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# Ecological and taxonomic diversity of nematode communities in soils of the Zarafshan Valley (Uzbekistan) and its edaphic determinants

**DILNOZA M. NURMATOVA[1], SARDORBEK B. NARZULLAYEV[1,2,3,♥], OCHIL MAVLYANOV[1], UKTAM N. MIRZAEV[2], RUSTAM SH. URALOV[4], SHAHLO SH. TURSUNOVA[2], FERUZ A. SHODMONOV[1,3], JAKHONGIR E. OBLOKULOV[2], SARDORBEK S. KAMBAROV[5], INTIZOR R. AVAZMETOVA[6,7], KHULKAR SH. URINOVA[8], DILFUZA SH. YODGOROVA[9]**

[1]Samarkand State University. 15 University Boulevard St., Samarkand, 140104, Uzbekistan. Tel./fax.: +998-93 9972195,
♥email: narzullayevsardorbek1990@gmail.com
[2]Samarkand State Pedagogical Institute. 166 Spitamen St., Samarkand, 140102, Uzbekistan
[3]University of Economics and Pedagogy. 13 Islam Karimov St., Karshi, 180100, Uzbekistan
[4]Samarkand State Medical University. 18 Amir Temur St., Samarkand, 140100, Uzbekistan
[5]Department of Biology, Andijan State University. 129 University Street, Andijan City 170100, Uzbekistan
[6]Urgench State University. 14 Khamid Alimdjan St., Urgench, 220100, Uzbekistan
[7]Mamun University. 2 Bol-Khovuz St., Khorezm, 220900, Uzbekistan
[8]Navoi State University of Mining and Technologies. 76V Galaba St., Navoi, 210100, Uzbekistan
[9]National University of Uzbekistan. 4 University St., Tashkent, 100174, Uzbekistan

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**Abstract.** *Nurmatova DM, Narzullayev SB, Mavlyanov O, Mirzaev UN, Uralov RS, Tursunova SS, Shodmonov FA, Oblokulov JE, Kambarov SS, Avazmetova IR, Urinova KS, Yodgorova DS. 2026. Ecological and taxonomic diversity of nematode communities in soils of the Zarafshan Valley (Uzbekistan) and its edaphic determinants. Biodiversitas 27 (2): d270203. https://doi.org/10.13057/biodiv/d270203.* Soil nematodes are key bioindicators of belowground ecosystem functioning and soil health. This study analyzed the trophic and taxonomic structure of nematode communities in apple orchards of the Zarafshan Valley (Uzbekistan) and assessed their relationships with soil physicochemical properties. The study, conducted from 2023 to 2025, investigated the nematode diversity associated with intensive apple orchards in depth, in relation to soil factors. A total of 240 samples were collected from 8 apple orchards using the route method in spring, summer, and fall. The samples were processed using the modified Berman's funnel method and flotation method. A total of 1277 individuals representing 54 nematode species, 25 genera, and four orders were identified from root and soil samples collected at 0-20 and 20-40 cm depths. The highest diversity of species and individuals was observed in the top layer of soil. This layer contained 90% of the species and 59% of the individuals of the fauna. The dominant ecological groups were omnivores-predators (*Dorylaimus, Eudorylaimus*), bacterivores (*Cephalobus, Panagrolaimus*), and plant parasites (*Pratylenchus, Helicotylenchus*). Species richness and abundance were markedly higher in the upper soil layer, which contained more humus, nitrogen, and phosphorus, and had lower bulk density. Principal Component Analysis (PCA) revealed that humus, N, P, pH, and K were the main environmental determinants shaping nematode community composition. According to PCA analysis, bacterivores and omnivores had positive correlations with humus and N, while plant parasites were mainly associated with high P and K concentrations. These findings highlight the ecological sensitivity of nematode trophic groups to soil fertility gradients and physicochemical conditions. By studying the taxonomic and ecological diversity of nematodes, revealing their degree of association with soil factors, it is possible to improve intervention strategies to maintain soil health and stability in semi-arid horticultural ecosystems.

**Keywords:** Apple orchards, bioindicators, humus, PCA, trophic structure

## INTRODUCTION

Soil is one of the most complex, dynamic and multi-component ecosystems for living organisms, where important biogeochemical processes such as material cycling, energy flow and organic matter decomposition occur (Bardgett and van der Putten 2014; Orgiazzi et al. 2016). Soil nematodes play a central role in these processes. They feed on microorganisms and interact directly or indirectly with plant roots, thereby controlling the circulation of nitrogen and other elements through the food chain (Ferris 2010). Nematodes play an important role in ecological systems as bioindicators. Their abundance, diversity and trophic composition reflect the biological fertility, balance and level of pollution of the soil (Bongers and Ferris 1999). Changes in the structure of the nematode community are sensitive to physicochemical factors in the soil - moisture, pH, temperature, humus, nitrogen (N), phosphorus (P) and potassium (K), which are closely related to the composition of the plant cover and microflora (Leiva et al. 2020).

In recent years, the study of soil nematodes by trophic groups (bacterivores, fungivores, plant parasites, omnivores, predators) has become widespread, as this approach better reflects the functioning of food webs in the ecosystem (Li et al. 2024). Especially in agroecosystems, fertilization, irrigation, and agrotechnical measures have an impact on the composition and stability of the nematode community (Ewald et al. 2022).

Most studies show that increasing soil nitrogen and humus content increases the abundance of free-living trophic groups, namely bacteriophages and fungivorous nematodes. This indicates increased microbial activity (Rencho et al. 2020). Conversely, excess phosphorus (P) or high concentrations of mineralized fertilizers often reduce nematode diversity and lead to the dominance of plant parasitic species (especially *Pratylenchus, Helicotylenchus, Meloidogyne*) (Atira and Duarte 2025). Therefore, the effects of elements such as P and K on the nematode community may be complex and indirect: they do not act directly as a source of food, but rather create favorable conditions for parasitic species by stimulating root biomass and plant growth (Ferris and Matute 2003).

Plant parasitic nematodes - especially species such as *Pratylenchus, Helicotylenchus, Xiphinema* - are widespread in fruit tree agrocenoses, and their population is closely related to the soil nutritional regime (Bekmurodov and Saidova 2025; Kaushal and Vashisth 2025). They damage root tissues and slow down the process of plant nutrient absorption, which directly affects productivity (van den Hoogen et al. 2019).

Although many studies have been conducted on the distribution of invertebrates in various biotopes in Central Asia, in particular the Zarafshan Valley, Uzbekistan (Kambarov et al. 2025; Medetov et al. 2025; Shodmonov and Fomichev 2025), there are very few studies on the ecological-trophic structure and formation of soil nematodes in fruit agroecosystems. Although several studies have been conducted on the formation of invertebrate communities in Central Asia (Kudratov et al. 2025; Zokirova et al. 2025), including the formation of nematode fauna (Narzullayev 2022; Narzullayev and Subbotin 2025), there is no information on the nematode community formed under the influence of irrigation, soil physical parameters and mineral substances in gardens. Studies on the influence of soil factors on the formation of nematode communities and the indicator properties of nematodes in the region are very limited, and studies conducted only on the community of soil nematodes contaminated with heavy metals do not provide complete information about soil nematodes in agrocenoses (Pen-Mouratov et al. 2010). In this region, the continental nature of the climate, lack of moisture, carbonate and alkalinity of the soil, as well as agrotechnical factors (fertilization, irrigation) can play an important role in the formation of the nematode community. Especially in areas where soil degradation occurred as a result of long-term monoculture during the Soviet era, data on soil micro- and mesofauna in agrocenoses irrigated with river waters saturated with organic matter can provide valuable information in assessing the condition of soil layers at various depths. Therefore, the study of the nematode fauna of apple agrocenoses soils in the Zarafshan Valley from an ecological point of view is of practical importance not only for local, but also for regional soil ecology.

