

Composition and vertical distribution of free living and plant parasitic nematodes in hop gardens in the Czech Republic

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Summary

Composition and vertical distribution of soil nematode communities within soil profile were investigated in eight hop gardens in Czech Republic. In total, the presence of 78 nematode genera was confirmed. Genus *Drilolophobus* (Coomans & Coomans, 1990) is new for fauna of the Czech Republic. The highest abundance of soil nematodes was found at a depth of 0–10 cm and declined with increasing depth of soil profile. The most dominant genus was *Bitylenchus*, followed by genera *Acrobeloides*, *Ditylenchus*, *Chiloplacus* and *Cervidelus*. Ten genera of plant parasitic nematodes were recorded: *Bitylenchus* (with prevalence of *B. dubius*), *Helicotylenchus*, *Heterodera* (with absolute prevalence of *H. humuli*), *Geocenamus*, *Longidorella*, *Longidorus* (only *L. elongatus*), *Merlinius* (with prevalence of *M. brevidens*), *Paratylenchus* and *Pratylenchus*. Low population densities of predators and omnivores, low values of the community indices (MI, ΣMI, SI, and CI), and high values of NCR, EI, and PPI/MI ratio indicated disturbed nematode communities in hop gardens and bacteria-dominated decomposition pathways in the soil food web.

Keywords: Nematoda; diversity; vertical distribution; trophic groups; hop gardens

Introduction

Hops (*Humulus lupulus* L.) are a perennial plant, which are often grown in the same field for more than 20 years. A long growing period, large and deep root system should be connected with more stable and diverse soil biota assemblages, especially nematodes, which play an important role in nutrient cycling in soil. Nevertheless, until now, only limited information about the occurrence of nematodes in hop gardens and their vertical distribution has been available worldwide, as well as in the Czech Republic.

The studies were mainly focused on the plant parasite cyst

nematode *Heterodera humuli* (Number, 1958; Simon, 1958; Hogger, 1988; Eppler, 1999; Mende & McNamara, 1995). The nematode communities in hop gardens were more extensively investigated by Hay & Pethybridge (2003) in Tasmania, by Eppler (1999) in Germany and by Malan *et al.* (1991) in the South Africa. Nematode vectors of plant viruses in hops were studied by Valdez *et al.* (1974) and McNamara and Eppler (1989). Lišková and Renčo (2007) and Renčo *et al.* (2010a) published detailed information on the composition and seasonal fluctuation of nematode communities in hop gardens in Slovakia.

The first record of *H. humuli* in Czech literature was published by Hrabě (1954), a branding of this nematode as a pest comes from Šály and Kříž (1961). More detailed study about the distribution of *H. humuli* in 45 Czech hop gardens was published by Šedivý (1963). *H. humuli* was detected at all sites with the abundances from 3 to 124 cysts per 100 g of soil in hop gardens younger than 20 years or 342 cysts per 100 g of soil in older gardens. No survey, however, evaluating the whole spectrum of nematodes in hop soil has been conducted. Therefore, the objective of this study was to describe assemblages of free living and plant parasitic nematodes and their vertical distributions in hop garden soil in Moravia and Bohemia and to evaluate the disturbance of nematode communities in these agroecosystems.

Material and methods

This study was conducted within the Tršice hop-growing area in Moravia and the Žatec hop-growing area in North-west Bohemia. The climate of the areas is temperate with an average annual temperature of 8.0–9.5 °C (the monthly average ranges from -1.5 °C in January to 20.1 °C in July) with annual precipitation of 450–530 mm. During the vegetation period, average air temperatures reach 14–16 °C and rainfalls average is 342 mm. The soils are deep,

Table1. The abundance of nematodes in hop gardens (ind. per 100 g of fresh soil in whole soil profile), mean nematode abundance (n = 32), dominance (D%)

Nematodes	c-p	M1	M2	M3	M4	B1	B2	B3	B4	Mean	D (%)
Bacterivores (B)		1497	398	1709	309	1342	2781	2228	1953	1527.13	39%
<i>Acrobeles</i>	2	35	4	1	0	34	123	35	173	50.63	1.29
<i>Acrobeloides</i>	2	401	209	792	47	332	321	209	939	406.25	10.36
<i>Acrolobus</i>	2	0	0	0	0	136	2	2	0	17.5	0.45
<i>Alaimus</i>	4	0	10	3	0	0	0	2	0	1.88	0.05
<i>Amphidelus</i>	4	0	12	1	0	0	0	0	0	1.63	0.04
<i>Aulolaium</i>	3	0	1	0	0	0	0	0	0	0.13	0.01
<i>Bursila</i>	1	0	0	0	0	0	103	0	20	15.38	0.39
<i>Cephalobus</i>	2	78	40	55	12	115	182	87	26	74.38	1.90
<i>Cervidelus</i>	2	178	18	26	0	132	879	115	253	200.13	5.11
<i>Chiloplacus</i>	2	227	17	76	20	38	258	653	343	204	5.20
<i>Chronogaster</i>	3	0	8	0	0	0	0	0	0	1	0.03
<i>Diploscapter</i>	1	34	0	0	0	1	19	1	10	8.13	0.21
<i>Drilocephalobus</i>	2	0	0	0	0	45	48	27	0	15	0.38
<i>Ereptonema</i>	2	54	6	24	7	47	23	35	0	24.5	0.63
<i>Eucephalobus</i>	2	140	22	111	12	25	0	43	0	44.13	1.13
<i>Eumonhystera</i>	1	19	8	17	0	24	276	88	17	56.13	1.43
<i>Heterocephalobus</i>	2	0	9	45	2	37	170	156	96	64.38	1.64
<i>Mesorhabditis</i>	1	103	5	93	0	0	0	11	0	26.5	0.68
<i>Panagrolaimus</i>	1	41	0	8	3	0	0	0	0	6.5	0.17
<i>Paraamphidelus</i>	4	0	6	0	0	2	0	13	0	2.63	0.07
<i>Parasitorhabditis</i>	1	0	0	0	37	0	0	0	0	4.63	0.12
<i>Pelodera</i>	1	7	3	0	0	0	0	0	0	1.25	0.03
<i>Plectus</i>	2	0	1	6	12	2	7	22	1	6.38	0.16
<i>Prismatolaimus</i>	3	0	0	0	0	30	0	0	0	3.75	0.10
<i>Pristionchus</i>	1	0	0	0	0	0	1	9	0	1.25	0.03
<i>Protorhabditis</i>	1	23	4	53	61	0	0	0	0	17.63	0.45
<i>Rhabditis</i>	1	43	4	244	10	33	19	10	11	46.75	1.19
<i>Rhabditis juvs., D.L.</i>	1	114	11	152	86	309	350	710	64	224.5	5.73
<i>Rhomborhabditis</i>	1	0	0	2	0	0	0	0	0	0.25	0.01
Fungivores (F)		724	193	782	105	398	1087	440	855	573.00	14.6%
<i>Aphelenchoides</i>	2	333	51	115	47	232	210	129	332	181.13	4.62
<i>Aphelenchus</i>	2	140	47	255	35	95	34	232	242	135	3.44
<i>Deladenus</i>	2	0	0	0	0	0	0	0	15	1.86	0.05
<i>Ditylenchus</i>	2	154	84	344	23	71	843	79	266	233	5.94
<i>Hexatylyus</i>	2	5	0	0	0	0	0	0	0	0.63	0.02
<i>Paraphelenchus</i>	4	92	9	50	0	0	0	0	0	18.88	0.48
<i>Safianema</i>	2	0	2	15	0	0	0	0	0	2.13	0.05
<i>Tylencholaimellus</i>	4	0	0	2	0	0	0	0	0	0.25	0.01
<i>Tylencholaimus</i>	4	0	0	1	0	0	0	0	0	0.13	0.01
Root-fungal feeders (RFF)		115	214	445	63	776	175	82	17	235.90	6.0%
<i>Basiria</i>	2	35	31	92	8	0	0	0	0	20.75	0.53
<i>Boleodorus</i>	2	4	4	261	5	721	89	0	2	135.75	3.46

