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# EFFECT OF ORCHARD SITE AND CLIMATIC CONDITIONS ON PLANT NEMATODE DENSITY LEVELS

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## ABSTRACT

Phytoparasitic nematodes are commonly found in the soil and their presence can lead to plant diseases, weaker growth, reduced yields and lower fruit quality. A study conducted in 2006–2009, involving the monitoring of climatic conditions, identified the influence of precipitation and temperature on the number of nematodes, in 7 sites within a cherry orchard. Soil samples to assess nematode populations were taken from 7 sites that differed in terms of cultivation and age: 5 cherry orchards established in different years. Not all nematode taxa responded in the same way to temperature increase. Members of the families *Belonolaimidae*, *Trichodoridae* and the genus *Aphelenchus* increased in number with rising temperatures. The negative water balance limited the number of nematodes in the soil in the layer up to 30 cm, whereas the increase in soil moisture had a positive effect on the development of *Paratylenchus* spp., and mebers of the family *Hoplolaimidae* and *Heterodera*. The largest total number of nematodes was found on the strip cultivated with agricultural crops after orchard liquidation. However, parasitic nematodes accounted for were at low levels (17%). The size of fruits from trees growing on sites with a large number of nematodes decreased with a simultaneous increase in total soluble solids and fruit firmness.

**Key words:** nematodes, sour cherry, climatic conditions, replantation, soil

## INTRODUCTION

Plant parasitic nematodes (PPN) can act as ectoparasites or endoparasites [Yeates 2007]. Their occurrence on tree crops is often associated with reduced yields, on many fruit species. Losses induced on the world main horticultural crops caused by PPN are estimated at 13.5% [Askary et al. 2012]. Roots damaged by nematodes use less efficiently both water and nutrients available in the soil. Symptoms of PPN infestation on fruit plants often include weaker growth, chlorosis, with a decrease in photosynthesis, followed by wilting, and eventual plant death. All these effects lead indirectly to a reduction in yields and a deterioration in the quality of fruit [Bahadur 2021], most often reflected by lower fruit weights [Chitambar et al. 2018].

It is believed that perennial fruit crops favor the PPN development [Kanfra et al. 2018]. However, studies conducted in a 1–5 year old apple orchard did not show any significant differences in PPN numbers, depending on the age of the orchard [Mazzola 1999]. It was noted that *Mesocriconema xenoplax* and *Xiphinema americanum* tended to be more abundant in older vineyards, but at the same time there was no clear relationship between the abundance of *Pratylenchus* and *Paratylenchus* spp., and the age of the vineyard [Pinkerton et al. 1999].

It is known that the composition of nematode species can be modified through appropriate crop rotation [Biggs et al. 1994]. It is assumed that during a one or

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two year preparation period the use of crop rotation allows to reduce the PPN number, enriching the soil with organic matter [Halbrendt 1996]. Plant species recommended for cultivation during the preparation of a new orchard site are, for example, *Tagetes patula*, *Brassica napus* or *Crotalaria juncea*, all reported to reduce the PPN number [Wang et al. 2001]. The use of species that are poor hosts for PPN may also limit their number [Wang and McSorley 2005].

Fruit crops are exposed to, among others, nematodes of genera *Pratylenchus*, *Paratylenchus* and members of other families such as *Hoplolamidae*, *Tylenchulidae*, and *Criconematidae* [Szczygiel and Zepp 2004].

The main damage that PPN inflict to plants is produced when they puncture the tissues of a host plant, followed by the introduction of enzymes causing a biochemical imbalance in the whole plant, as well as weakening and limiting the root system development [Dobies 2004]. Some nematodes are not only direct pests, but also act as carriers of specific viruses associated with some orchard crops [Szczygiel and Zepp 2004]. Another very serious negative effect of the damage to the root system caused by nematodes is the higher vulnerability of the host plant to common soil pathogens, the most important of which are *Rhizoctonia*, *Phytophthora*, *Cylindrocarpon* and *Pythium* [Kanfra et al. 2018]. The PPN presence often induces defence mechanisms in plants. Therefore, when the level of parasitism is low, plants increase their N, P and K content, to offset the negative effects of nematodes activity [Gebremikael et al. 2016].

Not all soil nematodes have a detrimental effect on cultivated plants. Some of them, feeding on bacteria or parasitic fungi, reduce their numbers and may affect the soil microbial composition [Djigal et al. 2004]. This activity may have a positive effect on plant growth, because the catabolites resulting from biomass and organic matter recycling are often simple compounds, easily available to plants [Bardgett et al. 1999]. High content of organic matter causes an increase in total soluble solids [Dziedzic et al. 2016], fruit firmness [Kurlus et al. 2020] and tree nutrition [Wrona 2011]. In addition, nematodes living in grass strips can mineralize up to 22% of the available N [Elliott et al. 1988].