This study aims to analyze the trophic and taxonomic structure of nematode communities in the root system and soil layers of apple orchards in the Zarafshan Valley, and to analyze their relationship with soil physicochemical parameters using Principal Component Analysis (PCA).

## MATERIALS AND METHODS

### Study area

Samples of intensive apple (*Malus domestica* (Suckow) Borkh.) orchards and their rhizosphere soils were collected from the central part of the Zarafshan Valley (Uzbekistan). Sampling locations in the central part of the Zarafshan Valley are shown in Figure 1. The Zarafshan Valley is a semi-arid region with well-developed irrigated agriculture. This region is one of the regions most affected by climate change in recent years. The development of agriculture and horticulture in the valley is partly directly related to rainfall and mainly to artificial irrigation. The intensive apple orchards studied are 5-6-year-old orchards, where the "Golden apple" variety is grown. The row spacing is 3 meters, and no other crops are planted between the rows. Continuous plowing is carried out to prevent the growth of weeds (Babakholov 2021).

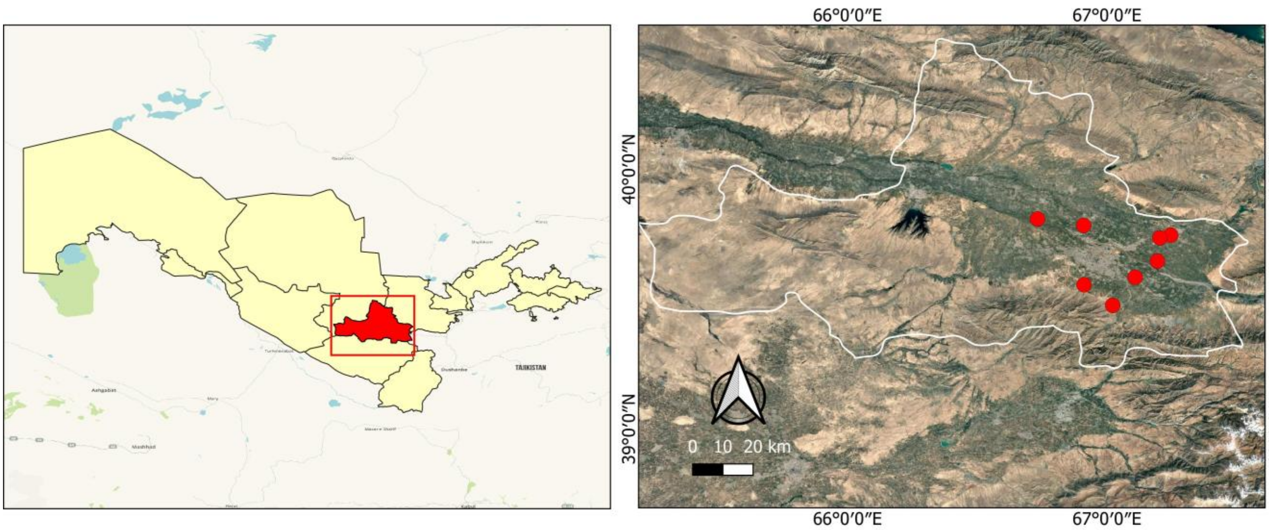

**Figure 1.** Locations of sample collection

**Table 1.** Physicochemical properties of soils at the study sites (Values represent the mean ± SD calculated from composite samples for each orchard and soil depth (n = 10))

| Soil layers | pH | Humus (%) | $N\text{-}NH_4$ (mg/kg) | $P_2O_5$ (mg/kg) | $K_2O$ (mg/kg) | *Soil density |
|---|---|---|---|---|---|---|
| 0-20 | 7.5 | 1.435 ± 0.257 | 34.9 ± 5.7 | 45.3 ± 5.5 | 306.3 ± 33.1 | 1.20 ± 0.05 |
| 20-40 | 8,05 | 1.107 ± 0.112 | 28.13 ± 4.3 | 35.2 ± 4.6 | 270.8 ± 27.1 | 1.32 ± 0.06 |

Note: pH: Soil environment indikator, $N\text{-}NH_4$: Nitrogen in a mobile form that can be absorbed by plants, $P_2O_5$: Phosphorus in a mobile form that can be absorbed by plants, $K_2O$: Exchangeable potassium that can be absorbed by plants, Humus: The amount of organic matter in the soil; *: Soil density was taken from data in the available literature (Uzokov et al. 2018)

## Sampling design

Samples were collected from 8 apple orchards. Below are the coordinates of the locations where the samples were collected: 39,7459910, 67,2463250; 39,7351836, 67,2044491; 39,7834310, 66,9110420; 39.808179, 66.733010; 39,5550010, 66,9120710; 39.583626, 67.109346; 39.475575, 67.022533; 39.646317, 67.194994.

Between April and September, samples were taken from 10 points in each apple orchard. Separate samples were taken from the apple root system, 0-20 and 20-40 cm soil layers. Between April and September, samples were taken from 10 points in each apple orchard. Separate samples were taken from the apple root system, 0-20 cm and 20-40 cm soil layers. The route method was used to collect samples. According to this, plant and soil samples were taken diagonally across the field area. 200 g of soil samples were taken from each layer. Each soil sample was mixed separately in the laboratory and after cleaning of foreign objects, 50 g of it was taken and placed in funnels filled with water. Root samples were cleaned of soil, washed in running water and 15 g of roots were placed in funnels filled with water. Thirty samples from a total of 240 samples (80 root and 160 soil samples) were taken from each of the 8 apple orchards and analyzed for the presence of nematodes in the laboratory. 176 of the samples (73%) were found to be infected with nematodes, including 124 soil and 52 root samples.

## Isolation, identification, taxonomic, and trophic classification of nematodes

Nematodes were extracted from the samples using the modified Baermann funnel technique (Van Bezooijen 2006). In this method, soil and root samples were left in water funnels for 14-15 hours. In addition, flotation was used to isolate relatively large soil nematodes. Nematodes were isolated from soil samples by the flotation method. For this purpose, several 300-500 mL containers are taken, and 10-15 (20) g of soil from one sample are dissolved in the water in them and shaken. Then, the liquid part of the shaken solution is poured into the next container. This process is repeated 5-6 times. Nematodes are lighter than the soil and come to the solution's surface. This method is particularly useful for isolating larger nematodes (*Mononchus, Xiphinema, Criconemoides, Longidorus*) (Coyne et al. 2018). The extracted nematodes were fixed in a 4% formalin solution. To improve the visibility of internal structures, specimens were kept in a glycerin-alcohol (1:1) solution for 18-20 hours. Cleaned nematodes were used to prepare both temporary and permanent microscope slides. Permanent mounts were prepared using a glycerin-gelatin medium. Observations were made under light microscopes (MBI-1, MBI-3, AS ONE SL-700-LED, Micromed MC-2-ZOOM Digital). Species identification was based on morphological and morphometric characteristics, following standard taxonomic keys (Matveeva et al. 2018), additional sources were used to identify species belonging to the order Tylenchida (Siddiqi 2000).

The taxonomic classification of the identified nematodes was made according to the system proposed by Hodda (2022). Trophic grouping was based on the classification developed by Yeates et al. (1993) and accepted by nematologists (Yeates et al. 1993).