<i>Coslenchus</i>	2	2	2	10	1	0	0	0	0	1.88	0.05
<i>Filenchus</i>	2	70	172	62	49	53	86	51	11	69.25	1.77
<i>Lelenchus</i>	2	0	0	1	0	0	0	0	0	0.125	0.01
<i>Psilenchus</i>	2	0	0	2	0	0	0	0	0	0.25	0.01
<i>Tylenchus</i>	2	4	5	17	0	2	0	31	4	7.88	0.20
Plant parasites (PP)		450	447	1687	161	342	744	1428	5975	1404.25	35.8%
<i>Bitylenchus</i>	3	0	203	1209	79	53	16	1049	5533	1017.25	25.96
<i>Geocenamus</i>	3	127	0	0	25	0	0	0	0	19	0.48
<i>Helicotylenchus</i>	3	104	0	112	1	6	57	2	0	35.25	0.90
<i>Heterodera</i>	3	130	200	37	47	134	106	21	285	120	3.06
<i>Longidorella</i>	4	4	0	0	0	4	8	6	0	2.75	0.07
<i>Longidorus</i>	5	0	0	0	0	31	146	0	0	22.13	0.56
<i>Merlinius</i>	3	0	27	56	7	106	409	337	153	136.88	3.49
<i>Paratylenchus</i>	2	25	10	256	1	4	0	13	0	38.63	0.99
<i>Pratylenchus</i>	3	60	7	15	1	4	2	0	4	11.63	0.30
<i>Quinisulcus</i>	3	0	0	2	0	0	0	0	0	0.25	0.01
Predators (P)		33	12	17	18	13	4	79	100	34.5	0.9%
<i>Anatonchus</i>	4	0	0	1	1	0	0	0	0	0.25	0.01
<i>Clarcus</i>	4	0	0	0	7	0	0	25	0	4	0.10
<i>Coomansus</i>	4	0	0	0	5	1	0	0	0	0.75	0.02
<i>Mononchus</i>	4	0	0	0	3	0	0	0	0	0.25	0.01
<i>Mylonchulus</i>	4	0	2	6	2	11	2	50	0	9.13	0.23
<i>Paravulvulus</i>	5	0	0	6	0	0	0	0	0	0.75	0.02
<i>Prionchulus</i>	4	0	0	0	0	1	0	2	2	0.63	0.02
<i>Seinura</i>	2	33	10	4	0	0	2	2	98	18.63	0.48
Omnivores (O)		21	47	52	24	171	280	214	14	102.90	2.6%
<i>Actinolaimus</i>	5	0	0	0	2	0	0	0	0	0.25	0.01
<i>Aporcelaimellus</i>	5	2	7	29	13	49	69	57	6	29	0.74
<i>Aporcelaimus</i>	5	0	0	0	2	0	0	0	0	0.25	0.01
<i>Crassolabium</i>	4	2	3	2	0	0	8	0	0	1.88	0.05
<i>Chironema</i>	5	0	0	0	0	0	0	1	0	0.13	0.01
<i>Discolaimium</i>	5	0	3	4	4	0	0	0	0	1.38	0.04
<i>Diptherophora</i>	3	11	0	0	0	59	0	0	0	8.75	0.22
<i>Ecumenicus</i>	5	0	0	3	0	0	0	21	5	3.63	0.09
<i>Epidorylaimus</i>	4	0	1	0	0	0	0	0	0	0.13	0.01
<i>Eudorylaimus</i>	4	0	6	12	0	0	29	32	3	10.25	0.26
<i>Mesodorylaimus</i>	4	0	1	0	2	0	0	13	0	2	0.05
<i>Microdorylaimus</i>	4	6	26	1	1	63	174	88	0	44.88	1.14
<i>Oxidiurus</i>	5	0	0	1	0	0	0	0	0	0.13	0.01
<i>Sectonema</i>	5	0	0	0	0	0	0	2	0	0.25	0.01
Insect parasites (IP)		3	0	0	0	0	27	26	284	42.5	1.1
<i>Steinernema juvs.</i>	1	3	0	0	0	0	27	26	284	42.5	1.08

