* individuals were recorded from destroyed parenchymal cells of maize plants (cv. Pioneer 473). Their activity had resulted in small canals being formed in the plant tissue (Swanepoel et al. 1987). Also, infection by lesion nematodes can result in the formation of brown/black lesions on roots, which is difficult to identify when other pests and/or diseases are present (Mc Donald and Nicol 2005).

Generally no typical above-ground symptoms are visible in plant-parasitic nematode-infested maize fields. The occurrence of stunted and poorly developed plants (often chlorotic) (Fig. 8.3a) is, however, often attributed to high infection levels of root-knot and/or other nematode pests. Nevertheless, damage by pests and diseases other than nematodes, as well as nutrient deficiencies (Fig. 8.3b), drought conditions, excessive rainfall (water logging) and/or even plant-genetic disorders, may make it difficult to distinguish nematode-induced symptoms (Mc Donald and Nicol 2005).

8.2.3 Damage Potential

The damage potential of nematode pests is dependent on the length of their life cycle, but it is also affected by various abiotic and biotic factors. The life cycles of the two predominant nematode pests of maize are illustrated, that of *Meloidogyne* spp. in Chap. 7 (Sect. 7.3.1, Fig. 7.3) and that of *Pratylenchus* spp. below (Fig. 8.4).

The first publications on local maize nematode research (Walters 1979a, b) created an awareness of the incidence and damage potential of plant-parasitic nematodes on maize. The high sand and low organic matter contents of soils in most of the maize production areas, as well as the practice of monoculturing maize, were the main factors argued to predispose maize crops to nematode pests.

Keetch (1989) estimated a 12 % reduction in maize yields as a result of nematode damage. However, this figure referred to plant-parasitic nematodes collectively and not to a specific genus or species. Riekert (1996a, b) and Riekert and Henshaw (1998) subsequently reported maize yield losses of up to 60 % as a result of root-knot nematode parasitism, present as either single or mixed populations of *M. incognita* and *M. javanica*, in sandy soils in the North-West and Free State provinces.

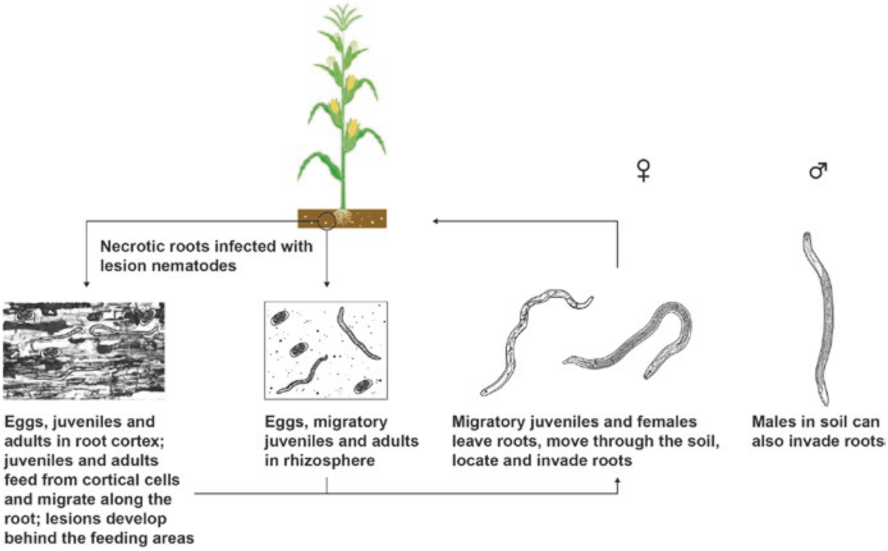

Fig. 8.4 The life cycle of lesion nematodes (Hannes Visagie, North-West University, Potchefstroom, South Africa)

Quantification of the adverse effects of nematode pests on maize is, however, difficult since the yield effect is confounded by the ability of maize plants to compensate for root damage by growing new roots to replace the damaged ones (Walters 1979b; Riekert 1996a, b). Also, due to the microscopic nature of plant-parasitic nematodes, farmers are sceptical of the extent of damage that these nematodes can cause to maize in particular. This is because maize is a so-called ‘low cash’ crop, with the income per MT grain being relatively small (Grain 2016) in relation to other crops such as potato or table grape (Anonymous 2016a). Any production inputs on maize that could not be related to an increase in yield would hence be considered a risk. Therefore, nematode control and particularly the application of nematicides fall into this category (see Chap. 6). This scenario is especially applicable to rain-fed maize production.