The density level and structure of the PPN populations vary during the year, being lowest during the plant dormancy period [Verschoor et al. 2001]. The PPN development depends on many environmental factors, the most important of which are the type of soil [Kaya and Gaugler 1993], the content of organic substances or minerals [Thoden et al. 2011], pH, water content [Pacholak et al. 2006], the cultivation system, the climatic conditions, as well as their interaction with the host plants [Piskiewicz 2007]. All these factors together affect the PPN numbers in the soil, also influencing the physiological processes in the tree [Bieniek et al. 2017, Skwiercz 1987, Szot et al. 2019, Tomala 1996, Verschoor et al. 2001]. The attractiveness of plants as potential hosts for PPN depends on their growth dynamics and the timing of cultivation [Yeates 2007]. In addition, the development of the PPN populations depends on the host species, and the presence and number of soil microorganisms, as well [Szczygiel and Zepp 2004].

The optimal conditions for the development of most PPN species occur within a soil layer from 5 to 25 cm in depth. Only nematodes from families *Trichodoridae* and *Liongidoridae*, which are sensitive to low soil moisture levels, can usually be found in greater numbers in deeper soil layers (5–45 cm and deeper) [Skwiercz 1987]. The PPN distribution along the soil profile also depends on the activity of the root system [Fan-Xiang et al. 2006] and, indirectly, on agricultural treatments that affect the activity of the roots, such as mulching or the use of organic fertilizers [Mahran et al. 2009]. The application of organic substances, such as compost, reduces the level of root-damaging nematodes [Thoden et al. 2011], as did the use of mycorrhizal fungi that limited the incidence of *P. penetrans* [Ceustermans et al. 2018].

The water balance calculation makes it possible to determine a plant water needs, based on evapotranspiration, rainfall and soil moisture. It is important to take into account the parameters of soil texture, which affects the water holding capacity of soil, with clay soil showing a higher water holding capacity than sandy ones. The measurement of water level in the soil and soil moisture can help farmers, by improving the efficacy of decisions about irrigation [Fries et al. 2020].

Changes in the soil environment indirectly float on the abundance and structure of nematode communities [Kardol et al. 2010]. The increase in temperature affects the greater reproduction of nematodes, which

is the result of more nematodes and subsequent generations of nematodes due to the extension of the growing season [Colagiero and Ciancio 2012]. An increase in soil temperature of about 2°C resulted in a rotary increase in the number of threads [Ruess et al. 1999]. However, rising temperatures cause greater evaporation and water deficit in the soil, with soil moisture having the greatest impact on population size [Bakonyi and Nagy 2000].

This paper describes a study conducted in cherry orchards with the aim to find out how the number of PPN present is affected by climatic and site conditions.

## MATERIALS AND METHODS

**Experiment location.** Field studies were carried out in the experimental farm of Poznań University of Life Sciences (52°31'23.6"N 16°39'18.6"E) in the years 2006–2009. The orchard was located on luvisol composed of clay sands deposited on light clay. The share of flowing soil particles was 20–21% and the humus content was 1.15–1.35%. The orchard was fertilized annually, based on chemical analyses, in accordance with the recommendations for production orchards.

The cherry cultivar grown in all cherry orchards was 'Łutówka' grafted on *Prunus mahaleb.* Soil samples were taken to assess the nematode population from seven sites that differed in terms of cultivation and age.

Three cherry orchards were established in the following years:

– (CHO1) 1999 was planted with spacing of 4.0 × 2.0 m and had a tree density of 1250 trees $h^{-1}$;

– (CHO2) 2001 and (CHO3) 2002 were planted with spacing of 4.0 × 1.3 m and density of 1920 trees $h^{-1}$.

The orchards (CHO 1–3) were planted on the same field, on grey brown podzolic soil created on boulder clay sandy loam. Organic matter content was 1.25%. The share of flowing soil particles was 23%.

– (CHO4) an old cherry orchard where no fruit trees had been cultivated before, was planted in 1988 with spacing of 4.0 × 3.0 m and density of 830 trees $h^{-1}$. The orchard was located on the same farm, on an adjacent field with a similar soil type. Organic matter content was 1.15%. The share of flowing soil particles was 21%;

– (CHO5) a young cherry orchard planted on the site of a former cherry orchard following a several years break planted in 2006 with spacing of 4.0 × 1.3 m and density of 1920 trees $h^{-1}$. The share of organic matter was 1.19% and the share of flowing soil particles was 20%;

– (CHO6) a young cherry orchard planted on a site where no fruit trees had been cultivated before. It was planted in 2006 with spacing of 4.0 × 1.3 m and density of 1920 trees $h^{-1}$. Total organic matter in the soil was 1.35% and the share of flowing soil particles was 24%;

– OG (orchard grass) the samples were taken from former inter-rows covered with grass
and

– OT (orchard trees) and former rows of trees – from strip located on the site of a former cherry orchard, where agricultural crops, including *Brassicaceae*, were grown at the time of the experiment. The orchard had been planted in 1984 with spacing of 4.0 × 3.0 m and density of 830 trees $h^{-1}$. Organic matter content was 1.3% and the share of flowing soil particles was 20%.

**Soil sampling.** A sampling station was set up on each site in a representative site in terms of location and terrain. The sampling station was divided into 4 sections, each with an area of 150 $m^2$. In each section, 10 samples were taken from the arable layer (0–30 cm) with a soil sampler (30 mm in diameter; 3 puncture probes on an area of about 0.5 $m^2$, which were then poured into a container. A final soil sample of 500 ml was taken from the container after mixing the individual sub-samples.

