Fundam. appl. Nematol., 1992, **15** (6), 531-537

Plant-parasitic nematodes on field crops in South Africa. 5. Wheat

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Accepted for publication 10 February 1992.

Summary — Nineteen plant-parasitic nematode species were recovered from 175 wheat fields in the seven major wheat-production areas of the Republic of South Africa. The predominant ectoparasites were *Merlinius brevidens* and *Paratrichodorus minor*. Both species occurred in almost 25 % of all soil samples. *Scutellonema brachyurum, S. dreyeri, Paratylenchus minutus, Hoplolaimus pararobustus, Rotylenchus unisexus, R. mabelei* and *Xiphinema* sp. were also found. The predominant endoparasites were *Pratylenchus neglectus* and *P. thornei*, which occurred in 28 and 18.9 %, respectively, of all root samples. *Pratylenchus zeae, P. brachyurus, P. penetrans, P. crenatus, Rotylenchulus parvus, Ditylenchus destructor* and *Tylenchorhynchus* sp. were also found. A *Heterodera* species, closely resembling *Heterodera avenae*, was recovered from six wheat fields. The seven wheat-producing areas surveyed could be ranked on the basis of the incidence of the plant-parasitic nematodes. The incidence of *P. neglectus* was negatively related to altitude. Positive relationships were found between the incidence of *R. parvus* and *P. zeae* and average annual rainfall and temperature. The incidence of *R. parvus* was also positively related to altitude and of *P. zeae* to percent sand.

Résumé — ***Les nématodes parasites des cultures en Afrique du Sud. 5. Le blé*** — Dix-neuf espèces de nématodes phytoparasites ont été identifiés dans 175 champs de blé provenant des sept régions céréalières d'Afrique du Sud. Les nématodes ectoparasites dominants sont *Merlinius brevidens* et *Paratrichodorus minor*, présents dans presque 25 % des échantillons. *Scutellonema brachyurum, S. dreyeri, Paratylenchus minutus, Hoplolaimus pararobustus, Rotylenchus unisexus, R. mabelei* et *Xiphinema* sp. ont été également identifiés. Les endoparasites dominants sont *Pratylenchus neglectus* et *P. thornei*, présents dans 28 et 18.9 %, respectivement, des échantillons. *Pratylenchus zeae, P. brachyurus, P. penetrans, P. crenatus, Rotylenchulus parvus, Ditylenchus destructor* et *Tylenchorhynchus* sp. ont été également identifiés. Une espèce ressemblant à *Heterodera avenae* est présente dans six champs de blé. Il est possible de classer les sept régions de production de blé en Afrique du Sud en fonction de la présence des nématodes phytoparasites. La présence de *P. neglectus* est corrélée négativement à l'altitude. Des corrélations positives existent entre la présence de *R. parvus* et *P. zeae* d'une part, et les précipitations et la température d'autre part. La présence de *R. parvus* est corrélée positivement à l'altitude et celle de *P. zeae* au pourcentage de sable dans le sol.

Key-words : Nematodes, wheat, South Africa.

Approximately 1.9 million ha of wheat (*Triticum aestivum* L.) are grown annually in South Africa. Wheat production has increased from 1.6 million tons in 1985 to 3 million tons in 1990. This comprises 1 % of the total world production of wheat. Since the local demand for wheat increases by 3 to 4 % each year, it is one of the major field crops in South Africa. The seven main wheat-producing areas of South Africa are the Western, Central and Eastern Orange Free State, the Springbok Flats in the Transvaal Province, the Vaalharts irrigation area in the Northern Cape Province and the Swartland and Rûens areas in the South Western Cape Province (Fig. 1). Winter wheat is planted during autumn (April to May) in the Orange Free State and the Cape Province while summer wheat is planted during spring (September to November) in the Springbok Flats. The areas in the Orange Free State, the Vaalharts irrigation area and the Springbok Flats are situated in the summer rainfall region while the Swartland and Rûens areas are situated in the winter rainfall region. Wheat is cultivated in rotation with many other crops including maize, barley, groundnut and potato.

