

Diversity of onion nematode fauna in agrocenoses of different altitudinal zones in Fergana Valley, Uzbekistan

SARDORBEB KAMBAROV^{1,*}, KHOLISA ESHOVA², SARDORBEB NARZULLAYEV^{3,5},
FARKHOD TO'XTASINOV⁴, ODILJON ZOKIROV¹, ZAFARBEB TURDIEV¹, BEKZOD OTAKULOV³,
SHAHLO TURSUNOVA⁵, SHAHBOZ KHUJAMOV⁵

¹Department of Biology, Andijan State University. 129 University Street, Andijan City 170100, Uzbekistan. Tel./fax.: +998-742238830,
*email: sardorqambaro1989@gmail.com

²Department of Zoology, National University of Uzbekistan. University St. 4, Almazor District, Tashkent City 100174, Uzbekistan

³Institute of Biochemistry, Samarkand State University. University Boulevard 15, Samarkand 140104, Uzbekistan

⁴Department of Zoology and General Biology, Fergana State University. Mourabbiilar St. 19, Fergana 150100, Uzbekistan

⁵Department of Biology, Samarkand Pedagogical Institute. Spitamen Avenue St. 166, Samarkand 140102, Uzbekistan

Manuscript received: 20 August 2025. Revision accepted: 18 September 2025.

Abstract. Kambarov S, Eshova K, Narzullayev S, To'xtasinov F, Zokirov O, Turdiev Z, Otakulov B, Tursunova S, Khujamov S. 2025. Diversity of onion nematode fauna in agrocenoses of different altitudinal zones in Fergana Valley, Uzbekistan. *Biodiversitas* 26: 4479-4489. During research conducted from 2020 to 2024, the biodiversity of nematode fauna associated with onion plants (*Allium cepa*) cultivated in agrocenoses across different altitudinal zones of the eastern part of the Fergana Valley was thoroughly investigated. As part of the study objectives, a total of 276 samples were collected from the onion root system and its surrounding rhizosphere soils during the spring, summer, and autumn seasons using the route survey method, of which nematodes were detected in 245 samples. The samples were processed following Berman's funnel technique. Based on the obtained results, 39 nematode species belonging to 7 orders and classified within the classes Adenophorea and Secernentea were identified in the onion root system and rhizosphere soils, representing 22 genera. An uneven distribution of the identified species across the altitudinal zones was observed. Within the faunal composition, species of the order Rhabditida were the most diverse in terms of species richness. The study demonstrated that nematode species composition and ecological structure vary significantly depending on the altitudinal zones. In the lower hill zone, 34 species were recorded, whereas 30 species were documented in the upper hill zone and 12 species in the lower mountain zone. This indicated a link between these patterns and the region's ecological characteristics. According to Bongers' classification, nematodes identified in onion fields were assigned as follows: 7 species to the Cp-1 group, 26 species to Cp-2, 2 species to Cp-3, 3 species to Cp-4, and 1 species to Cp-5. *Aporcelaimellus obtusicaudatus* (C-p 5), which occurred across all three zones, is considered a highly specialized and adaptable species. The results of the study provide a scientific basis for a deeper understanding of the region's biodiversity and for managing the dynamics of nematode fauna in agrocenoses.

Keywords: *Allium cepa*, altitudinal zones, onion, Rhabditida, root system, Tylenchida

INTRODUCTION

Soil organisms are considered among the most important factors ensuring its formation and functional state. Within the soil, organisms ranging from microorganisms to vertebrates occupy different ecological niches and perform their respective functions. Among these communities, nematodes, though microscopic, attract attention as organisms with a profound impact. They are among the most widespread multicellular organisms in the soil (Bardgett and van der Putten 2014), contributing to the decomposition of plant residues and standing out due to their crucial role in the food web (Wilschut and Geisen 2021). Studying the nematode fauna in natural and artificial ecosystems, as well as conducting comparative analyses, allows for understanding soil successional processes, assessing soil health, and revealing the specific features of nematode fauna formation in agrocenoses. These natural and artificial ecosystems not only contribute to the climatic characteristics of their respective regions but also serve as habitats and food sources for numerous living organisms

(Narzullayev 2022; Narzullayev et al. 2023). Furthermore, due to their wide distribution and ease of extraction from soil, nematodes are frequently studied as indicators reflecting the organic and mineral properties of soil (Lu et al. 2020; Suyadi et al. 2021). Mycophagous fungi in rhizosphere soils are known to affect the mycorrhizal sheath, thereby indirectly influencing the plant defense system (Zhang et al. 2020), whereas ectoparasitic nematodes mechanically damage roots, facilitating the entry of pathogenic microorganisms (Öztürk et al. 2018; Archidona-Yuste et al. 2020).

Currently, as part of global efforts to ensure food security, managing pests and parasitic species in the cultivation of economically important vegetable crops remains a critical challenge. Among the most significant agricultural parasites, Plant-Parasitic Nematodes (PPN) occupy a distinct position, as they cause considerable yield losses in crops. This issue is particularly relevant in the cultivation of economically important crops, especially onion production. To date, more than 4,100 PPN species

have been identified, many of which cause severe damage to major agricultural crops (Bernard et al. 2017).

Onion (*Allium cepa* L.), a biennial plant belonging to the family Amaryllidaceae, is an economically important vegetable crop (Yavuzaslanoglu et al. 2019). Although typically biennial, certain cultivars have been developed through breeding that can produce marketable bulbs directly from seeds within a single growing season. In its wild form, onion produces a small bulb in the first year, the main bulb developing in the second year, followed by flowering and seed production. The structure of the onion plant includes a root system and a bulb protected underground by 2-5 layers of outer scales, whereas aboveground it is characterized by green leaves (Sekara et al. 2017).

Onion is widely consumed in its dried form and as green onion in salads, highlighting its versatility in various culinary and cultural applications. It is not only valued for its unique flavor and aroma but also for its nutritional benefits, being rich in health-promoting phytochemicals that confirm its dietary significance (Kumar et al. 2022). In Uzbekistan, rapid population growth has increased the demand for food products, which has, in turn, driven the expansion of major agricultural crops like onions. According to statistical data, onion production in Uzbekistan amounted to 1,200 and 1,214.3 tons in 2021 and 2022, respectively, while in 2023 this figure increased to 1,318.5 tons, reflecting the annual growth trend in demand for onions (National Statistics Committee 2025). However, merely expanding onion plantations will not resolve this issue. Identifying the species composition of pests that affect onions and developing effective pest control strategies is essential. This is particularly critical for newly established agrocenoses, where the nematode fauna has yet to be thoroughly studied. Research on the nematode fauna in the Eastern Fergana region has been limited since the 1970s-1980s (Adylova 1972; Karimova 1974). Recently, modern molecular-genetic techniques have been applied to

study nematode fauna in Uzbekistan (Mirzaev et al. 2024; Narzullayev and Subbotin 2025), and some studies have explored nematode fauna patterns in agrocenoses (Narzullayev et al. 2024). With increasing conversion of biocenoses into agrocenoses, the spread of nematodes from natural habitats poses greater risks. Therefore, research in this field is vital for identifying parasitic species impacting onion cultivation and providing a scientific foundation for their management.

MATERIALS AND METHODS

Study area

The study was conducted in the eastern part of the Fergana Valley, Uzbekistan, a region of Central Asia located between the Tianshan and Alay mountain ranges (Figure 1). The Fergana Valley is surrounded by mountains, with its geographical structure consisting of the Turkestan and Alay ranges in the south, the Fergana and Otoynoq ranges in the east, the Chatkal range in the north, and the Qurama and Qoramozor ranges in the northwest (Kholikov 2020). The study area is divided into different altitudinal zones according to vegetation cover. Based on the classification of K.Z. Zokirov, the distribution is categorized into desert, foothill, mountain, and pasture zones. In particular, the desert zone is defined at an altitude of 0-400 meters above sea level (masl), the foothill zone at 400-1,200 masl, and the mountain zone at 1,200-3,000 masl. Each altitudinal zone is further subdivided into several subzones (National Atlas of Uzbekistan 2020). For the study of onion nematode fauna, the foothill zone (lower and upper foothill subzones) and the mountain zone (lower mountain subzone) were selected. This choice was made because, in recent years, biocenoses in these areas have been developed and converted into onion plantations.