In each year of the experiment, samples were taken by the end of May, when the soil was moderately moist (it was not too moist or dry). The samples were collected in the morning, when the air temperature was relatively low and there was relatively little sunlight. The samples were placed in polyethylene bags, which were then sealed and labelled, protected from direct light and stored at temperatures below 10°C, until extraction. Four samples were taken from each section.

**Soil analysis for PPN presence.** A quantitative analysis of nematodes was carried out at the Department of Nematology of the Institute of Plant Protection in Poznań, using the centrifuge method. In the first stage of extraction, the nematodes were identified using the

Christie and Perry method [Van Bezooijen 2006], in which a nematode suspension was decanted five times by passing it through a sieve with a mesh diameter of 28 μm. In the second stage, the centrifugal method was used [Szczygiel 1971]. After centrifugation, the nematode suspension was flushed using a sieve with a mesh diameter of 5 μm.

Plant parasitic nematodes feeding on plants growing on the experimental sites were extracted, using the Oostenbrink apparatus, the modified Baermann method and the centrifugal method. The PPN species were identified using image analysis to assess their morphological characteristics. The marking was based on an image key, which contains its own database of nematode images and published keys for identifying nematodes. The extracted nematodes were killed with hot water and preserved in liquid TAF (tri-ethylamine, distilled water, formalin). The PPN in suspension were counted using a stereomicroscope (Olympus SZ60, Tokyo, Japan) at a magnification of 40× and examined on temporary microscope slides.

Morphological observations and morphometric analysis were performed using an Axioskop 2 plus light microscope, with the Nomarsky differentiated contrast.

**Analysis of weather conditions.** Weather conditions were analysed based on readings from the iMETOS® 2 meteorological station (Pessl Instruments, Austria) set up in the orchard. The station recorded the air temperature at a height of 2 m and at the ground, and relative humidity, precipitation, wind speed and direction, and the soil temperature. Data were provided in a table or graph illustrating the climate course.

Water demand of trees from April through September was calculated in the three following stages using the Treder model [Stachowski et al. 2021]:

$$ET = \alpha \times T \times kc \times cf$$

where: ET – evapotranspiration of the orchard, taking into account the size of trees; α – empirically determined crop coefficient; T – average temperature on a given day (°C); kc – crop coefficient adopted for a particular species and month; cf – correction factor read from the graph and determined based on the ground surface shading by tree crowns (%, proportional tothe ground surface shaded by tree crowns).

Water balance was calculated taking into account precipitation and water demand of trees.

The average air temperature, within 4 weeks before sampling, was the highest in 2006 and 2007 (14.1°C and 14.7°C, respectively). Lower temperatures were recorded in the last two years of the experiment (12.6°C and 11.9°C, respectively). Total rainfall before sampling was the highest in 2007 (98.8 mm) and the lowest in 2008 (8.2 mm). Water balance, calculated based on the meteorological data, was positive and amounted to 21.4 mm in the first year of study, whereas it was negative in the spring of the subsequent years. The lowest water balance was recorded in 2007, when the rainfall deficiency was –132.6 mm (Tab. 1).

**Fruit quality analysis.** Fruit quality was assessed based on the weight of 100 fruit, firmness and total soluble solids (TSS). The sample taken from each site consisted of 400 fruit collected from 40 trees (100 fruit from 10 trees in each of the 4 sampling sections), at a height of 120–160 cm above the ground, from the

**Table 1.** Weather conditions 4 week before sampling

| Year | Temperature | | | Soil temperature (°C) by depth (cm) | | | | Precipitation (mm) | | WB | ET |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tmax | Tmin | Tavg | 5 | 10 | 20 | 50 | Avg | Σ | | |
| 2006 | 19.2 | 8.6 | 14.1 | 15.2 | 14.8 | 14.2 | 14.1 | 1.3 | 35.2 | 21.4 | 1.7 |
| 2007 | 15.4 | 14.1 | 14.7 | 17.4 | 17.1 | 16.6 | 15.2 | 3.5 | 98.8 | –132.6 | 1.8 |
| 2008 | 13.3 | 11.8 | 12.6 | 15.1 | 14.6 | 14.2 | 13.9 | 0.3 | 8.2 | –110.3 | 1.5 |
| 2009 | 12.6 | 11.2 | 11.9 | 15.6 | 15.2 | 14.6 | 13.5 | 1.4 | 40.4 | –83.6 | 1.3 |

Tmax – average maximum temperature; Tmin – average minimum temperature; Tavg – average temperature. Precipitation: Avg – mean precipitation; Σ – total precipitation; WB – water balance; ET – evapotranspiration

outer parts of the canopy. Fruit firmness was measured on 25 fruit using a FT 02 penetrometer (Facchini Srl, Italy), with a pin diameter of 2.5 mm. Total soluble solids were measured on 25 fruit randomly chosen from each section of the respective sites using a PR-101α digital referactometer (Atago, Japan).