The status of plant-parasitic nematodes as a limiting factor in wheat production has only recently been the subject of detailed study. Today, the cereal cyst nematode, *Heterodera avenae* Woll., the ear-cockle nematode,

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ISSN 1164-5571/92/06/531 07 $ 2 / © Gauthier-Villars - ORSTOM

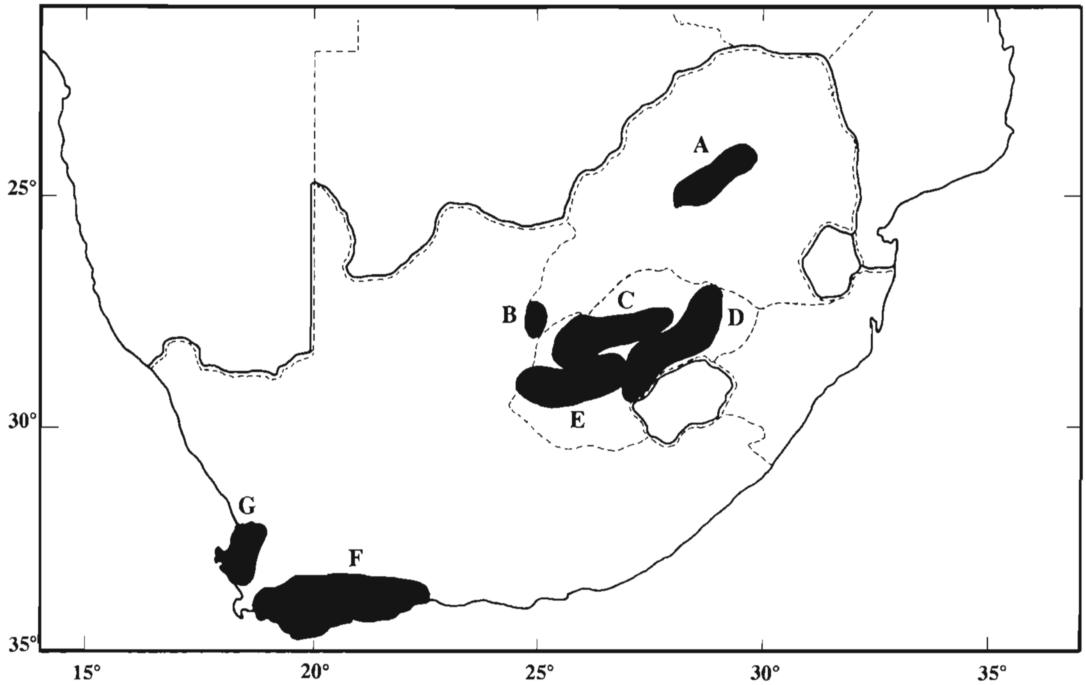

Fig. 1. Main wheat-producing areas in South Africa. A : Springbok Flats; B : Vaalharts; C: Western Orange Free State; D : Eastern Orange Free State; E : Central Orange Free State; F : Rûens; G : Swartland.

Anguina tritici (Steinbuch) Chitwood, root-knot nematodes, *Meloidogyne* spp., and root-lesion nematodes, *Pratylenchus* spp., are considered economically important on wheat (Swarup & Sosa-Moss, 1990). Annual wheat yield losses due to damage by plant-parasitic nematodes are estimated at 7 % worldwide, representing an annual monetary loss of 5.8 billion US $ (1984 figures and prices *in* : Sasser & Freckman, 1987).

