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Damage potential and reproduction of *Heterodera avenae* on wheat and barley under Saudi field conditions

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Summary – This study was conducted to determine the effect of *H. avenae* initial population densities (*Pi*) on the yield of wheat (two growing seasons) and barley (one season) and on nematode reproduction, under Saudi field conditions. At increasing *Pi*, *H. avenae* suppressed ($P \leqslant 0.05$) the number of spikes, weight of spikes, weight of 1000 kernels, grain yield and straw yield of wheat and barley. Grain yields were reduced by 40 to 92% for wheat (during the two seasons) and 17 to 77% for barley. Straw yields were also reduced, by 50 to 85 for wheat and 30 to 77% for barley. As *Pi* increased, final populations of *H. avenae* increased ($P \leqslant 0.05$) on both hosts, but the nematode reproduction factor (*Rf*) decreased. Significant negative linear regressions were obtained between *H. avenae Pi* and grain yield of wheat and barley. Final populations (*Pf*) were positively correlated with *Pi* on wheat and on barley. *Rf* was negatively correlated with *Pi* on wheat and barley.

Zusammenfassung – ***Schädigungspotential und Vermehrung von* Heterodera avenae *an Weizen und Gerste unter Freilandbedingungen in Saudiarabien*** – Die vorliegende Untersuchung wurde durchgeführt, um die Wirkung unterschiedlicher Ausgangspopulationen (*Pi*) von *Heterodera avenae* auf den Ertrag von Weizen (zwei Vegetationsperioden) und Gerste (eine Vegetationsperiode) sowie auf die Vermehrung der Nematoden unter saudiarabishen Freilandbedingungen zu ermitteln. Bei steigender *Pi* verminderte ($P \leqslant 0.05$) *H. avenae* die Anzahl der Ähren, das Ährengewicht, das Tausendkorngewicht, den Korn- und den Strohertrag von Weizen und Gerste. Die Kornerträge wurden bei Weizen (zwei Vegetationsperioden) um 40-92% vermindert, bei Gerste um 17-77%. Auch die Stroherträge gingen zurück, bei Weizen um 50-85% und bei Gerste um 30-77%. Mit zunehmender *Pi* stiegen die Endpopulationsdichten von *H. avenae* bei beiden Wirtspflanzen an ($P \leqslant 0.05$), doch nahm der Vermehrungsfaktor (*Rf*) der Nematoden ab. Zwischen *Pi* von *H. avenae* und dem Kornertrag von Weizen und Gerste wurden signifikante negative Regressionen erhalten. Die Endpopulationen (*Pf*) waren an Weizen und Gerste positiv korreliert mit *Pi*. *Rf* war an Weizen und Gerste negativ korreliert mit *Pi*.

Keywords – cereal cyst nematode, grain yield, *Hordeum vulgare*, Saudi Arabia, straw yield, *Triticum aestivum*.

The cereal cyst nematode (CCN), *Heterodera avenae* Woll., has been reported as the most prevalent and damaging nematode to wheat and barley in different parts of the world (Holdeman & Watson, 1977; Meagher, 1977). More recently, CCN has been reported on wheat and barley in Saudi Arabia, where most of the wheat and barley cultivars grown in Saudi fields were found to be susceptible (Al-Hazmi, 1992; Al-Hazmi *et al.*, 1994; El-Meleigi & Al-Rokibah, 1996).

The relationship between the initial population density (*Pi*) of CCN and growth and yield of wheat and barley is very important in determining the economic impact on these crops. It has been estimated that every increase of 10 eggs/g soil of *H. avenae* causes yield losses of 188 kg/ha of wheat and 75 kg/ha of barley in the UK (Dixon, 1969). In the temperate semi-arid regions of Australia, a somewhat similar climate to that of Saudi Arabia, *H. avenae* decreased the yield of wheat and barley by 20% at a *Pi* of 2 eggs and juveniles/g soil, and 40% at 16 eggs and juveniles/g soil (Meagher & Brown, 1974). The damage threshold of *H. avenae* in the temperate semi-arid regions of Asia is considered to be 5-20 eggs and juveniles/g soil for wheat and barley in India (Gill & Swarup, 1971; Dhawan & Nagesh, 1987). At 100-150 cysts/plant on barley in Pakistan, all root and shoot growth was inhibited (Shahina & Maqbool, 1990).

