Proc. Estonian Acad. Sci. Biol., 1989, 38, N 3, 189—194
https://doi.org/10.3176/biol.1989.3.06
УДК 632.651

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THE RELATIONSHIPS BETWEEN THE CEREAL CYST NEMATODE POPULATION DENSITY, BARLEY YIELD AND NEMATODE MULTIPLICATION IN FIELD PLOTS

The relation between the initial population density of a nematode and the damage it causes to plants has been described as a linear regression between log nematode density and weight or length of the damaged plants (Jones, 1956; Hesling, 1957; Seinhorst, 1960). Most plant root parasitic nematodes decrease the size of the root or leaf system. In this way in many crops the yield of leaf tissue, grain or tubers is affected indirectly. J. W. Seinhorst (1965) derived a mathematical equation and calculated regression coefficients to predict the relation between the density of stem nematode *Ditylenchus dipsaci* and the productiveness of onion plants. S. Andersson (1984) showed that Seinhorst's equation proved to be sufficiently satisfactory for predicting the yields of potatoes, when yields were related to initial densities of the potato cyst nematode *Globodera rostochiensis*.

Density-dependence of population growth has been well documented for *Globodera rostochiensis* in the field (Jones, 1965; Ward et al., 1985) and in the glasshouse (Seinhorst, 1966, 1967; Jones, Perry, 1978; Phillips, 1984). Davies and Fisher (1976) found with cereal cyst nematode *Heterodera avenae* that at low and medium inoculum densities the percentage of invading juveniles was strongly density dependent but remained constant at higher inoculum densities. J. W. Seinhorst (1967) derived a model for the relation between the initial population density and the rate of increase of sedentary nematodes.

In this study the Seinhorst's equation (1965) was applied to calculate the expected grain yield of barley in relation to initial population density of the cereal cyst nematode (*Heterodera avenae* Wollenweber) in soil. The second purpose of this study was to investigate the reproduction of the cereal cyst nematode in the Estonian SSR and to predict the population density in autumn according to Seinhorst's equation (1967).

Material and methods

The population studies of the cereal cyst nematode were carried out in a barley field at Koruste in Tartu district in the years 1984—1986. Twenty-five microplots, each 1 m² in size, were laid out every year. One-kilogramme soil sample was taken from each plot twice a season: in spring after sowing and in summer before harvesting. At the same time the grain weight and number of grains were estimated in the plots before harvesting. After drying, the soil samples were stored until the following winter, when the cysts were extracted from soil and the cyst contents were counted under a binocular dissecting microscope.

After logarithmic transformation the relationships between the initial (P_i) and final (P_f) population densities, the reproduction rate (P_f/P_i), the minimum yield and tolerance limits of barley were calculated. The data of population densities and the amount of the yield were plotted on logarithmic scales with the estimation of the logistic equilibrium level.

It is a straight line plotted on logarithmic scales, drawn at an angle of 45°, showing neither an increase nor a decrease of the population. The points on the line indicate the multiplication rate ×1 throughout the year.

Comparing the theoretical relation between nematode density and yield with the results of field plot the following Seinhorst's (1965) equation is used:

$$y = m + (1 - m) \cdot z^{P-T}, \tag{1}$$

where y is the expected yield, m — the minimum yield, P — the initial population density and T — the tolerance limit. The equation is valid for $P \geqslant T$, z is a constant <1 and equal to the proportion of the plants not infected at a nematode density $P=1$.

In order to analyse the effect of initial population density on the reproduction of *Heterodera avenae* the following equation by Seinhorst (1967) has been used:

$$P_f = \frac{a \cdot E \cdot P_i}{(a-1) P_i + E}, \tag{2}$$

where P_i is the initial population density, P_f — the final population density, a — the maximum multiplication rate and E — the equilibrium density. The curves derived from Eq. 2 were plotted against log nematode initial density.

The results predicted in this work were compared to those obtained by observing the real system. If the predicted results differ from the observed ones, the equation must be changed according to our conditions.