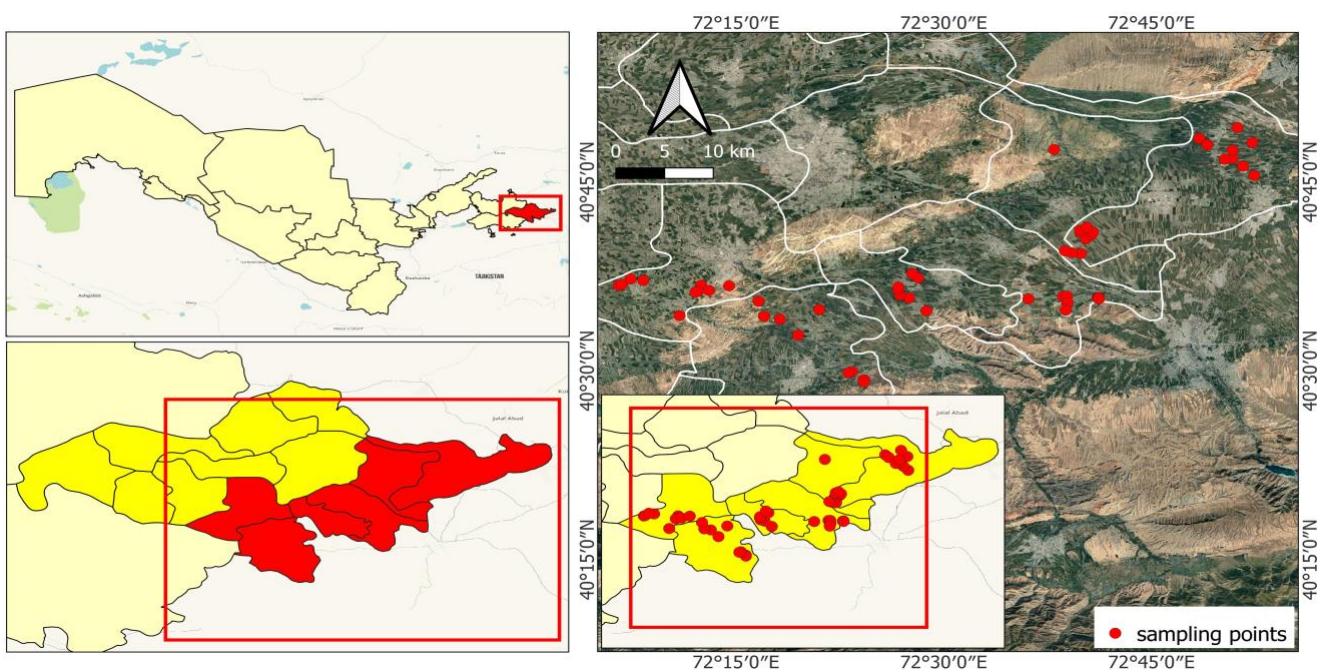


Figure 1. Coordinates of the sampling sites in Fergana Valley, Uzbekistan

Table 1. Geographic coordinates of the sampling sites and their associated host plants

Latitude	Longitude	Host plant	Location
40.799197	72.817350	Onion	Eastern Fergana Valley
40.799198	72.817351	Onion	Eastern Fergana Valley
40.799199	72.817352	Onion	Eastern Fergana Valley
40.758517	72.873750	Onion	Eastern Fergana Valley
40.758517	72.873750	Onion	Eastern Fergana Valley
40.770856	72.860161	Onion	Eastern Fergana Valley
40.781075	72.847594	Onion	Eastern Fergana Valley
40.780025	72.838161	Onion	Eastern Fergana Valley
40.791983	72.847581	Onion	Eastern Fergana Valley
40.802031	72.871422	Onion	Eastern Fergana Valley
40.821972	72.853442	Onion	Eastern Fergana Valley
40.799197	72.817350	Onion	Eastern Fergana Valley
40.807775	72.860553	Onion	Eastern Fergana Valley
40.655014	72.665125	Onion	Eastern Fergana Valley
40.656339	72.653911	Onion	Eastern Fergana Valley
40.658803	72.645747	Onion	Eastern Fergana Valley
40.674517	72.671125	Onion	Eastern Fergana Valley
40.679892	72.677244	Onion	Eastern Fergana Valley
40.683258	72.679564	Onion	Eastern Fergana Valley
40.683258	72.664286	Onion	Eastern Fergana Valley
40.686319	72.664153	Onion	Eastern Fergana Valley
40.689978	72.672131	Onion	Eastern Fergana Valley
40.793047	72.632725	Onion	Eastern Fergana Valley
40.596511	72.685058	Onion	Eastern Fergana Valley
40.596722	72.686447	Onion	Eastern Fergana Valley
40.597144	72.686733	Onion	Eastern Fergana Valley
40.595519	72.686869	Onion	Eastern Fergana Valley
40.598600	72.643444	Onion	Eastern Fergana Valley
40.598892	72.648353	Onion	Eastern Fergana Valley
40.589722	72.648950	Onion	Eastern Fergana Valley
40.580431	72.646914	Onion	Eastern Fergana Valley
40.595144	72.601908	Onion	Eastern Fergana Valley
40.579269	72.479031	Onion	Eastern Fergana Valley
40.579269	72.479031	Onion	Eastern Fergana Valley
40.596372	72.458450	Onion	Eastern Fergana Valley
40.600347	72.447294	Onion	Eastern Fergana Valley
40.607542	72.444975	Onion	Eastern Fergana Valley
40.610803	72.445403	Onion	Eastern Fergana Valley
40.622867	72.469181	Onion	Eastern Fergana Valley
40.628625	72.462158	Onion	Eastern Fergana Valley
40.488147	72.403947	Onion	Eastern Fergana Valley
40.485125	72.404028	Onion	Eastern Fergana Valley
40.498944	72.389778	Onion	Eastern Fergana Valley
40.497400	72.385214	Onion	Eastern Fergana Valley
40.547128	72.324736	Onion	Eastern Fergana Valley
40.568331	72.302644	Onion	Eastern Fergana Valley
40.572061	72.283672	Onion	Eastern Fergana Valley
40.580956	72.350217	Onion	Eastern Fergana Valley
40.572061	72.283672	Onion	Eastern Fergana Valley
40.592161	72.277047	Onion	Eastern Fergana Valley
40.613417	72.207881	Onion	Eastern Fergana Valley
40.605672	72.204331	Onion	Eastern Fergana Valley
40.603817	72.201144	Onion	Eastern Fergana Valley
40.619581	72.138350	Onion	Eastern Fergana Valley
40.612969	72.108803	Onion	Eastern Fergana Valley
40.614331	72.112575	Onion	Eastern Fergana Valley
40.621589	72.123203	Onion	Eastern Fergana Valley
40.573019	72.182062	Onion	Eastern Fergana Valley
40.606337	72.217483	Onion	Eastern Fergana Valley
40.612365	72.241684	Onion	Eastern Fergana Valley

Note: Onion: *Allium cepa* L.

Soil sampling and nematode extraction

Samples were collected during the spring, summer, and autumn seasons from the root systems of onion plants and the surrounding soils in various agrocenoses of the eastern regions of the Fergana Valley using the route method. For plant sampling, a trench 0.3 m wide and 20 cm deep was dug around the plant, which enabled the collection of the finest roots from the soil. A total of 276 samples were collected to determine the nematode fauna of onion (*Allium cepa*), of which nematodes were detected in 245 samples. A total of 92 samples (46 from the root system and 46 from rhizosphere soils) were collected from the lower hill zone of the eastern regions of the Fergana Valley, 92 from the upper hill zone, and 92 soil samples from the lower mountain zone in onion fields. The soils of the study area are predominantly gray and gypsum-rich gray soils (Kholikov 2020). The collected samples were processed on the same day. Soil particles adhering to the vegetative parts of the plants were washed off.