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In pot and concrete-tube experiments in Slovakia, *H. avenae* at 180 cysts/kg soil suppressed grain yield by 17-44% for wheat and 20-32% for barley, and straw yield by 2-32% and 20-26%, respectively (Sabova *et al.*, 1981). Reductions of wheat and barley yields by *H. avenae* have also been reported from Germany (Sachse, 1986), Libya (Siddiqui & Khan, 1986), India (Dhawan & Nagesh, 1987), France (Rivoal & Sarr, 1988), Pakistan (Shahina & Maqbool, 1990), Spain (Romero *et al.*, 1988), Italy (Greco *et al.*, 1993), China (Zhang *et al.*, 1994), and Morocco (Rammah, 1994).

Studies on the relationship between initial population densities of *H. avenae* and nematode reproduction on wheat and barley showed significant negative correlations (Dhawan & Nagesh, 1987). Generally, initial nematode population densities (*Pi*) greatly affect the reproductive rate of *H. avenae*; the final number of eggs and juveniles (*Pf*) increases with increasing *Pi* but the reproductive rate decreases (Magi, 1989).

The objective of this work was to determine the effects of initial nematode population density of *H. avenae* on the yield of wheat and barley and on nematode reproduction under the local field conditions of Saudi Arabia.

Materials and methods

The effects of different (*Pi*) of CCN on the yield of wheat cv. Yecora Rojo and barley cv. Justo, as well as on nematode reproduction, were determined in the field over two consecutive growing seasons for wheat, and only one growing season for barley. Wheat and barley fields (50 ha each), which were naturally infested with different population densities of *H. avenae*, were selected in the agricultural region of Al-Kharj, near Riyadh in central Saudi Arabia. The soil of these two adjacent fields is mostly loamy sand, with pH 7.5, EC 6.46 ds m^{-1}, 0.67% organic matter, 82% sand, 4% silt, and 14% clay. The two fields were cultivated with monocultures of wheat or barley for several seasons under irrigation.

Based on levels of infestation in the previous season, infested and non-infested experimental sites in both fields were selected. At planting, sites with varying levels of infestation were sampled and plots were then selected to give a range of *Pi* (Table 1). Plots free of nematodes were designated as controls. Five replicated plots (1 m^2) were defined for each *Pi*.

For sampling, composite soil samples, each of five to seven random cores (5.5 cm diam.) to a depth of 20-30 cm, were collected from each plot at planting to determine *Pi*, and also at harvest (140 days after sowing) for *Pf*. Each soil sample was thoroughly mixed and a 250 g subsample was taken and processed to extract cysts by the method described by Krusberg *et al.* (1994). However, a 38 μm pore sieve was added to the nested 850 and 250 μm pore sieves to collect second-stage juveniles (J2) which were then extracted by the modified centrifugal floatation technique described by Barker (1985).

Cysts from each sample were picked into a beaker and crushed in 20 ml of tap water. The egg suspension was then stirred on a magnetic stirrer, and two 1 ml samples were removed by automatic pipetter to count eggs (Seinhorst & Den Ouden, 1966). *Pi* and *Pf* were expressed as the number of J2 + mean number of encysted eggs/100 g soil. Reproduction factors ($Rf = Pf/Pi$) were also calculated.

During the growing season, all cultural practices commonly used by the local growers, including irrigation with a central pivot system, were followed. At harvest, all plants within each plot were removed manually and data on the yield components (number of spikes/m^2, weight of spikes, weight of 1000 kernels, total grain yield/m^2, and total straw yield/m^2) were recorded.

Data from each harvest were subjected to ANOVA, and means were separated by Fisher's protected LSD. Regression analyses were also performed on data from wheat (second season) and barley to describe the relationship of *Pi vs* grain yield, *Pf*, and *Rf* (SAS, 1989).

Results

H. avenae suppressed ($P \leqslant 0.05$) straw yield, and the various components of grain yield of wheat cv. Yecora Rojo and barley cv. Justo (Table 1). Percent reductions in grain yield of wheat ranged between 40 and 92% (during the two seasons), and for barley from 17 to 77%. Straw yield was also reduced, by 50 to 85% for wheat and by 30 to 77% for barley. Reduction in the grain yield of wheat in the first season was greater than in the second season. Generally, as *Pi* of *H. avenae* increased, grain and straw yields of wheat and barley decreased (Table 1).

As the initial population densities of *H. avenae* increased, the final nematode populations at harvest (*Pf*) increased ($P \leqslant 0.05$) on both crops, but the nematode reproductive factors (*Rf*) decreased ($P \leqslant 0.05$) (Table 2).