In South Africa, plant-parasitic nematodes have not been regarded as important constraints of the local wheat production, although some extension officers consider nematode infestation as one of the reasons underlying rotation schemes. Recently, annual yield losses caused by plant-parasitic nematodes to South African wheat was estimated at 11 % or 89.6 million Rand (1988 figures and prices *in* Keetch, 1989). Keetch and Buckley (1984) listed 22 plant-parasitic nematode species associated with wheat in South Africa but no differentiation between common and rare species was made. Root-knot and root-lesion nematodes are common on field crops in South Africa (De Waele & Jordaan, 1988*a*, *b;* Bolton *et al.*, 1989; Venter *et al.*, 1992) but their frequency of occurrence and population densities in the wheat-producing areas is unknown. Identification of the predominant ecto- and endoparasitic nematode species of wheat is a prerequisite to initiate specific pathogenicity experiments.

This paper presents the results of a study to *i)* identify the predominant plant-parasitic nematode species associated with wheat in South Africa, *ii)* determine their relationship to soil texture, average annual rainfall, altitude and temperature, and *iii)* rank the wheat-producing areas of South Africa on the basis of the incidence of the predominant plant-parasitic nematodes.

Materials and methods

During the 1988/1989 growing season, soil and root samples were collected from 175 different wheat fields in the seven main wheat-producing areas of South Africa. All samples were taken about 3 months after planting. The properties of the soil, average annual rainfall, annual minimum and maximum temperature and altitude are given in Table 1. The agronomic practices of the selected wheat fields are representative for the prevailing production conditions used by the farmers in the different areas. In all areas, except in Vaalharts and some fields in the Western Orange Free State, wheat was grown under dryland conditions. Soil texture was determined by a rapid hydrometer method based on Day's (1965) modification of Bouyoucos' (1951) technique. Soil type was determined according to the triangular textural diagram (Hodgson, 1974).

In each wheat fields, three soil and three root samples

Table 1. Main soil properties, average annual rainfall, average temperature (minimum and maximum) and altitude of the main wheat producing areas in South Africa.

Areas	Soil		Rain	Average temp. (°C)		Altitude
	Sand (%)	Clay (%)	(mm/year)	min.	max.	(m)
A. Springbok Flats	56.6	29.7	605	6.0	39.3	1092
B. Vaalharts	89.3	7.8	442	9.3	41.2	1175
C. Western Orange Free State	87.3	8.5	462	8.4	39.1	1272
D. Eastern Orange Free State	78.3	8.2	679	10.1	35.0	1617
E. Central Orange Free State	63.0	8.6	596	8.9	37.2	1474
F. Rûens	61.0	10.2	544	1.3	40.3	193
G. Swartland	72.2	10.9	397	0.9	41.6	242

were collected at random in a 10 × 10 m area and combined to form one soil and one root sample. The soil samples were taken in the rhizosphere of the wheat plants. The soil nematodes were extracted from two 200 ml soil subsamples by a modified decanting and sieving method (Flegg, 1967) using 710 and 45 μm sieves, followed by the sugar centrifugal-flotation method (Jenkins, 1964). The root nematodes were extracted from one 5 g fresh root subsample by the sugar centrifugal-flotation method (Coolen & D'Herde, 1972). The extracted nematodes were killed and fixed in hot 4 % formalin. The cyst nematodes were extracted from 200 ml soil using an elutriator. Nematode population levels were determined in a counting dish with a stereomicroscope and expressed either as the number of nematodes per 200 ml soil or per 5 g fresh roots. For species identification, plant-parasitic nematodes were transferred to anhydrous glycerin (De Grisse, 1969), and mounted on slides by the paraffin-ring method.

Prominence values (*P.V. = population density* × $\sqrt{}$frequency of occurrence/10) were calculated for each species. Chi-squared contingency values were calculated pairwise for the predominant species to ascertain the significance of joint occurrences. The Kruskal-Wallis rank sum test with Yates' correction factor was used to rank the areas according to the frequency of occurrence and average density of each of the predominant species. A canonical correlation analysis was performed to correlate the incidence of the predominant species with soil texture (percentages of sand and clay), average annual rainfall, altitude and average temperature (minimum and maximum).