## Physicochemical analysis of soil

pH: Measured in a 1:2.5 soil-water suspension using a calibrated pH meter (FE20K, Mettler-Toledo). Macronutrients (N, P, K): Quantified via elemental analyzer (EA 3000, Euro Vector). Humus content: Soil organic matter (humus) was determined using the Tyurin method, where excess dichromate after oxidation was back-titrated with $FeSO_4$ solution. Bulk density: Derived from regional soil datasets (Uzokov et al. 2018, see Table 1).

## Statistical analysis

To assess the relationships between soil physicochemical properties and nematode trophic groups, a Principal Component Analysis (PCA) was performed following the approach described by Jolliffe and Cadima (2016). The analysis was conducted in PAST version 4.03. Prior to ordination, nematode abundance data were subjected to a log(x+1) transformation to reduce the influence of skewed count distributions, while soil physicochemical variables were standardized to zero mean and unit variance (z-transformation) to ensure comparability across different measurement scales. Principal Component Analysis (PCA) was performed using a Pearson correlation matrix, as recommended when variables are measured in different units. Prior to analysis, nematode abundance data were log(x + 1) transformed, and soil physicochemical variables were standardized (z-transformation). This multivariate method was used to identify the major environmental gradients influencing nematode community structure and to visualize associations among soil variables (humus, N, P, K, and pH) and nematode trophic groups. The maturity indices of nematodes in different biotopes were calculated based on the Shannon (H´), Simpson, and Margelef Indices (Konopiński 2020). Shannon (H′), Simpson (1-D), and Margalef (d) Diversity Indices were calculated using pooled nematode abundance data for each biotope (soil layer × root-associated habitat) across all sampled orchards. Pooled datasets were constructed by summing species abundances from composite samples per orchard and soil depth. This approach was adopted to characterize habitat-level community structure rather than within-orchard variability.

## RESULTS AND DISCUSSION

### Results

During 2023-2025, a total of 1277 nematode individuals belonging to 54 species were isolated from apple orchards in the Uzbek part of the Zarafshan Valley. The identified species represented three classes of the phylum Nematoda (Enoplea, Dorylaimea, and Chromadorea) and four orders: Tripylida, Dorylaimida, Rhabditida, and Panagrolaimida. Comparison of nematode community composition across the studied biotopes - apple roots, upper soil layer (0-20 cm), and lower soil layer (20-40 cm) - revealed distinct differences in species composition and ecological-trophic structure between habitats. In total, 105 individuals representing 17 species were identified from the root system of apple trees. Among them, *Ditylenchus intermedius* (de Man, 1880) Filipjev, 1936, *Pratylenchus vulnus* Allen & Jensen, 1951, *Pratylenchus coffeae* (Zimmermann, 1898) Filipjev & Schuurmans Stekhoven, 1941, *Ditylenchus dipsaci* (Kühn, 1857) Filipjev, 1936, and *Pratylenchus pratensis* (de Man, 1880) Filipjev, 1936 were the most abundant species, whereas *Aphelenchoides parietinus* (Bastian, 1865) Steiner, 1932, *Rotylenchus robustus* (de Man, 1876), and *Helicotylenchus tylenchiformis* Steiner, 1945 were found in very low numbers (1-2 individuals each).

In the 0-20 cm layer of rhizosphere soil, 760 individuals belonging to 49 species were identified, representing 90.1% of all recorded species and 59% of total individuals in the nematode fauna. Within this layer, nematodes of the genera *Eudorylaimus*, *Aphelenchus*, *Ditylenchus*, *Dorylaimus*, *Longidorus*, and *Pratylenchus* were dominant in terms of individual numbers (Table 2). In contrast, species belonging to *Tylenchus*, *Merlinius*, *Panagrolaimus*, *Mesorhabditis*, and *Boleodorus* were represented by relatively few individuals. The following species were recorded exclusively in this layer: *Eudorylaimus lautus* Andrássy, 1959, *Ethmolaimus pratensis* de Man, 1880, *D. laetificans* Andrássy, 1956, *M. irregularis* (Körner in Osche, 1952) Dougherty, 1955, *Cephalobus persegnis* Bastian, 1865, *Paratylenchus macrophallus* (de Man, 1880) Goodey, 1934, *Merlinius bogdanovi-katjakovi* (Kirjanova, 1941) Siddiqi, 1970, and *Merlinius quadrifer* (Andrássy, 1954) Siddiqi, 1970.

In the deeper 20-40 cm rhizosphere layer, 412 individuals representing 38 species were found, accounting for 70.4% of total species and 32% of all individuals. These nematodes belonged to 12 genera, including *Dorylaimus*, *Eudorylaimus*, *Longidorus*, *Discolaimus*, *Mesodorylaimus*, *Xiphinema*, *Panagrolaimoides*, *Aphelenchus*, *Tylenchus*, *Aglenchus*, *Tetylenchus*, *Helicotylenchus*, *Rotylenchus*, and *Hoplolaimus*. Among these, *Eudorylaimus* species were the most abundant in terms of individual numbers.

Nematode maturity indices were calculated in different biotopes. The results showed that the upper soil layer had a predominance in all indices (Table 3).

**Table 2.** Occurrence of nematode genera across different biotopes (root system and soil layers)

| Genus | Number of species | Biotopes | | |
|---|---|---|---|---|
| | | **Root** | **0-20 cm** | **20-40 cm** |
| *Prismatolaimus* de Man, 1880 | 1 | | + | + |
| *Dorylaimus* Dujardin, 1845 | 3 | + | + | + |
| *Eudorylaimus* Andrassy, 1959 | 10 | + | + | + |
| *Discolaimus* Cobb, 1913 | 1 | - | + | + |
| *Mesodorylaimus* Andrassy, 1959 | 2 | - | + | + |
| *Xiphinema* Cobb, 1913 | 3 | - | + | + |
| *Mesorhabditis* Osche, 1952 | 1 | - | + | - |
| *Cephalobus* Bastian, 1865 | 2 | + | + | + |
| *Eucephalobus* Steiner, 1936 | 3 | + | + | + |
| *Heterocephalobus* (Brzeski, 1960) Brzeski, 1961 | 1 | - | + | + |
| *Panagrolaimus* Fuchs, 1930 | 2 | - | + | + |
| *Aphelenchus* Bastian, 1865 | 2 | - | + | + |
| *Aphelenchoides* Fisher, 1894 | 3 | + | + | - |
| *Tylenchus* Bastian, 1865 | 3 | - | + | + |
| *Aglenchus* Andrassy, 1954 | 1 | - | + | + |
| *Ditylenchus* Filipjev, 1936 | 2 | + | + | + |
| *Pratylenchus* Filipjev, 1936 | 3 | + | + | + |
| *Boleodorus* Thorne, 1941 | 1 | - | + | - |
| *Helicotylenchus* Steiner, 1945 | 1 | + | + | + |
| *Paratylenchus* Micoletzky, 1922 | 1 | - | + | + |
| *Rotylenchus* Filipjev, 1934 | 1 | + | + | - |
| *Hoplolaimus* Daday, 1905 | 1 | + | + | - |
| *Merlinius* Siddiqi, 1979 | 2 | - | + | + |
| *Longidorus* Micoletzky, 1922 | 3 | - | + | + |
| *Meloidogyne* Göldi, 1892 | 1 | + | - | - |

Note: +: This symbol indicates the habitat of species belonging to a certain genus, -: This symbol indicates that species belonging to a particular genus have not been recorded in the biotope