Regression analyses showed that grain yield of wheat was negatively correlated with *Pi* ($y = 582 - 0.13\,Pi$, $r^2 = 0.87$, $P \leqslant 0.001$). Similarly, a negative response to *Pi* was obtained for grain yield of barley ($y = 406 -$

Table 1. *Effects of cereal cyst nematode,* Heterodera avenae, *on growth and yield of wheat (cv. Yecora Rojo) and barley (cv. Justo), under field conditions.*[1]

Initial nematode density (Pi)[2]	No. of spikes per m^2	Weight of spike (g)	Weight of 1000 kernels (g)	Grain yield		Straw yield	
				(g/m^2)	% reduction	(g/m^2)	% reduction
Wheat (first season)							
0	737 *a*	1.26 *a*	40.7 *a*	999 *a*	–	1408 *a*	–
1140	338 *b*	1.06 *b*	37.1 *b*	209 *b*	79	363 *b*	74
3180	347 *b*	0.59 *c*	25.2 *c*	76 *c*	92	210 *c*	85
Wheat (second season)							
0	545 *a*	1.14 *a*	43.9 *a*	620 *a*	–	993 *a*	–
1590	330 *b*	1.07 *b*	37.0 *b*	371 *b*	40	493 *b*	50
2340	234 *c*	0.86 *c*	32.6 *c*	202 *c*	67	381 *bc*	62
3960	243 *c*	0.52 *d*	30.0 *d*	123 *d*	80	308 *c*	69
Barley (one season)							
0	248 *a*	1.54 *a*	35.8 *a*	380 *a*	–	711 *a*	–
1620	232 *a*	1.36 *b*	37.6 *a*	314 *b*	17	495 *b*	30
3390	155 *b*	0.56*c*	36.7 *a*	89 *c*	77	161 *c*	77

[1] Values are means of five replicates. Means in a column, for each crop and season, followed by the same letter are not different ($P \leqslant 0.05$) according to Fisher's protected LSD.

[2] Pi = no. of J2 + mean number of encysted eggs/100 g soil, at the begining of the experiment.

Table 2. *Effect of initial population density of the cereal cyst nematode,* Heterodera avenae, *on its reproduction on wheat (cv. Yecora Rojo) and barley (cv. Justo), under field conditions.*[1]

Initial nematode density (Pi)[2]	Nematode counts/100 g soil			Reproduction factor Pf/Pi
	J2	Cysts	Pf[3]	
Wheat (first season)				
1140	196 *a*	59 *a*	8370 *a*	7.34 *a*
3180	403 *b*	121 *b*	17 250 *b*	5.42 *b*
Wheat (second season)				
1590	27.2 *a*	76 *a*	15 960 *a*	10.05 *a*
2340	65.2 *b*	90 *b*	19 170 *b*	8.20 *b*
3960	95.0 *c*	121 *c*	25 300 *c*	6.38 *c*
Barley (one season)				
1620	136 *a*	113.0 *a*	20 590 *a*	12.72 *a*
3390	822 *b*	141 *b*	26 270 *b*	7.75 *b*

[1] Values are means of five replicates. Means in a column, for each crop and season, followed by the same letter are not different ($P \leqslant 0.05$) according to Fisher's protected LSD.

[2] Pi = no. of J2 + mean number of encysted eggs/100 g soil, at the begining of the experiment.

[3] Pf = no. of J2 + mean number of encysted eggs/100 g soil, at the end of season (140 days after sowing).

0.09 Pi, $r^2 = 0.85$, $P \leqslant 0.001$) (Fig. 1A, B). The nematode final population (Pf) was positively correlated with Pi on wheat ($y = 9860 + 3.9\ Pi$, $r^2 = 0.81$, $P \leqslant 0.001$), and on barley ($y = 15400 + 3.2\ Pi$, $r^2 = 0.50$, $P \leqslant 0.02$) (Fig. 1C, D). However, Rf was negatively correlated with Pi on wheat ($y = 12.1 - 0.002\ Pi$, $r^2 = 0.72$, $P \leqslant 0.001$), and on barley ($y = 17.3 - 0.003\ Pi$, $r^2 = 0.76$, $P \leqslant 0.001$) (Fig. 1E, F).