Effect of initial population levels of *Heterodera avenae* on final population density and barley yield on 10 field microplots in 1985 and 1986

	P_i, eggs/kg of soil	P_f (expected), eggs/kg of soil	P_f (observed), eggs/kg of soil	P_f/P_i	y (% of maximum yield) expected	y (% of maximum yield) observed
1985	12683±225.2	15505	13224±230.0	1.04	63.0	60.2
	10290±202.8	12452	13896±235.8	1.35	63.3	64.5
	8923±188.8	9077	10705±206.8	1.19	64.6	60.6
	11063±215.6	11117	12176±220.6	1.10	62.8	63.0
	13403±231.6	20753	21600±294.0	1.61	61.1	51.2
	10576±205.6	10440	11336±212.8	1.07	63.1	60.6
	12001±219.0	12002	14394±240.0	1.19	62.1	62.2
	14825±243.6	15796	16156±254.2	1.08	60.3	56.1
	15089±245.6	15117	17302±263.0	1.14	60.2	55.0
	5701±151.0	18749	18176±269.6	3.18	68.6	76.4
1986	8904±188.8	9077	10954±209.2	1.23	64.6	68.8
	11534±214.6	11814	13695±234.0	1.18	62.4	63.3
	10152±200.4	10328	11826±217.4	1.16	63.5	65.1
	11582±215.2	11085	13941±236.2	1.20	62.3	63.3
	12834±262.4	15505	14008±236.6	1.09	61.5	62.0
	10848±208.2	11076	13554±232.8	1.24	63.0	65.0
	7570±174.0	13365	16805±259.2	2.21	66.0	69.2
	5852±153.0	15040	16166±254.2	2.76	68.4	78.3
	13214±229.8	13388	15985±252.8	1.20	61.3	55.6
	11567±215.0	12814	14493±240.8	1.25	62.4	63.4
	10082±200.8	11399	12783±246.2	1.26	63.6	65.9

Results

The Table and Fig. 1 present the results of the relation between the population density of the nematode and yield in field microplots in 1985 and 1986.

According to Eq. 1 the tolerance limit T in our field conditions was 374 eggs/kg soil, while the minimum yield of plants constituted 8.8% of the maximum yield (in the absence of nematodes). Constant z was 0.7. According to the Table, the differences between the expected and observed yield (the weight of crop per m^2) were below 10%. Mostly the difference was 1—5%. Fig. 1 shows the linear regression between log nematode density and grain weight of the damaged plants. However, according to Fig. 1 at very high nematode densities of the initial population level with $P>13000$ eggs per kg of soil, regression of the observed yield lines was greater than that of the expected ones. Low population densities with $P<7000$ eggs per kg of soil affected the yield in lesser extent.

To study the effect of initial population density on the reproduction of *Heterodera avenae*, a logarithmic transformation was applied to both P_f and P_f/P_i (reproductive rate) cyst values. In order to describe the data, Eq. 2 has been used, where $a=11.3$ and $E=12205$ eggs/kg of soil. The curves derived from Eq. 2 are plotted in Fig. 2. The results (the Table, Fig. 2) demonstrate that the initial population density affects the multiplication rate of nematode. The final number of eggs per kg of soil (P_f)