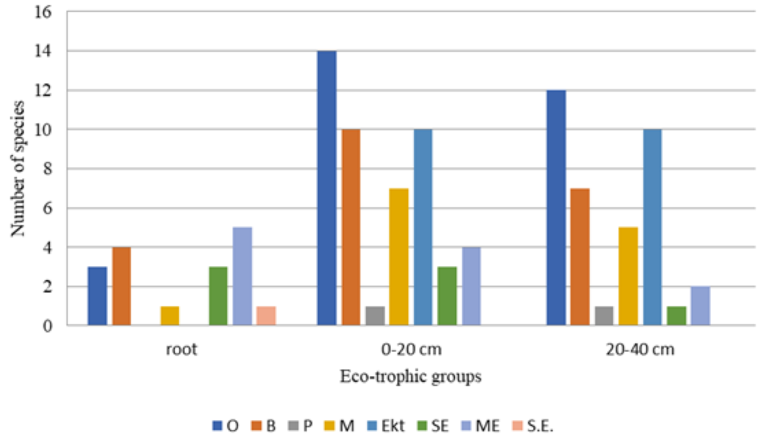

**Figure 2.** Ecological composition of apple orchard nematode fauna (based on species number across biotopes). Note: O: Omnivores; B: Bacterivores; M: Mycohelminths (Fungivores); P: Predators; Ect: Ectoparasites; SE: Semi-Endoparasites; ME: Migratory Endoparasites; S.E.: Sedentary Endoparasites. The number of individuals of root-knot nematodes was not counted

The identified nematode species were further classified into several ecological-trophic groups based on their feeding habits and degree of association with plant roots (Figure 2). Within the apple orchard nematode fauna, the omnivore (polytrophic) group was identified as one of the dominant ecological categories, represented by 15 species. Members of the genera *Dorylaimus*, *Eudorylaimus*, and *Mesodorylaimus* were the main representatives of this group. Polytrophic nematodes were primarily distributed in the rhizosphere soil layers, and among them, *Eudorylaimus* species were the most widespread and abundant both in terms of species richness and individual numbers. These nematodes were recorded in both soil layers but were absent in the root system.

The bacterivorous nematode group included 10 species belonging to the genera *Prismatolaimus*, *Mesorhabditis*, *Cephalobus*, *Eucephalobus*, *Heterocephalobus*, *Panagrolaimus*, and *Panagrolaimoides*. Most of these species occurred in the rhizosphere soil, though a few - such as *Cephalobus cornis* (Thorne, 1925) Thorne, 1937, *Eucephalobus elongatus* (de Man, 1880) Thorne, 1937, and *Eucephalobus striatus* (Bastian, 1865) Thorne, 1937 - were also found in small numbers within the root system.

Among the predatory nematodes, only a single species, *Discolaimus cylindricum* Thorne, 1939, was recorded, represented by a few individuals.

The fungivorous (mycohelminth) group consisted of seven species belonging to the genera *Aphelenchus*, *Aphelenchoides*, and *Tylenchus*. Within this group, *A. parietinus* was the only species detected in the root system, albeit in low numbers, while all others were confined to the rhizosphere soil. Overall, fungivores were recorded in much lower abundance than other ecological groups.

A total of 21 plant-parasitic nematode species were identified and further subdivided according to their feeding strategies and host associations. The ectoparasitic group included members of the genera *Paratylenchus*, *Merlinius*, *Aglenchus*, *Boleodorus*, *Longidorus*, and *Xiphinema*. These species were evenly distributed across both soil layers.

The semi-endoparasitic (partially endoparasitic) group was represented by *Helicotylenchus multicinctus* (Cobb, 1893) Golden, 1956*, Rotylenchus robustus* (de Man, 1876)*,* and *Hoplolaimus tylenchiformis* Daday, 1905. These nematodes occurred mainly in the 0-20 cm rhizosphere layer, though *R. robustus* and *H. tylenchiformis* were also occasionally found in the root system.

The endoparasitic nematodes comprised six species. Among them, *D. dipsaci*, *D. intermedius*, *P. pratensis*, *P. coffeae*, and *P. vulnus* were classified as migratory endoparasites, occurring in both the root system and, to a lesser extent, in the upper rhizosphere layer (0-20 cm). The only sedentary endoparasite recorded was *Meloidogyne hapla* Chitwood, 1949. To better understand the relationship between soil physicochemical properties and nematode ecological groups, a Principal Component Analysis (PCA) was performed (Table 4).

**Table 3.** Diversity indices of nematode communities in different soil depths and root zone

| | **Root** | **0-20 cm** | **20-40 cm** |
|---|---|---|---|
| Shannon H´ | 2.418 | 3.527 | 3.1 |
| Simpson D | 0.109 | 0.0398 | 0.06 |
| Simpson (1-D) | 0.891 | 0.960 | 0.940 |
| Margelef | 3.179 | 7.242 | 5.986 |

**Table 4.** Loadings of soil properties on Principal Components (PC1 and PC2) for 0-20 cm and 20-40 cm soil layers

| **0-20 cm** | | **Variable** | **20-40 cm** | |
|---|---|---|---|---|
| **PC1** | **PC2** | | **PC1** | **PC2** |
| +0.71 | +0.52 | pH | +0.63 | +0.61 |
| -0.88 | -0.28 | Humus (%) | -0.79 | -0.41 |
| -0.90 | -0.19 | N-$NH_4$ (mg/kg) | -0.82 | -0.36 |
| -0.87 | -0.3 | $P_2O_5$ (mg/kg) | -0.78 | -0.45 |
| -0.85 | -0.38 | $K_2O$ (mg/kg) | -0.74 | -0.52 |
| +0.79 | -0.41 | Density | +0.71 | -0.55 |

## Discussion

The results of the present study revealed that nematode community diversity varied notably across different biotopes (Figure 3). These findings are consistent with previous studies (Huang et al. 2023; Narzullayev et al. 2024). However, taxonomic composition and abundance data alone are not sufficient to fully explain the patterns of nematode diversity in soil ecosystems. Recent phytoparasitological studies emphasize that the ecological-trophic structure of nematode communities provides deeper insights into their formation and functional organization (Nisa et al. 2021).

Although the difference in the number of nematode species between the 0-20 and 20-40 cm soil layers was not substantial (49 > 38), the number of individuals decreased noticeably in the lower layer (765 > 407). In our view, this indicates that the ecological-trophic composition rather than taxonomic diversity plays a more role in explaining these differences. When analyzing the distribution of various ecological groups by soil depth, nearly all groups showed a decline in species richness toward the deeper layer (Figure 4). Only a single predatory species was recorded in both layers.

The most pronounced difference was observed in individual abundance, which dropped noticeable in the deeper (20-40 cm) soil layer (Figure 3). This pattern can be attributed to several interrelated environmental and edaphic factors influencing nematode distribution and activity within the soil profile.

The distribution, diversity, and abundance of nematode species differed among the studied biotopes. In the root system, most of the recorded species belonged to plant-parasitic nematodes, while only a few non-parasitic species such as *Cephalobus parvus* Thorne, 1937*, C. brevicaudatus* Zimmermann, 1898, *Acrobeloides butschlii* (de Man, 1884) Steiner & Buhrer, 1933 (bacterivores), *Aphelenchus avenae* Bastian, 1865*, Aphelenchoides talonus* Thorne, 1935 (fungivores), and *Dorylaimus similis* de Man, 1876 (omnivore) were found in small numbers. The occurrence of bacterivores in root cavities can be explained by their ability to feed on bacteria inhabiting the rhizosphere and sometimes even to stimulate root growth through synergistic interactions (Matus-Acuña et al. 2018; Trap et al. 2021). The presence of omnivorous nematodes within the roots appears to be incidental and related to their feeding flexibility (Yeates et al. 1993). Moreover, necrotic processes in root tissues may promote the proliferation of bacteria and fungi, indirectly attracting opportunistic omnivores such as *D. similis*.