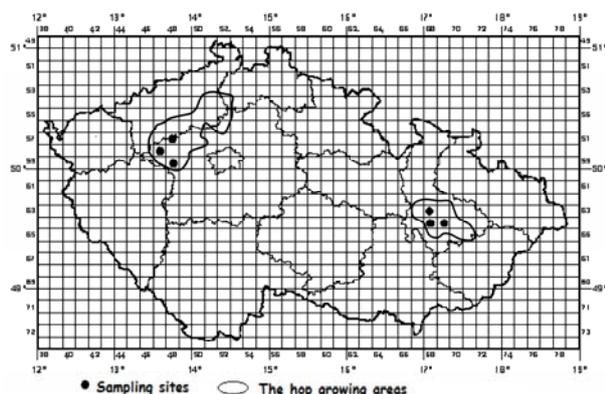


Fig. 1. Hop-growing areas and sampling sites in the Czech Republic

permeable, loamy or loamy-clay, soil type Luvisol with pH (H₂O) 6.5 – 7.5. An exception is a shallow Marly soil with pH (H₂O) 8 at locality B4. Except for hop plants, the soil surface was almost bare with only infrequently growing weeds (*Galium aparine* L., *Elitrigia repens*, *Urtica dioica*, *Chenopodium album*). All investigated hop gardens are designated as hop gardens with intensive production. Each year the industrial fertilizers (NPK) are applied in spring; cow manure in autumn every 3 years; liming in autumn every 3 – 4 years and during each summer lacking microelements may be applied. Row cultivation is conducted in spring (soil loosening and fertilizer placement); in summer (ploughing – adding 13 – 15 cm of soil on the base of hop plants); in autumn row cultivation by ploughing to depth of 18 – 20 cm and deep ploughing of rows to the depth of 50 – 60 cm ones per 5 – 6 years.

Localities in Moravia (M1 – M4) GPS:

- M1: Senice na Hané - N49 37.192, E17 06.611 (256 m a.s.l.),
- M2: Domaželice - N49 25.244, E17 32.706 (231 m a.s.l.),
- M3: Tršice - N49.31.149, E17.23.606 (286 m a.s.l.),
- M4: Nelešovice - N49 31.149, E17 23.473 (278 m a.s.l.).

Localities in Bohemia (B1-B4) GPS:

- B1: Lubná – N50 05.515, E13 42.920 (347m a.s.l.),
- B2: Kněževés – N50 08.785, E13 37.282 (365m a.s.l.),
- B3: Hořesedly – N50 09.748, E13 35.832 (389m a.s.l.)
- B4: Třeboc – N50 12.385, E13 45.649 (528m a.s.l.).

Ten replicated profiles for each of 8 hop gardens (4 Moravian and 4 Bohemian; Fig. 1) were sampled to a depth of 0 – 40 cm in either August 2007 or in May 2008 and subdivided into layers of 0 – 10, 10 – 20, 20 – 30 and 30 – 40 cm. The soil was taken with semi-circular soil core of 5 cm in diameter. Extraction of nematodes was done from 100 g soil of bulk samples by Cobb's flotation-sieving method (Cobb, 1918). Extracted nematodes were killed and fixed by hot 3 % formaldehyde and transferred to the glycerin according to the De Grisse (1969) and identified under the light microscope. The Maturity Index (MI) (genus *Ditylenchus* included) and Plant Parasite Index (PPI) (all specimens of the trophic groups plant parasites and root-fungal feeders included) were calculated according to Bongers (1990) and Σ Maturity Index (Σ MI) according to Yeates (1994). Channel Index (CI), Enrichment index (EI), and Structure Index (SI) were calculated according to Ferris *et al.* (2001) with weightings of nematode taxa as suggested by these authors. Nematodes were assembled to trophic groups (Table 1) according to their feeding habits as outlined by Yeates *et al.* (1993), and Tylenchidae were classified as root fungal feeders. Nematode Channel Ratio (NCR) and Basal Index (BI) were calculated according to Yeates (2003) and Berkelmans *et al.* (2003) respectively. The Shannon index (H'^{gen}) based on natural logarithm was calculated from nematode genera (Shannon-Weaver, 1949). Ratios of trophic groups [B/F, B/(F+RFF), (B+F)/PP, (B+F)/(RFF+PP), (O+P)/(B+F+RFF+PP)] were calculated according to Wasilewska (2004). Statistical calculations were performed using the STATISTICA (StatSoft, 2001). ANOVA and cluster analyses of nematode genera were

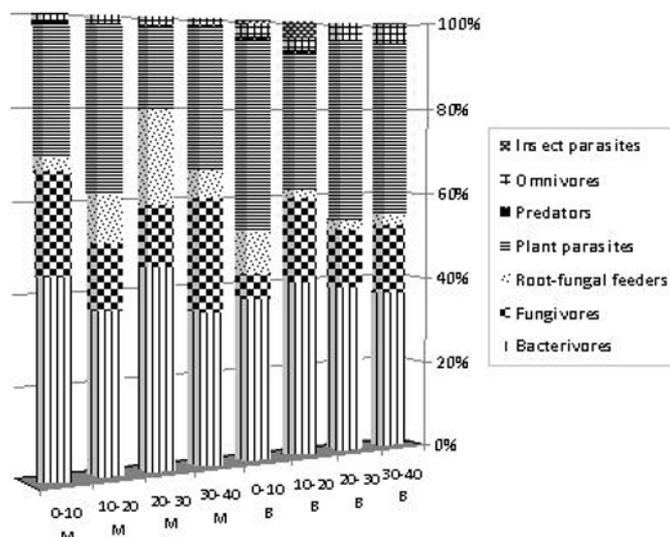


Fig. 2. Distribution of the trophic groups within soil profile, percentages of mean abundance

