

Case Report

A case study of soil nematode populations under intensive cucumber monoculture in Hungary

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Summary

A 25-year-old intensive monoculture of cucumber (*Cucumis sativus* 'Monolit F1') has been chosen for monitoring the effect of continuous fertilization, drip irrigation and various soil disinfection on free-living nematodes in soil. Densities, relative abundance of nematode genera, trophic groups and c-p classes, in addition, numerous nematological indices were determined besides certain soil properties. Concerning the nematological indices, all the values proved a stressed, depleted and unstable environment with degraded food web condition. The exaggerated application of fertilizers through irrigation caused high salinity values (0.62 %) which is much higher than the indicated toxicity threshold (0.4 %) for cultivated plants. The number of individuals of the bacterivore *Acrobeloides* and *Cuticularia* genera, which have a very high stress tolerance, was outstanding in the area. Besides juveniles, the appearance of *Meloidogyne incognita* males was also recorded which could lead to a change in the genetic composition of the population to adapt to environmental stressors. All these changes may result from salt stress indicated by intensive drip irrigation and the use of artificial fertilizers.

Keywords: artificial fertilizers; irrigation; salinity; free-living nematodes

Introduction

Free-living nematodes play an important role at different levels of soil life. They improve physical properties of soil and participate in nitrogen mineralization as decomposers and regulators (Ferris *et al.*, 2001; Neher, 2001). Several authors agree that nematode communities indicate soil quality by providing information on the soil food web, biodiversity and agroecosystem stability (Bongers *et al.*, 1997; Yeates & Bongers, 1999; Ferris *et al.*, 2001; Ruess, 2003; Neher *et al.*, 2005; Villenave *et al.*, 2009). In particular, plant-parasitic and predatory nematodes respond specifically to human activities on soil (Wasilewska, 1997).

As a result of irrigation, there is a positive correlation in the number

of nematodes living in the soil, especially the numbers of bacterivores increase. However, among drier conditions, the presence of fungivores is more dominant (Ferris *et al.*, 2001; Ewald *et al.*, 2022). Besides irrigation, tillage and nutrient supply also strongly influence the abundance of nematodes. Conventional tillage significantly increases the number of fungivores, while direct sowing increases the number of bacterivore nematodes (Zhang *et al.*, 2015). Moldboard plow significantly reduced the number of nematodes compared to direct sowing or rotary harrow. Nevertheless, the density of plant-parasitic nematodes was higher under moldboard plow cultivation method (Ito *et al.*, 2015).

Application of fertilizers enhances bacterial pathways; therefore, grazer nematodes can reach higher abundance (Ewald *et al.*,

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2022). Fertilization increases the number of individuals, however, decreases the distribution in trophic groups, and also reduces the structure of the population, i.e. fewer species are present in these samples compared to the control (Niu *et al.*, 2023). On the other hand, organic manure makes nematode community more diverse (Mulder & Maas, 2017), however, according to some other studies, the application of compost does not affect the trophic groups of the nematodes (Herren *et al.*, 2020).

Nitrogen supplementation generally enhances nematode abundance, especially the number of bacterivores (Qi *et al.*, 2023), decreases the number of fungivores and increases the number of plant-parasitic nematodes (Herren *et al.*, 2020), reduces the damage, oviposition and viability of *Meloidogyne incognita* (Kofoid & White, 1919) (Shakeel *et al.*, 2022). On the other hand, addition of phosphorus fertilizers reduces the abundance of plant-parasitic nematodes (Qi *et al.*, 2023).

Jászág Region (Heves County, Hungary) is characterized by the cultivation of cucumbers, which has a tradition dating back several decades. Monoculture, continuous fertilization, drip irrigation and soil disinfection are an integral part of this cultivation technology. In such a farm, where monoculture cucumber cultivation has been going on for 25 years, we examined nematode communities at the end of the growing season, as the producer suspected severe root-knot nematode damage. In addition to the measured soil parameters, we would like to share the results of the nematological survey, which is the result of a momentary picture in the life of a “real life farming”.

