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Yield Loss Caused by *Pratylenchus thornei* on Wheat in South Australia

Julie M. Nicol,[1] Kerrie A. Davies,[2] Trevor W. Hancock,[2] and John M. Fisher[3]

Abstract: A two-year field trial with 130 plots was conducted at Tanunda, South Australia. Ten cereal cultivars differing in susceptibility to *Pratylenchus thornei,* two poor host crops (non-leguminous), and a bare fallow treatment were used to manipulate the numbers of nematodes in the plots in the first year. Initial and final densities were determined for each plot and varied from 0 to 9,400 nematodes/200 g oven-dried soil at the beginning of the second year. A highly susceptible wheat cultivar, Warigal, and two wheat lines known to have some resistance to *P. thornei,* GS50A and AUS4930, were planted in the second year. High densities of *P. thornei* caused more extensive lesions and severe cortical degradation in roots of Warigal than in GS50A or AUS4930. There was a significant linear relationship between initial density of *P. thornei* and Warigal grain yield (t/ha), with the estimated regression equation Y = 1.86 – 0.0000557x, where Y is the grain yield in t/ha and x is the number of *P. thornei*/200 g oven-dried soil. High initial densities (9,000 *P. thornei*/200 g oven-dried soil) caused up to 27% yield loss of this commercial Australian wheat. In contrast, the yield of the two resistant lines was not affected by initial density, suggesting that both were tolerant as well as resistant in the field.

Key words: cereals, nematode, *Pratylenchus thornei,* resistance, root lesion nematodes, yield loss.

Pratylenchus thornei Sher & Allen, a polyphagous, migratory endoparasitic nematode, is an important pathogen of wheat in Europe, Africa, North America, Asia, the Middle East, and Australia (Ammati, 1987; Fortuner, 1977; Greco et al., 1988; Lamberti, 1981; Maqbool, 1987; Orion et al., 1982; Troccoli et al., 1992). In Australia, *P. thornei* is widely distributed in the cereal cropping areas of Queensland, New South Wales, Victoria, and South Australia (Nicol, 1996; Pattison, 1993; Thompson et al., 1997).

Pratylenchus spp. are difficult to work with due to their migratory biology and patchy field distributions, and because the aboveground symptoms are non-specific and easily confused with other pathogen or nutritional disorders, such as *Rhizoctonia* infection or nitrogen deficiency. Infected plants generally appear stunted and unthrifty, sometimes with reduced numbers of tillers and yellowed lower leaves (Doyle et al., 1987; Van Gundy et al., 1974). Root lesions are formed on susceptible hosts with browning of the cortical tissue and cortical degradation, which can extend to the stele.

Under aseptic laboratory conditions, *P. thornei* can reduce the growth of wheat (Mardueno, 1969; Nicol, 1991; Van Gundy et al., 1974), and field studies by Thorne (1961) in Utah found stunted wheat plants with shrunken grain in the presence of *P. thornei.* Evidence from work in California (Larson, 1953), England (Jones, 1968), and Mexico (Avila, 1968; Lawn and Sayre, 1992) also suggested that *P. thornei* was associated with yield loss under field conditions. However, *P. thornei* has been reported to cause major yield reductions on susceptible, intolerant wheat cultivars of up to 32% in Sonora, Mexico (Van Gundy et al., 1974), and, in Australia, of up to 50% in New South Wales (Doyle et al., 1987), 50–85% in Queensland (Thompson and Clewett, 1986; Thompson et al., 1993), 70% in South Australia (Taylor and McKay, 1993), and 44% in Victoria (Eastwood et al., 1994). In all these studies, nematode control with nematicides was used to assess the difference in yield between treated and control plots.

While chemical control is useful for the investigation of yield relationships, results from such work may be affected by treat-

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[1] Post-Doctoral Fellow, CIMMYT International, Wheat Program, Lisboa 27, Apartado Postal 6-641, 06600, Mexico, D.F.

[2] Senior Lecturers, University of Adelaide, Waite Campus, Departments of Crop Protection and Plant Science, PMB 1, Glen Osmond, SA, 5064, Australia.