8.2.4 Management Strategies

8.2.4.1 Chemical Control

Field Studies

The application of synthetically derived nematicides was shown to substantially alleviate plant-parasitic nematode problems in maize production on sandy soils. Walters (1979b) reported yield increases (ranging from 28 to 42 %) as a result of carbofuran application in the Free State Province where *P. zeae* dominated. In the same study, 14–60 % increases in maize yields were recorded in plots that were fumigated with DD®. However, no mention was made regarding the economic implications of such nematicide treatments on the crop. Research by Zondagh and Van Rensburg (1983) showed a considerable variation in maize yield increases (ranging between 0 and 129 %) as a result of various fumigant and non-fumigant nematicide applications in the same area where Walters (1979b) did his research.

A few years later, Mc Donald and De Waele (1987b) demonstrated in five field experiments, conducted in the Free State and North-West provinces, that yield increases after nematicide applications were substantially lower than those reported by Walters (1979b) and Zondagh and Van Rensburg (1983). Mc Donald and De Waele (1987b), however, recorded yield data from one site to be significantly higher (791 kg ha^{-1}) for EDB® treated compared to untreated control plots. The plant-parasitic nematode complex at this site constituted *Criconemoides sphaerocephalus* Taylor, 1936*; Nanidorus minor* (Colbran, 1956) Siddiqi, 1974 (then reported as *Paratrichodorus minor);* a mixed population of *P. zeae* and *P. brachyurus* (95:5 ratio); *R. parvus*; and *Scutellonema brachyurus* (Steiner 1938) Andrássy, 1958. Conversely, in another site, plots treated with EDB® yielded significantly less than that of the untreated control plots, which was ascribed to a phytotoxic effect of bromide residues. Application of aldicarb, however, did not result in significantly higher yields but suppressed plant-parasitic nematode population levels significantly at two of the sites (Mc Donald and De Waele 1987b).

In another study, application of products with active substances (a.s.) cloethocarb and carbofuran were shown to reduce nematode pest complexes significantly (constituting Dorylaimidae, *Meloidogyne* spp., *Paratrichodorus* spp., and *Pratylenchus* spp.) in two field experiments in the Mpumalanga Province (Van Rensburg 1988). Concurrently, maize yield increases as a result of cloethocarb applications ranged from 52 to 110 % compared to the untreated control, whilst that for carbofuran was 59 %.

Riekert (1996a) later conducted seven field experiments with granular nematicides over four seasons in the western maize production areas in SA where *M. incognita* and *M. javanica* dominated as either single or mixed populations. Yield increases, ranging from 50 to 500 kg ha^{-1}, were recorded in these experiments as a result of nematicide application. The major feature of Riekert's nematode control research was, however, inconsistency in the results. Significant yield increases were obtained in some experiments, but in the majority the cost of the nematicide treatment was greater than the monetary value of the increase in yield. Unfortunately, these field experiments covered a period (1991–1994) during which seasonal rainfall patterns fluctuated substantially. Erratic rainfall is a reality in local maize production and thus presents an inherent risk when using a nematicide. This risk has considerable financial implications since nematode damage in maize is more commonly disregarded until severe infestation build-up becomes a reality.

Glasshouse Studies

Glasshouse experiments during which nematicides were evaluated for their efficacy on maize were also conducted. However, no correlations were evident between population levels of a nematode pest complex comprising *Criconemoides*, *Helicotylenchus*, *Meloidogyne*, *Pratylenchus*, *Rotylenchulus* and *Xiphinema* spp. and plant variables (height, shoot mass and root mass) after planting with carbofuran (Meintjies 1993).

Riekert (1996b), however, recorded significant maize yield increases (ranging from 8 to 23 %) due to nematicide applications in a glasshouse experiment although inconsistencies occurred.