Table 2. Frequency of occurrence, mean population density and prominence value of the plant-parasitic nematodes recovered from soil and wheat roots in the wheat-producing areas of South Africa (n = 175) *(PV = population density* × $\sqrt{}$*frequency of occurrence/10).*

Nematode species	Frequency of occurrence (%)	Mean population density (Range) (Nematodes 200 ml soil or 5 g roots)	Prominence value
Soil			
Hoplolaimus pararobustus	1.1	198 (45-350)	19.8
Paratrichodorus minor	24.0	177 (3-1742)	86.7
Rotylenchus unisexus	7.4	74 (2-353)	20.0
Rotylenchus mabelei	1.1	12 (10-13)	1.2
Scutellonema brachyurum	12.0	82 (4-424)	28.7
Scutellonema dreyeri	0.6	24	1.9
Xiphinema sp.	3.4	63 (2-185)	11.3
Tylenchorhynchus sp.	6.9	136 (4-594)	35.4
Merlinius brevidens	23.4	193 (4-781)	92.6
Paratylenchus minutus	1.1	318 (58-578)	31.8
Roots			
Pratylenchus zeae	33.7	91 (5-892)	52.8
Pratylenchus brachyurus	9.1	323 (2-2087)	96.9
Pratylenchus penetrans	5.1	85 (14-218)	19.6
Pratylenchus crenatus	0.6	30	2.4
Pratylenchus neglectus	28.0	1030 (2-6412)	545.9
Pratylenchus thornei	18.9	1010 (2-9259)	434.3
Rotylenchus parvus	5.7	88 (5-475)	21.1
Ditylenchus destructor	1.7	235 (10-390)	30.6
Heterodera sp.	3.4	175 (3-705)	31.5

Results

Nineteen plant-parasitic nematode species were recovered from the rhizosphere and roots of wheat in the seven wheat-producing areas surveyed (Table 2). The predominant ectoparasites were *Merlinius brevidens* Allen and *Paratrichodorus minor* (Colbran) Siddiqi. Both species occurred in almost 25 % of all soil samples. *Scutellonema brachyurum* (Steiner) Andrássy was present in 12 % of all the soil samples but its average population density was less than 100 individuals/200 ml soil (*vs* 193 and 177 individuals/200 ml soil for *M. brevi-*

dens and *P. minor*, respectively). The average population densities of *Paratylenchus minutus* Linford and *Hoplolaimus pararobustus* (Schuurmans Stekhoven & Teunissen) Sher (318 and 198 individuals/200 ml soil, respectively) were higher than those of *M. brevidens* and *P. minor* but these two species occurred in less than 2 % of all soil samples. The other ectoparasitic nematode species recovered were *Tylenchorhynchus* sp., *Rotylenchus unisexus* Sher, *Xiphinema* sp. (only juveniles found), *Rotylenchus mabelei* Van den Berg & De Waele and *Scutellonema dreyeri* Van den Berg & De Waele. The predominant endoparasites were *Pratylenchus neglectus* (Rensch) Filipjev & Schuurmans Stekhoven and *Pratylenchus thornei* Sher & Allen which occurred in 28 and 18.9 %, respectively, of all the root samples. Their population densities averaged about 1000 individuals/5 g fresh roots. The highest population densities recovered were 9259 and 6412 individuals/5 g fresh roots for *P. thornei* and *P. neglectus*, respectively. *Pratylenchus zeae* Graham was present in about one third of all root samples but its average population density was less than 100 individuals/5 g fresh roots. The population density of *Pratylenchus brachyurus* (Godfrey) Filipjev & Schuurmans Stekhoven averaged more than 300 individuals/5 g fresh roots but this species occurred in less than 10 % of all root samples. A *Heterodera* species closely resembling *Heterodera avenae* Woll. was found in six of the wheat fields. The average number of cysts recovered from the soil was 20/200 ml soil while on average 175 juveniles were extracted from 5 g fresh roots. The other endoparasitic nematode species recovered were *Rotylenchulus parvus* (Williams) Sher, *Pratylenchus penetrans* Cobb, *Ditylenchus destructor* Thorne and *Pratylenchus crenatus* Loof.