[3] Formerly Principal Lecturer, Nematology, University of Adelaide, Waite Campus, PMB 1, Glen Osmond, SA, 5064, Australia, now retired.

E-mail: jnicol@cgiar.org

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ment used (e.g., possible bromine toxicity or increased availability of nutrients after fumigation). In England, Jones (1968) found that plants grown on fumigated plots suffered bromine toxicity, making it difficult to measure the response to nematode control. Since most chemical treatments are applied before or at planting, the persistence of the treatment must be considered when dealing with a polycyclic pathogen such as *P. thornei,* together with factors such as the depth of distribution of the pathogen, the depth of chemical penetration and its efficacy, and the variation in population density of the pathogen due to changes such as soil type, moisture levels, and host status. Thus, Avila (1968) failed to show yield responses with nematicide treatments in Mexico due to low numbers of *P. thornei* in his experimental field. In many field studies, there is insufficient information on nematode population densities, particularly the numbers of *P. thornei* that cause economic yield loss. In many earlier studies no assessment of nematode populations was made or insufficient sampling prevented the determination of any relationship between the extent of nematode infection and crop yield.

Understanding the relationship between yield and initial density of the nematode is an important prerequisite to keeping the nematode density below the economic damage threshold. This relationship has been determined for other nematodes and crops (e.g., Fisher and Hancock, 1991; Phillips and Trudgill, 1985; Rivoal and Sarr, 1987). The objective of our 2-year study was to assess the relationship between wheat yield and *P. thornei* density in the field by a nonchemical approach that used resistant and susceptible plants to manipulate *P. thornei* population densities during the first year.

Materials and Methods

The two-year (1993–94) field study was conducted on a gray cracking clay at Tanunda, in the Barossa Valley, South Australia. Table 1 provides information about the cultivars planted, sowing rates, and cultivar susceptibility to *P. thornei.* Meteorological data for the trial are in Table 2. The trial received 130 kg/ha di-ammonium phosphate at sowing and appropriate herbicide treatment for control of broadleaf and grass weeds throughout the growing season. In addition, before sowing, soil samples were collected to ensure that other root diseases such as cereal cyst nematode and *Rhizoctonia* sp. were not significant.

Experimental design: In the first year of the trial, 10 replicate plots of 12 plant species and cultivars were sown alongside 10 bare fallow plots. The cultivars selected included a range of barley, oat, durum, and bread wheats as well as linseed and canola. The plots were arranged in a randomized complete-block design. The trial area was 80 m × 48 m, comprising 130 experimental plots surrounded by 62 guard plots. Each plot was 2 m × 10 m, and the area within each plot sampled for nematodes was 1.5 m × 8 m. Selection of cultivars sown in the first year was based on differing susceptibility to *P. thornei,* determined by prior laboratory screening (Nicol, 1996); these cultivars were used to produce a range of population den-

Table 1. Sowing rates and susceptibility to *Pratylenchus thornei* of cultivars used in the 2-year trial (1993, 1994) at Tanunda, South Australia.

Cultivar[a]	Seeds/ m^2	Sowing rate (kg/ha)	Susceptibility[b]
	Year 1		
Glenelg (linseed)	—	45	Low
Barossa (canola)	—	5	Low
Grimmett (barley)	200	77	Low-moderate
Echidna (oat)	250	100	Low-moderate
Yallaroi (durum)	200	87	Low-moderate
Currency (triticale)	200	92	Moderate
Tahara (triticale)	200	97	Moderate
GS50A (wheat)	200	82	Moderate
Molineux (wheat)	200	67	Moderate
Machete (wheat)	200	74	High
Spear (wheat)	200	78	High
Warigal (wheat)	200	79	High
Fallow			
	Year 2		
Warigal (wheat)	200	79	High
AUS 4930 (wheat)	200	79	Low
GS50A (wheat)	200	82	Low

[a] Cultivars selected are commonly grown in South Australia, and the sowing rates reflect common commercial practice.

[b] Susceptibility of *P. thornei* derived from laboratory screening studies (Nicol, 1996).