The period of the late 1980s and early 1990s was dominated not only by major political changes in SA but also in agriculture, and, along with it, applied plant nematology research took on new dimensions. The era, during which the frequent use of nematicides in low cash crops such as cereals boomed, ended due to an array of external factors. Some of the most effective nematicides came under immense global pressure not only due to environmental concerns but also because the benefits of chemical control did not exceed the cost for rain-fed maize production in particular.

8.2.4.2 Genetic Host Plant Resistance

During the initial testing of nematicides on maize, Walters (1979b) included different genotypes in some of his experiments and found variable genetic responses. All genotypes (e.g. cvs., hybrids and open-pollinated varieties), viz. PNR 95, SA 4, SSM 48, SA 11, SR 52 and A 471 W, were evaluated for their host suitability to a nematode pest complex that mainly consisted of *P. zeae*. Most were identified as susceptible.

Resulting from another study, Zondagh and Van Rensburg (1983) were surprised by the lack of resistance to plant-parasitic nematodes in a local composite (referred to as composite PWA). This composite was developed by maize breeders over many seasons in field sites where soils contained high population levels of plant-parasitic nematodes, including root-knot nematodes.

In a glasshouse experiment, Van Biljon and Meyer (2000) reported that maize cv. SNK 2340 supported the highest population levels of *P. zeae* and *P. delattrei* compared to tobacco (*Nicotiana tabacum*), weeping love grass (*Eragrostis curvula*), Rhodes grass (*Chloris gayana*), oat, soybean (*Glycine max*), pearl millet and wheat. High reproduction factor values obtained for *P. zeae* (ranging from 3 to 25) and *P. delattrei* (ranging from 30 to 143) demonstrated the high susceptibility of this maize cv.

Jordaan and De Waele (1987) compiled a comprehensive review of nematode resistance in maize in SA. They noted that nematodes were not considered a priority input-related item on breeders' or marketers' agendas for various reasons. At the time of the review, it was generally accepted that, as in other countries, *Pratylenchus* spp. were predominant and the major causal nematode pests that damaged maize plants. It was suggested that the interaction between lesion nematodes and maize needs to be better understood before major inroads could be made in terms of maize-nematode resistance (Jordaan and De Waele 1987).

More recently, the host status of root-knot nematodes in local commercially available maize genotypes was investigated (Ngobeni et al. 2011). Numerous genotypes planted by both commercial and smallholding farmers were screened against local populations of *M. incognita* race 2 and *M. javanica,* along with an inbred line (MP712W) from the USA with proven resistance (Aung et al. 1990; Windham and Williams 1987). Various cvs, e.g. DKC80-10 and AFG4410, proved highly susceptible to both nematode species, whilst others such as DKC78-15B, PHB3203 and DKC61-25B were resistant to one but not to the other. This scenario poses a problem since *M. incognita* and *M. javanica* often occur in mixed populations in local maize-based production areas (Kleynhans 1991; Riekert 1996a; Riekert and Henshaw 1998). Also, cvs resistant to one of these species but susceptible to the other can stimulate one to dominate in a particular field and hence adversely affect successive crops. The genetic variability in local maize germplasm with regard to resistance to the two predominant *Meloidogyne* spp. was demonstrated in the study by Ngobeni et al. (2011). In addition, the potential use of the USA line as a resistant donor parent in local maize breeding was realised.

The main concern about developing nematode resistance in maize is the lack of incentives to breeders of seed companies or even public breeding institutions (Mc Donald and Nicol 2005). The occurrence and effect of nematodes on the crop are generally still not regarded as a priority. However, this perception might soon change as a result of several interrelated factors starting to dominate in modern-day agriculture. These include the decreasing availability of effective nematicides (see Sect. 6.3) for use on maize. Another major new development is the number of maize farmers that are forced by constant economic pressures to revert to conservation or precision agriculture to reduce input costs. These two types of production are of such a nature that maize nematology research will require a new approach. Nematode control will require much more intensive and regular management inputs and closer interaction between nematology advisor and grower. Hence nematode resistance in maize genotypes will become much more important, based on its usefulness in nematode management systems. An important consideration in this sense is that sufficient nematode-resistant material has to be available for introgression into popular, high-yielding and mostly genetically modified maize genotypes. It would be unwise to rely on too few resistance donors, even should they be genetically modifiable. In SA, ways also need to be found to provide nematode resistance in the informal seed market, where maize is commonly rotated or intercropped with crops that are highly susceptible to root-knot nematodes. Such crops are soybean (Fourie et al. 2015), sunflower (*Helianthus annuus*) (Bolton and De Waele 1989; Bolton et al. 1989), tomato (*Solanum lycopersicon*) (Fourie et al. 2012), cowpea (*Vigna unguiculata*) (Riekert and Henshaw 1998) and Bambara (*Vigna subterranea*) (Mc Donald and De Waele 1989).