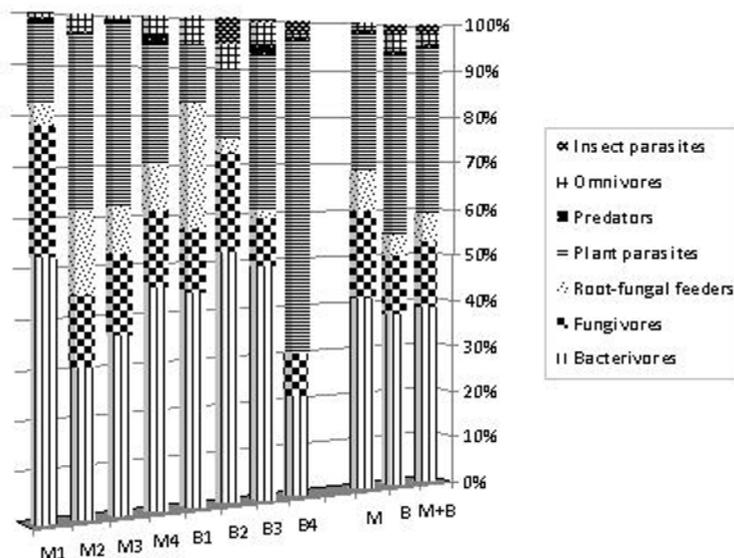


Fig. 3. Distribution of the trophic groups within localities, percentages of mean abundance

performed on $\ln(x+1)$ transformed data. The nematode genera were characterized as eudominant at $D > 10\%$, dominant at $D = 5 - 10\%$, subdominant at $D = 2 - 5\%$, recedent $< 2\%$ (Losos *et al.*, 1984).

Results

Composition of nematode communities in hop gardens studied

The total abundance of nematodes in hop gardens ranged

from 680 to 9198 ind. per 100 g of fresh soil (Table 1). The most nematode individuals belonged to bacteriovores (39%) followed by plant parasites (35.8%) and fungal feeders (14.6%) (Tab. 1; Fig. 2, 3). The total mean abundance over all soil layers was significantly greater in hop gardens in Bohemia (1365 ind. per 100g of fresh soil) than in Moravia (595 ind. per 100 g of fresh soil) $F_{(1,30)} = 8.873, p = 0.006$. A trend of decreasing nematode abundance with decline of soil depth was observed (Fig. 4). Nevertheless, significant differences between the mean values of total abundance in

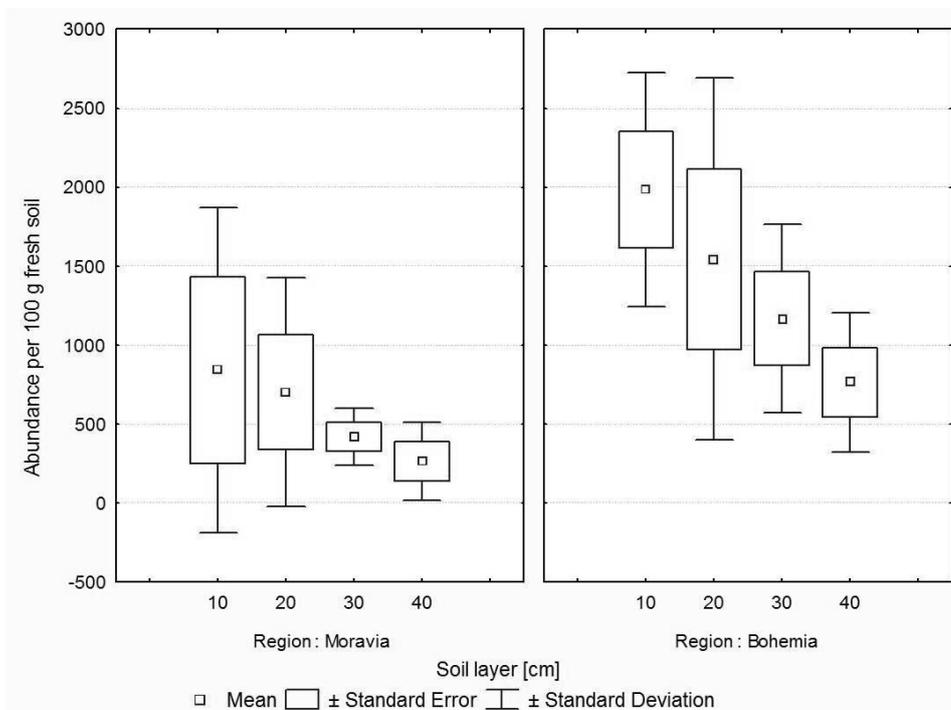


Fig. 4. Categorized box graph of nematode abundance in particular soil layer and region (numbers 10, 20, 30, and 40 refer soil depth layers 0 – 10, 10 – 20, 20 – 30, 30 – 40 cm)

Tab 2. Community indices of soil nematodes in hop gardens.
B = bacterivores; F = fungivores; RFF = root-fungal feeders; PP = plant parasites; O = omnivores, P = predators

Locality	M1	M2	M3	M4	B1	B2	B3	B4
Numer of genera	37	44	50	37	37	34	42	29
n	2843	1311	4692	680	3042	5098	4497	9198
MI	1.86	2.66	2.67	2.71	2.07	1.97	1.96	1.97
ΣMI	2.03	2.43	2.22	2.07	2.18	2.17	2.28	2.61
PPI	2.76	2.66	2.67	2.71	2.36	3.14	2.94	3.00
PPI/MI	1.49	1.21	1.44	1.55	1.14	1.59	1.50	1.52
B/F	2.07	2.08	2.23	2.94	3.37	2.56	5.06	2.28
B/(F+RFF)	1.78	0.98	1.41	1.84	1.14	2.20	4.27	2.24
(B+F)/PP	4.94	1.31	1.45	2.57	5.09	5.20	1.87	0.47
(B+F)/(RFF+PP)	5.19	1.79	1.72	2.96	7.36	5.43	1.93	0.47
(O+P)/(B+F+RFF+PP)	0.02	0.05	0.01	0.06	0.06	0.06	0.07	0.01
H'gen	3.03	2.75	2.70	2.93	2.81	2.81	2.65	1.67
EI	82.37	86.78	79.79	64.68	84.50	83.13	82.48	89.33
SI	12.91	65.45	23.17	41.27	60.99	48.69	57.37	16.53
CI	13.99	12.89	14.63	18.99	9.54	11.89	7.36	10.45
BI	17.18	10.59	19.05	28.30	12.48	14.54	14.17	10.45
NCR	0.64	0.50	0.59	0.65	0.53	0.69	0.81	0.70

individual layers were not detected either for all hop gardens ($F(3,28) = 2.418$, $p = 0.087$) or Moravian ($F(3,12) = 1.178$, $p = 0.359$) as well as Bohemian ($F(3,12) = 1.806$, $p = 0.200$) hop gardens. The assumption of homogeneity of variances in one-way ANOVA was not violated, and analyses performed of $\ln(x + 1)$ transformed abundance gave practically the same results. On the other hand one-way ANOVA, performed on $\ln(x + 1)$ transformed data, detected significantly different abundance of predators in individual layers ($F_{(3,28)} = 4.415$, $p = 0.012$). Poc-hoc Fisher LSD test at $\alpha = 0.05$ suggested significantly greater abundance of predators in the layers 0 – 10 cm (16.6 ind. per 100 g of fresh soil) and 10 – 20 cm (13.5) than in 20 – 30 (2.5) and 30 – 40 cm (1.5).