TABLE 2. Meterological data and management practices applied to a *Pratylenchus thornei* wheat 2-year field trial at Tanunda, South Australia.

Parameter	1993	1994–1995
Planting date	2 June	16 June
Harvest date	4 December	17 December
Initial sampling date	Pi (year 1)—17 August	Pi (year 2)—20 June 1994 Pi (year 3)—6 May 1995
Pre-harvest root sampling	6 November	9 November
Mean maximum and minimum seasonal temperatures (°C)[a]		
Summer	26.6 (25–28)–13 (12–14)	26 (25–28)–11.8 (10–13.5)
Fall	18.5 (13.5–24)–6.5 (5–8)	18.3 (14.5–22.5)–6.8 (6–8)
Winter	16 (14–17)–5.2 (5–6.5)	15.5 (14.5–17)–3.8 (3–5)
Spring	2.23 (19–24)–10 (7.5–12)	24.3 (21–29.5)–10.3 (9–12)
Mean seasonal rainfall in mm (range)		
Summer	24.3 (13–46)	13.6 (1–30)
Fall	33.3 (4–76)	39 (4–80)
Winter	56.6 (38–73)	28.3 (16–46)
Spring	54.3 (45–71)	30 (4–44)
Total rainfall	168.5	110.9

[a] All climatic data obtained from the South Australian Bureau of Meteorology, Adelaide.

sities in individual field plots. In the first year of the trial, the initial *P. thornei* density (P_i [year 1]) in each plot was determined at the start of the season, and grain yield was measured from each at the end of the season.

In the second year, 30 plots each of AUS4930 and GS50A wheats were sown in randomly selected positions across the trial, so that each was exposed to a range of *P. thornei* densities established in the previous year. GS50A is a *P. thornei*-resistant selection from Australia (Thompson and Clewett, 1986). AUS4930 has shown resistance to *P. thornei* in previous laboratory screening (Nicol, 1996) and has single-gene resistance to Australian populations of *Heterodera avenae* (F. Green, pers. comm.). The remaining 70 plots were sown to a known susceptible and intolerant South Australian wheat cultivar, Warigal. Densities of *P. thornei* were recorded for each plot as soon as possible after planting for 3 consecutive years, and the densities recorded after planting in years 2 and 3 were considered as the post-harvest densities for years 1 and 2, respectively. In addition, final grain yield was determined in each plot for the first 2 years.

Sampling and analysis of soil P. thornei *populations:* Soil was sampled to a depth of 20 cm, as most *P. thornei* in South Australia are located in the 0- to 20-cm soil horizon (Taylor and Evans, 1998). A modified soil corer was used based on the model described by Thompson et al. (1988). Fourteen cores spaced 1 m apart were taken from each plot, with samples taken in approximately the same position each year (between plant rows 3 and 4 and 7 and 8). The number of cores per plot required for accurate estimation of the numbers of nematodes was assessed before the trial began (Nicol, 1996). Soil samples were taken as early in the season as possible, when the soil was moist enough to allow use of the corer. For each plot, cores were bulked and nematodes were extracted from a 200-g subsample in a Whitehead tray (Southey, 1986) over a 2-day period at room temperature. The nematodes were collected, the volume of the suspension was reduced to approximately 20 ml, and the number of *P. thornei* per 200 g oven-dried soil was estimated from a 1-ml subsample.

Plant parameters: A number of plant characters were assessed after anthesis. In the first year, random samples of three plants were taken on 6 November from the plots with the highest and lowest initial densities of *P. thornei* for the 12 crop treatments and the fallow. In the second year, three plants of each of the three different wheats were

sampled on 9 November from the plots with the five highest and lowest initial densities of *P. thornei*. The roots of the plants taken from each plot were washed and combined and the nematodes were extracted for 3 days in a mist chamber (Southey, 1986), after which the numbers of nematodes were counted in a 1-ml subsample from a bulk of approximately 20 ml. In the second year of the trial, toward the end of the season (9 November), quantitative measurements were made on 10 plants from each plot, selected at random from each of the five highest and lowest initial-density plots (with each plot considered as an individual replicate). Measurements included maximum height of plants, length of individual heads, and number of tillers. For both years, the final grain yield was determined in each experimental plot.