8.2.4.3 Crop Rotation and Alternative Hosts

Since the large-scale expansion of the local maize market following the success of the green revolution (Borlaug et al. 1969), monoculturing of the crop became common practice in SA. However, Louw (1982) concluded that maize monoculture was not successful in suppressing most plant-parasitic nematode populations that infected the crop.

The negative effects of crop rotation were highlighted by Riekert and Henshaw (1998) when rotating maize (cv. PAN6043) with oilseed crops in a sandy soil in the Free State Province. Significant increases (up to 189-fold) in levels of a mixed *M. incognita* and *M. javanica* population (70:30 ratio) were demonstrated in this study when cowpea (cv. Glenda) and soybean (cv. Knap) were included once in a maize-based rotation sequence over four consecutive growing seasons. Where initial root-knot nematode populations were already relatively high (>20,000 50g roots^{-1}), a 3-fold increase in root-knot nematode numbers in maize-soybean rotations was recorded. Concomitant yield losses of 44 % after one groundnut rotation (cv. Sellie), 55 % after one soybean rotation and 60 % after one cowpea rotation were recorded for maize in this study.

The importance of the above data is to demonstrate that nematode pest population composition and levels need to be assessed and monitored regularly in maize-based cropping systems. The intention is not to discourage crop rotation. Several other crops that are commonly rotated with maize have been demonstrated either to host nematode species that could damage maize or that maize could be an intermediary host to species that could damage crops that are rotated with maize. Bolton and De Waele (1989), however, reported that maize could be rotated with sunflower to reduce *P. zeae* populations. The same authors cautioned that when *M. incognita* and *M. javanica* are present in such fields, rotation of maize and sunflower is not advisable. Ntidi et al. (2012, 2015) also demonstrated that weeds commonly found in maize fields are susceptible to root-knot nematodes and serve as reservoirs of these pests.

8.2.4.4 Alternative Control Options

Safer and less expensive alternatives were also investigated for their effects on nematode pests associated with local maize crops. These included evaluation of a seaweed concentrate (De Waele et al. 1988) as well as that of various popular herbicides (Jordaan and De Waele 1988).

In terms of the seaweed product, the reproduction of *P. zeae* in an in vitro experiment was significantly reduced (47–63 %) when compared to an untreated control. However, in a glasshouse experiment, the reduction range was substantially lower (22–31 %). Furthermore, a phytotoxic effect was evident on maize plants, which apparently made plants more susceptible to attack by *P. zeae*. The authors concluded that the correct time and method of application as well as the concentration of the seaweed product influenced the reproduction of this lesion nematode species. From the herbicide study, it was concluded that products that contained different a.s., viz. atrazine, alachlor and 2,4-D, did not reduce *P. zeae* population levels in roots of maize plants (Jordaan and De Waele 1988).

At present only two biologically based products are registered on maize in South Africa. Both are seed coat products, viz. the one being Avicta® 500FS (Van Zyl

2013) that contains secondary metabolites of the soil-inhabiting bacterium *Streptomyces avermitilis* as a.s. The other biological product with nematicidal properties registered is Poncho®VOTiVo® with *Bacillus firmus* as the a.s. against nematode pests (Anonymous 2016b).