Within investigated hop gardens, 78 nematode genera in total material of 31 361 nematodes were recorded. The genus *Drilocephalobus* was recorded in the Czech Republic for the first time. The *Bitylenchus* (26.0 %) was found as eudominant genera; *Acrobeloides* (10.4 %), *Ditylenchus* (5.9 %), *Chiloplacus* (5.7 %), and *Cervidelus* (5.1 %) as dominant genera. Ten plant parasitic genera were found: *Bitylenchus* (with prevalence of *B. dubius*, *Helicotylenchus*, *Heterodera* (with absolute prevalence of *H. humuli*), *Geocenamus*, *Longidorella*, *Longidorus* (only *L. elongatus*), *Merlinius* (with prevalence of *M. brevidens*), *Paratylenchus* and *Pratylenchus*. The most common species from the genus *Aphelenchoides* were *A. limberi* Steiner, 1936 and *A. bicaudatus*, which are not considered to be plant parasites.

Distribution of nematodes within soil profile showed, that in the first soil depth (0 – 10 cm) the eudominant genera were *Acrobeloides* (21.5 %), *Bitylenchus* (18.8 %) in Mo-

ravia region and *Bitylenchus* (35.0 %) in Bohemia region. The similar dominance of nematode genera was recorded in the second soil layer (10 – 20 cm) as well, where in Moravia hop gardens the *Bitylenchus* (20.3 %) and *Acrobeloides* (14.2 %) dominated and in Bohemia hop gardens *Bitylenchus* (24.0 %) was eudominant genus. However, in the third soil layer investigated (20 – 30 cm) in Moravia region the different genera dominated, namely *Rhabditis* (13.8 %) and *Filenchus* (10.1 %), while in Bohemia region it was the same with eudominance of the genus *Bitylenchus* (34.1%). As showed the results from the fourth investigated soil depth (30 – 40 cm) in Moravia were the most dominant *Aphelenchoides* (12.9 %) and *Bitylenchus* (10.7 %) genera, in Bohemia *Bitylenchus* (26.3 %) and *Acrobeloides* (12.2 %).

Insect parasitic nematodes were represented by only one genus (*Steinernema*), which was present in half of the sampling sites with the highest abundance 223 specimens per 100 g of soil sample (locality B4) in the layer 10 – 20 cm.

Evaluation of nematode communities by ecological and diversity indices, statistical analysis

Evaluation of soil nematode communities by community indices within investigated hop gardens is presented in Table 2. Dominance of bacterivorous nematodes reflected high values of NCR, EI, and CI and higher values of ratios B/F and B/(F+RFF). The highest dominance of bacterivorous nematode in soil food web was at locality B3. The values of H'gen were relatively high except B4 locality, but this locality showed the highest value of ΣMI. MI varied from 1.86 to 2.71, whereas the values of PPI were always greater than 2.30, resulting in high values of the PPI/MI ratio of 1.14 – 1.59. Low values of SI at localities

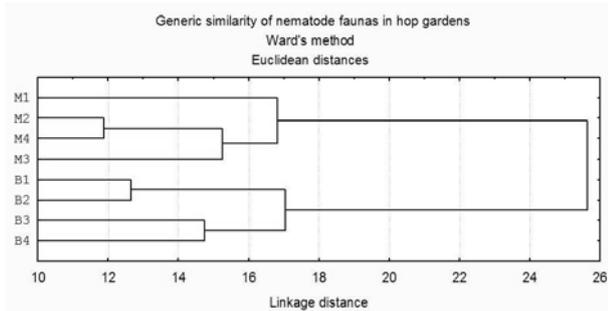


Fig. 5. Cluster analysis of $\ln(x+1)$ transformed soil nematode genera in whole soil profile of hop gardens sampled in the Czech Republic (M = Moravia, B = Bohemia, numbers 1-4 refer to replicate sites)

M1, M3 and B4 correspond with very low values of the $(O+P)/(B+F+RFF+PP)$ ratio. The ratios $(B+F)/PP$ and $(B+F)/(RFF+PP)$ were greater at localities M1, B1 and B2 and the lowest at locality B4. The values of BI were the greatest at locality M4 and the lowest at M2 and B4. Cluster analysis performed on $\ln(x+1)$ transformed genera population densities in whole soil profile (Fig. 5) showed Moravian sites were clearly distinct from Bohemian sites. Position of the site M1 was influenced by the absence of *Bitylenchus dubius*. Cluster analysis of nematode genera

based on $\ln(x+1)$ transformed abundance data in individual sites and soil layers (Fig. 6) provided a similar picture of clearly distinct Bohemian and Moravian sites, except for B1 (30 – 40 cm) and B3 (30 – 40 cm) in the upper cluster. The position of B1 and B3 sites on the same cluster with M2 (0 – 10 cm) is the result of low abundances of root fungal feeders and the absence of genus *Steinernema*.