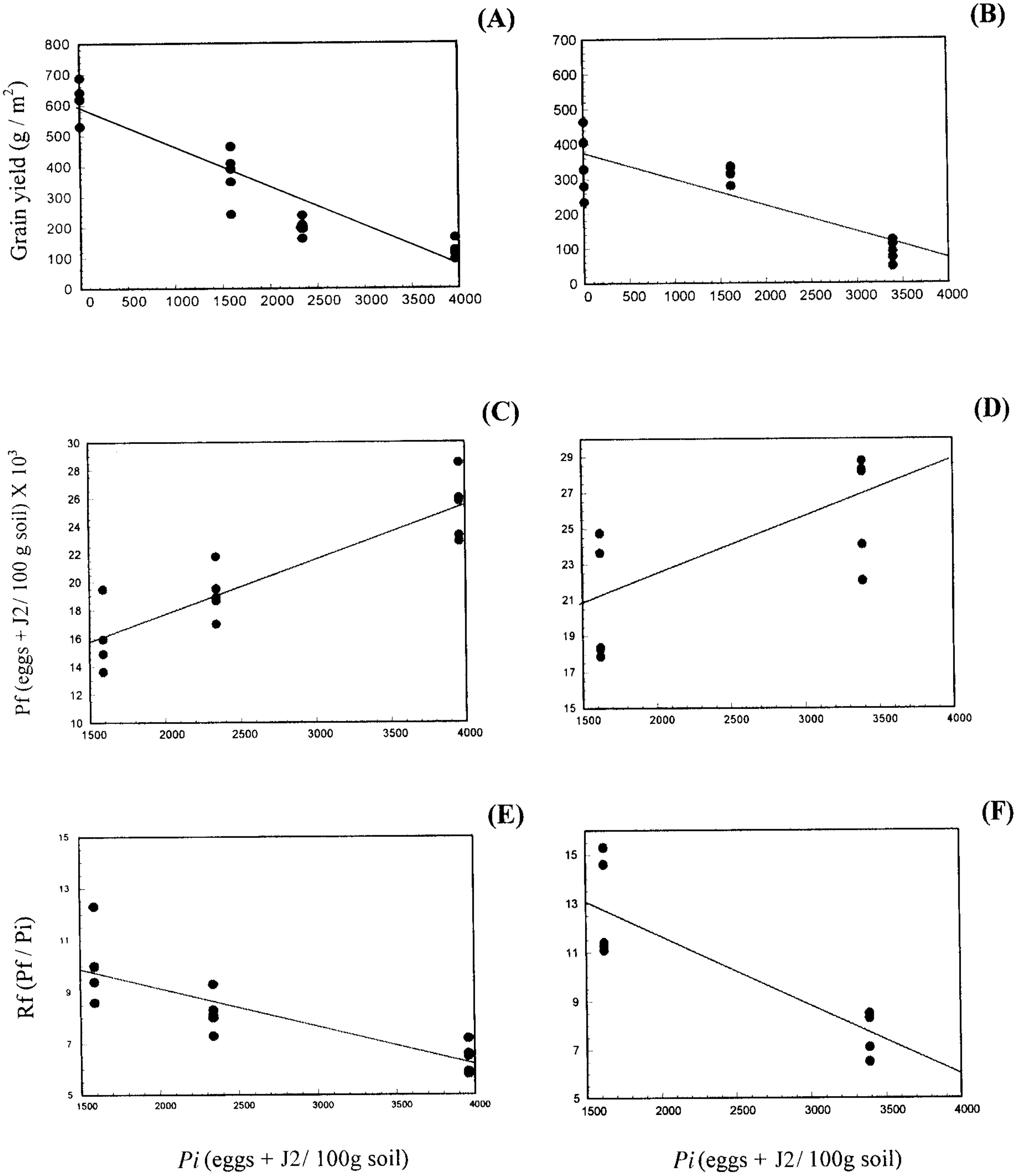

Fig. 1. *Relationship between initial population densities* (Pi) *of* Heterodera avenae *and A: grain yield of wheat cv. Yecora Rojo* ($y = 582 - 0.13$ Pi, $r^2 = 0.87$, $P \leqslant 0.001$)*; B: grain yield of barley cv. Justo* ($y = 406 - 0.09$ Pi, $r^2 = 0.85$, $P \leqslant 0.001$)*; C: nematode final population* (Pf) *on wheat* ($y = 9860 + 3.9$ Pi, $r^2 = 0.81$, $P \leqslant 0.001$)*; D: nematode final population* (Pf) *on barley* ($y = 15400 + 3.2$ Pi, $r^2 = 0.50$, $P \leqslant 0.02$)*; E: nematode reproductive factor* (Rf) *on wheat* ($y = 12.1 - 0.002$ Pi, $r^2 = 0.72$, $P \leqslant 0.001$)*; F: nematode reproductive factor* (Rf) *on barley* ($y = 17.3 - 0.003$ Pi, $r^2 = 0.76$, $P \leqslant 0.001$).