Materials and Methods

Study area and sampling

Intensive cultivation of cucumber (*Cucumis sativus* L.) Monolit F1 in monoculture has been carried out continuously since 1995, with two growing seasons each year in Csány (Heves county, Hungary). The unheated foil tent has a floor area of 40×7 m (280 m²) with a silt loam soil texture.

The same technology has been used in the cultivation of cucumbers in the investigated foil tent from the beginning. After subsoiling, seedlings were planted, then drip irrigation tapes were installed in rows to distribute irrigation water and fertilizers. Soil was treated with soil sterilants every year against southern root-knot nematode (*M. incognita*). Previously, Ipam (metam-ammonium) soil disinfectant was used through the drip irrigation system until 2016. After this year, Nemathorin (fosfiazate) and Basamid (dazomet) were applied. From 2020, Tervigo (abamectin) soil disinfectant was used. During the first 4 weeks, Tervigo was distributed once a week through drip irrigation tapes close to cucumber stems. During growing season, irrigation water was applied daily. At the same time, nutrients were supplied through the irrigation system for the whole tent as 1.2 kg of Poly-Feed 17-10-27+2Mg + Me, 0.3 kg of Epsó Top bitter salt (Mg-sulfate), and 5 g of ferric iron. In addition, 0.8 kg of calcium nitrate (Ducanit) was added to the

nutrient solution twice a week.

In the last growing season, four-week-old cucumber seedlings were planted on April 6, 2022, at the distance of 100×20 cm, in a total of 6 rows.

Grower continuously harvested marketable crops three or four times a week. The growing season ended on 29 June, 2022. Then, soil samples were collected from the root zone of 7×3 randomly chosen plants.

The measured properties of soil at the moment of sampling were the following: soil moisture content 31.05 %, pH (H₂O) 7.1, CaCO₃ 1.48 %, salinity 0.62 %, organic matter content 17.39 %, NO₂⁻ 0.51 mg/kg, NO₃⁻ 1204.33 mg/kg, NH₄⁺ 3.33 mg/kg, K₂O 1166 mg/kg, P₂O₅ 5537.33 mg/kg.

Nematode analysis

Active free-living nematodes were extracted from soil samples using a modified Baermann funnel technique (Szakálas *et al.*, 2015) for 48 hours. The number of individuals was determined under an Olympus SZH10 transmission stereomicroscope at 30× magnification. Then aqueous samples were stored in 4 % formaline.

From each sample, from 100 to 250 randomly selected individuals were identified to genus level under a VWR VisiScope DBL124 light microscope. Determination was based on the descriptions of Andrassy and Farkas (1988) and Bongers (1988), while the classification into trophic groups was based on the descriptions of Yeates *et al.* (1993). Indices (Maturity Index, Channel Index, Basal Index, Enrichment Index, Structure Index) were calculated by using Nematode Indicator Joint Analysis (NINJA) online software (Sieriebriennikov *et al.*, 2014).

Ethical Approval and/or Informed Consent

For this study, formal consent is not required.

Results

A total of 27 nematode genera were found in the experimental site. These consisted of 18 bacterivore, 3 fungivore, 2 herbivore, 2 omnivore and 2 predator genera. Bacterivore nematodes were the dominant trophic group, including *Acrobeloides* (28.8 %), *Theristus* (12.3 %) and *Acrobeles* (7.9 %) genera. Within fungivore trophic group, the appearance of *Ditylenchus* were the highest (3.9 %). Plant-feeder nematodes were subdominant with the genera of *Meloidogyne* and *Filenchus*, their relative abundance was 25.9 % and 0.1 %, respectively. Besides infective juveniles, 7 individuals of *M. incognita* male were detected and identified from 6 different samples. In the case of potential natural regulatory of plant-parasitic nematodes, omnivore was more dominant than predatory (0.8 %) trophic group, but still underrepresented with totally 6.4 % of relative abundance (Table 1).

Based on c-p (colonizer-persister) classification, relative abundance of group c-p 2 and c-p 3 were the highest with 34.6 and

Table 1. Density (individuals/25 g soil) and relative abundance (%) of free-living nematode genera in an intensive cucumber culture in greenhouse (Csány, Hungary). Density values are mean $\pm$ 95% of confidence interval (mean $\pm$ CI95%).