Discussion

The soil nematode communities in the hop gardens studied are characterized by a dominance of bacterivores and plant parasites, which is consistent with the trophic composition of nematode faunas previously found in agroecosystems of the Czech Republic (Háněl, 2003) or in Poland (Wasilewska, 1979). A similar trophic structure of nematodes was also found in hop gardens in Slovakia (Lišková & Renčo, 2007). Nevertheless, the dominant genera were different. In Slovakia, the genus *Rhabditis* was the most dominant bacterial feeding nematodes which were further confirmed by Renčo *et al.* (2010a), whereas in Moravia and Bohemia hop gardens the most dominant bacterivore was *Acrobeloides*. The prevalence of bacterial feeders and

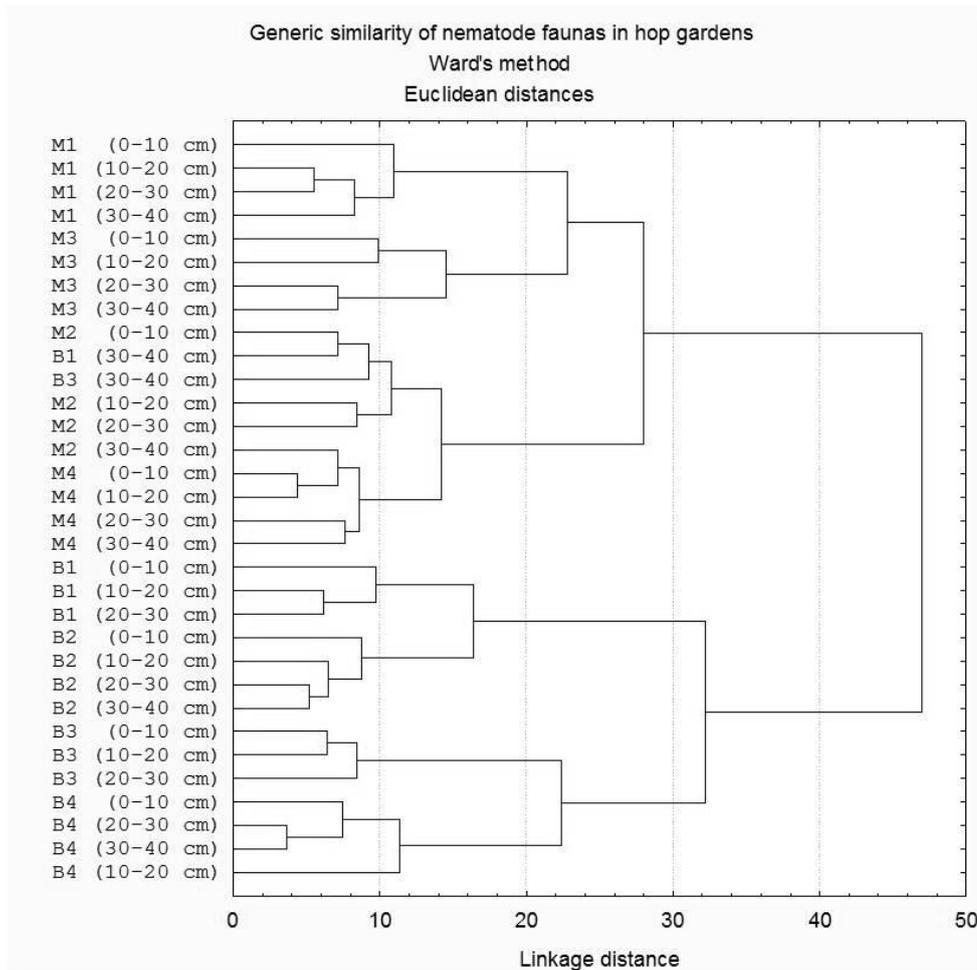


Fig. 6. Cluster analysis of nematode genera based on $\ln(x+1)$ transformed abundance data (M = Moravia, B = Bohemia, numbers 1 – 4 refer to replicate sites, numbers 10 – 40 refers soil depth layer in cm)

plant parasitic nematodes were observed in other agroecosystems as well (Bouwman & Zwart, 1994; Renčo & Valocká, 2002). These results correspond to a general pattern of nematode communities in agroecosystems in temperate areas. Generally, the nematode communities in agricultural soils of Central Europe are less diverse compared to those in more stable ecosystems like forests (Háněl & Čerevková, 2010) or meadows (Háněl & Čerevková, 2006), but always with a greater proportion of bacterivores and plant parasites (Háněl, 2010).

The prevalence of bacterivores in hop gardens studied may be caused by regular fertilization with manure per each 2–3 years and with industrial fertilizers each year. This result is similar to those published by Lišková and Renčo (2007). The manner of decomposition of organic matter can be evaluated by B/F index, which is focused on the dominant way of decomposition either by bacteria or fungi. Relatively high values of B/F index show relatively greater participation of bacteria in the breakdown of soil organic matter. The highest value of B/F index 5.06 was found in B3 sampling site. This deviation from other sites was the result of the high abundance of the genus *Chiloplacus* and *Acroboloides* and the low presence of the genus *Ditylenchus*. On the other hand, the lack of knowledge about nematodes' biology and trophic characterization can affect the resulting values of indexes. For example, some species from genus *Aphelenchoides* or *Ditylenchus* are classified as plant parasites, but can be cultivated on fungi (Hooper & Cowland, 1986; De Waele *et al.*, 1997). Many species from the order *Tylenchida* are classified as fungal feeders or root fungal feeders only because of their short stylet (Yeates, 1986), especially from the family *Tylenchidae* or from the genus *Ditylenchus*. The species from the genus *Cephalobus* are generally classified as bacterivores (Yeates *et al.*, 1993), but it was discovered that they can also be reproduced on fungi *Verticillium dahliae* Klebahn, or roots of clover or maize infected by fungi and on callus culture of alfalfa (Solovyeva *et al.*, 1976).

Similar results are also seen in a group of free-living nematodes that could generally be classified as omnivores. They usually have different trophic cycles based on favourable or unfavourable living conditions, mainly on availability of sources of nutrients and their kinds. Analogically some species of the genus *Aphelenchoides* (Hooper & Ibrahim, 1994) and some *Ditylenchus* species are classified as fungal feeders in general, but are often found inside damaged plants (Wasilewska, 1965; Brzeski, 1991). Their pathogenicity was not tested or only fragmentary information is known, and the species can feed under the enriched conditions on the most convenient source of nutrient, and in a nutritionally stressed environment, feed on other organisms, which they are able to attack.