Results

Numbers of nematodes in plant roots: The data for samples of roots from both years were analyzed separately as an analysis of variance. The number of *P. thornei* per plant showed heterogeneity of variance so the data were $\log_e (x + 1)$ transformed for both years. In the first year, there were no significant differences in initial density of *P. thornei* to which the 12 plant cultivars were exposed. In the second year of the trial there was a significant interaction of cultivar and initial *P. thornei* density on the numbers of nematodes found in hosts after anthesis (Table 3); however, the mean numbers of nematodes in individual cultivars were not significantly different. Within cultivars, roots of Warigal contained significantly more *P. thornei* at high than at low initial densities, but differences for AUS4930 and GS50A were not significant.

Effects of nematodes on plant growth: In the first year, most of the wheat root systems had lesions with cortical degradation on nodal, lateral, and seminal roots, and the weights of the root systems were less at high than at low initial densities (particularly with the cultivars Spear, Machete, and Warigal, three of the most commonly grown South Australian wheat cultivars). In contrast, exposure to a range of population densities of *P. thornei* caused no differences in the size or degree of lesioning of the root systems of linseed and canola. Triticale, barley, and oat had some root lesions, but there was no apparent relation between size of the root systems and initial densities of *P. thornei*.

Analysis of the quantitative growth characters during the second year of the trial is in Table 4. There was no significant interaction between cultivar and initial nematode density for any variable, but plant height, head length, and tiller number were significantly different between cultivars. The unadapted landrace AUS 4930 was more vigorous and had more tillers than either GS50A or Warigal.

Initial densities of *P. thornei* affected root symptoms of the three cultivars grown in the second year differently. Warigal suffered greater cortical degradation and lesioning at high Pi (9,000 *P. thornei*/200 g oven-dried soil) than at low Pi (40 *P. thornei*/200 g oven-dried soil). GS50A, with putative resistance to *P. thornei*, showed some lesioning and reduced root volume at high Pi (9,500 *P. thornei*/200 g oven-dried soil) relative to plants grown at low Pi (60 *P. thornei*/200 g oven-dried soil). In contrast, AUS4930, also

Table 3. Effect of interaction between wheat cultivars and initial nematode densities on the numbers of *Pratylenchus thornei* extracted from roots after anthesis, 1994.[a]

Initial density/plot	AUS4930	GS50A	Warigal
High	6.55	6.65	8.00
Low	5.80	5.95	4.22

[a] Means of $\log_e(x + 1)$ *P. thornei* per plant in each column are considered to be statistically different if mean differences are greater than the Standard Error of Difference (SED) of 0.96.

Table 4. Differences in development of three wheat cultivars before harvest, 1994.

Growth parameters	AUS4930	GS50A	Warigal	SED[a]
Plant height (cm)	74.93[a]	63.30	57.76	1.30
Seed heads per plant	9.37	7.40	7.35	0.22
Tillers per plant	7.62	4.48	3.01	0.36

[a] Means in a row are considered to be statistically different if the difference between means exceeds the Standard Error of Difference (SED).

thought to be resistant to *P. thornei,* showed little evidence of nematode attack at either high or low Pi (2,500 or 10 *P. thornei*/200 g oven-dried soil).

Relationship between nematode density and plant yield: The initial soil density of *P. thornei* for each individual plot in the first year was regressed against the grain yield for the plot within each of the cultivars. Only Machete and Spear had significant linear relationships ($P < 0.05$) between density and yield, with yield decreasing as nematode density increased (Fig. 1A).