Taxon	Guild	Density	RA%
<i>Butlerius</i>	Ba1	0.3 $\pm$ 0.3	0.1
<i>Cuticularia</i>	Ba1	3.0 $\pm$ 2.9	1.3
<i>Diploscapter</i>	Ba1	0.1 $\pm$ 0.2	0.1
<i>Rhabditidae</i>	Ba1	4.3 $\pm$ 1.7	1.8
<i>Acrobeles</i>	Ba2	18.9 $\pm$ 6.0	7.9
<i>Acrobeloides</i>	Ba2	69.1 $\pm$ 15.9	28.8
<i>Cephalobus</i>	Ba2	1.3 $\pm$ 0.7	0.5
<i>Cervidellus</i>	Ba2	0.4 $\pm$ 0.3	0.2
<i>Chiloplacus</i>	Ba2	9.3 $\pm$ 3.6	3.9
<i>Eucephalobus</i>	Ba2	2.8 $\pm$ 1.3	1.2
<i>Heterocephalobus</i>	Ba2	3.3 $\pm$ 1.3	1.4
<i>Monhysteridae</i>	Ba2	0.2 $\pm$ 0.3	0.1
<i>Theristus</i>	Ba2	29.5 $\pm$ 15.0	12.3
<i>Bastiania</i>	Ba3	0.1 $\pm$ 0.1	0.0
<i>Metateratocephalus</i>	Ba3	0.1 $\pm$ 0.1	0.0
<i>Prismatolaimus</i>	Ba3	4.4 $\pm$ 2.4	1.8
<i>Teratocephalus</i>	Ba3	0.1 $\pm$ 0.1	0.0
<i>Alaimus</i>	Ba4	2.9 $\pm$ 1.9	1.2
Total bacterivores		149.9 $\pm$ 26.3	62.6
<i>Aphelenchoides</i>	Fu2	0.3 $\pm$ 0.3	0.1
<i>Aphelenchus</i>	Fu2	0.8 $\pm$ 0.5	0.3
<i>Ditylenchus</i>	Fu2	9.4 $\pm$ 4.2	3.9
Total fungivores		10.42 $\pm$ 4.4	4.3
<i>Filenchus</i>	H2	0.3 $\pm$ 0.3	0.1
<i>Meloidogyne</i>	H3	62.1 $\pm$ 17.0	25.9
Total herbivores		62.43 $\pm$ 17.0	26.0
<i>Eudorylaimus</i>	Om4	13.0 $\pm$ 5.1	5.4
<i>Aporcelaimellus</i>	Om5	2.3 $\pm$ 1.8	1.0
Total omnivores		15.2 $\pm$ 5.5	6.4
<i>Tobrilus</i>	Pr3	0.6 $\pm$ 0.7	0.2
<i>Mylonchulus</i>	Pr4	1.3 $\pm$ 0.9	0.5
Total predators		1.9 $\pm$ 1.3	0.7

Functional guild classification: Ba: bacterivore, Fu: fungivore, H: herbivore, Om: omnivore, Pr: predator. 1–5: C-p values by Bongers 1990. RA: relative abundance

34.7 %, followed by c-p 4 with 17.6 %, while c-p 5 and c-p 1 did not exceed 10 % (7.2, and 5.9 %). Group c-p 1 and 2 were represented by bacterivore nematodes, latter with *Acrobeles*, *Acrobeloides* and *Theristus* genera, while in c-p 3 *Meloidogyne* dominated. *Eudorylaimus* and *Mylonchulus* formed c-p 4, and only *Aporcelaimellus* appeared as c-p 5 (Table 1, Table 2).