8.2.5 Interaction of Plant-Parasitic Nematodes with Soil-Inhabiting Micro-organisms

Several authors emphasised the potential adverse impact of soilborne pathogens, other than nematodes, that occur in local maize fields and limit production. These primarily include a range of root rots caused by *Fusarium* spp. that occur concomitantly with nematode pests (Walters 1979a, b; Zondagh and Van Rensburg 1983; Mc Donald and De Waele 1987a, b). Already during the early years of maize nematode research, Walters (1979a, b) warned that the contribution of root pathogens in terms of losses in local maize plantings would increase.

Results from a glasshouse study showed that the combined effect of two lesion nematode species (*P. brachyurus* and *P. zeae*) and the root rot fungus *Fusarium moniliforme* was greater than that of the individual organisms (Jordaan et al. 1987). This suggested the existence of a synergistic effect between the nematode pests and fungal pathogen. Plant height and stalk length of plants inoculated with both the fungus and lesion nematodes were significantly lower 2 weeks after planting compared to those where the organisms were applied individually. Furthermore, a treatment that contained both lesion nematodes and fungus suppressed plant growth more during the seedling stage than did the separate treatments with the individual organisms. The latter study also showed that *P. brachyurus* or *P. zeae* did not enhance fungal infection when they were inoculated prior to the fungus. The inoculation of lesion nematodes after fungi inoculation, however, resulted in an overall lower plant growth index 12 weeks after planting, indicating that *F. moniliforme* infection possibly facilitated nematode attraction/penetration. Results from this study showed that inoculation of approximately 500 lesion nematodes seedling^{-1} induced severe root rot symptoms, ranging from less than 10 but up to 60 %.

8.3 Grain Sorghum

Grain sorghum production was estimated at 265,000 MT during the 2014/2015 growing season from 71,000 ha being harvested. This crop is mainly cultivated in drier areas of SA (Grain 2016), with the Free State and Mpumalanga provinces representing the major production areas (Du Plessis 2008).

A range of plant-parasitic nematodes are associated with sorghum in SA (De Waele and Mc Donald 2000; SAPPNS). According to an extensive nematode survey from eight sorghum production areas, *Pratylenchus* spp. were the most abundant in root samples followed by *R. parvus*, *Meloidogyne* spp. and individuals from the Hoplolaimidae (De Waele and Jordaan 1988b). The predominant lesion nematode species was *P. zeae*, followed by *P. penetrans*, *P. crenatus* and *P. brachyurus*. In terms of the Hoplolaimidae, *Rotylenchus devonensis* Van den Berg, 1976; *Rotylenchus mabelei* Van den Berg and De Waele, 1989; and *Scutellonema brachyurus* and *Scutellonema sorghi* Van den Berg and De Waele, 1989, were reported (De Waele and Jordaan 1998a; Van den Berg and De Waele 1989a; Kleynhans et al. 1996). The latter authors also listed the root-knot nematode species *Meloidogyne acronea* Coetzee, 1956; *M. arenaria; M. incognita*; and *M. javanica* as infecting grain sorghum.

Basson et al. (1990) identified grain sorghum as a host for the peanut pod nematode *Ditylenchus africanus* Wendt, Swart, Vrain and Webster, 1995 (then reported as *Ditylenchus destructor* Thorne, 1945). Furthermore, *Longidorus pisi* Edward, Misra and Singh, 1964; *Paralongidorus lutosus* (Heyns, 1965) Escuer and Arias, 1997; *Paratrophurus anomalus* Kleynhans and Heyns, 1983; *N. minor*; *Xiphinema bourkei* Stocker and Kruger, 1988; *Xiphinema limpopoensis* Heyns, 1977; and *Xiphinema mluci* Heyns, 1976, were identified from soil samples obtained from sorghum fields (De Waele and Jordaan 1998a; Kleynhans et al. 1996; SAPPNS).

Mc Donald and Van den Berg (1993) reported that no effect on plant growth variables was recorded when *P. zeae*-infected sorghum (cv. NK304) was exposed to water stress in a glasshouse experiment. However, *P. brachyurus*-infected plants were significantly longer and had significantly higher root masses compared to uninfected plants.