An analysis of variance was used to compare the yields of the three wheat cultivars used in the second year to test whether the plants grown in the first year had influenced the results in 1994. There was no significant effect of treatment (plant cultivar in year 1) on yield in year 2 ($P < 0.05$). Therefore, a

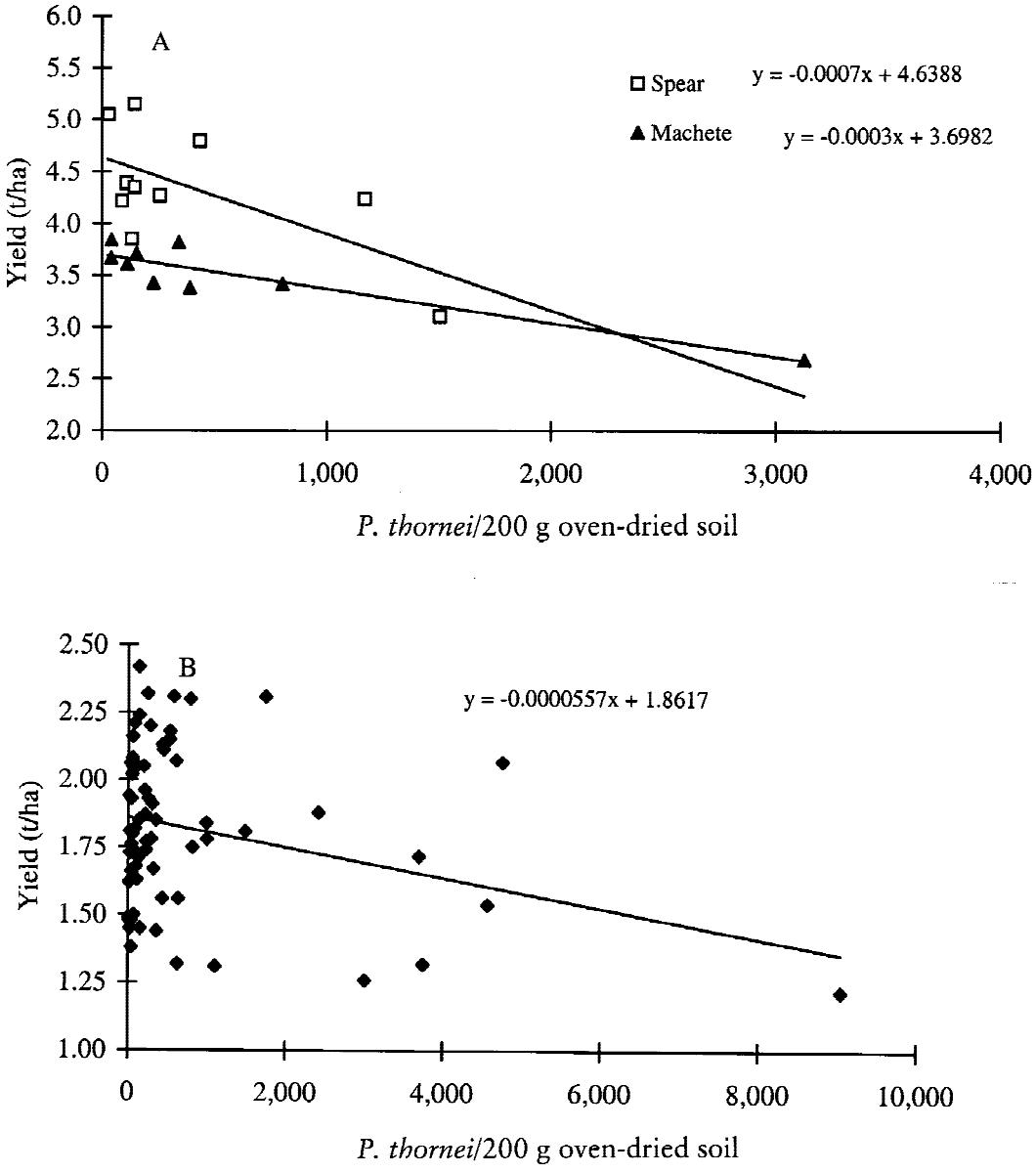

FIG. 1. Relationship between initial density of *Pratylenchus thornei* and grain yield of wheat cultivars. A) Machete and Spear wheats, 1993. B) Warigal wheat, 1994.

regression analysis of *P. thornei* Pi for the second year of the trial against the individual plot yields for AUS4930, GS50A, and Warigal was conducted. Yields of the resistant wheats were not significantly related to Pi (year 2), but the relationship was significant ($P < 0.05$) for Warigal, with yield decreasing as initial density increased (Fig. 1B).