The different indices of studied area were the following:

- Maturity Index: 2.21 $\pm$ 0.08
- Channel Index: 30.50 $\pm$ 11.70
- Basal Index: 53.15 $\pm$ 5.54
- Enrichment Index: 20.08 $\pm$ 5.19
- Structure Index: 32.25 $\pm$ 7.83
- Soil food web analysis: Quadrat D

Discussion

The exaggerated application of fertilizers through irrigation may enhance soil salinization (Rhoades *et al.*, 1992). Saline soil can be defined with a salt content of more than 0.2 % (Yang *et al.*, 2021). According to Bacsó *et al.* (1972), salinity higher than 0.4 % can be harmful for crops. Cucumber is known to be a particularly sensitive crop to high salt content in soils (Baysal *et al.*, 2007). In highly saline soils, bacterivore nematodes are dominant, which can lead to the conclusion of the main food source being bacteria (Pankhurst *et al.*, 2001). This is supported by the fact that bacteria thrive under neutral to alkaline pH condition, while fungi prefer acidic pH levels (Kautz *et al.*, 2001; Szegi, 1988). In our studied area, pH level was 7.1 which could be in line with this statement. In an abandoned farmland in China with high salinity value, similar tendency emerged as in our area: dominant bacterivores were

Table 2. Density (individuals/25 g soil) and relative abundance (%) of free-living nematode genera according to c-p classes in an intensive cucumber culture in green house (Csány, Hungary). Density values are mean $\pm$ 95% of confidence interval (mean $\pm$ CI95%), RA: Relative abundance.

C-p class	Density	RA%
c-p 1	40.5 $\pm$ 41.5	5.9
c-p 2	235 $\pm$ 222.6	34.6
c-p 3	235.7 $\pm$ 420.1	34.7
c-p 4	119.7 $\pm$ 149.5	17.6
c-p 5	49.0 $\pm$ 0.0	7.2

followed by herbivore nematodes (Yang *et al.*, 2021). In addition, omnivores and predatory nematodes, mainly the representatives of c-p 4 and 5, occurred in low abundance in our samples, which is in line with the findings of Šalamún *et al.* (2014). According to Šalamún *et al.* (2014) and Van Gundy (1965), these sensitive groups cannot properly regulate the osmotic stress through their cuticles, which could be the reason of areas with higher salinity levels being unfavourable for them.

Concerning the nematological indices, all the values prove a stressed, depleted and unstable environment with degraded food web condition (Bongers, 1990; Ferris *et al.*, 2001). As a result of continuous disturbance, K-strategist genera of higher c-p categories belonging to different trophic groups lack the appropriate conditions for building a stable population and regenerate more slowly. In the studied area, mainly stress-tolerant r-strategist species from lower trophic levels could become adapted for the local environmental conditions, which is also a consequence of the degraded ecosystem (Yang *et al.*, 2021).

Cuticularia species belong to group c-p 1 meaning that they are extreme opportunists with a short life cycle, often occurring in disturbed environment (Ferris *et al.*, 2001). They can be found even in Antarctica (Andrássy, 2005). The appearance of *Cuticularia* individuals could have been supported by their double cuticle layer which is characteristic for the genus. This morphological development can also provide protection against extreme soil salinity.

Most representatives of the genus *Theristus* are marine species, but some can also be found in terrestrial habitats. In Hungary, *Theristus terricola* Andrásy, 1985 lives on land (Andrásy, 2005). Most *Meloidogyne* species reproduce parthenogenetically. Although *Meloidogyne* males do not play any role in parthenogenetic reproduction, with their appearance, they can influence the adaptation of the population to unfavourable ecological conditions (Triantaphyllou, 1973; Jones *et al.*, 2013; Chitwood & Perry, 2009). All these changes may result from salt stress which was indicated by the intensive drip irrigation and the use of artificial fertilizers.

Exaggerated intensive cultivation technological elements like fertilization or the use soil disinfection can lead to the deterioration of soil life, which inhibit the natural suppressiveness of the soil. This leads to the accumulation of plant-parasitic nematode populations that are much more resistant to the prevailing conditions. Furthermore, these conditions are not suitable for the viability of natural enemies (microorganisms, predatory nematodes) of harmful pests. Therefore, involving alternative agricultural techniques into

farming practice, like the spread of organic matters and mulching are encouraged in order to stop degrading process.

Conflict of Interest

The authors declare that they did not have any conflict of interest in conducting this study. In addition, the authors do not have any potential conflict of interest pertaining to this submission to Helminthologia.

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