Nematodes were extracted from the root system and rhizosphere soil samples using the modified Baermann funnel technique and primarily from soil samples using the flotation method (Van Bezooijen 2006). The Baermann funnel technique involves attaching a thin rubber tube to a glass funnel, after which the funnel is placed on a multi-position wooden stand. The funnel is half-filled with distilled water, and each funnel is labeled with an identification tag. Subsequently, the plant root system is cut into small pieces (0.5-1.5 cm). One of the objectives of our study was to determine the distribution of nematode species across different biotopes of onion plants. Therefore, the root system and soils were separated and finely chopped; then 10-15 g were weighed, placed in a 15 × 15 cm piece of gauze, gently tied, and immersed in the designated funnel filled with water. This procedure was repeated for the subsequent rhizosphere soil samples. Each soil sample was thoroughly mixed, with stones and other foreign materials removed; then 20 g were weighed, placed into a 15 × 15 cm piece of gauze, and tied. Before placing the samples into the funnels, a wire mesh was placed at the bottom to prevent the soil-filled gauze from blocking the funnel. The labeled funnel was then carefully immersed in water. After all plant and rhizosphere soil samples collected within a single day were placed into the funnels, they were kept in water-filled funnels for 12 hours (at 30-35°C), 24 hours (at 20-25°C), 48 hours (at 15°C), and 72 hours (at 10°C). During this period, nematodes from the root system and rhizosphere soils migrated into the water and accumulated at the bottom of the funnel.

The nematodes collected from the water were fixed in a 4% formalin solution. Subsequently, nematodes were isolated, and both temporary and permanent microscope slides were prepared. For temporary preparations, several drops of glycerin were placed on a glass slide, fixed nematodes were added, and then covered with a cover slip. For permanent slide preparation, nematodes were isolated using an entomological needle, collected in a watch glass, and immersed in 15-20 drops of a glycerin-alcohol mixture (1:1) for 18-20 hours. During this process, the cuticle became transparent and acquired light-transmitting properties. Afterwards, a glycerin-

gelatin solution was added, and 5-10 nematodes were mounted on a slide, making them ready for microscopic examination. The permanent preparations are stored in the zoology laboratory of Andijan State University.

Nematode analysis

The nematodes isolated from plant and soil samples and fixed in 4% formalin solution were examined to determine species composition and the number of individuals. For this purpose, all samples were studied using MBC-9 or MBC-10 series and Olympus CH binocular microscopes (Olympus Optical, Tokyo, Japan). The nematodes were collected, and temporary glycerin or permanent glycerin-gelatin microslides were prepared. Species identification was primarily based on adult female individuals (rarely male individuals were used).

For the systematic analysis of species, both classical and modern phylogenetic systematics were applied (Chitwood 1958; De Ley and Blaxter 2002; Hodda 2022). The life cycle characteristics of nematodes were classified according to the colonizer-persister (c-p) scale (1-5) proposed by Bongers (1990) and Bongers and Ferris (1999), while their trophic groups were determined following the classification of Yeates et al. (1993).

Statistical analysis

Community similarity was calculated using Sørensen-Dice (Caras et al. 2020) and Jaccard indices (Moulton and Jiang 2018). Diversity metrics (α-diversity) were Simpson, Shannon, Pielou, Menhinick, Margalef, and Berger-Parker indices computed using PAST 4.0 (Hammer et al. 2001). The Simpson index (1-D) reflects the probability that two individuals randomly selected from a sample will belong to different species; values closer to 1 indicate higher diversity. The Shannon index is based on both species richness and evenness; higher values denote greater diversity. The Pielou index measures the degree of evenness relative to the maximum possible diversity, ranging from 0 to 1. The Menhinick index represents the ratio of the number of species to the square root of the number of individuals; higher values indicate greater diversity. The Margalef index measures species richness, with larger values indicating higher species diversity. The Berger-Parker index is based on dominance, where lower values correspond to greater diversity.

RESULTS AND DISCUSSION

Taxonomic diversity

During the study, a total of 39 nematode species associated with onion agrocenoses were identified (Table 2). Taxonomic analysis revealed that these species belong to phylum Nematoda, represented by the classes Adenophorea and Secernentea. Among them, the orders Plectida and Mononchida were represented by a single species each, Dorylaimida by 5 species, Aphelenchida by 3 species, Tylenchida by 10 species, and Rhabditida by 19 species. Overall, the recorded 7 orders encompassed 22 genera.

Among them, the genera *Chiloplacus*, *Ditylenchus*, *Eucephalobus*, *Heterocephalobus*, and *Panagrolaimus*, were found to be more widely distributed in terms of both the number of species and individuals compared to other genera. However, according to the obtained results, the composition of nematode communities showed significant differences across altitudinal zones. In particular, 34 species were recorded in the lower hill zone, 30 species in the upper hill zone, and 12 species in the lower mountain zone.

The recorded species were classified into five groups according to their feeding behavior and interactions with plants. (i) Plant-Parasitic Nematodes (PPN). This represents the dominant trophic group. Within this group, several subgroups were identified: (a) Ectoparasites: *Tylenchorhynchus claytoni*, *Tylenchorhynchus capitatus* (recorded in the lower and upper hill zones). (b) Feeders on epidermal cells or root hairs: *Psilenchus clavicaudatus* (recorded only in the upper hill zone). (c) Semi-endoparasites: This subgroup was represented only by *Helicotylenchus multicinctus*. The species was recorded in both the lower and upper hill zones. (d) Migratory endoparasites: Comprised of representatives of the genera *Ditylenchus* and *Pratylenchus*. Among them, *Pratylenchus pratensis*, *Pratylenchus tulaganovi*, and *Ditylenchus dipsaci* were found to be widely distributed across all altitudinal zones. (ii) Fungivores: This group includes nematodes feeding on fungi, represented by species of the genera *Aphelenchus* and *Aphelenchoides*. (iii) Bacterivores: Within the fauna, this group was widely represented by the genera *Plectus*, *Cephalobus*, *Rhabditis*, *Prismatolaimus*, *Eucephalobus*, *Acrobeloides*, *Cervidelus*, *Diphtherophora*, *Panagrolaimus*, *Diploscapter*, *Mesorhabditis*, and *Heterocephalobus* (iv) Polytrophs: This group was represented by species belonging to the genus *Eudorylaimus*. These species were recorded in both the lower and upper hill zones. (v) Predatory nematodes: This trophic group consisted of predatory nematodes, represented solely by a single species, *Aporcelaimellus obtusicaudatus*, of the genus *Aporcelaimellus*, which was recorded across all altitudinal zones.

In addition, specific species were also encountered for each region. In particular, *Aporcelaimellus obtusicaudatus* (AP), *Diploscapter rhizophilus*, *Rhabditis brevispina*, *Rhabditis filiformis*, *Heterocephalobus elongatus* (BF), *Diphtherophora obesus* (HF), *Aphelenchus avenae* (HF), *Pratylenchus pratensis*, and *Pratylenchus tulaganovi*, as well as *Ditylenchus dipsaci* (PPN), were recorded in all altitudinal zones. Some nematodes within the faunal composition were observed exclusively in certain altitudinal zones. In the lower hill region, nematodes specific to this zone comprised 11 species (*Eudorylaimus parvus*, *Eucephalobus mucronatus* (O), *Heterocephalobus laevis*, *Chiloplacus propinquus*, *Chiloplacus symmetricus* (BF), *Aphelenchus eremitus*, *Aphelenchoides parietinus* (HF), *Ditylenchus misellus*, *Ditylenchus trififormis* (PPN)). In the upper hill region, only *Psilenchus clavicaudatus* (PPN) was detected, whereas in the lower mountainous area, solely *Cervidelus insubricus* (BF) was identified.