Among six of the most predominant ecto- and endoparasitic nematode species, seven negative ($P = 0.01$) and five positive ($P = 0.01$) relationships were found (Table 3). Only joint occurrences between *P. thornei* and *P. neglectus*, and between *P. thornei* and *S. brachyurum* were not significantly correlated. *P. minor* and *P. zeae* were each recovered from six of the seven wheat-producing areas (Table 4). *P. minor* was not found in the Swartland while *P. zeae* was absent in the Rûens area. *M. brevidens* and all other *Pratylenchus* spp., except *P. crenatus*, were present in Vaalharts and in both other areas situated in the Cape Province but not elsewhere (*P. penetrans* was also absent in the Rûens area). *S. brachyurum* and *R. parvus* showed a similar geographical distribution : the Western and Eastern Orange Free State and the Springbok Flats. The *Heterodera* species was only recovered from the Swartland and Rûens areas in the South Western Cape Province.

Table 3. Chi-squared values for joint occurrences of the predominant plant-parasitic nematodes recovered from soil and wheat roots in the wheat-producing areas of South Africa.

	Pn	*Pt*	*Pm*	*Sb*	*Mb*
P. zeae	– 15.40**	– 6.34**	4.00*	8.61**	– 18.27**
P. neglectus		1.29ns	– 13.33**	– 8.26**	40.55**
P. thornei			– 6.82**	– 4.91ns	30.12**
P. minor				14.86**	– 15.23**
S. brachyurum					– 6.28*

Pratylenchus neglectus (*Pn*), *P. thornei* (*Pt*), *Paratrichodorus minor* (*Pm*), *Scutellonema brachyurum* (*Sb*), *Merlinius brevidens* (*Mb*).

Significant at $*P = 0.05$, $**P = 0.01$.

Negative values indicate a deficit of joint occurrences and consequently a negative association between species.

Of the most predominant ecto- and endoparasitic nematode species listed in Table 4, nine were found in the Swartland and eight in both the Rûens area and in

Table 4. Ranking order (R) of the wheat-producing areas of South Africa, based on frequency of occurrence (%, F) and mean population density (PD) of the plant-parasitic nematodes.

Areas	*Pz*			*Pb*			*Pp*			*Pn*			*Pt*			*H*		
	F	*PD*	*R*	*F*	*PD*	*R*	*F*	*PD*	*R*	*F*	*PD*	*R*	*F*	*PD*	*R*	*F*	*PD*	*R*
Vaalharts	10	8	6	40	20	1	30	45	1	60	97	2	50	208	2	0	0	5
Western OFS	47	187	2	0	0	5.5	0	0	5.5	0	0	5.5	0	0	5.5	0	0	5
Central OFS	29	98	3	0	0	5.5	0	0	5.5	0	0	5.5	0	0	5.5	0	0	5
Eastern OFS	77	60	1	0	0	5.5	0	0	5.5	0	0	5.5	0	0	5.5	0	0	5
Springbok Flats	15	5	5	0	0	5.5	0	0	5.5	0	0	5.5	0	0	5.5	0	0	5
Swartland	24	55	4	8	91	3	24	105	2	36	95	3	80	1406	1	20	149	1
Rûens	0	0	7	27	490	2	0	0	5.5	92	1411	1	22	532	3	3	305	2
χ^2 for ranking	39.80			8.81			5.58			78.7			42.6			2.4		
P value	0.0001			0.18			0.47			0.0001			0.0001			0.87		