Nematode diversity was generally higher in soil layers than in the root system, which agrees with previous findings (Lazarova et al. 2021; Narzullayev et al. 2024). This pattern can be attributed to variations in the physicochemical properties of the soil, which strongly influence nematode community structure (Lazarova et al. 2021). However, differences were observed not only between the root zone and soil but also between the upper (0-20 cm) and lower (20-40 cm) soil layers, particularly in terms of species abundance (Figure 3).

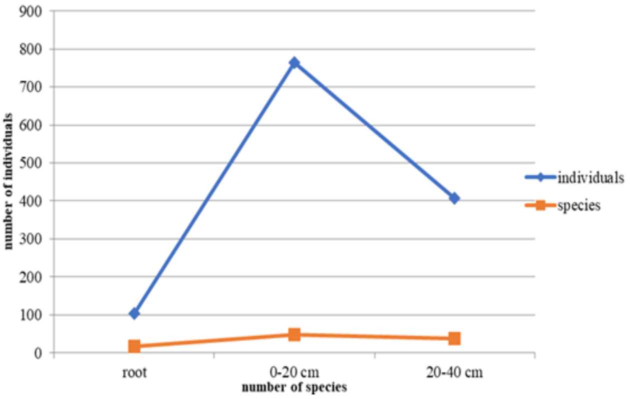

**Figure 3.** Variation in the number of nematode species and individuals across different biotopes

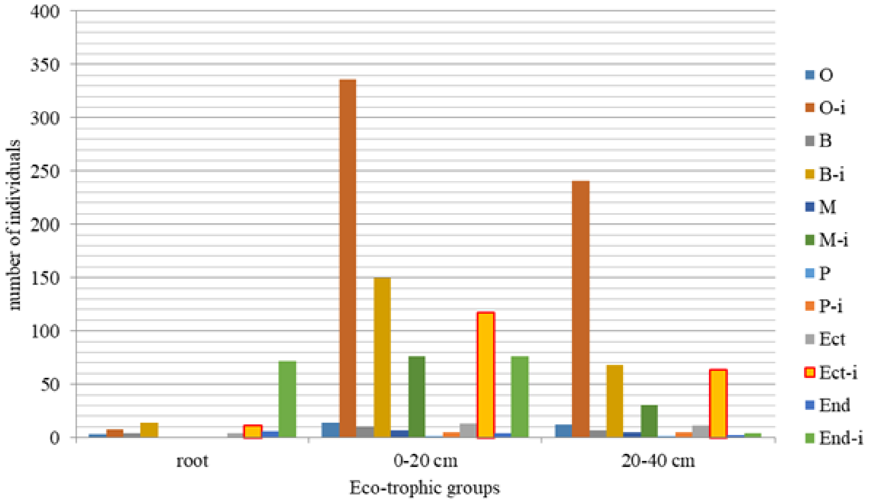

**Figure 4.** Comparative distribution of nematodes across different biotopes in apple orchards (based on the number of species within ecological groups). Note: O: Omnivores, O-i: Number of omnivore individuals, B: Bacterivores, B-i: Number of bacterivore individuals, M: Mycohelminths (Fungivores), M-i: Number of mycohelminth individuals, P: Predators, P-i: Number of predator individuals, Ect: Ectoparasites, Ect-i: Number of ectoparasite individuals, End: Endoparasites, End-i: Number of endoparasite individuals

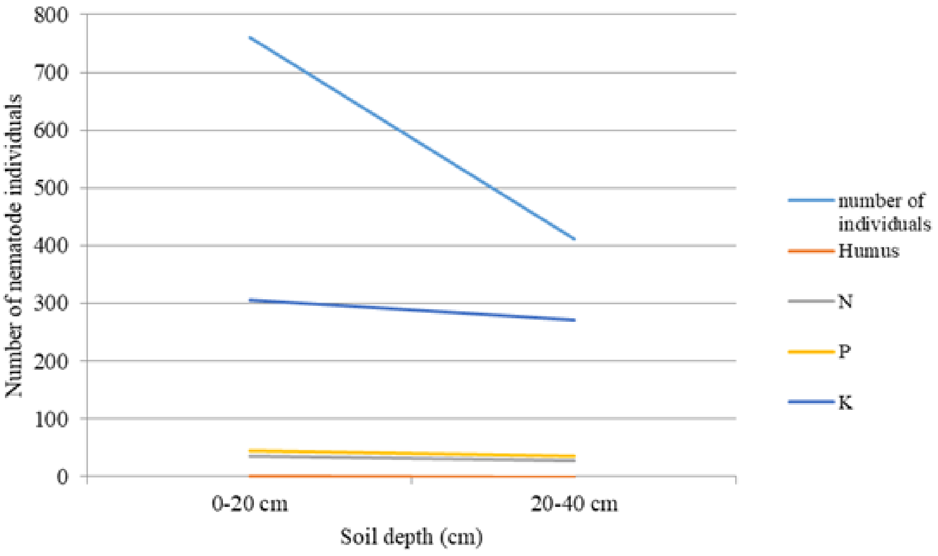

**Figure 5.** Changes in the number of nematode individuals in relation to variations in edaphic factors across soil layers

The higher species richness and abundance of nematodes in the 0-20 cm layer can be explained by several ecological and agrochemical factors. First, the higher humus content in the upper layer (1.435% > 1.1%) supports greater microbial and fungal biomass (Mokuah et al. 2023), thereby providing more food resources for bacterivorous, fungivorous, and omnivorous nematodes. Similar conclusions have been reported in earlier studies, where organic matter availability was identified as a major driver of nematode diversity (Yang et al. 2016; Song et al. 2017).

Secondly, the near-neutral pH of the soil provides favorable conditions for most nematodes, as they thrive and reproduce more efficiently within this pH range (Leiva et al. 2020).

Thirdly, the relatively low bulk density of the soil (approximately 1.1 g/cm³) may contribute to the higher nematode abundance. In general, a bulk density between 1.1 and 1.4 g/cm³ is considered optimal for soil organisms, including nematodes (Uzokov et al. 2018). Higher soil density can hinder nematode mobility (Ortiz and Brye 2023) and may also reduce oxygen availability, which is another critical factor affecting their survival and activity (Maciūte et al. 2021). Due to these conditions, the upper soil layer represents a more nutrient-rich and biologically active habitat, creating a favorable environment for nematodes - especially free-living forms, such as bacterivores (van den Hoogen et al. 2019). Consequently, while plant-parasitic nematodes (endoparasites, semi-endoparasites, and ectoparasites) were more diverse in terms of species, their individual abundance was lower than that of free-living groups.

Overall, the high nematode diversity observed in the upper soil layer corresponds to the fact that this stratum is the most biologically active part of the soil profile (Crowther et al. 2016). In contrast, the lower soil layer (20-40 cm) showed a noticeable decline in both species and individual numbers (Figure 5). This decrease can be explained by the reduction of humus content, the shift of pH from neutral to alkaline, and the increase in soil density (Zhang et al. 2012). Collectively, these factors reduce the availability of food resources, restrict nematode movement, and make the environment less suitable for sustaining diverse nematode populations.

Bacterivorous and fungivorous nematodes are widely recognized as key indicators of soil microbial diversity (Kouser et al. 2021). In our study, these two ecological groups exhibited only slight reductions in species richness from the upper to lower layer (10 > 7 and 7 > 5, respectively), but their individual numbers declined more than twofold (150 > 68 and 76 > 30) (Figure 4), reflecting the influence of edaphic conditions on nematode abundance and distribution.