Table 2. Distribution of nematodes across ecological zones. The sign + indicates the presence of the species in this biotope, and the space indicates that the species is not recorded

Nematode species	Ecological groups	Lower hill	Upper hill	Lower mountain
<i>Plectus cirratus</i> (Bastian, 1865)	BF	-	+	-
<i>Prismatolaimus intermedius</i> (Bütschli, 1873) de Man, 1880	BF	+	+	-
<i>Eudorylaimus ettersbergensis</i> (de Man, 1885) Andrassy, 1959	O	+	+	-
<i>Eudorylaimus monhystera</i> (De Man, 1880)	O	+	+	-
⁺ <i>Eudorylaimus parvus</i> (de Man, 1880) Andrassy, 1959	O	+	-	-
<i>Aporcelaimellus obtusicaudatus</i> (Bastian, 1865) Altherr, 1968	AP	+	+	+
<i>Diphtherophora obesus</i> (Thorne, 1939)	HF	-	+	+
<i>Rhabditis brevispina</i> (Claus, 1862) Bütschli, 1873 (Osche, 1952)	BF	+	+	+
<i>Rhabditis filiformis</i> (Bütschli, 1873) Osche, 1952	BF	+	+	+
<i>Mesorhabditis monhystera</i> (Bütschli, 1873) Dougherty, 1955	BF	+	+	-
<i>Caenorhabditis dolichurus</i> (A.Schneider, 1866) Dougherty, 1955	BF	+	-	-
<i>Diploscapter rizophilus</i> (Rahm, 1928)	BF	+	+	+
<i>Cephalobus persegnis</i> (Bastian, 1865)	BF	+	+	-
<i>Heterocephalobus laevis</i> (Thorne, 1937) Andrassy, 1967	BF	+	-	-
<i>Heterocephalobus elongatus</i> (de Man, 1880) Brzeski, 1961	BF	+	+	+
<i>Eucephalobus kipchaus</i> (Atakhnov, 1958) Andrassy, 1967	BF	+	+	-
<i>Eucephalobus oxyuroides</i> (de Man, 1876) Steiner, 1936	BF	+	+	-
<i>Acrobeloides butschlii</i> (de Man, 1884) Steiner & Buhner, 1933	BF	+	+	-
<i>Acrobeloides nanus</i> (de Man, 1880) Anderson, 1968	BF	+	+	-
<i>Cervidellus insubricus</i> (Steiner, 1914) Thorne, 1937	BF	-	-	+
<i>Chiloplacus bibigulae</i> (Erzhanova, 1964)	BF	+	+	-
<i>Chiloplacus symmetricus</i> (Thorne, 1925) Thorne, 1937	BF	+	-	-
<i>Chiloplacus propinquus</i> (de Man, 1921) Thorne, 1937	BF	+	-	-
<i>Panagrodontus armatus</i> (Thorne, 1937) Rühm, 1956	BF	+	+	-
<i>Panagrodontus rigidus</i> (Schneider, 1866) Thorne, 1937	BF	-	+	+
<i>Panagrodontus multidentatus</i> (Ivanova, 1958)	BF	+	+	-
⁺ <i>Psilenchus clavicaudatus</i> (Micoletzky, 1922) Thorne, 1949	PF-e	-	+	-
<i>Aphelenchus avenae</i> (Bastian, 1865)	HF	+	+	+
<i>Aphelenchus eremitus</i> (Thorne, 1961)	HF	+	-	-
<i>Aphelenchoides parietinus</i> (Bastian, 1865) Steiner, 1932	HF	+	+	-
⁺ <i>Tylenchorhynchus capitatus</i> (Allen, 1955)	PF-d	+	+	-
⁺ <i>Tylenchorhynchus claytoni</i> (Steiner, 1937)	PF-d	+	+	-
<i>Pratylenchus pratensis</i> (de Man, 1880) Filipjev, 1936	PF-b	+	+	+
<i>Pratylenchus tulaganovi</i> (Samibaeva, 1966)	PF-b	+	+	+
<i>Ditylenchus dipsaci</i> (Kühn, 1857) Filipjev, 1936	PF-b	+	+	+
<i>Ditylenchus intermedius</i> (de Man, 1880) Filipjev, 1936	PF-b	+	+	-
<i>Ditylenchus misellus</i> (Andrassy, 1958)	PF-b	+	-	-
⁺ <i>Ditylenchus triformis</i> (Hirschmann & Sasser, 1955)	PF-b	+	-	-
<i>Helicotylenchus multicinctus</i> (Cobb, 1893) Golden, 1956	PF-c	+	+	-

Note: BF: Bacterial Feeding, HF: Hypal Feeding, Ap: Animal predation, O: Omnivorous, PF-b: Migratory endoparasites, PF-c: Semi-endoparasites, PF-d: Ectoparasites, PF-e: Epidermal cell and root hair feeders. ⁺: These species were identified in the study area for the first time

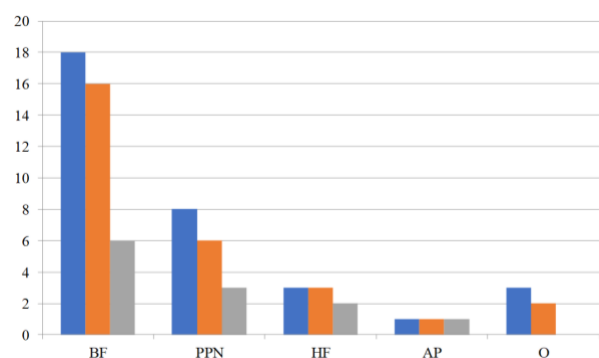


Figure 2. Distribution of nematode ecological groups across different altitudinal zones. a. Lower hill, b. Upper hill, c. Lower mountain. BF: Bacterivores, PPN: Plant-Parasitic Nematodes, HF: Fungivores, AP: Predatory nematodes, O: Omnivores (A value of 0-20 indicates the number of species)

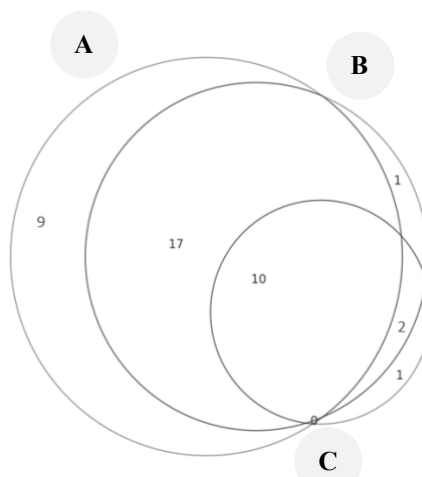


Figure 3. Distribution of total and zone-specific nematode species in: A. Lower hill, B. Upper hill, and C. Lower mountain regions

The occurrence of nematodes in certain altitudinal zones is associated with the physicochemical properties of the soil, moisture levels, and organic matter content (edaphic factors). For example, in the lower hill zone, sufficient moisture and organic fertilizers promote the proliferation of species such as *H. elongatus* (bacterivore) and *D. dipsaci* (phytoparasite). In the upper hill zone, stable soil conditions support *P. clavicaudatus*, whereas in the lower mountain zone, cooler climate and lower organic matter content favor *C. insubricus*. These factors enhance the adaptation of each species to the ecosystem and its activity within the respective habitats (Chen et al. 2024). Based on the above data, the similarity of nematode communities across different regions was compared (Figure 3). During the research, the nematode fauna of onion fields was statistically analyzed using various ecological indices. According to the obtained results, the Lower hill region showed higher values in terms of species diversity, richness, dominance index, and other related parameters (Table 3).

Based on the above data (Table 2), the classification of species and the study of their ecological characteristics in nematode ecosystems play an important role in assessing biological diversity. In this context, the use of Bongers' (1990) C-p (colonizer-persister) index serves as an effective tool for determining environmental stability and the degree of soil disturbance. The following analysis is aimed at an in-depth study of the ecological groups of nematode species and their geographic distribution, with particular attention paid to the adaptation of each segment to its natural habitat (Table 4). For instance, the species included in the first group (C-p 1), such as *R. brevispina*, *R. filiformis*, *Mesorhabditis monhystera*, *Caenorhabditis dolichurus*, *Panagrodontus armatus*, *Panagrodontus rigidus*, and *Panagrodontus multidentatus*, possess rapid reproductive capabilities and an opportunistic life cycle, comprising a total of seven species. These species are widely distributed across regions of different altitudes, including the Lower hill, Upper hill, and Lower mountain, and their high reproductive rate provides a distinct advantage under unstable soil conditions. Members of this group play a significant role in the recovery of ecosystems under ecological stress conditions, as their adaptive capacity enables them to withstand environmental changes (Bongers 1990).

The second group (C-p 2), which includes *Plectus cirratus*, *Cephalobus persegnis*, *Eucephalobus kipchaus*, *E. oxyuroides*, *H. laevis*, *H. elongatus*, *Acrobeloides butschlii*, *Acrobeloides nanus*, *Diploscapter rizophilus*, *Cervidellus insubricus*, *Chiloplacus bibigulae*, *Ch. symmetricus*, *Ch. propinquus*, *P. clavicaudatus*, *A. avenae*, *A. eremitus*, *A. parietinus*, *T. capitatus*, *T. claytoni*, *P. pratensis*, *P.*

tulaganovi, *D. dipsaci*, *D. intermedius*, *D. misellus*, *D. triformis*, and *H. multincinctus*, comprises 26 species characterized by moderate adaptability. Most of these species are equally present across the three regions and thrive well under moderately stable soil conditions. Representatives of this group occupy an important position in the soil food web and contribute to maintaining the functional balance of the ecosystem (Maina et al. 2021).