Areas	*Ty*			*Rp*			*Pm*			*Ru*			*Sb*			*Mb*		
	F	*PD*	*R*	*F*	*PD*	*R*	*F*	*PD*	*R*	*F*	*PD*	*R*	*F*	*PD*	*R*	*F*	*PD*	*R*
Vaalharts	30	432	1	0	0	5.5	30	791	3	0	0	6	0	0	5.5	20	452	3
Western OFS	3	107	5	3	71	3	33	252	2	7	347	3	7	285	3	0	0	5.5
Central OFS	0	0	6.5	0	0	5.5	29	167	4	0	0	6	0	0	5.5	0	0	5.5
Eastern OFS	0	0	4	6	22	2	49	71	1	15	10	2	41	59	1	0	0	5.5
Springbok Flats	0	0	6.5	54	109	1	23	6	5	0	0	6	31	53	2	0	0	5.5
Swartland	20	149	2	0	0	5.5	0	0	7	12	52	1	0	0	5.5	60	476	2
Rûens	3	305	3	0	0	5.5	3	194	6	5	32	4	0	0	5.5	65	194	1
χ^2 for ranking	3.02			9.91			16.72			1.59			14.98			45.2		
P value	0.81			0.12			0.01			0.95			0.02			0.0001		

Pratylenchus zeae (*Pz*), *P. brachyurus* (*Pb*), *P. penetrans* (*Pp*), *P. neglectus* (*Pn*), *P. thornei* (*Pt*), *Heterodera* sp. (*H*), *Tylenchorhynchus* sp. (*Ty*), *Rotylenchus parvus* (*Rp*), *Paratrichodorus minor* (*Pm*), *Rotylenchus unisexus* (*Ru*), *Scutellonema brachyurum* (*Sb*), *Merlinius brevidens* (*Mb*).

Table 5. Canonical correlation between population densities of plant-parasitic nematodes recovered from soil and roots of wheat in the wheat-producing areas of South Africa, and 4 environmental factors.

Canonical variable	Canonical correlation	Chi-square	Standardized canonical coefficients																			
			Left hand variables												Right hand variables							
																			Temperature (°C)***			
			Pz	*Pb*	*Pp*	*Pn*	*Pt*	*H*	*Ty*	*Rp*	*Pm*	*Sb*	*Mb*	*Dd*	sand	clay	Av. ann. rainfall (mm)	Altitude (m)	TnAv.	TnN	TxAv.	TxX
C1	0.899	429.32**	0.1	0.0	0.1	−0.6	−0.3	−0.1	0.0	−0.0	0.0	0.1	−0.1	0.0	0.1	0.2	0.1	0.9	−0.2	0.3	0.1	0.1
C2	0.558	156.64**	0.3	0.0	−0.2	0.4	−0.2	0.0	−0.0	−0.6	0.1	0.3	−0.1	0.0	0.4	−0.2	−0.4	−0.4	−0.4	−0.4	−0.5	−[illegible]
C3	0.428	95.15**	0.1	−0.0	0.0	0.3	0.0	−0.0	0.1	0.2	0.2	−0.1	−0.2	0.1	−0.0	−0.1	0.1	−0.4	0.5	−0.8	0.0	0.0
C4	0.396	61.81**	0.4	0.1	0.3	−0.1	0.3	0.1	0.1	−0.1	0.1	0.1	0.0	0.2	0.8	−0.0	0.4	0.0	0.1	0.4	0.0	0.2
C5	0.301	33.77*	0.1	0.3	−0.0	0.0	−0.0	0.3	−0.3	0.2	−0.1	0.2	−0.1	0.0	0.3	0.5	0.2	−0.0	−0.3	−0.3	−0.3	0.3
C6	0.223	18.12	0.1	−0.1	−0.1	0.0	0.0	0.1	0.0	0.0	−0.2	−0.2	−0.1	0.0	−0.0	0.1	0.1	0.6	−0.1	0.5	−0.2	0.6

Pratylenchus zeae (*Pz*), *P. brachyurus* (*Pb*), *P. penetrans* (*Pp*), *P. neglectus* (*Pn*), *P. thornei* (*Pt*), *Heterodera* sp. (*H*), *Tylenchorhynchus* sp. (*Ty*), *Rotylenchus parvus* (*Rp*), *Paratrichodorus minor* (*P*), *Scutellonema brachyurum* (*Sb*), *Merlinius brevidens* (*Mb*), *Ditylenchus destructor* (*Dd*).