8.4 Wheat

Wheat was produced on 477,000 ha during the 2014/2015 growing season, with approximately 1.8 million MT being harvested (Grain 2016). The major wheat production areas are in descending order: the southwestern parts of the Western Cape (Swartland and Rûens), Northern Cape, Free State, North-West, Mpumalanga, Limpopo, KwaZulu-Natal, Gauteng and Eastern Cape provinces (DAFF 2010a).

Numerous plant-parasitic nematodes have been associated with wheat crops (Jordaan et al. 1992; Kleynhans et al. 1996; SAPPNS). *Pratylenchus* spp. dominated as reported from a nematode survey that was conducted in seven major wheat production areas of SA, with *P. neglectus* being the most abundant. Other lesion nematode species identified during this study included *P. brachyurus*, *P. crenatus* and *P. zeae*, whilst *P. penetrans* and *Pratylenchus thornei* Sher and Allen, 1953, were also listed to infect wheat (Kleynhans et al. 1996; SAPPNS). Jordaan et al. (1992) also recorded the presence of *D. africanus* (then reported as *D. destructor*); *Hoplolaimus pararobustus*; *Heterodera avenae* Wollenweber, 1924; *Geocenamus brevidens* (Allen, 1955) Brzeski, 1991; *N. minor*; *Rotylenchulus parvus*; *Rotylenchus* *unisexus* Sher, 1965; *Rotylenchus mabelei*; *Scutellonema brachyurus; Scutellonema dreyeri* Van den Berg and Heyns, 1973; *Paratylenchus minutus* Linford, Oliveira and Ishii, 1944; *Tylenchorhynchus* sp.; and *Xiphinema* sp. Kleynhans et al. (1996) listed the root-knot nematode species *M. arenaria*; *Meloidogyne chitwoodi* Golden, O'Bannon, Santo and Finley, 1980; *M. incognita*; and *M. javanica* in association with wheat, whilst *Criconema*, *Criconemoides*, *Dorylaimellus*, *Geocenamus*, *Helicotylenchus*, *Hemicycliophora*, *Longidorus*, *Paralongidorus*, *Paratylenchus*, *Pratylenchoides, Rotylenchulus, Quinisulcius, Scutellonema* and *Xiphinema* spp. are also associated with wheat (SAPPNS).

In a glasshouse host suitability experiment, Van Biljon and Meyer (2000) reported that wheat cv. SST 825 maintained low population levels of both *P. zeae* and *P. brachyurus* (reproduction factor values <1), indicating the poor host status of the cv.

8.5 Rice

Only 1,150 ha of rice were planted in SA during 2013 from which 3,000 MT were produced (FAO 2016).

The first records of plant-parasitic nematodes associated with local rice plants listed *Ditylenchus angustus* (Butler, 1913) Filipjev, 1936; *M. arenaria; M. incognita*; and *M. javanica* (Keetch and Buckley 1984). Added to this list were *Brachydorus tenuis* De Guiran and Germani, 1968; *Criconema corbetti* (De Grisse, 1967) Raski and Golden, 1966; *Criconemoides incisus* Raski and Golden, 1966; *Criconemoides obtusicaudatus* Heyns, 1962; *C. sphaerocephalus*; *Helicotylenchus digonicus* Perry in Perry, Darling and Thorne, 1959; *H. dihystera*; *Helicotylenchus erythrinae* Zimmermann, 1904; *Hemicriconemoides brachyurus* (Loos, 1949) Chitwood and Birchfield, 1957; *Hemicriconemoides cocophilus* (Loos, 1949) Chitwood and Birchfield, 1957; *Hemicycliophora oryzae* (De Waele and Van den Berg, 1988); *Hemicycliophora typica* de Man, 1921; *H. pararobustus*; *L. pisi*; *N. minor*; *P. lobatus*; *P. brachyurus*; *P. zeae*; *Rotylenchus gracilidens* (Sauer, 1958) Sauer, 1958; *R. unisexus; S. brachyurus*; and *Trichodorus petrusalberti* De Waele, 1988 (De Waele and Van den Berg 1988; Van den Berg and De Waele 1989b; SAPPNS).