The third group (C-p 3), which includes *Prismatolaimus intermedius* and *D. obesus*, is recognized for its adaptation to stable environments and is primarily observed in the upper hill and lower mountain regions. These recorded species play a crucial ecological role in maintaining soil structural stability (Yeates et al. 1993).

The fourth group (C-p 4), which includes *Eudorylaimus ettersbergensis*, *Eudorylaimus monhystera*, and *E. parvus*, is characterized by long-lived species adapted to stable ecosystems and is primarily distributed in the upper hill and lower mountain regions. The presence of these species provides clear indications of soil stability and quality, as they are rarely found in disturbed soil conditions (Bongers and Ferris 1999).

The fifth group (C-p 5), represented by a single species, *Aporcelaimellus obtusicaudatus*, is characterized by high environmental stability requirements and sensitivity, occurring across all three regions. Species within this group are predominantly distributed in soils with high ecological quality and minimal anthropogenic impact, enhancing their significance as bioindicators (Yeates 2003).

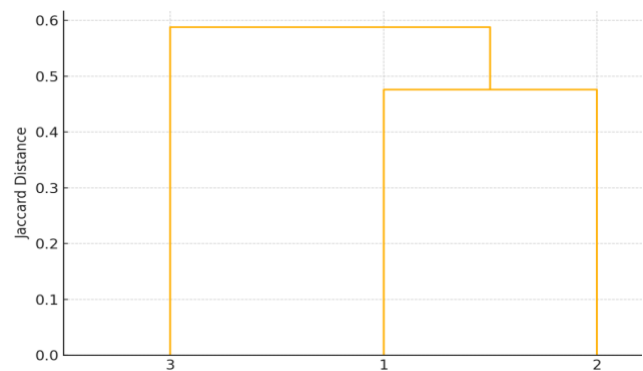


Figure 4. Similarity of nematode communities across altitudinal zones based on the Jaccard index. The dendrogram shows hierarchical clustering; heatmap intensity reflects similarity values (0-1 scale), UPGMA method, bootstrap values >80%. 1. Lower hill, 2. Upper hill, 3. Lower mountain

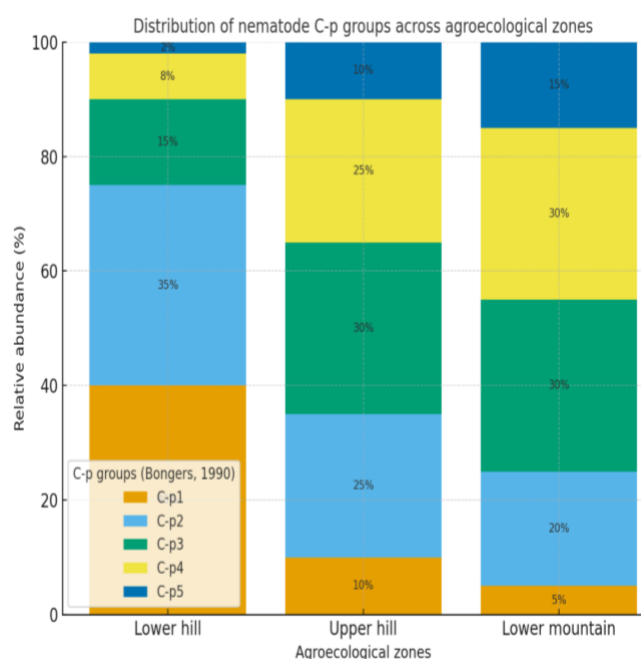
Table 3. Alpha diversity of nematode communities in onion agrocenoses across different regions

Study area	Simpson (1-D)	Shannon (H')	Pielou (J')	Menhinick (R = S/√N)	Margalef (d = (S-1)/ln N)	Berger-Parker (d = Nmax/N)
Lower hill	0.969	3.466	0.97	5.657	8.945	0.031
Upper hill	0.967	3.401	0.96	5.477	8.526	0.033
Lower mountain	0.833	1.792	0.91	2.449	2.791	0.167

Note: All indices calculated using PAST 4.0 software (Hammer et al. 2001)

Table 4. Classification of nematode species by Bongers' C-p groups, their distribution, and ecological characteristics in different regions

C-p group	Species (examples)	Number of species	Geographical distribution	Ecological characteristics
C-p 1	<i>Rhabditis brevispina</i> , <i>Rhabditis filiformis</i> , <i>Mesorhabditis monhystera</i> , <i>Caenorhabditis dolichurus</i> , <i>Panagrodontus armatus</i> , <i>Panagrodontus rigidus</i> , <i>Panagrodontus multidentatus</i>	7	Lower hill, Upper hill, Lower mountain	Opportunistic species; rapid reproduction; tolerant to unstable conditions; important for ecosystem recovery
C-p 2	<i>Plectus cirratus</i> , <i>Cephalobus persegnis</i> , <i>Eucephalobus kipchaus</i> , <i>Eucephalobus oxyuroides</i> , <i>Heterocephalobus laevis</i> , <i>Heterocephalobus elongatus</i> , <i>Acrobeloides butschlii</i> , <i>Acrobeloides nanus</i> , <i>Diploscapter rizophilus</i> , <i>Cervidellus insubricus</i> , <i>Chiloplacus bibigulae</i> , <i>Chiloplacus symmetricus</i> , <i>Chiloplacus propinquus</i> , <i>Psilenchus clavicaudatus</i> , <i>Aphelenchus avenae</i> , <i>Aphelenchus eremitus</i> , <i>Aphelenchoides parietinus</i> , <i>Tylenchorhynchus capitatus</i> , <i>Tylenchorhynchus claytoni</i> , <i>Pratylenchus pratensis</i> , <i>Pratylenchus tulaganovi</i> , <i>Ditylenchus dipsaci</i> , <i>Ditylenchus intermedius</i> , <i>Ditylenchus misellus</i> , <i>Ditylenchus trififormis</i> , <i>Helicotylenchus multicinctus</i>	26	All three regions	Moderately adaptable; important in the soil food web; contributes to maintaining ecosystem balance
C-p 3	<i>Prismatolaimus intermedius</i> , <i>Diphtherophora obesus</i>	2	Upper hill, Lower mountain	Adapted to stable environments; involved in maintaining soil structural stability
C-p 4	<i>Eudorylaimus ettersbergensis</i> , <i>Eudorylaimus monhystera</i> , <i>Eudorylaimus parvus</i>	3	Upper hill, Lower mountain	Long-lived species; indicators of stable ecosystems; rarely found in disturbed soils
C-p 5	<i>Aporcelaimellus obtusicaudatus</i>	1	All three regions	Highly sensitive; found in soils of high ecological quality with minimal disturbance; important bioindicator

**Figure 5.** Ecological distribution of nematode C-P functional groups across geomorphologic regions

Discussion

During our study, the nematode fauna composition of onion agroecosystems exhibited certain taxonomic peculiarities.

Notably, the occurrence of nematode orders did not differ from the order composition reported in agroecosystems located in nearby regions (Narzullayev et al. 2023; Nurmatova et al. 2025). Other studies conducted in Central Asia and Uzbekistan (Bazarbekov 1970) indicate that the nematode fauna associated with onion plants includes widely distributed species, particularly *Aphelenchoides kuhnii*, *A. parietinus*, *D. dipsaci*, *P. pratensis*, and *H. multicinctus*, which aligns with the findings of our research. However, some studies have described the onion nematode fauna as comprising a relatively larger number of nematode species (Karimova 1974; Rizayeva 1984). The high number of species may be related to continuous monitoring of the development and dynamics of the onion nematode fauna. That is, the studies above were conducted concerning different vegetation stages of the plant and seasonal variations.

When analyzing the distribution of onion nematode fauna by genera, representatives of the genera *Ditylenchus*, *Tylenchorhynchus*, and *Pratylenchus*, as well as fungivorous nematodes such as *Aphelenchus* and *Aphelenchoides*, and bacterivorous representatives including *Acrobeloides*, *Cephalobus*, *Eucephalobus*, and *Rhabditis*, were widely distributed, which is consistent with previous studies (Yavuzaslanoglu et al. 2019; Peralta-Ccayahuallpa et al. 2024). However, in some studies, representatives of the genus *Meloidogyne*, described as causing serious damage to onion plants, were not detected at all (Abd Allah et al. 2023; Beesa et al. 2023).