Significant at * $P = 0.05$, ** $P = 0.01$.

*** TnAv. = average minimum temperature, TnN = absolute minimum temperature, TxAv. = average maximum temperature, TxX = absolute maximum temperature.

Vaalharts. In the Central Orange Free State only two species, *P. minor* and *P. zeae* were present.

The seven wheat-producing areas could be ranked on the basis of the frequency of occurrence and average population density of the most predominant ecto- and endoparasitic nematode species (Table 4). In Vaalharts, high population densities of three ectoparasitic species, *P. minor*, *M. brevidens* and *Tylenchorhynchus* sp., were recovered (on average 791, 452 and 432 individuals/100 ml soil, respectively). In the Rûens and Swartland areas, high population densities of two endoparasitic species, *P. neglectus* and *P. thornei*, respectively, were found (on average 1441 and 1406 individuals/5 g fresh roots, respectively).

Three of the canonical correlations between nematode species and environmental factors were significant (Table 5). The first canonical variable was interpreted as a negative correlation ($P = 0.01$) of the incidence of *P. neglectus* with the altitude. The second canonical variable was interpreted as a positive correlation ($P = 0.01$) of the incidence of *R. parvus* with the average annual rainfall, altitude, average minimum and maximum and absolute minimum temperature. The fourth canonical variable was interpreted as a positive correlation ($P = 0.01$) of the incidence of *P. zeae* with percentage sand, average annual rainfall and absolute minimum temperature.

Discussion

Only five of the eighteen plant-parasitic nematode species identified during the present survey have previously been reported from wheat in South Africa. Among these are the two predominant ectoparasitic species, *M. brevidens* and *P. minor*, and two other ectoparasitic species, *S. brachyurum* and *R. unisexus* (Keetch & Buckley, 1984). Both *M. brevidens* and *P. minor* are considered potentially important pathogens of wheat (Swarup & Sosa-Moss, 1990).

The two predominant endoparasitic species, *P. neglectus* and *P. thornei*, and all other endoparasitic species, except *P. brachyurus*, have not previously been reported from wheat in South Africa (Keetch & Buckley, 1984). *P. thornei* is considered an important pathogen of wheat in North America, Mexico, Israel and Australia (Baxter & Blake, 1968; Van Gundy *et al.*, 1974; O'Brien, 1983; Orion *et al.*, 1984) causing significant yield losses. Parasitism of wheat by other *Pratylenchus* species, including *P. neglectus*, was reported (Griffin, 1984) but their status as pathogens of wheat is unknown. Several *Tylenchorhynchus* species caused poor growth of wheat in North America and India (Griffin, 1984) and are considered potentially important pathogens of wheat (Swarup & Sosa-Moss, 1990). Wheat apparently is not a good host for *R. parvus* which occurred in only 6 % of the fields sampled. In contrast, in sorghum and maize fields *R. parvus* was found in 100 and 93 %, respectively, of all fields sampled (De Waele & Jordaan, 1988*a*, *b*). The data of the present study confirm that wheat is also a poor host for *D. destructor* (Basson *et al.*, 1990). *D. destructor* was only found in irrigated fields where wheat is cultivated in rotation with groundnut. The absence of *Meloidogyne* species in the wheat fields investigated is surprising since *M. incognita* and *M. javanica* have been found on many crops in South Africa including maize, barley, groundnut and potato which are cultivated in rotation with wheat (Keetch & Buckley, 1984).