The results were subject to one-way analysis of variance using Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA, USA). The average values were compared using Duncan's test at $p \leq 0.05\%$. Pearson's correlation coefficient was also calculated. Principal component analysis (PCA) was used to determine the relationship between climatic factors and the PPN numbers.

## RESULTS AND DISCUSSION

The total number of nematodes varied among the years of the experiment (Fig. 1) and appeared to be affected by the site and weather conditions during the growing season. As expected, soil humidity, reflected in the amount of precipitation, had a strong impact on the presence of nematodes. Precipitation and evapotranspiration in the period before sampling were positively correlated with the total number of nematodes in soil (Tab. 2). Soil temperature and moisture change the metabolic activity of nematodes thus directly affecting their activity in the soil [McSorley 1998]. Soil humidity is considered one of the most important factors affecting the seasonal fluctuations of nematode populations. The high temperature and low moisture in the soil is prevented nematode activity [Bucki et al. 2020]. Soil temperature and moisture change the metabolic activity of nematodes thus directly affecting their activity in the soil [McSorley 1998]. It can be assumed that in such circumstances nematodes interact with host plants because the same factors change the activity of the of host root system or other food sources [Verschoor et al. 2001]. The total number of nematodes in the soil layer up to 30 cm was positively correlated with evapotranspiration. The negative water balance limited the development of parasitic nematodes, whereas the increase in precipitation, resulting in improved soil moisture, favoured their development. An increase in the air temperature in the period before sampling was reflected by an increase in the total number of nematodes (Tab. 2). Of these two factors, temperature appeared to have a greater impact on nematode abundance than soil moisture [Bakonyi and Nagy 2000]. The development of many invertebrates and plants very strongly depends on the so-called „physiological time", which determines the total amount of heat that a given organism must absorb in a specific period of time in order to reach

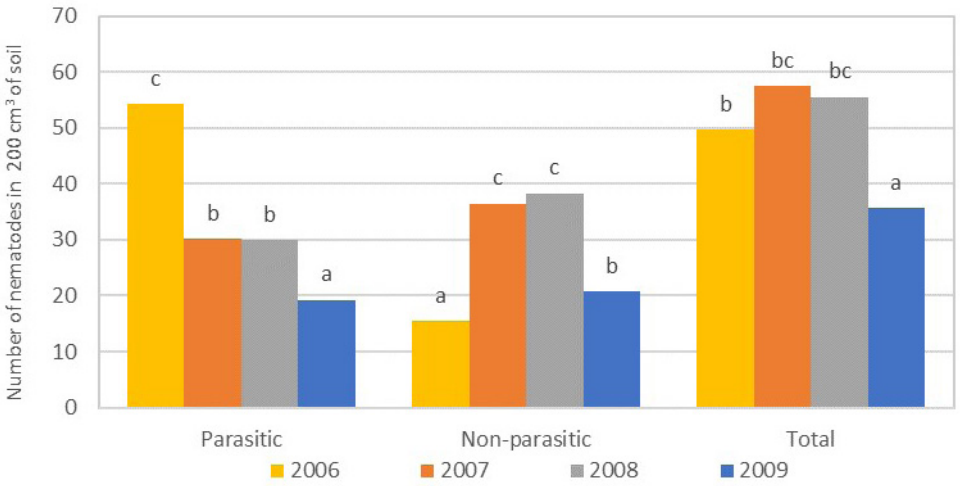


**Fig. 1.** The number of nematodes in 2006–2009. One-way ANOVA. Means followed by the same letters are not significantly different at $\alpha = 0.05$ (Duncan's test). Statistical analysis performed separately for parasitic, non-parasitic and total nematode counts

**Table 2.** Correlation matrix showing the link of climatic variables with the number of neatodes, per taxa or groups

| Nematodes | T | PR | WB | ET | Sum of active temperatures | | | Soil temperature at depth | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | T > 0°C | T > 5°C | T > 10°C | 5 cm | 10 cm | 20 cm |
| *Tylenchidae* | –0.14 | 0.06 | 0.53* | 0.36 | –0.05 | –0.04 | 0.23 | 0.54** | –0.19 | –0.25 |
| *Trichodoridae* | 0.28 | 0.18 | –0.09 | 0.25 | 0.30 | 0.29 | 0.21 | 0.01 | –0.27 | –0.25 |
| *Paratylenchus* | –0.05 | 0.50* | 0.53* | 0.31 | 0.11 | 0.26 | 0.53* | 0.61** | –0.17 | –0.12 |
| *Hoplolaimidae* | –0.19 | 0.50* | 0.66** | 0.25 | 0.00 | 0.16 | 0.53* | 0.71*** | –0.07 | –0.03 |
| *Aphelenchus* | 0.56** | 0.31 | –0.15 | 0.56** | 0.60** | 0.56** | 0.41* | 0.04 | –0.59** | –0.56** |
| *Aphelenchoides* | –0.07 | –0.46* | 0.02 | 0.12 | –0.14 | –0.29 | –0.30 | –0.04 | –0.08 | –0.20 |
| *P. neglectus* | –0.21 | 0.12 | 0.39 | 0.07 | –0.13 | –0.07 | 0.15 | 0.37 | 0.05 | 0.03 |
| *P. penetrans* | 0.00 | –0.24 | –0.01 | 0.09 | –0.04 | –0.13 | –0.15 | –0.03 | –0.07 | –0.13 |
| Parasitic n. | –0.11 | 0.38 | 0.50* | 0.23 | 0.03 | 0.15 | 0.42* | 0.55** | –0.09 | –0.07 |
| Non-parasitic n. | 0.28 | 0.16 | –0.14 | 0.20 | 0.29 | 0.28 | 0.18 | –0.05 | –0.24 | –0.21 |
| Total | 0.15 | 0.48* | 0.37 | 0.46* | 0.29 | 0.39 | 0.56** | 0.51* | –0.35 | –0.32 |