Previous studies on the composition of nematodes occurring in onion agroecosystems have shown that nematodes belonging to the genera *Filenchus*, *Tylenchus*, *Tylenchorhynchus*, *Helicotylenchus*, *Aphelenchus*, *Boleodorus*, *Paratylenchus*, and are widely distributed and are considered important pest groups (Konate et al. 2019; Muhammad et al. 2024). Our analyses corroborate these scientific findings. Specifically, in the foothill agroecosystems of the eastern Fergana Valley, nematodes belonging to the genera *Tylenchorhynchus*, *Pratylenchus*, and *Helicotylenchus* were recorded in the root zones of cultivated onion plants.

Additionally, certain representatives of some genera, particularly nematodes of the genus *Ditylenchus*, are considered highly dangerous pathogens not only for onion but also for other important vegetable crops. These nematodes parasitize both the root system and aboveground tissues of plants, causing significant damage to plant health (Yavuzaslanoglu et al. 2020; Riascos-Ortiz et al. 2023; Aksay and Yavuzaslanoglu 2023). Specifically, *D. dipsaci* exhibits rapid reproduction under cold and moist environmental conditions and induces morphological changes in the stem and leaf tissues of plants, resulting in leaf fragility, deformation, and potentially plant death (Brinkman and Teklu 2022). This nematode species, in particular, penetrates the plant through stomata and, following primary infestation, facilitates the entry of pathogenic fungi and bacteria. This leads to severe phytopathological consequences, including root rot, swelling of growth zones, and disruption of vegetation processes (Malysheva and Tarasova 2019). In our study, *D. dipsaci* was recorded across agroecosystems in all altitudinal zones. This finding indicates the need for further research to assess the distribution and damage levels of this species in the study area.

Studies from other geographic regions also indicate the potential emergence of new nematode species in onion agroecosystems. For instance, research conducted in the state of Georgia, USA, identified the previously unreported species *Paratrichodorus minor*, highlighting that the composition of nematode fauna can vary significantly depending on regional characteristics (Hajihassani et al. 2018). Furthermore, our research in the Eastern Fergana region of Uzbekistan revealed the presence of several previously unrecorded nematode species associated with onion plants. This finding opens new perspectives for studying the region's biodiversity and contributes to a deeper understanding of the complexity of soil ecosystems. In particular, the species *E. parvus*, *E. kipchaus*, *D. triformis*, *T. claytoni*, *T. capitatus*, and *P. clavicaudatus* were observed in this region for the first time, highlighting the need to assess their ecological roles within the ecosystem and their potential impact on plant health. Their activity is influenced by the soil's physicochemical properties, moisture content, and organic matter composition, which determine the stability and distribution of nematode populations. Consequently, future studies on soil quality and structure are of critical importance for assessing the impact of these newly recorded species on the agroecosystem, as soil conditions can either enhance or restrict their biological activity, thereby affecting plant health and crop productivity.

It is known that specific soil properties, as well as variable environmental factors, influence nematode communities (Dong et al. 2017). The diversity of nematode communities becomes particularly evident when analyzing ecological groups. The ecological composition of the nematode fauna associated with onion plants examined in our study shows some differences compared to previously conducted research (Yavuzaslanoglu et al. 2019). Specifically, in this study, bacterivores accounted for 53.84% of the nematode community (the dominant ecological group), while omnivores 7.7% and fungivores (guild feeders) comprised 10.25%. In contrast, according to other data, bacterivores represented 29.5%, plant-parasitic nematodes 25.5%, fungivores 24.7%, omnivores 19.9%, and predatory nematodes 0.5% of the community (Yavuzaslanoglu et al. 2019).

Such diversity in the ecological composition of nematodes is primarily associated with soil characteristics. In the agroecosystems of Eastern Fergana, the organic matter content of soil layers does not exceed 0.20-1.77% (Kholikov 2020). This limits the availability of saprobial products and microorganisms (bacteria, fungal hyphae), thereby restricting the increase in populations of free-living bacterivorous and predatory nematodes. This factor can also explain the finding of a predatory nematode represented by only a single species. However, analyzing their distribution across regions is crucial for understanding the influence of environmental factors on nematodes (Dong et al. 2017; Narzullayev 2022). As shown in Figure 2, the diversity of nematode species and their ecological groups exhibits an inverse correlation with elevation zones. This pattern slightly differs from the results obtained in studies conducted in natural biocenoses (Eshova 2016; Dong et al. 2017; Narzullayev 2022). The reason for this can be attributed to the study area encompassing only the lower zones of mountainous biocenoses, meaning the research was conducted in a limited region.

Additionally, differences in the level of anthropogenic impact may have influenced the structure of the nematode communities. For instance, in the lower hill areas, the richness of nematode species and the diversity of ecological groups are higher, which can be associated with factors such as sufficient soil moisture due to continuous irrigated agriculture, the application of organic fertilizers to the soil, and relatively lower soil compaction. Overall, with increasing altitude, changes in ecological diversity are directly proportional to the decrease in species number, and this pattern is characteristic for nearly all ecological groups, with the exception of predatory nematodes.

By comparing the nematode fauna of adjacent areas at different altitudes, conclusions can also be drawn regarding the formation of the fauna (Figure 3). The obtained results are consistent with previously conducted studies (Dong et al. 2017; Narzullayev 2022). Only the species specific to the lower hill (a) and upper hill (b) regions were the most numerous (17 species), whereas no shared species were identified for only the lower hill (b) and lower mountain (c) regions. The species unique to only the upper hill (b) and lower mountain (c) amounted to one. Based on these observations, it can be inferred that the passive dispersal of

these organisms (via water and natural technogenic factors) played primary role in shaping the nematode communities in adjacent biotopes.

As a result of the influence of several ecological factors mentioned above, it can be concluded that in each altitudinal zone, a nematode community has been formed that reflects the ecological condition of the respective habitat. In particular, a total of 34 species were recorded in the lower hill zone. These include *P. intermedius*, *E. ettersbergensis*, *E. monohystera*, *E. parvus*, *A. obtusicaudatus*, *R. brevispina*, *R. filiformis*, *M. monhystera*, *C. dolichurus*, *D. rhizophilus*, *C. persegnis*, *H. laevis*, *H. elongatus*, *E. kipchaus*, *E. oxyuroides*, *A. butschlii*, *A. nanus*, *C. bibigulae*, *Ch. symmetricus*, *Ch. propinquus*, *P. armatus*, *P. multidentatus*, *A. avenae*, *A. eremitus*, *A. parietinus*, *T. capitatus*, *T. claytoni*, *P. pratensis*, *P. tulaganovi*, *D. dipsaci*, *D. intermedius*, *D. misellus*, *D. triformis*, and *H. multicinctus*. The distribution across C-p functional groups revealed that C-p1 nematodes dominated with 40% (≈ 14 species), followed by C-p2 with 35% (≈ 12 species). In contrast, C-p3 (≈ 5 species), C-p4 (≈ 3 species), and C-p5 (≈ 1 species) were less represented. This pattern indicates that opportunistic nematodes adapted to dynamic and fluctuating soil conditions were widely prevalent in the studied lower hill ecosystem (Bongers 1990).

A total of 30 species were identified in the upper hill zone. These included *P. cirratus*, *P. intermedius*, *E. ettersbergensis*, *E. monhystera*, *A. obtusicaudatus*, *D. obesus*, *R. brevispina*, *R. filiformis*, *M. monhystera*, *D. rhizophilus*, *C. persegnis*, *H. elongatus*, *E. kipchaus*, *E. oxyuroides*, *A. butschlii*, *A. nanus*, *C. bibigulae*, *P. armatus*, *P. rigidus*, *P. multidentatus*, *P. clavicaudatus*, *A. avenae*, *A. parietinus*, *T. capitatus*, *T. claytoni*, *P. pratensis*, *P. tulaganovi*, *D. dipsaci*, *D. intermedius*, and *H. multicinctus*. The graphical analysis demonstrated that in this zone, C-p3 nematodes accounted for 30% (≈ 9 species) and C-p4 for 25% ($\approx 7-8$ species), representing the most dominant groups. C-p2 was also relatively abundant at 25% ($\approx 7-8$ species), whereas C-p1 (≈ 3 species) and C-p5 (≈ 3 species) contributed lower proportions. These results indicate a relatively stable soil ecosystem (Maina et al. 2021).