The occurrence of plant parasites was generally higher in comparison to the ecosystem of hop gardens in Slovakia (Lišková & Renčo, 2007). The nitrogen is generally regarded as a limiting factor for many herbivores, including nematodes (Mattson, 1980) and a higher C:N ratio will reduce the number of nematodes (Renčo *et al.*, 2007). The

availability of nitrogen and phosphorus generally depends on the host plant species and the changes do not occur during the succession of growth (Oloff *et al.*, 1994), and interactions with other elements of ecosystem. The changes in C:N ratio can influence the plant parasitic nematodes. The higher C:N ratio may be connected with a higher level of defensive compounds in plant tissues (Hartley *et al.*, 1995), which might deter plant-feeding nematodes (Mattson, 1980; Renčo *et al.*, 2009, 2010b). Due to the regular application of manure and fertilizers in the investigated hop gardens, the low C:N ratio, good availability of N and P, and rich root system can be expected and those can explain high abundances of "large" plant parasitic nematodes. Especially for nematode species with high nutrient and energy needs, a decrease in food quality can have a considerable effect on the population size. This effect was confirmed by Verschoor *et al.* (2001) during their investigation of changes in the composition of the plant-feeding nematode community in grassland after cessation of fertilizer application. Particularly, relatively large nematode genera such as *Longidorus*, *Heterodera*, *Helicotylenchus* and *Tylenchorhynchus* declined or even disappeared when the nutrient availability decreased, whereas smaller nematode taxa such as *Aglenchus*, *Filenchus*, *Pratylenchus* and *Paratylenchus* were abundant in all sites and dominated in the nutrient-poor sites.

The investigated hop gardens are characterized by a low diversity of plant parasites (only 10 genera) but with high abundances. The number of plant parasitic genera is lower in comparison with other agroecosystems studied in Czech Republic or in Slovakia. Háněl (2010) found 13 plant parasitic genera during his investigation of six fields (one cultivated and five abandoned). Six of them (*Rotylenchus*, *Xenocriconemella*, *Mesocriconema*, *Criconema*, *Meloidogyne* and *Trichodorus*) were not recorded in our investigated hop gardens. Their absence, especially of the members of family Criconematidae, which are characteristic for growth of perennial crops such as vineyards and fruit orchards (Lišková *et al.*, 2004), and genus *Meloidogyne*, was probably due to the type and kind of soil. The low numbers of plant parasitic genera and species as the most frequent plant parasitic genera (*Bitylenchus*, *Merlinius* and *Heterodera*) are also characteristic for hop gardens of Slovak Republic (Lišková & Renčo, 2007). *Bitylenchus dubius* prevailed in the group of plant parasites in the hop gardens in the Czech Republic whereas this species was less prominent in the hop gardens in Slovakia. Although the abundance of *B. dubius* varied with locality, in both regions a cluster analysis showed that the composition of whole nematode fauna in Moravian and Bohemian hop gardens is evidently different. The association of *Meloidogyne* spp. with hop was recorded in Tasmania (Hay & Pethybridge, 2003) and *M. hapla* in USA (Maggenti, 1962), should be an alarm signal for Czech hop production because of widely spread *M. hapla* in the Province of Central Bohemia (Zouhar *et al.*, 2003).

Nevertheless, the very low abundance of predators and omnivores in the hop gardens studied can be interpreted as

a sign of negative influence of agricultural practices upon soil nematode communities (Wasilewska, 1997). The most abundant omnivores here were genera *Microdorylaimus*, *Aporcelaimellus* and *Eudorylaimus*. Lišková & Renčo (2007) also found a low abundance of omnivores and plant parasites in hop gardens in Slovakia, with the exception of two species with high dominance and frequency of occurrence of *Eudorylaimus* juvs. and *Aporcelaimellus obtusicaudatus*. It seems that genera *Eudorylaimus*, *Aporcelaimellus* and *Mesodorylaimus* are the most common and abundant omnivores independent of type of ecosystem or climatic conditions (McSorley, 1997; Háněl 1994, 2008; Wasilewska, 2006). All of these genera belong to the superfamily Dorylaimoidea (Andrássy, 2009) and are considered to be the first colonizers in early successional stages because of their ability to feed on algae, bacteria, fungi, mosses, plant roots and microfauna (Bongers & Ferris, 1999) and can include species that can either behave as colonizers or persisters (Háněl, 2010). For those reasons, they were probably able to survive stressful conditions in cultivated hop soil.

The genus *Microdorylaimus* was most abundant omnivore in our study with $D = 1.14\%$. Ettema and Bongers (1993) discovered temporary increasing of abundance of genus *Microdorylaimus* on manured plots in contrast to untreated ones, therefore its high abundance was attributed to the organic treatment and indicated a possible relation between the abundant algae growth in the food-rich soil in summer and species abundance in the upper 15 cm of investigated soil profile, because of green intestine determined as algae. The water content, together with soil porosity, temperature and food webs are one of the main factors influenced the occurrence and abundance of soil nematodes (Yeates *et al.*, 2002; Sohlenius & Boström, 2001). Bakonyi *et al.* (2007) indicates the increase of dominance of this genus in dried and warmed poplar and bare soil plots compared to the control and decreasing in fescue soil plots; no significant response of genus *Eudorylaimus* and variable responses of genus *Aporcellaimellus* were detected. Moreover, the reason for the high occurrence of *Microdorylaimus* in dry soils without plant cover (except hop plants) can be the result of smaller body size in comparison with other two genera. The smaller body size allow them to occupy the soil food web niche (algae etc.) through the soil profile, which are for larger genera unreachable because of decreasing water content in soil, starts from larger to smaller pores due to lower tension of larger pores in comparison with smaller pores (Jandák *et al.*, 2001). According to Griffiths *et al.* (2003) only a small quantity of water-filled pores in the soil is sufficient to maintain nematode activity and the densities of larger species are more affected by soil temperature and moisture changes than are those of smaller ones (Griffin *et al.*, 1996). The ability to feed on various food sources, positive reaction to increasing food source and small body size, should be the most important features for explanation of the rich distribution of genus *Microdorylaimus* through the whole soil profile in our investigated hop gardens. Renčo *et al.* (2010a) established that

decreasing abundances of the majority of omnivores and predators during the July were positively correlated with decreasing precipitation and high temperatures. Omnivores and predators have great sensitivity to disturbances (Bongers *et al.*, 1991; Brmež *et al.*, 2006). The high temperatures, low amount of precipitation and frequent agricultural practices (tillage and application of pesticides and fertilizers) should be the main factors that influenced the abundances of nematodes belonging to these trophic groups in the investigated hop gardens.