The asterisk (*) in columns indicate a significant correlation coefficient (r) at * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n = 24; T – average temperature 2 weeks before sampling; PR – precipitation 2 weeks before sampling; WB – water balance 30 days before sampling; ET – evapotranspiration; sum of active temperatures 2 weeks before sampling; soil temperature: 2 weeks before sampling at depths of 5, 10 and 20 cm

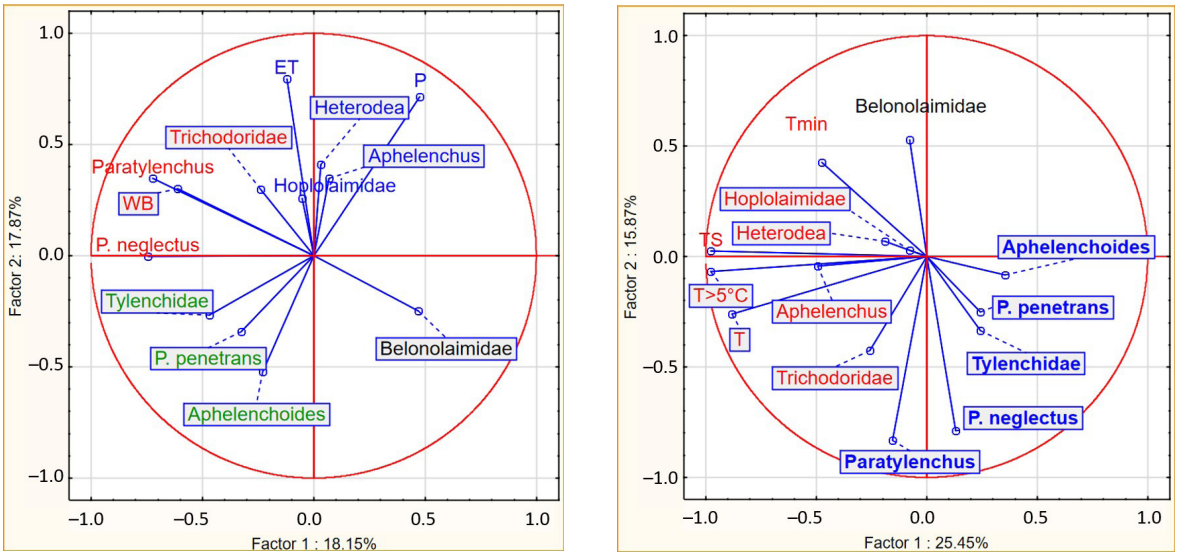


**Fig. 2.** PCA analysis showing the effect of basic climate variables on the abundance of nematode taxa in 2006–2009; T – average temperature 4 weeks before sampling; T > 5°C – sum of active temperatures; TS – soil temperature at a depth of 20 cm 4 weeks before sampling; P – total rainfall 4 weeks before sampling; ET – evapotranspiration; WB – water balance 4 weeks before sampling

a specific stage of development [Juszczak et al. 2008, Łysiak 2012]. The above findings were in accord with the study by Verschoor et al., in which the overall abundance of *Pratylenchus* sp. in soil increased with the rise in temperature and decreased with the decrease in soil moisture [Verschoor et al. 2001]. The density of this pest can vary significantly during the growing season, remaining at a high level throughout the winter because they either overwinter inside roots, where they are protected against adverse winter