Relationship between initial and final nematode density: Regression analysis of the initial vs. the final *P. thornei* density for 1994 was carried out for all three wheat cultivars used in the second year of the trial. Both AUS4930 and GS50A had significant linear relationships between initial and final *P. thornei* densities ($P < 0.05$) (Fig. 2). In contrast, a quadratic relationship was more appropriate for Warigal (Fig. 2). Population densities of *P. thornei* were dramatically decreased under GS50A and AUS4930 with multiplication rates of 0.375 and 0.276, respectively, and were increased strongly with a mean rate of 3.88 under the susceptible host Warigal. No statistical analysis of multiplication rates was performed because multiplication rate is highly dependent on initial density. The maximum multiplication rates were observed for Warigal and were up to 20–30× at low densities but were generally much less at higher initial densities (Fig. 3).

Discussion

Instead of using nematicides or artificial infestations to establish varying population densities in plots, a range of initial nematode densities was created by growing plants with different susceptibilities. This method was used successfully to evaluate the effect of *P. thornei* on yield in the field. Elston et al. (1991) used a similar method to manipulate population densities of *Globodera pallida* by growing a range of resistant and susceptible potato genotypes in a field in Scotland.

The symptoms caused by *P. thornei* were comparable to those described previously (Doyle et al., 1987; Fulton, 1960; Van Gundy et al., 1974). Damage was more extensive on the susceptible wheats Warigal, Spear, and Machete than on resistant AUS4930 and GS50A. Barley, triticale, and other nonleguminous hosts suffered less damage. Microscopic examination of stained roots

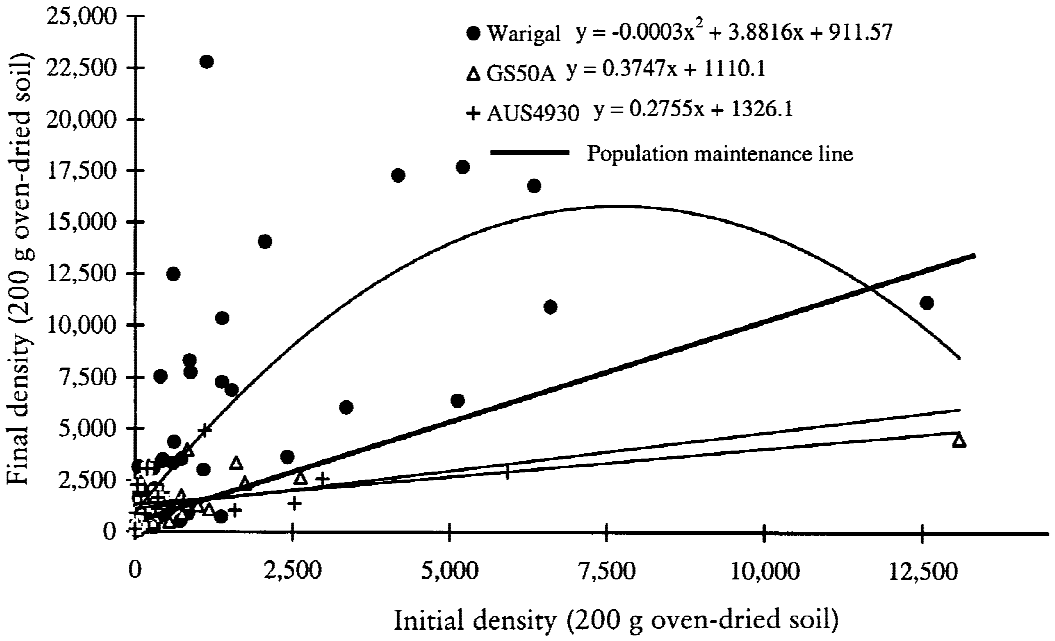

Fig. 2. Relationship between the initial and final densities of *P. thornei* with three different wheats in the second year (1994) of a field trial.