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Discussion

Our study indicated that *H. avenae* has great potential to damage and reproduce on wheat cv. Yecora Rojo and barley cv. Justo. The nematode, even at the lowest *Pi*, caused substantial reduction of grain yield of wheat and barley. The same trend was found with straw yields of both crops. As the initial population density of *H. avenae* increased, losses in the grain and straw yields of wheat and barley greatly increased. These results indicate that CCN is a serious pathogen and therefore potentially a limiting factor in the production of wheat and barley in Saudi Arabia. Since *H. avenae* is widely distributed throughout the wheat and barley growing regions in the Kingdom (Al-Hazmi, 1992; Al-Hazmi *et al.*, 1994; El-Meleigi & Al-Rokibah, 1996), and wheat cv. Yecora Rojo and barley cv. Justo (the most popular cultivars) are grown in monoculture by most local growers, the problem of CCN is becoming more serious. Our results on the yield reduction of wheat and barley by *H. avenae* are in agreement with several reports from different parts of the world (Dixon, 1969; Brown, 1984; Brennan & Murray, 1988). For example, *H. avenae* caused grain yield losses of about 40-50% of wheat in Morocco (Rammah, 1994), 20-40% of wheat and barley in Australia (Meagher & Brown, 1974), and up to 90% of wheat in Spain (Romero *et al.*, 1988).

H. avenae, at increasing *Pi*, decreased the yield components of wheat and barley. Previous reports have concluded that losses in the grain yield of wheat and barley caused by *H. avenae* are mainly due to the reduction of the number of spikes/m^2, number and weight of grains/spike, and weight of 1000 kernels (Goent, 1982; Romero *et al.*, 1988; Romero *et al.*, 1991; Zancada & Althofer, 1994). However, we have found in an earlier study (Al-Yahya *et al.*, 1998) that CCN caused disturbances in certain growth and physiological aspects of infected wheat plants including the suppression of root growth, total chlorophyll content, concentration of N, Fe, Mn and Cu in shoots, intercepted light by leaves, and an increase of the plant canopy temperature. Certainly, these disturbances play a major role in grain yield loss. Although, the two fields were under irrigation and well fertilized, the efficiency of the infected roots in soil exploration and uptake of minerals and water was probably greatly reduced. This would increase the hydric stress during the day resulting in higher plant canopy temperature (Nicolas *et al.*, 1991; Al-Yahya *et al.*, 1998). Furthermore, synchronization between hatching of CCN and the sowing period of wheat and barley, as has been found under mediterranean conditions (Rivoal, 1982) would result in heavy early infection and crop losses.

The substantial reduction of the grain and straw yields of wheat and barley found in this study indicates that even the lowest *Pi* (11.4 eggs and J2/g soil), exceeded the damage threshold level. Similar findings were reported from India (Gill & Swarup, 1971; Dhawan & Nagesh, 1987) and Australia (Meagher & Brown, 1974). However, it is well established that the damage threshold varies greatly with plant cultivar, soil type, pathotype and ecotype of nematodes, and climatic conditions within a geographical area (Rivoal & Sarr, 1988). The pathotype of our CCN population was found to be very similar to that of Ha21 (Cook & Al-Hazmi, 1997).

H. avenae reproduced readily on both wheat and barley cultivars and *Pf* increased as *Pi* increased, with *Rf* ranging between 5.4 and 12.7. Generally, the reproductive rate was higher on barley than on wheat, which support the findings of Wolny (1990) and Al-Hazmi *et al.* (1994). Although *Pf* increased with *Pi*, reproductive factors on both cultivars were negatively correlated with *Pi*, as has been previously reported (Rivoal & Sarr, 1988; Magi, 1989). This could be attributed to the competition for feeding sites and the greater damage of infected roots with increasing *Pi*, which decreases the suitable area of the roots for nematodes to infect, establish and reproduce.

Our study shows that CCN is a real threat to Saudi Arabian wheat and barley production and suggests that we urgently need to develop or introduce resistant, or at least tolerant cultivars, as well as to develop effective integrated control strategies to protect our cereal crops.

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