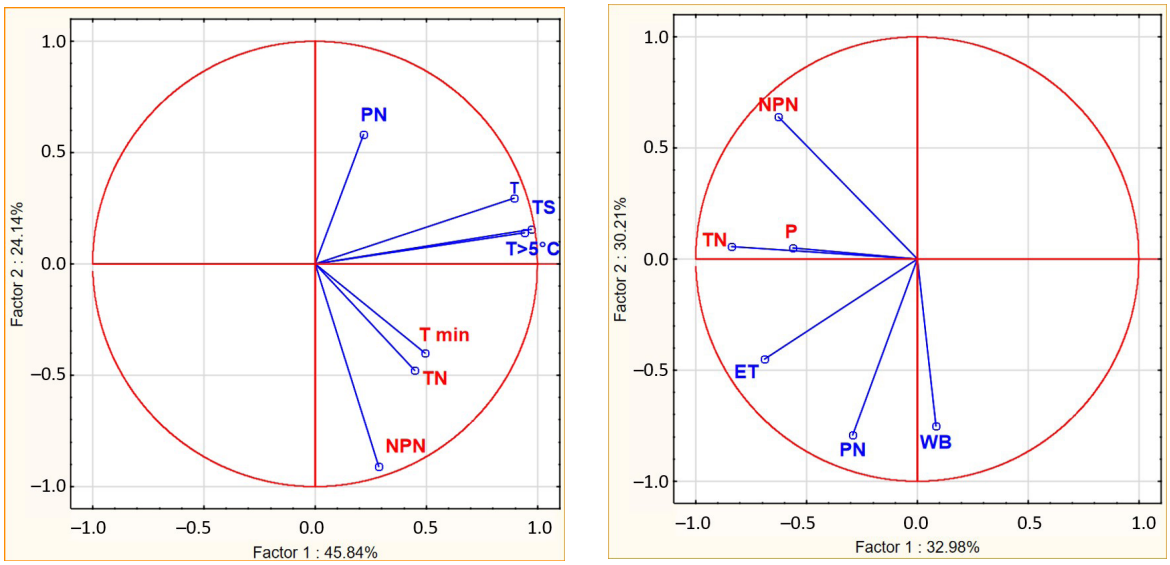


**Fig. 3.** Effect of the basic climate variables on the abundance of nematode groups in 2006–2009, as shown by PCA. PN – parasitic nematodes; NPN – non-parasitic nematodes; TN – total number of nematodes; T – average temperature 4 weeks before sampling; T > 5°C – sum of active temperatures; TS – soil temperature at a depth of 20 cm 4 weeks before sampling; P – total precipitation 4 weeks before sampling; ET – evapotranspiration; WB – water balance 4 weeks before sampling

conditions, or move to deeper soil layers [Nombela et al. 1993, Verschoor et al. 2001]. In addition, changes in the abundance of some ectoparasitic nematodes may result from disturbance in their development cycle caused by low temperatures during winter and precipitation deficits in spring [Sharma 1971]. Another important factor that affects the number of nematodes exposed to low winter temperatures is the length of the development cycle [Taylor 1960, Verschoor et al. 2001]. During the research period, the lowest temperatures were in the winter of 2006, where the temperature in January dropped to –25.2°C. In the following 2 years, the minimum temperature did not drop below –13.3°C. Only in 2009 the temperature in January dropped to –17.3°C.

Not all taxa identified on the studied sites responded equally to climatic conditions (Tab. 2, Fig. 2). The *Belonolaimidae* grew in number along with the rise in temperature. The maximum temperature in the pre-sampling period had a significantly greater impact on their abundance than the average minimum temperature. The increase in precipitation in spring caused a decrease in the number of *Belonolaimidae*. Some species of this family may be parasitic to perennial plants, but studies conducted in orchards have found these ectoparasites mainly in soil, being isolated from roots, rarely and usually in small numbers [Szczygiel and Zepp 2004]. Similar relationships were found for members of *Trichodoridae*, that also feed as ectoparasites, and in the numbers of *Aphelenchus* sp., feeding on fungi [Skwiercz 2012], were positively correlated with higher air temperatures (max., medium and min.) and with evapotranspiration. On the other hand, increase in soil moisture had a positive effect on the development of *Paratylenchus* spp., members of *Hoplolaimidae* and juveniles of *Heterodera* sp. It was found out that especially the *Trichodoride* and *Longidoride* reacted strongly to changes in soil moisture and temperature [Ploeg 1998, Wyss 1970].

The PCA showed that the minimum temperature and rainfall in the pre-sampling period were strongly positively correlated with the total number of nematodes. Precipitation had the strongest impact on the abundance of *Aphelenchus*, *Hoplolaimidae* and *Trichodoridae*, like on all physiological processes [Kowalczyk et al. 2022]. The minimum air temperature was positively correlated with the number of *Belonolaimidae* (Figs 2 and 3).

**Table 3.** Nematode densities by taxa and orchard, during the sampling period 2006–2009

| Orchards | Number of nematodes in 200 $cm^3$ of soil | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Belonolaimidae* | *Tylenchidae* | *Trichodoridae* | *Paratylenchus* | *Hoplolaimidae* | *Aphelenchus* | *Aphelenchoides* | *P. neglectus* | *P. penetrans* | *Parasitic nematodes* | *Non-parasitic nematodes* | Total |
| CHO1 | 9.1 ab[1] | 1.0 a | 9.8 b | 19.7 b | 2.1 a | 2.6 ab | 1.2 a | 22.6 c | 0.8 a | 54.9 d | 14.0 ab | 68.9 d |
| CHO2 | 8.1 ab | 1.4 a | 6.4 ab | 18.9 b | 0.2 a | 0.6 a | 1.3 a | 9.8 b | 0.0 a | 35.2 c | 11.4 a | 46.6 bc |
| CHO3 | 13.8 ab | 2.4 a | 0.1 a | 10.1 ab | 0.9 a | 1.8 a | 0.4 a | 10.4 b | 2.9 a | 24.4 bc | 18.3 ab | 42.7 a-c |
| CHO4 | 5.2 a | 2.6 a | 17.8 c | 2.3 a | 0.0 a | 1.0 a | 0.1 a | 3.2 a | 0.0 a | 23.3 bc | 8.8 a | 32.2 ab |
| OG | 63.2 d | 1.4 a | 0.0 a | 1.0 a | 13.2 a | 0.6 a | 1.3 a | 2.3 a | 0.8 a | 17.3 ab | 66.5 d | 83.8 d |
| OT | 46.3 cd | 1.3 a | 0.3 a | 1.2 a | 2.2 a | 1.0 a | 0.8 a | 1.6 a | 0.1 a | 5.3 a | 49.6 cd | 54.9 bc |
| CHO5 | 33.2 bc | 1.2 a | 1.1 a | 0.9 a | 0.3 b | 4.7 b | 0.6 a | 5.3 ab | 0.0 a | 7.5 ab | 39.7 bc | 47.2 bc |
| CHO6 | 12.8 ab | 0.9 a | 0.0 a | 1.5 a | 0.6 a | 0.0 a | 0.6 a | 0.0 a | 0.0 a | 2.1 a | 14.3 ab | 16.4 a |