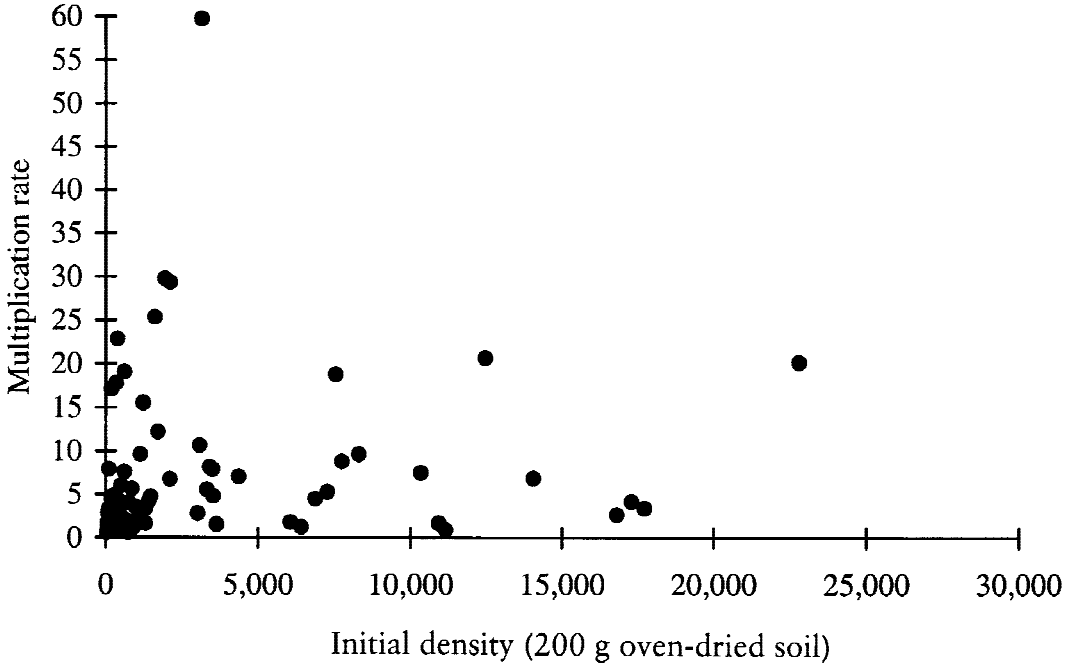

FIG. 3. Relationship between initial density and multiplication rate of *P. thornei* on Warigal wheat in the second year (1994) of a field trial.

(Southey, 1986) showed that *P. thornei* nematodes and eggs were usually situated in the cortex, parallel to the long axis of the root. Plants grown in plots with high initial densities, particularly the wheats susceptible to *P. thornei,* had more severe cortical degradation.

The results of this 2-year field study indicate that *P. thornei* can damage wheat under South Australian conditions. A range of initial densities of *P. thornei* was produced in the field by using various cereals differing in susceptibility, two poor non-leguminous hosts, and fallow. There was no indication that the 12 different plant treatments or the fallow treatment used in the first year affected yield in the second year.

The primary aim of the first year of the trial was to manipulate nematode numbers. However, it was also found that *P. thornei* significantly reduced yield of two commonly grown, susceptible wheats: Spear (38% reduction with 1,500 *P. thornei*/200 g oven-dried soil) and Machete (27% reduction with 3,100 *P. thornei*/200 g oven-dried soil). Similar trends may have occurred with some of the other cereals grown, but the naturally occurring range of initial densities may not have been broad enough to make differences apparent as there were only 10 pairs of values for each regression. In the second year, Warigal wheat was highly susceptible to and intolerant of *P. thornei,* with yield losses of 3% at low initial densities (1,000 *P. thornei*/200 g oven-dried soil) and 27% at higher initial densities (9,000 *P. thornei*/200 g oven-dried soil). This regression was more powerful than those for Machete and Spear in the first year, being based on 70 individual points with a far greater range of initial *P. thornei* densities.