The results of the present survey confirm that *P. minor* and *P. zeae* are among the most common parasitic nematode species associated with field crops in South Africa. In maize, groundnut, sunflower and sorghum, *P. minor* and *P. zeae* were found in 100, 88, 71 and 25 % and 93, 63, 79 and 100 %, respectively, of all fields sampled (De Waele & Jordaan, 1988*a*, *b*; Bolton *et al.*, 1989; Venter *et al.*, 1992). Although *M. brevidens*, *P. neglectus* and *P. thornei* were recovered from 23, 28 and 19 %, respectively, of the wheat fields sampled during the present survey, they were not found during the above mentioned surveys in maize, sorghum, sunflower and groundnut fields.

This is the first report of a *Heterodera* species on wheat in South Africa. This nematode may be *H. avenae*, the cereal cyst nematode which occurs in temperate, subtropical and tropical regions and is an important pathogen of wheat worldwide (Swarup & Sosa-Moss, 1990). In Africa, *H. avenae* has only been reported from some semi-arid regions (parts of Morocco, Libya and Tunisia) of North Africa (Sikora, 1988).

The reasons for the positive and negative relationships observed between the predominant ecto- and endoparasitic nematode species are unknown. Joint occurrences between nematode species are not only determined by the environment but also by interspecific competition. The two predominant ectoparasitic species, *M. brevidens* and *P. minor*, prefer different areas and, consequently, a negative relationship was found. However, although both predominant endoparasitic species, *P. neglectus* and *P. thornei*, occur in the same areas, no significant relationship was found. Apparently these species attack wheat independently of each other. In contrast, a positive relationship was found between *M. brevidens* and *P. neglectus* and *P. thornei* which all prefer the same areas. The relationship of *P. minor* with *P. neglectus* and *P. thornei*, on the other hand, was negative.

Only one significant correlation between the incidence of the predominant ecto- and endoparasitic nematode species of wheat and soil texture, temperature, average annual rainfall and altitude was found. *P. neglectus* preferred low altitudes. Both *P. zeae* and *R. parvus* preferred high average rainfall. In addition, *P. zeae* also preferred sandy soils and low temperatures while *R. parvus* occurred at high altitudes and in both low and high temperatures. During a similar survey of maize fields, the incidence of *R. parvus* was also positively correlated with average annual rainfall (Jordaan *et al.*, 1989). The highest frequency of occurrence and the highest average population densities of *P. thornei* were observed in the Swartland. This area is characterized by sandy loam soils, high temperatures and low annual rainfall. In Israel, Orion *et al.* (1984) reported that the highest population densities of *P. thornei* on wheat occurred during drier years.

The results of the present survey allow the identification of these wheat-producing areas in which the environmental conditions for the incidence of potentially harmful nematodes are favourable. Especially at risk are both areas in the South Western Cape Province and the Vaalharts irrigation area in the Northern Cape Province. In these areas, both the frequency of occurrence and the soil and root population densities of *M. brevidens*, *P. minor*, *P. neglectus* and *P. thornei* were high. In addition, the *Heterodera* species was also found in the Swartland and Rûens areas. With 60 % of all wheat rhizospheres sampled infested with on average almost 500 individuals/200 ml soil of *M. brevidens* and 80 % of all roots infested with on average almost 1500 individuals/5 g roots of *P. thornei*, considerable losses in yield of wheat may be suffered in the Swartland area. This area is the first where yield losses of wheat due to nematodes should be investigated.

Several of the parasitic nematode species found during the present survey are potential pathogens of wheat. The influence of at least the predominant species, especially *P. thornei* and the *Heterodera* species, on the growth and yield of this important crop in South Africa will have to be established. In South Africa, the population densities of *P. thornei* averaged 1406 and 532 individuals/5 g roots in the Swartland and Rûens areas, respectively. Although numerous abiotic and biotic factors will determine the extent of the damage caused by *P. thornei*, the observed population densities are high enough to suspect damage.

Acknowledgments

The authors thank E. Pieterse, R. Swanepoel and R. Wilken for their help with the survey, A. van Wyngaard, R. Jantjies, E. Setlhare and S. Kwena for technical assistance, K. Kleynhans for his help with identification of species and P. van Rooyen for biometrical analyses.

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