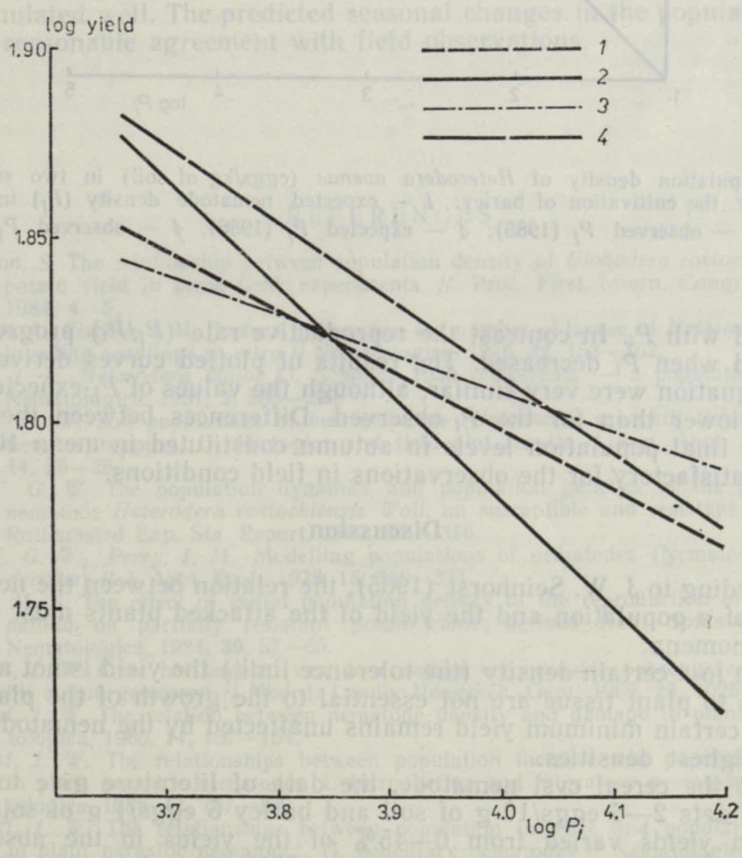

Fig. 1. Relationships between the population density of *Heterodera avenae* and the barley grain weight (% of maximum yield) in two successive years: *1* — expected yield (1985), *2* — observed yield (1985), *3* — expected yield (1986), *4* — observed yield (1986).

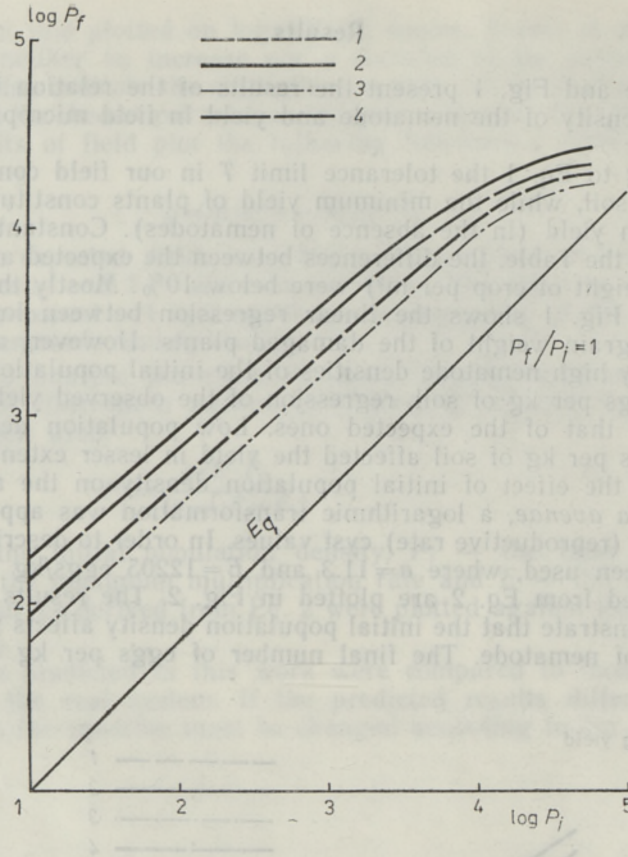

Fig. 2. Population density of *Heterodera avenae* (eggs/kg of soil) in two successive years after the cultivation of barley: *1* — expected nematode density (P_f) in autumn (1985), *2* — observed P_f (1985), *3* — expected P_f (1986), *4* — observed P_f (1986).

increased with P_i. In contrast the reproductive rate (P_f/P_i) progressively increased when P_i decreased. The results of plotted curves derived from the P_f-equation were very similar, although the values of P_f-expected were slightly lower than for the P_f-observed. Differences between theoretical and real final population levels in autumn constituted in mean 10—15% that is satisfactory for the observations in field conditions.

Discussion

According to J. W. Seinhorst (1965), the relation between the nematode density of a population and the yield of the attacked plants must express two phenomena:

1) up to a certain density (the tolerance limit) the yield is not affected, damages to plant tissue are not essential to the growth of the plant;

2) a certain minimum yield remains unaffected by the nematodes even at the highest densities.

As to the cereal cyst nematode, the data of literature give tolerance limits of oats 2—6 eggs/10 g of soil and barley 5 eggs/1 g of soil, while minimum yields varied from 0—45% of the yields in the absence of nematodes (Seinhorst, 1981; Andersson, 1984). Our data show that the corresponding threshold of barley was 3.7 eggs/10 g soil and the minimum yield — 8.8% — which agree with the data of literature.

Population studies of *Heterodera avenae*, knowledge of the nematode multiplication rate and the establishment of the tolerance level indicate that one possibility to avoid the nematode damage is to grow such varieties of cereals, the tolerance limit of which is higher than the densities of a nematode occurring in the field. Breeding and selection of such varieties requires experiments in which these limits are determined. According to M. S. Phillips (1984) the P_f/P_i values are also needed. They are too sensitive to changes in initial nematode density that they can be used either to define and separate categories of resistance in the plant or to identify pathotypes in the nematode.