During the study, the contents of nitrogen (N), phosphorus (P), and potassium (K) in different soil layers were also analyzed. The results showed a clear decrease in N, P, and K concentrations in the lower soil layer, which coincided with a reduction in nematode abundance (Figure 5). This pattern indicates a positive correlation between nematode population density and the levels of these macronutrients. A positive relationship between soil nitrogen content and nematode populations has also been reported previously (Qi et al. 2023).

However, some studies have documented negative effects of N, P, and K fertilization on nematode populations (Al-Hazmi and Dawabah 2014). In general, the increase in N, P, and K concentrations is known to promote the abundance of bacterivorous nematodes (Zhang et al. 2016), and our findings are consistent with these observations. The contradictory results reported in different studies may be attributed to local soil conditions, the type and dosage of fertilizers applied, and the specific ecological traits of the nematode species involved. Therefore, further research is required to clarify these complex relationships.

To better understand the relationship between soil physicochemical properties and nematode ecological groups, a principal component analysis was performed (Table 4). The first two principal components explained the majority of the total variance. PC1 was higher associated with humus content, total nitrogen, and phosphorus, representing the main axis of variation in the dataset, while PC2 reflected the influence of pH and potassium concentrations.

According to the PCA, the first two principal components explained 80.9% of the total variance in the 0-20 cm layer and 70.7% in the 20-40 cm layer (Figures 6 and 7), with PC2 accounting for 19.1% and 29.3%, respectively (Figures 6 and 7). This indicates that the selected soil parameters (humus, N, P, K, and pH) effectively capture the environmental variation affecting nematode trophic composition across both layers.

The obtained biplot diagrams clearly illustrated the spatial relationships between soil properties and nematode ecological groups. For instance, certain ecological groups - particularly bacterivorous nematodes - were positioned close to the vectors representing humus and nitrogen, indicating that these groups are more active and abundant under nutrient-rich conditions.

In the diagrams, the proximity of ecological groups to the vectors reflects the strength of their correlation with specific soil factors. Groups located near a vector are higher and positively correlated with that factor, while those farther away show weaker or no association.

Overall, the PCA results highlighted the adaptive responses of nematode groups to different soil properties and identified the key ecological determinants influencing their distribution patterns within the soil profile.

Analysis of soil properties across different depths revealed distinct relationships between edaphic factors and nematode ecological groups. The population indices of bacterivorous nematodes showed strong positive correlations with humus content, pH, and nitrogen (N) levels. Omnivorous (polytrophic) nematodes were mainly associated with N content and pH, while plant-parasitic nematodes exhibited closer relationships with phosphorus (P) and potassium (K) concentrations.

In contrast, fungivorous (mycophagous) nematodes displayed negative correlations with soil mineral content in both soil layers, suggesting that high mineralization may create less favorable conditions for this group. The predatory nematodes, however, appeared to be neutral with respect to soil factors, indicating little to no dependence on these physicochemical parameters.

These findings are in line with previous studies reporting that soil nematodes are primarily influenced by humus, N, and pH levels (Kashyap et al. 2022). The observed correlation between parasitic nematodes and phosphorus in this study, although somewhat debatable, might be explained by the fact that most parasitic species were found in the upper 0-20 cm soil layer, where P and K concentrations were relatively higher. These results indicate that nematode responses are driven not by absolute nutrient concentrations but by the balance and plant-available forms of N, P, and K. A more realistic conceptual model is that nutrient ratios regulate microbial turnover and root exudation, which in turn shape trophic group dynamics. Thus, nematode community structure reflects nutrient equilibrium and bioavailability rather than total nutrient levels.

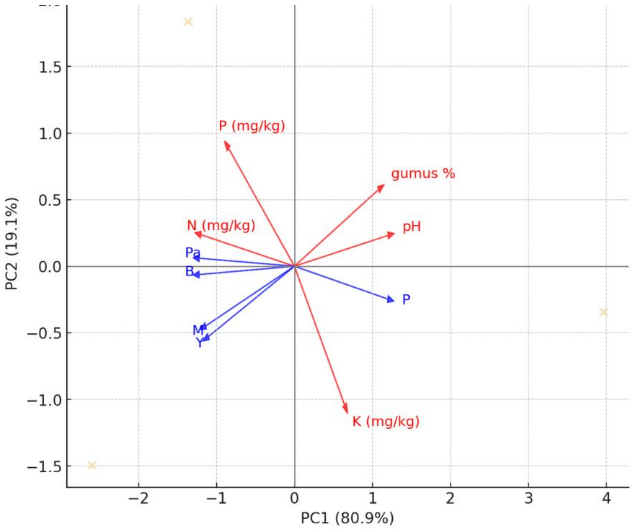

**Figure 6.** Principal Component Analysis (PCA) biplot showing relationships between soil properties and nematode trophic groups in the 0-20 cm soil layer (PC1 = 80.9%, PC2 = 19.1%). PC1 is the component that explains the largest variance (in percent) in the data, PC2 is the component that explains the next largest variance

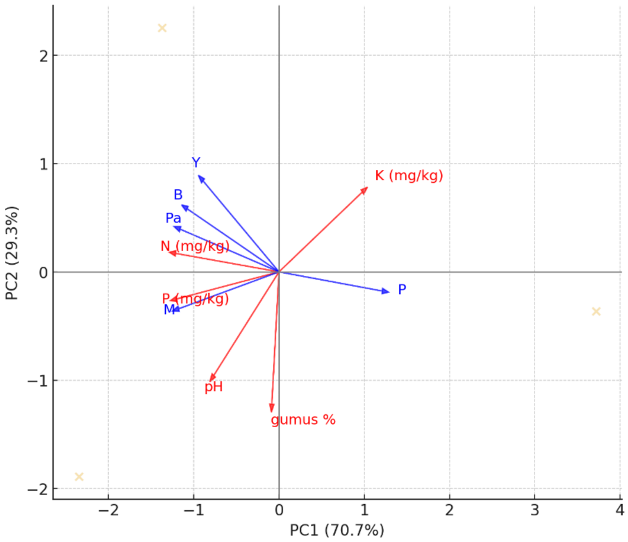

**Figure 7**. PCA biplot showing relationships between soil properties and nematode trophic groups in the 20-40 cm soil layer (PC1 = 70.7%, PC2 = 29.3%). PC1 is the component that explains the largest variance (in percent) in the data, PC2 is the component that explains the next largest variance

This study provides the first integrated dataset on the taxonomic and functional structure of nematode communities in orchard soils of the semi-arid Zarafshan Valley, combining vertical distribution patterns with detailed soil physicochemical measurements. Unlike previous surveys focused on crop monocultures or irrigated fields, our multi-layer approach reveals how soil fertility gradients and nutrient balance shape trophic groups along the soil profile. These results contribute new bioindicator-based insights for perennial systems in Central Asian drylands, a region where nematode ecology remains poorly documented. The dataset highlights practical priorities for orchard management. It has been shown that increased nutrient availability in the upper soil layers, especially in P- and K-dominated profiles, can increase the abundance of phytoparasitic nematodes and support microbial feeders in the rhizosphere. This suggests that fertilization strategies, organic amendments, and root-zone irrigation should account not only for nutrient input but also for its depth-wise distribution. Future research should integrate seasonal monitoring, functional indices, and long-term management trials to develop nematode-based bioindication tools tailored to semi-arid orchards of Zarafshan Valley.