[1] One-way ANOVA. Means followed by the same letters did not significantly differ at $\alpha = 0.05$ (Duncan's test). Statistical analysis was performed separately for all taxa. For orchards description see text.

The highest total nematode numbers of were found in the sampling site with crops cultivated after the liquidation of a cherry orchard (OT/OG) (Tab. 3). Tillage is an important factor that affects soil properties and nematode populations [Dong et al. 2013]. The total number of nematodes was the highest in former inter-rows (OG). Most of nematodes identified on the entire site were non-parasitic, and the number of PPN was similar in the former tree rows (OT) and the former inter-rows (OG). On the other hand, on each cherry orchard site the number of nematodes increased with the orchard age, whereas the PPN number increased significantly and considerably exceeded the population of non-parasitic microbiovorous taxa, feeding on fungi or soil bacteria.

The use of mechanized agricultural practices and the introduction of crop residues into the soil every year led to a change in the nematode species structure (Fig. 4). At the same time, the lack of soil cultivation treatments and the growing of perennial plants led to greater abundance of PPN. Growing of e.g. cereals or cruciferous plants contributed to a change in composition and population of nematode species. Plants from the *Brassicaceae* family have a nematicidal effect because of a wide range of secondary metabolites produced as a defense against pests and abiotic environmental stresses [Brennan et al. 2020]. The crop grown on the OT/OG site probably killed many nematodes (Tab. 3), contributing to the low population in the upper soil layers [Boag 1981]. Only the *Belonolaimidae* and *Hoplolaimidae*, especially in the strip of grass, were higher than in other orchards (Tab. 3). Overdrying of the top soil as a result of agrotechnical treatments helps management of *Paratrichodorus* and *Trichodorus* [Agrios 2005]. The presence and distribution of the roots of the host plant is relevant for the nematode population as well [Boag 1981]. Finally, cultivated soil is supplied every year with organic matter being a good medium for the development of bacteria which contribute to the change in the nematode species composition [Skwiercz 2012].