In the lower mountain zone, a total of 12 nematode species were recorded. These included *A. obtusicaudatus*, *D. obesus*, *R. brevispina*, *R. filiformis*, *D. rhizophilus*, *H. elongatus*, *C. insubricus*, *P. rigidus*, *A. avenae*, *P. pratensis*, *P. tulaganovi*, and *D. dipsaci*. The distribution of C-p functional groups in this zone revealed that C-p3 (30%, ≈ 4 species) and C-p4 (30%, ≈ 4 species) were dominant, while C-p5 (15%, ≈ 2 species) also represented a considerable proportion. In contrast, C-p2 ($\approx 2-3$ species) and C-p1 (≈ 1 species) were less frequently encountered. These findings indicate that the soil environment in this zone is characterized by relatively stable ecological conditions (Yeates et al. 1993).

Nematode assemblages identified from onion fields in the Eastern Fergana region were evaluated according to the C-p (colonizer-persister) scale proposed by Bongers (1990). The results revealed that in the lower hill zone, where a total of 34 species were recorded, seven species belonging to the C-p1 group were particularly abundant.

This dominance highlights the prevalence of opportunistic taxa adapted to dynamic and frequently disturbed soil conditions (Bongers and Ferris 1999). In contrast, the upper hill zone harbored 30 species, where the broad representation of C-p2 and C-p3 groups reflected a more stable and complex soil ecosystem (Maina et al. 2021). The lower mountain zone, with 12 species, also showed a similar pattern, where the proportion of C-p2, C-p3, and C-p4 nematodes confirmed the relative ecological stability of the habitat. Notably, the species *A. obtusicaudatus* belonging to the C-p5 group was consistently present across all three altitudinal zones, indicating its high degree of ecological specialization and considerable potential for wide distribution (Yeates 2003).

In conclusion, the conducted studies have revealed that nematode communities across different altitudinal zones exhibit significant differences in both taxonomic and ecological composition. These findings, which can be primarily explained by variations in the soil's physicochemical properties, moisture content, and organic matter composition (edaphic factors), are of immense importance to the scientific community. They underscore the crucial role of soil properties and anthropogenic influences in shaping the structure of nematode communities, thereby enhancing our understanding of these complex ecosystems. Looking to the future, there is a vast potential for more comprehensive studies. A deeper analysis of the relationship between soil properties and nematode communities could provide crucial insights into the formation characteristics of nematode assemblages in a given area. Furthermore, the prospect of molecular identification of dominant nematode species in agroecosystems and assessing their bioindicator properties is a promising avenue for future research. This could lead to the development of ecologically safe recommendations for controlling plant-parasitic nematodes, based on a thorough understanding of their population dynamics, and bring about significant advancements in the field of nematology.

ACKNOWLEDGEMENTS

The authors extend their heartfelt gratitude to Andijan State University for providing the essential scientific equipment and organizational assistance for the study. We express our profound appreciation to the laboratory of the Department of Zoology and Biochemistry at the university for their invaluable support during the processing and analysis of samples. Additionally, we acknowledge with thanks the constructive comments from anonymous official reviewers, whose contributions have significantly improved the quality of the manuscript. This research was supported by the Andijan State University project No.04-12, approved on February 7, 2024.

REFERENCES

- Abd Allah AM, El-Mehy AA, Abdel-Baset SH. 2023. Effect of intercropping onion with sugar beet on productivity of both crops and root-knot nematodes control under different onion plant densities and slow-