The results of this study showed that the composition, trophic and ecological structure of the nematode community in apple agrocenoses of the Zarafshan Valley are related to the physicochemical properties of the soil. In total, 1,277 nematode individuals belonging to 54 species, 25 genera, 4 orders, and 3 classes were identified. Among them, omnivorous (polytrophic), bacterivorous, and plant-parasitic nematodes represented the dominant ecological groups.

The analyses revealed that the upper soil layer contained higher levels of humus, nitrogen, phosphorus, and potassium, making it the most biologically active biotope for nematodes. Free-living ecological groups, particularly bacterivores and omnivores, were more abundant in this layer, whereas their populations noticeable decreased in the lower layer. This reduction was likely associated with the increase in soil bulk density (from 1.20 to 1.32 g/cm$^3$), which restricts nematode movement, feeding processes, and oxygen exchange.

According to the principal component analysis, humus, N, P, pH, and K were identified as the key ecological determinants shaping nematode community structure. Bacterivorous nematodes were positively correlated with humus, nitrogen, and pH, omnivores with N and pH, while plant-parasitic nematodes showed stronger associations with P and K. This relationship is likely not due to the direct chemical influence of P and K, but rather to their indirect effect on root biomass and microbial activity, creating more favorable feeding conditions for parasitic species. Accordingly, more in-depth studies are needed on the relationship between ecological groups and soil chemical composition, especially the P/K of plant parasites. In future studies, a more comprehensive understanding of nematode diversity in semi-arid ecosystems such as the Zarafshan Valley requires the adoption of an integrated approach that incorporates not only chemical but also physical (soil density, moisture) and microbiological soil parameters. Such a holistic framework would enhance the effectiveness of using nematodes as bioindicators for assessing agroecosystem conditions, monitoring ecological stability, and supporting sustainable management practices. At the same time, several limitations of the present study should be acknowledged, including the lack of consideration of seasonal dynamics of nematode communities, the reliance on literature-based values for soil density, and the omission of irrigation and fertilization regimes. Therefore, future research should focus on a more detailed investigation of the relationships between nematode community diversity and irrigation and fertilization practices, explicitly accounting for seasonal variation and soil density effects.

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## REFERENCES

Al-Hazmi AS, Dawabah AAM. 2014. Effect of urea and certain NPK fertilizers on the cereal cyst nematode (*Heterodera avenae*) on wheat. Saud J Biol Sci 21 (2): 191-196. https://doi.org/10.1016/j.sjbs.2013.10.002.

Atira LS, Duarte TK. 2025. Implications of fertilisation on soil nematode community structure and nematode-mediated nutrient cycling. Crops 5 (4): 50. https://doi.org/10.3390/crops5040050.

Babakholov SH. 2021. Climate change impacts and agriculture: Empirical evidence from Zarafshan River Basin, Uzbekistan. Am J Business Econo Manag 9 (1): 1-8.

Bardgett RD, van der Putten WH. 2014. Belowground biodiversity and ecosystem functioning. Nature 515 (7528): 505-511. https://doi.org/10.1038/nature13855.

Bekmurodov AS, Saidova EA. 2025. Plant parasitic nematodes of fruit trees in southern Uzbekistan. Russian J Parasitol 19 (3): 394-403. https://doi.org/10.31016/1998-8435-2025-19-3-394-403.

Bongers T, Ferris H. 1999. Nematode community structure as a bioindicator in environmental monitoring. Trends Ecol Evol 14 (6): 224-228. https://doi.org/10.1016/S0169-5347(98)01583-3.

Coyne DL, Nicol JM, Claudius-Cole B. 2018. Practical Plant Nematology: A Field and Laboratory Guide. 3rd Edition. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Crowther TW, Todd-Brown KE, Rowe CW, Wieder WR, Carey JC, Machmuller MB, Snoek B, Fang S, Zhou G, Allison SD, Blair JM. 2016. Quantifying global soil carbon losses in response to warming. Nature 540 (7631): 104-108. https://doi.org/10.1038/nature20150.

Ewald M, Rusch D, Rißmann C, Trost B, Theuerl S, Rues L. 2022. Effects of irrigation and fertilization practice on soil nematode communities in arable land. Appl Soil Ecol 177: 104546. https://doi.org/10.1016/j.apsoil.2022.104546.

Ferris H, Matute MM. 2003. Structural and functional succession in the nematode fauna of a soil food web. Appl Soil Ecol 23 (2): 93-110. https://doi.org/10.1016/S0929-1393(03)00044-1.

Ferris H. 2010. Contribution of nematodes to the structure and function of the soil food web. J Nematol 42 (1): 63-67.

Hodda M. 2022. Phylum Nematoda: A classification, catalogue, and index of valid genera, with a census of valid species. Zootaxa 5114 (1): 1-289. https://doi.org/10.11646/zootaxa.5114.1.1.

Huang F, Xu Y, Wang J, Liu X. 2023. Research on the community structure and diversity of soil nematodes in the orchards of Shanxi Province. J Fruit Sci 40 (12): 2591-2597. https://doi.org/10.13925/j.cnki.gsxb.20230199.

Jolliffe IT, Cadima J. 2016. Principal component analysis: A review and recent developments. Philos Trans Royal Soc A 374 (2065): 20150202. https://doi.org/10.1098/rsta.2015.0202.

Kambarov S, Eshova K, Narzullayev S, Tukhtasinov F, Zokirov O, Turdiev Z, Otakulov B, Tursunova SH, Khujamov SH. 2025. Diversity of onion nematode fauna in agrocenoses of different altitudinal zones in Fergana Valley, Uzbekistan. Biodiversitas 26: 4479-4489. https://doi.org/10.13057/biodiv/d260920.

Kashyap P, Afzal S, Rizvi AN, Ahmad W, Uniyal VP, Banerjee D. 2022. Nematode community structure along elevation gradient in high altitude vegetation of Gangotri National Park (Uttarakhand), India. Sci Rep 12: 1428. https://doi.org/10.1038/s41598-022-05472-9.

Kaushal A, Vashisth S. 2025. Distribution and ecological diversity of plant-parasitic nematodes in fruit tree nurseries of the North-Western Himalayan Foothills. J Phytopathol 173 (6): e70191. https://doi.org/10.1111/jph.70191.

Konopiński MK. 2020. Shannon diversity index: A call to replace the original Shannon's formula with unbiased estimator in the population genetics studies. PeerJ 29 (8): e9391. https://doi.org/10.7717/peerj.9391.

Kouser Y, Shah AA, Rasmann S. 2021. The functional role and diversity of soil nematodes are stronger at high elevation in the lesser Himalayan Mountain ranges. Ecol Evol 11 (20): 13793-13804. https://doi.org/10.1002/ece3.806.

Kudratov J, Pazilov A, Zokirova D, Otakulov B, Jalilov J, Urinova X, Khalimov F, Izzatullaev Z. 2024. Complexes of terrestrial molluscs of various biotopes in the Gissar Range, Uzbekistan. Acta Biologica Sibirica 10: 349-359. https://doi.org/10.5281/zenodo.11160044.

Lazarova S, Coyne D, Rodríguez MG, Peteira B, Ciancio A. 2021. Functional diversity of soil nematodes in relation to the impact of agriculture - A review. Diversity 13 (2): 64. https://doi.org/10.3390/d13020064.

Leiva NPF, de Melo SG, Zabini AV, Velázquez LMG, Dias-Arieira CR. 2020. Soil chemical properties and their relationship with phytonematode populations inside and outside soybean patches. Rhizosphere 15: 100231. https://doi.org/10.1016/j.rhisph.2020.100231.