From the theory of population dynamics it may be concluded that the final density of each generation tends to approach with increasing initial density a stable equilibrium level (in this work $E = 12205$ eggs/kg soil). K. A. Davies and J. M. Fisher (1976) found with *H. avenae* that at low and medium inoculum densities the percentage of invading juveniles was strongly density-dependent but remained constant at high inoculum densities. An upper limit of the P_i number in our conditions was not detected.

The equations described in this work have been proposed by J. W. Seinhorst (1965, 1967) to simulate the population dynamics of the plant parasitic nematodes and its effect on the yield of attacked plants.

Parameters in the Seinhorst's equation used in our work were estimated from field plot observations. According to the results, it may be concluded that these equations can provide realistic predictions of the real system. The predicted relation between the initial nematode density and the annual multiplication rate, and the effect of the nematode density on cereal yield, are simulated well. The predicted seasonal changes in the population level are in reasonable agreement with field observations.

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Received Feb. 10, 1988

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KAERA-KIDUUSSI ARVUKUSE SÕLTUVUS ODRASAAGIST JA NEMATOODI PALJUNEMISEST PÕLLU-KATSELAPPIDEL

Töö eesmärk oli selgitada võimalused Seinhorsti (1965, 1967) valemite kasutamiseks Eesti tingimustes, et prognoosida kaera-kiduussist nakatatud põldudel parasiidi populatsiooni arvukuse kasvu ja oletatavat saagikadu. Töö tulemustest on järeldatud, et tulevast saaki on võimalik välja arvutada protsentides nn. maksimaalsest saagist, mis saadakse sama põllu nakatamata osadelt. Vastavalt valemile $y=m+(1-m)z^{P-T}$, kus y tähistab loodetavat saaki, m on minimaalne saak, mida on võimalik saada suurima mulla saastatuse korral nematoodidega samalt põllult, P on populatsiooni algnakkus kevadel ja T odra nematooditaluvuse aste, z on konstant <1 ja väljendab nakatamata taimede hulka algnakkuse puhul $P=1$. Tegelike tulemuste ja teoreetiliste arvutuste erinevus oli keskmiselt 1—5%. Sügisese lõppnakkuse prognoosimiseks mullas kasutati valemit $P_f=\frac{a\cdot E\cdot P_i}{(a-1)\cdot P_i+E}$, kus P_i kujutab populatsiooni algnakkust kevadel, P_f on sügisene nematoodisisaldus mullas, a maksimaalne paljunemiskoefitsient ja E nakkustaseme tasakaalu nivoo. Mullaproovide analüüsist ja teoreetilistest arvutustest saadud andmed näitasid, et kevadisest mulla algnakkusest lähtudes on võimalik prognoosida sügisest nematoodi arvukust mullas keskmiselt 10—15% erinevusega tegelikkusest.

Эрика МЯГИ

ВЗАИМООТНОШЕНИЯ МЕЖДУ ЧИСЛЕННОСТЬЮ ОВСЯНОЙ НЕМАТОДЫ, УРОЖАЕМ ЯЧМЕНЯ И РАЗМНОЖЕНИЕМ НЕМАТОДЫ НА ПОЛЕВЫХ ДЕЛЯНКАХ

Работа по изучению роста численности овсяной нематоды и его влияния на урожайность ячменя проводилась в 1984—1986 гг. на полевых делянках Тартуского района ЭССР. Результаты статистического анализа дают возможность прогнозировать будущий урожай (в процентах от максимального урожая) на незараженных участках поля. Согласно уравнению Сайнхорста (1965) и результатам анализа почвенных проб выявлена разница между теоретически ожидаемым и действительным урожаем в среднем на 1—5%. Для прогнозирования послеуборочной плотности популяции нематод в почве использовали уравнение Сайнхорста (1967). Согласно данным автора показано, что разница между ожидаемой численностью паразита (по уравнению) и действительной численностью, установленной по анализам почвенных проб осенью, не превышала в среднем 10—15%.

Логарифмическая трансформация данных показывает хорошее совпадение полученных теоретических результатов с фактическими относительно урожая и численности овсяной нематоды.