- release N fertilizer rates. *J Plant Prod Sci* 9 (1): 61-75. DOI: 10.21608/jpps.2020.157286.
- Adylova NA. 1972. Helminths of onions. In: Helminths in Food Products. Abstracts of Reports from the Inter-Republican Scientific Conference, Samarkand University, Uzbekistan. [Russian]
- Aksay G, Yavuzaslanoglu E. 2023. Status of onion production in Türkiye and in the world, effects of abiotic and biotic stress factors. *Anatol J Bot* 7 (1): 32-39. DOI: 10.30616/ajb.1240014.
- Archidona-Yuste A, Cai R, Cantalapiedra-Navarrete C, Carreira JA, Rey A, Viñeña B, Liébanas G, Palomares-Rius JE, Castillo P. 2020. Morphostatic speciation within the dagger nematode *Xiphinema hispanum*-complex species (Nematoda: Longidoridae). *Plants* 9 (12): 1649. DOI: 10.3390/plants9121649.
- Bardgett RD, van der Putten WH. 2014. Belowground biodiversity and ecosystem functioning. *Nature* 515: 505-511. DOI: 10.1038/nature13855.
- Bazarbekov KU. 1970. The fauna of onion and garlic nematodes in Southeast Kazakhstan and measures for controlling *Ditylenchus*. [Dissertation]. Leningrad. [Russian]
- Beesa N, Suwannam A, Puttawong K, Phanbut P, Jindapunnapat K, Sasnarukkit A, Chinnsari B. 2023. First report of the root-knot nematode *Meloidogyne graminicola* on shallot (*Allium cepa* var. *aggregatum*) in Thailand. *New Dis Rep* 47 (1): e12158. DOI: 10.1002/ndr.12158.
- Bernard GC, Egnin M, Bonsi C. 2017. The impact of plant-parasitic nematodes on agriculture and methods of control. In: Shah MM, Mahamood M (eds). *Nematology Concepts, Characteristics and Control*. InTech Open, London. DOI: 10.5772/intechopen.68958.
- Bongers T, Ferris H. 1999. Nematode community structure as a bioindicator in environmental monitoring. *Trends Ecol Evol* 14 (6): 224-228. DOI: 10.1016/s0169-5347(98)01583-3.
- Bongers T. 1990. The maturity index: An ecological measure of environmental disturbance based on nematode species composition. *Oecologia* 83: 14-19. DOI: 10.1007/BF00324627.
- Brinkman P, Teklu MG. 2022. Integrated nematode management of *Ditylenchus dipsaci* in onion: A nematode in a world all on its own. In: Sikora R, Desaegeer J, Molendijk L (eds). *Integrated Nematode Management: State-of-the-Art and Visions for the Future*. CAB International, Wallingford. DOI: 10.1079/9781789247541.0041.
- Carass A, Roy S, Gherman A, Reinhold JC, Jesson A, Arbel T, Maier O, Handels H, Ghafoorian M, Platel B, Birenbaum A, Greenspan H, Pham DL, Crainiceanu CM, Calabresi PA, Prince JL, Gray Roncal WR, Shinohara RT, Oguz I. 2020. Evaluating white matter lesion segmentations with refined Sørensen-Dice analysis. *Sci Rep* 10 (1): 8242. DOI: 10.1038/s41598-02064803-w
- Chen J, Zhang Y, Liu C, Huang L. 2024. Distribution pattern of soil nematode communities along an elevational gradient in arid and semi-arid mountains of Northwest China. *Front Plant Sci* 15: 1466079. DOI: 10.3389/fpls.2024.1466079.
- Chitwood BG. 1958. The Classification of plant parasitic nematodes and related forms // XV-th. International Congress of Zoology.
- De Ley P, Blaxter ML. 2002. Systematic position and phylogeny. In: Lee DL (eds). *The Biology of Nematodes*. CRC Press, London.
- Dong K, Moroenyane I, Tripathi B, Kerfahi D, Takahashi K, Yamamoto N, An C, Cho H, Adams J. 2017. Soil nematodes show a mid-elevation diversity maximum and elevational zonation on Mt. Norikura, Japan. *Sci Rep* 7: 3028. DOI: 10.1038/s41598-017-03655-3.
- Eshova KS. 2016. Nematodes of arid areas of Uzbekistan. *Eur J Biomed Pharm Sci* 3 (12): 129-132.
- Hajihassani A, Hamidi N, Dutta B, Tyson C. 2018. First report of stubby-root nematode, *Paratrichodorus minor*, on onion in Georgia, U.S.A. *J Nematol* 50 (3): 453-455. DOI: 10.21307/jofnem-2018-038.
- Hammer Ø, Harper DAT, Ryan PD. 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontol Electron* 4 (1): 1-9.
- Hodda M. 2022. Phylum Nematoda: A classification, catalogue and index of valid genera, with a census of valid species. *Zootaxa* 5114 (1): 1-289. DOI: 10.11646/zootaxa.5114.1.1.
- Karimova MM. 1974. Dynamics of nematode fauna during the main developmental phases of onion *Allium sativa* L. Proceedings of Scientific Conferences, Moscow. [Russian]
- Kholikov RY. 2020. Fergana Valley (Natural Geography). Monograph, Tashkent.
- Konate AY, Ouuedraogo SL, Kone D. 2019. Etude faunistique des nématodes phytoparasites de l'oignon (*Allium cepae* L., Alliaceae) au Burkina Faso. *Intl J Biol Chem Sci* 13 (3): 1388-1395. DOI: 10.4314/IJBACS.V13I3.14. [French]
- Kumar M, Barbhai MD, Hasan M et al. 2022. Onion (*Allium cepa* L.) peels: A review on bioactive compounds and biomedical activities. *Biomed Pharmacother* 146: 112498. DOI: 10.1016/j.biopha.2021.112498.
- Lu Q, Liu T, Wang N, Dou Z, Wang K, Zuo Y. 2020. A review of soil nematodes as biological indicators for the assessment of soil health. *Front Agric Sci Eng* 7 (3): 275-281. DOI: 10.15302/j-fase-2020327.
- Maina S, Karuri H, Ng'endo RN. 2021. Free-living nematode assemblages associated with maize residues and their ecological significance. *J Nematol* 53: e2021-38. DOI: 10.21307/jofnem-2021-038.
- Malysheva NS, Tarasova TV. 2019. Biological diversity of nematodes of vegetable crops in the Kursk region. In: *Natural and Technical Sciences: Global Challenges, Trends, Opportunities*. Proceedings of the International Scientific and Practical Conference, May, Belgorod, Rusia.
- Moulton R, Jiang Y. 2018. Maximally consistent sampling and the Jaccard index of probability distributions. *International Conference on Data Mining 2018*: 347-356. DOI: 10.1109/ICDM.2018.00050.
- Mirzaev UN, Kuchboev AE, Mavlyanov O, Amirov OO, Narzullayev SB. 2024. Morphological and molecular characterization of root-knot nematodes from Uzbekistan. *Biosyst Divers* 32 (1): 135-141. DOI: 10.15421/012413.
- Muhammad B, Bibi K, Khan MS, Kiran A. 2024. Association of plant parasitic nematodes with some vegetable crops of Khyber Pakhtunkhwa, Pakistan. *Alex Sci Exch J* 45 (1): 21-25. DOI: 10.21608/asejaiqisae.2024.335700.
- Narzullayev S, Kambarov S, Mirzaev U, Tursunova S. 2023. Diversity of woody plant nematodes in a specially protected biocenosis of Zarafshan Mountain, Uzbekistan. *Biodiversitas* 24 (6): 3145-3151. DOI: 10.13057/biodiv/d240607.
- Narzullayev SB, Mirzaev UN, Mavlyanov O, Khakimov N, Jabborov AR, Khamidova AB, Tursunova SS, Khujamov S, Baysariyeva C, Ashrapov AA, Nurmatova DM. 2024. Diversity and habitat distribution of tomato (*Solanum lycopersicum*) nematode fauna (Zarafshan valley, Uzbekistan). *Acta Biol Sibirica* 10: 1147-1164. DOI: 10.5281/zenodo.13937701.
- Narzullayev SB, Subbotin SA. 2025. Characterisation of some gall-forming nematodes of the family Anguinidae from Uzbekistan. *Russ J Nematol* 33 (1): 1-7. DOI: 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. DOI: 10.13057/biodiv/d230814.
- National Atlas of Uzbekistan. 2020. *Natural Conditions and Resources, Ecology, and Environmental Protection of the Republic of Uzbekistan*, Tashkent.
- National Statistics Committee. 2025. *Agriculture*. <https://stat.uz/uz/rasmiy-statistika/agriculture-2>.
- Nurmatova DM, Narzullayev SB, Mavlyanov O, Khakimov N, Jabborov AR, Boltayev KS, Mirzaev UN, Ashrapov AA, Tursunova SS, Khujamov S. 2025. Trophic structure and soil depth stratification as ecological drivers of taxonomic and species diversity in the nematode community in Central Asian peach orchards. *Acta Biol Sibirica* 11 (1): 477-493. DOI: 10.5281/zenodo.15347466.
- Öztürk L, Behmand T, Sin B, Avcı GG, Elekcioglu IH. 2018. Morphologic and molecular identification of *Xiphinema americanum* associated with pine trees. *Intl J Mol Biol* 3 (3): 96-98. DOI: 10.15406/ijmboa.2018.03.00058.
- Peralta-Ccayahuallpa VA, Casa-Coila VH, Lima-Medina I, Cuadros-Fernández LA, Macedo-Valdivia DG. 2024. Characterization of *Meloidogyne* spp. and population density of phytoparasitic nematodes associated with Alliaceae crops in the Arequipa region, Peru. *Sci Agropec* 15 (2): 289-299. DOI: 10.17268/sci.agropecu.2024.022.
- Riascos-Ortiz D, Caicedo-Castro J, Arboleda-Riascos C, Sánchez F, Mosquera-Espinosa AT, De Agudelo FV. 2023. Morpho-molecular characterization of *Ditylenchus dipsaci* and alternatives for its management in green onion *Allium fistulosum* crops from Colombia. *Agric Sci* 14 (11): 1516-1534. DOI: 10.4236/as.2023.1411098.
- Rizayeva SM. 1984. Nematodes of major vegetable crops and potatoes in the northeastern zone of Uzbekistan. Author's abstract of dissertation for the degree of Candidate of Biological Sciences, Tashkent. [Russian]
- Sekara A, Pokluda R, Del Vacchio L, Somma S, Caruso G. 2017. Interactions among genotype, environment, and agronomic practices on production and quality of storage onion (*Allium cepa* L.) - A review. *Hortic Sci* 44 (1): 21-42. DOI: 10.17221/92/2015-hortsci.
- Suyadi, Sila S, Samuel J. 2021. Nematode diversity indices application to determine the soil health status of Lembo agroecosystem in West

- Kutai, East Kalimantan Province, Indonesia. *Biodiversitas* 22 (7): 2861-2869. DOI: 10.13057/biodiv/d220737.
- Van Bezooijen J. 2006. *Methods and Techniques for Nematology*. Revised Version. Wageningen University, Wageningen.
- Wilschut RA, Geisen S. 2021. Nematodes as drivers of plant performance in natural systems. *Trends Plant Sci* 26 (3): 237-247. DOI: 10.1016/j.tplants.2020.10.006.
- Yavuzaslanoglu E, Aksay G, Delen B, Çetinkaya A. 2020. The interaction of the mycorrhizae of the fungus *Rhizophagus irregularis* (Walker & Schüßler, 2010) (Glomerales: Glomeraceae) and the stem and bulb nematode (*Ditylenchus dipsaci* Kühn, 1857) (Tylenchida: Anguinidae) on the onion plant (*Allium cepa* L.) (Asparagales: Amaryllidaceae). *Türkiye Biyolojik Mücadele Dergisi* 12 (2): 120-129. DOI: 10.31019/tbmd.959958.
- Yavuzaslanoglu E, Sonmezoglu OA, Genc N, Akar ZM, Ocal A, Karaca MS, Elekcioglu IH, Ozsoy VS, Aydogdu M. 2019. Occurrence and abundance of nematodes on onion in Turkey and their relationship with soil physicochemical properties. *Nematology* 21 (10): 1063-1079. DOI: 10.1163/15685411-00003275.
- 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.
- Yeates GW. 2003. Nematodes as soil indicators: Functional and biodiversity aspects. *Biol Fertil Soils* 37: 199-210. DOI: 10.1007/s00374-003-0586-5.
- Zhang Y, Li S, Li H, Wang R, Zhang K-Q, Xu J. 2020. Fungi-nematode interactions: Diversity, ecology, and biocontrol prospects in agriculture. *J Fungi* 6 (4): 206. DOI: 10.3390/jof6040206.