The relationship between initial *P. thornei* densities and the yield losses of the wheat cultivars Warigal, Spear, and Machete found in this 2-year field trial suggest damage thresholds higher than those previously reported. Thompson et al. (1993) suggested that populations of 500 *P. thornei*/200 g oven-dried soil in Queensland were associated with economic yield loss in intolerant wheats. In New South Wales, populations of 500–1,000 nematodes/200 g oven-dried soil

caused yield loss, while greater numbers caused serious economic losses (Pattison, 1993). Taylor and McKay (1993) showed that populations of 750 *P. thornei*/200 g oven-dried soil resulted in yield losses of up to 70% in South Australia. Losses of about 14% occurred in sandy soil on Eyre Peninsula in South Australia when initial populations were 660 *P. thornei*/200 g oven-dried soil (Vanstone et al., 1998). The higher damage threshold suggested by the Tanunda trial could be associated with environmental factors such as rainfall, soil type, and fertility as well as type and efficiency of the techniques used to quantify nematodes. Also, the damage threshold for Warigal was much greater in the second year of the trial than for either Machete or Spear in the first, which may reflect differences in the tolerance level of the cultivars or better cropping conditions in the second year. The relationship between the initial *P. thornei* density and the multiplication rate on the three wheat cultivars in the second year of the trial is shown in Fig. 3.

The equilibrium density depends on environmental conditions as well as inherent characteristics of nematodes and host plants (Seinhorst, 1967). In this trial, the equilibrium density on the susceptible wheat Warigal was about 12,000 *P. thornei*/200 g oven-dried soil, which is higher than previously reported. Pattison (1993) found an equilibrium density of approximately 2,000 *P. thornei*/200 g oven-dried soil in New South Wales. Seinhorst (1967) found that *P. crenatus* reached a maximum of 2,400 nematodes/200 g oven-dried soil on cereals, but the equilibrium density varied widely in different fields during 7 consecutive years of observation in The Netherlands. Several seasons of data likely are required for good estimates of equilibrium densities and results probably should be based on averages, but with the understanding that the estimates will change with environmental conditions. The higher equilibrium density found at Tanunda also may have been due to more efficient extraction of nematodes from the soil.

As damage caused by root-feeding nematodes is proportional to their population density (Seinhorst, 1965), information about damage thresholds is required, together with management strategies to decrease populations to below densities threatening the next susceptible crop. Unfortunately, at the Tanunda site, data points were concentrated at the lower end of initial *P. thornei* densities, providing only a narrow range of nematode densities. Hence, no attempt was made to fit models such as those used by Elston et al. (1991) and Seinhorst (1965), and only linear and lower-order polynomial models were considered. For practical purposes, the linear relationship between initial *P. thornei* density and yield of Warigal indicated that if a 10% yield loss were considered economically unacceptable, then the nematode populations would need to be less than approximately 6,000/200 g oven-dried soil.

Resistance offers the most economical and environmentally favorable method for maintenance of nematode populations below the economic threshold for damage. To date, few plants with resistance to *P. thornei* have been identified (O'Brien, 1983; Van Gundy et al., 1974), with the exception of the line GS50A, which appears to be both resistant and tolerant (Thompson and Clewett, 1986). Our field trial confirms the resistance of GS50A and identifies a new source, AUS4930. The latter is particularly interesting because its resistance acts against both *P. thornei* and *H. avenae* pathotypes originating from Australia, Europe, and North Africa (Bekal et al., 1998; F. Green, pers. comm.).

While the initial and final densities, measured for both AUS4930 and GS50A over the second year of the field trial, provide evidence of resistance, plants sampled late in the season showed no significant differences in nematode numbers among cultivars (Table 3). Jones and Kempton (1978) experienced similar problems and suggested that populations of nematodes should be assessed at the start of the season and again 1 year later.

The resistance mechanism in AUS4930 and GS50A is unknown, and it is also pos-

sible that the seed planted was not completely homozygous for *P. thornei* resistance, particularly with the land race AUS4930. Thus, further selection may be required to establish pure lines.

The confirmation of field resistance to *P. thornei* in GS50A and the identification of a new source, AUS4930, resistant against *P. thornei* and *H. avenae* suggest that there is opportunity for development of control strategies to be used with rotations. Investigations to clarify the genetics and mechanism of the resistance occurring in these sources, and their incorporation into breeding programs, should be seen as priorities for future work.

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