Li L, Luo Z, Nian L, Li L, Niu Y, Prasath BB, Haider FU, Zhang Y, He R, Liu J. 2024. Response of soil nematode community structure and metabolic footprint to nitrogen addition in alfalfa fields on the Loess Plateau. Sci Rep 14: 17640. https://doi.org/10.1038/s41598-024-68393-9.

Maciūte A, Holavachov O, Berg P, Glud RN, Broman E, Nascimento FJA, Bonaglia S. 2021. A microsensor-based method for measuring respiration of individual nematodes. Methods Ecol Evolut 12 (8): 1524-1533. https://doi.org/10.1111/2041-210X.13674.

Matus-Acuña V, Caballero-Flores G, Reyes-Hernandez BJ, Martínez-Romero E. 2018. Bacterial preys and commensals condition the effects of bacteriovorus nematodes on *Zea mays* and *Arabidopsis thaliana*. Appl Soil Ecol 132: 99-106. https://doi.org/10.1016/j.apsoil.2018.08.012.

Matveeva EM, Sushchuk AA, Kalinkina DS. 2018. Methodological Principles of Studying Phytoparasitic Nematodes. Karelian Research Center, Russian Academy of Sciences, Petrozavodsk.

Medetov MZ, Abdullaeva JK, Reymov A, Miratdinova AM, Seytmuratov AK, Tajibaeva JD, Kadirov RS, Utemuratov NA, Kimyonazarov SK, Kudratov J, Urazova RS. 2025. Diversity of true bugs (Hemiptera: Heteroptera) of the Southern Aral Sea Region, Uzbekistan. Biodiversitas 26: 3125-3135. https://doi.org/10.13057/biodiv/d260704.

Mokuah D, Karuri H, Nyaga JM. 2023. Food web structure of nematode communities in irrigated rice fields. Heliyon 9 (2): e13183. https://doi.org/10.1016/j.heliyon. 2023.e13183.

Narzullayev SB, Mirzaev UN, Mavlyanov O, Khakimov N, Jabborov AR, Khamidova AB, Tursunova SS, Khujamov S, Baysarieva C, Ashrapov AA, Nurmatova DM. 2024. Diversity and habitat distribution of tomato (*Solanum lycopersicum*) nematoda fauna (Zarafshan Valley, Uzbekistan). Acta Biologica Sibirica 10: 1147-1164. https://doi.org/10.5281/zenodo.13937701.

Narzullayev SB, Subbotin S. 2025. Characterisation of some gall-forming nematodes of the family Anguinidae from Uzbekistan. Russian J Nematol 33 (1): 1-7. https://doi.org/10.24412/0869-6918-2025-1-1- 7.

Narzullayev SB. 2022. New data on the vertical distribution of nematode communities in mountain ecosystems of Mount Zarafshan, Uzbekistan. Biodiversitas 23 (8): 3967-3975. https://doi.org/10.13057/biodiv/d230814.

Nisa RU, Tantray AY, Kouser N, Allie KA, Wani SM, Alamri SA, Alyemeni MN, Wijaya L, Shah AA. 2021. Influence of ecological and edaphic factors on biodiversity of soil nematodes. Saudi J Biol Sci 28 (5): 3049-3059. https://doi.org/10.1016/j.sjbs.2021.02.046.

Orgiazzi A, Bardgett RD, Barrios E. 2016. Global Soil Biodiversity Atlas. Publications Office of the European Union, Luxembourg. https://doi.org/10.1093/oso/9780199668564.003.0007.

Ortiz LEE, Brye KR. 2023. Relationships among soil properties, nematode densities, and soybean yield in a long-term, double-crop system in Eastern Arkansas. Agric Sci 14 (12): 1605-1623. https://doi.org/10.4236/as.2023.1412104.

Pen-Mouratov S, Shukurov N, Steinberger Y. 2010. Soil free-living nematodes as indicators of both industrial pollution and livestock activity in Central Asia. Ecol Indic 10 (5): 955-967. https://doi.org/10.1016/j.ecolind.2010.02.005.

Qi Y, Sun X, Peng S, Tan X, Zhou S. 2023. Effects of fertilization on soil nematode communities in an alpine meadow of the Qinghai-Tibet Plateau. Front Ecol Evol 11: 1122505. https://doi.org/10.3389/fevo.2023.1122505.

Rencho M, Gömöryová E, Čerevková A. 2020. The effect of soil type and ecosystems on the soil nematode and microbial communities. Helminthologia 57 (2): 129-144. https://doi.org/10.2478/helm-2020-0014.

Shodmonov FA, Fomichev AA. 2025. New and poorly known species of Berlandina Dalmas, 1922 (Araneae: Gnaphosidae) from Uzbekistan. Acta Biologica Sibirica 11: 509-525. https://doi.org/10.5281/zenodo.15188746.

Siddiqi MR. 2000. Tylenchida Parasites of Plants and Insects, 2nd Edition. CABI Publishing, Wallingford, South Oxfordshire. https://doi.org/10.1079/9780851992020.0000.

Song D, Pan K, Tariq A, Sun F, Li Z, Sun X, Zhang L, Olusanya OA, Wu X. 2017. Large-scale patterns of distribution and diversity of terrestrial nematodes. Appl Soil Ecol 114: 161-169. https://doi.org/10.1016/j.apsoil.2017.03.010.

Trap J, Ranoarisoa MP, Raharijaona S, Rabeharisoa L, Plassard C, Mayad EH, Bernard L, Becquer T, Blanchart E. 2021. Agricultural practices modulate the beneficial activity of bacterial-feeding nematodes for plant growth and nutrition: Evidence from an original intact soil core technique. Sustainability 13 (13): 7181. https://doi.org/10.3390/su13137181.

Uzokov P, Kholikulov Sh, Bobokhujayev I. 2018. Soil Science. Science Publishing, Tashkent.

Van Bezooijen J. 2006. Methods and Techniques for Nematology. Wageningen University, Wageningen.

van den Hoogen J, Geisen S, Routh D, Ferris H, Traunspurger W, Wardle DA, De Goede RG, Adams BJ, Ahmad W, Andriuzzi WS, Bardgett RD. 2019. Soil nematode abundance and functional group composition at a global scale. Nature 572 (7768): 194-198. https://doi.org/10.1038/s41586-019-1418-6.

Yang L, Luo P, Wen L, Li D. 2016. Soil organic carbon accumulation during post-agricultural succession in a karst area, Southwest China. Sci Reports 6: 37118. https://doi.org/10.1038/srep37118.

Yeates GW, Bongers T, de Goede RGM, Freckman DW, Georgieva SS. 1993. Feeding habits in soil nematode families and genera-An outline for soil ecologists. J Nematol 25 (3): 315-331.

Zhang M, Liang WL, Zhang XK. 2012. Soil nematode abundance and diversity in different forest types at Changbai Mountain, China. Zool Stud 51 (5): 619-626. https://doi.org/10.1016/j.apsoil.2011.11.009.

Zhang Z, Zhang X, Mahamood M, Zhang S, Huang S, Liang W. 2016. Effect of long-term combined application of organic and inorganic fertilizers on soil nematode communities within aggregates. Sci Reports 6: 31118. https://doi.org/10.1038/srep31118.

Zokirova DF, Kudratov JA, Khamzaev RA, Khamidova AB, Otakulov B, Urinova G, Zohidova I, Abdllaev E, Rayimova F, Pazilov A, Tursunova S, Bakhrillayeva M, Khalimov FZ. 2025. Morphometric diversity of *Zabrus morio* (Coleoptera: Carabidae) in relation to sex and altitude in Uzbekistan's mountain ecosystems. Biodiversitas 26: 4730-4745. https://doi.org/10.13057/biodiv/d260943.