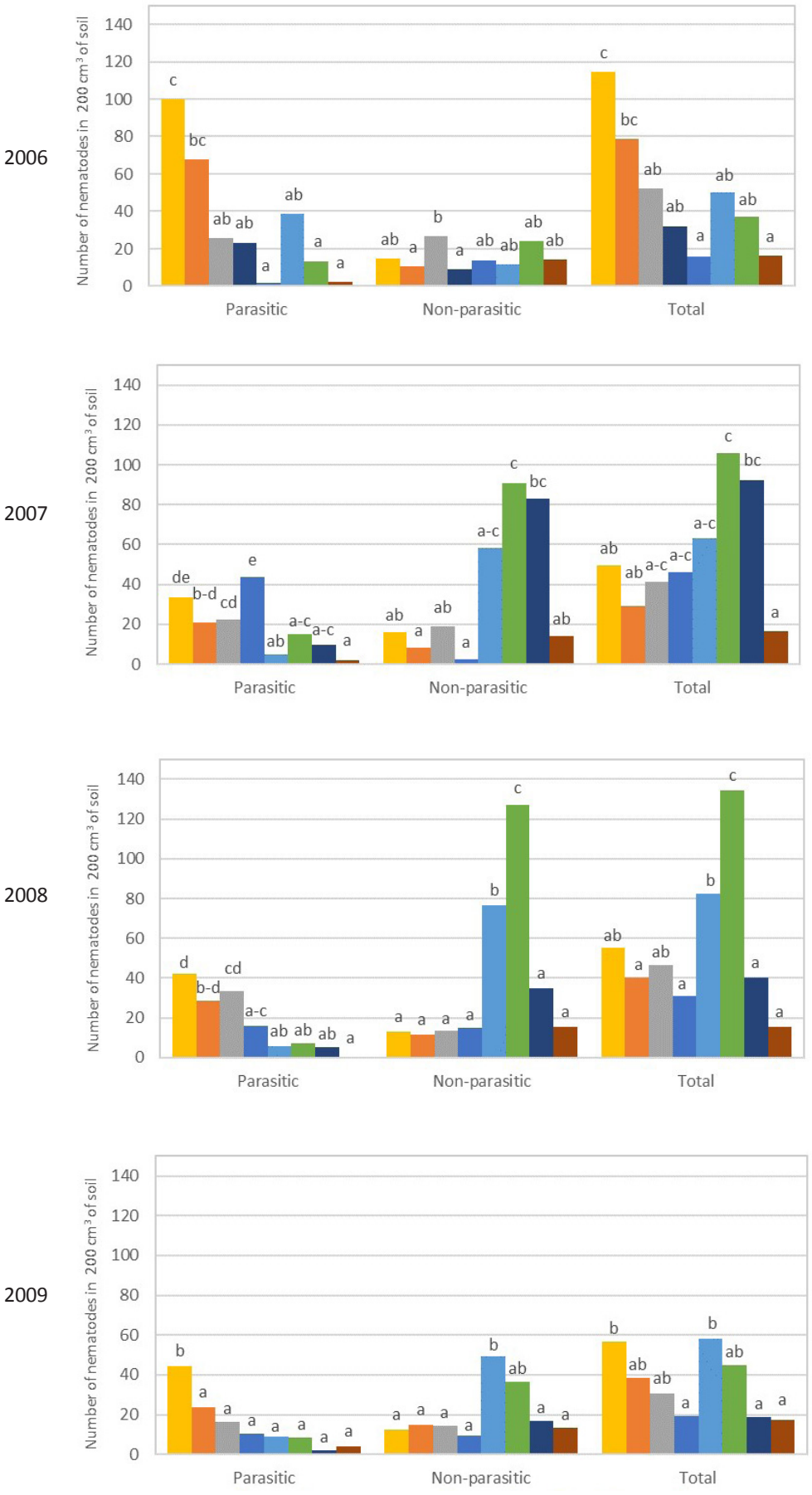


**Fig. 4.** The number of nematodes in 2006–2009. One-way ANOVA. Means followed by the same letters are not significantly different at $\alpha = 0.05$ (Duncan's test). Statistical analysis performed separately for parasitic, non-parasitic and total nematode counts. For orchards description see text

**Table 4.** Nematode counts and sour cherry fruit quality

| Year | TNN (200 cm$^3$) | MF (g) | % of 2006 | TSS (%) | % of 2006 | F (g) | % of 2006 |
|---|---|---|---|---|---|---|---|
| 2006 | 70.7 | 492.9 | 100.0 | 17.2 | 100.0 | 270.1 | 100.0 |
| 2007 | 51.8 | 499.5 | 98.7 | 15.5 | 111.0 | 260.8 | 103.6 |
| 2008 | 37.9 | 535.3 | 92.1 | 14.9 | 115.4 | 220.3 | 122.6 |
| 2009 | 30.3 | 601.4 | 82.0 | 14.0 | 122.9 | 184.9 | 146.1 |

TNN – total number of nematodes; MF – mass of 100 fruit; TSS – total soluble solids; F – firmness

Species of the family *Belonolaimidae* and the fungus-feeding *Aphelenchoides* and *Aphelenchus* spp. do not have a regular annual cycle. A short development cycle and low requirements regarding the reproduction temperature [Moens et al. 1996] explain their relatively large numbers in spring, on the OT/OG site (Tab. 3). Agricultural crop residues provide an environment for the multiplication of fungi, which are a source of nematode food in the early growing season [Verschoor et al. 2001].

No relationship was found between the overall number of nematodes and the cherry yields. The difference between the year with the highest and that with the lowest totals identified a PPN incidence by 4.9%. According to the literature, low nematode populations do not cause crop loss, on the contrary, there may be even small increases in yields as plants infected with nematodes may produce auxin-like compounds [Greco and Di Vito 2009]. With a low number of nematodes, plants can offset the negative effects of their activity [Gebremikael et al. 2016] and no decrease in yield is observed despite nematode presence. The relationships between the number of nematodes and the quality of the fruit were also insignificant. However, high abundance of nematodes in soil was found to negatively influence the fruit weight, which decreased in the above-cited studies. On the other hand, TSS and fruit firmness were higher (Tab. 4).

## CONCLUSIONS

The nematode population structure and their abundance depend on climatic conditions, the most important of which being the precipitation in spring. The increase in water balance and evapotranspiration in the cherry orchard, which depends on temperature and growing season, was strongly correlated with the overall abundance of nematodes.

The air temperature at the beginning of vegetation was much less relevant for the incidence of nematodes than sum active temperatures above 10°C and soil temperature at depth 5 cm 4 weeks, before sampling.

The change in the way the soil was cultivated had an impact on the abundance and structure of nematode taxa. Crop rotation and soil cultivation changed the composition of nematode population in the soil. The number of parasitic nematodes decreased, while the number of non-parasitic nematodes increased.

This can be explained by a change in soil conditions and the annual replenishment of organic matter in soil, promoting the growth of bacteria and fungi, thus directly affecting the microbial composition the soil. This, in turn, creates a favourable environment for microbivorous nematodes. However, it should be emphasized that the removal of a perennial plantation leaves a trace that is visible in the structure of the nematode population, and the number of nematodes in sampling places with previous trees rows and inter-rows.

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