Within the group of plant-virus vectors, only *Longidorus elongatus* was detected. This is the first official record of virus-vector nematode in hop gardens in Czech. Our finding is qualitatively very low in comparison with results from hop gardens in Germany, where McNamara and Eppler (1989) refer to 11 virus-vector nematodes species from 3 genera. Hay and Close (1992) refer species *Xiphinema diversicaudatum* from hop gardens in New Zealand. No one is referred from Slovakia or from Tasmania (Lišková & Renčo, 2007; Hay & Pethybridge, 2003). The low occurrence of virus-vector nematode species in Czech hop gardens in comparisons with Czech vineyards or fruit orchards (Erbenová, 1975; Kumari, 2006) can be explained (as in the case of Criconematidae) by the different sorts and types of soil, the low number of soil samples or non-suitable sampling patterns for virus-vector nematodes. Hay and Close (1992) found *X. diversicaudatum* in 31 from 240 diagnosed samples collected in hop gardens from which 28 were taken at the edge of fields. The same sampling pattern referred McNamara and Eppler (1989). Hay and Close (1992) considered that the prevalence of *X. diversicaudatum* at the edges of field is due to the preference of host plants in the outer areas including the species used as shelterbelts and many herbaceous weeds and grasses (Thomas, 1970). More over both *X. diversicaudatum* and Arabic Mosaic Virus are present in the Czech Republic (Polák, 1994; Kumari *et al.*, 2005). Therefore, further monitoring of the occurrence of virus-vector nematodes is required in the future.

Lower values of MI, $\sum MI$, H'gen, SI, CI and higher values of EI in our hop gardens investigated compared to those recored by Háněl and Čerevková (2006) in natural meadows or spruce forest (Čerevková & Renčo, 2009) indicate poorly-regulated, disturbed ecosystems (Ferris *et al.*, 2001). This conclusion was also supported by the results of $(O+P)/(B+F+RFF+PP)$, which also indicate a poor health ecosystem (Wasilewska, 1997). BI values were relatively low in comparison with results of Berkelmans *et al.* (2003) from fields grown with annual crops, at where the high BI values indicated poor ecosystem health. The BI values for localities B4 and M2 (10.45 and 10.59 respectively) are comparable with results of Háněl (2008) for localities on colliery spoils grown with broad leaves trees with grass understorey, which suggest shift from nutrient disturbance to balanced use of nutrient resources by higher plants (Bongers *et al.*, 1997). The higher values of $(B+F)/PP$ and $(B+F)/(RFF+PP)$ at localities M1, B1 and B2 show a trend of slower rates of mineralization via decomposition chan-

nel in the soil food web via plant feeders (Wasilewska, 1997) and may suggest higher content of organic compounds in that soil food web together with higher microbial biomass levels in those localities (Ferris *et al.*, 1996). The values of PPI/MI ratio in hop gardens varied from 1.14 – 1.59, which indicates habitats where higher plants started to make non-optimal use of nutrient or nutrient disturbances (Bongers *et al.*, 1997). Similar results were found in hop gardens in Slovakia (Lišková & Renčo, 2007) or in sugar beet or cereals fields (Renčo, 2002, 2003), while in the grass ecosystems lower values of PPI/MI ratio were found (Valocká *et al.*, 2001; Lišková & Čerevková, 2005). The great abundance of bacterivores, high values of NCR, high values of EI, and low values of CI could indicate relatively greater participation of bacteria in the breakdown of soil organic matter (Ferris *et al.*, 2001), although we would instead expect a decomposition pathway more dominated by fungi and fungivores in perennial crops (Neher & Campbell, 1994). The probability of more active bacterial based channel than the fungus based channel was also supported by higher values of B/F and B/(F+RFF), mainly at locality B3 (5.06 and 4.27 respectively). The composition of nematode in the hop gardens studied thus showed clear marks of disturbance, which could be caused by the long-term use of pesticides, regular soil loosening and ploughing. Nevertheless, there is also one other issue. A marked effect of region upon nematode faunas in agroecosystems shown in cluster analysis has been confirmed by Háněl (2003). The nematode faunas in grasslands on the western and eastern slopes of White Carpathians exhibited clearly detectable differences (Háněl & Čerevková, 2006), too. Because of a great variety of geomorphological units in the Czech Republic, and in a broader sense in the Central Europe, the effect of region upon composition of local nematode faunas (including plant parasites occurrence in agroecosystems) should be taken into consideration when evaluating their disturbance by human activities.

The vertical distribution of nematodes in soil shows two main patterns: 1) the majority of nematodes are concentrated in the upper soil layer of 0 – 10 cm (Yeates, 1980; Háněl, 1997), and 2) nematodes are distributed evenly within the soil profile (Šály, 1973; Castillo *et al.*, 1985). Usually 70 – 80 % of nematode individuals in various ecosystems occur at a depth of 0 – 30 cm (Ou *et al.*, 2005; Sohlenius & Sandor, 1987; McSorley & Dickson, 1990). Our data instead reflected a model of gradually decreasing nematode abundance, in which values in individual soil layers and regions overlapped. Nevertheless, it must be taken into consideration that the vertical distribution of nematodes is seasonally changeable (Pen-Mouratov *et al.*, 2003, Renčo *et al.*, 2010a) and our study was for technical reasons, carried out as a single survey of localities over two different periods. Other factors that could contribute to insignificant differences in total nematode densities between soil layers are soil cultivation by ploughing, different trophic groups and genera in soil profile that can respond to tillage differently (López-Fando & Bello, 1995) and the interaction with the application of agro-chemicals

(Fiskus & Neher, 2002). Elucidation of the vertical distribution of nematodes in hop gardens, with special emphasis on the distribution of plant parasites and virus vectors, will therefore need more detailed studies.

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