8.6 Millet

Pearl millet represents a small grain crop in terms of its local production and is mainly grown by subsistence farmers who use it as a staple food source and a beverage (DAFF 2011). Only a few plant-parasitic nematodes have been associated with pearl millet in SA, namely, *Meloidogyne acronea*; Coetzee, 1956; *M. incognita*; *M. javanica*;

Pratylenchus scribneri Steiner, 1943; *R. parvus*; and *Tylenchorhynchus brevilineatus* Williams, 1960 (Kleynhans et al. 1996; SAPPNS).

During 2000, Van Biljon and Meyer reported that an undisclosed pearl millet cv. supported medium to high reproduction factor values (up to 1.9) for *P. zeae* and (up to 13) *P. delattrei* in a glasshouse experiment. This illustrated the potential of high population level build-ups of lesion nematode species in fields where such nematode pests occur.

8.7 Barley, Rye and Oat

In 2013, barley production in SA amounted to 268,000 MT from 80,000 ha. Equivalent figures for oat were 59,000 MT from 27,000 ha and for rye 1,950 MT from 3,600 ha (FAO 2016). Barley is produced in various areas in the Western Cape, Northern Cape, Free State, Eastern Cape, KwaZulu-Natal, North-West and Limpopo provinces. Rye is a winter cereal which prefers subtropical to temperate areas in terms of its cultivation (Anonymous 2016c). Oat is suitable for all regions of SA due to its adaptability to a wide range of environmental conditions and high biomass production (DAFF 2010b).

An unidentified *Meloidogyne* sp. (SAPPNS), *M. incognita* and *R. incultus* have been reported to infect local barley crops (Kleynhans et al. 1996; Keetch and Buckley 1984).

The following plant-parasitic nematodes have been associated with rye: *C. sphaerocephalus*; *Ditylenchus* spp.; *H. dihystera; Hoplolaimus capensis* Van den Berg and Heyns, 1970; *M. arenaria*; *P. zeae*; *Rotylenchus incultus* Sher, 1965; *R. unisexus* as well as *S. brachyurus* (Keetch and Buckley 1984; Kleynhans et al. 1996; SAPPNS).

For oat several plant-parasitic nematodes have been recorded, viz. *Ditylenchus equalis* Heyns, 1964; *G. brevidens*; *H. dihystera; Hemicycliophora* spp.; *Meloidogyne* sp.; *M. javanica*; *M. hapla; M. incognita*; *P. crenatus*; *P. brachyurus*; *P. zeae*; *R. parvus*; and *S. brachyurus* (Keetch and Buckley 1984; Kleynhans et al. 1996; SAPPNS).

In a glasshouse experiment, Van Biljon and Meyer (2000) showed the poor host susceptibility of oat cv. Maluti to *P. zeae* (reproduction factors <1). For *P. delattrei*, the reproduction factors ranged from approximately 2 to 5. This illustrated that cv. Maluti can support high population levels of *P. delattrei* in fields where this nematode pest occur.

8.8 Conclusions

The most important challenge to local nematologists remains to find suitable, effective and sustainable measures for producers to manage cereal crops in ways that would keep plant-parasitic nematode populations below damage threshold levels. An important nematological aspect relating to all cereal crops produced in this country is the uncertainty of how widely economically important plant-parasitic nematodes are distributed and what the effects of different species have on each crop. Concrete proof and sound economic bases of damage could change general perceptions and bring greater benefits to producers and related concerns in the respective crop industries. Differences in crop-genotype susceptibility to the main nematode pests should also receive high priority in terms of research.

Another prominent knowledge gap is the effect that different forms of soil tillage might have on total nematode community structures and compositions under various cropping systems and abiotic conditions. Closely related to this is the need for investigations on interactions between root pathogens (fungi in particular) and nematode pests. Environmental conditions are another important variable to investigate and involve all possible crops and rotation-system variations. Nematode population dynamics and several other aspects of plant nematology relating to conservation and precision agriculture would not only contribute to support the development and adoption of these approaches but also would provide invaluable basic information about plant nematology that would previously have been very difficult to justify investigating.

Other aspects that are also often raised, speculated about but rarely been exploited include the reciprocal effects and/or dynamics between soil nematodes and important soil elements such as nitrogen (N), phosphate (P), potassium (K), microelements or even gas exchanges.

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