

山西省果树土壤线虫的群落结构及多样性研究

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摘要:【目的】明确山西省果树根际土壤线虫群落结构及其物种多样性。【方法】以山西省晋中市太谷区不同管理模式的3个代表性果园为研究对象,采用浅盘分离法对土壤线虫进行分离鉴定及营养类群分析,系统研究了杏树、葡萄树、枣树、苹果树、梨树、桃树和核桃树等7种果树根际土壤线虫多度和优势度、营养类群,并分析线虫在果树根际土壤中的垂直分布。【结果】在果园0~60 cm土层范围内都发现有土壤线虫,其中多集中于20~30 cm土层中。共鉴定出土壤线虫2纲4目15科26个属,包括捕食/杂食线虫2属,食真菌线虫3属,食细菌线虫6属,植物寄生线虫15属,其中食细菌线虫中的杆属(*Mesorhabditis*)以及植物寄生线虫中的丝尾垫刃属(*Filenchus*)为优势属。以果树根际土壤线虫群落作为研究对象,主要研究其营养类群,结果表明,食细菌线虫为第一大营养类群,植物寄生线虫为第二大类群,食真菌线虫为第三大类群,杂食-捕食性线虫为第四大类群。【结论】土壤线虫主要集中于果树根际20~30 cm土层中,果树根际土壤中共鉴定到2纲4目15科26个属线虫,优势营养类群为食细菌线虫。研究结果对山西果树土壤环境监测和提高果园管理具有重要意义。

关键词:果园;土壤线虫;多样性;优势度;营养类群

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Research on the community structure and diversity of soil nematodes in the orchards of Shanxi province

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Abstract:【Objective】It is crucial to study the community structure and diversity of nematodes in the rhizosphere of orchards for preventing soil degradation. This research aims to investigate the community structure and species diversity of nematodes in the rhizospheric soil of fruit trees in the orchards of Shanxi province. The study was conducted at three different locations, including seven species of fruit crops and six rhizosphere depths.【Methods】The test samples for this study were selected from the orchard of Shanxi Academy of Agricultural Sciences, Polomogy Institute, Shanxi Agricultural University and Hancun village orchards. Nematodes were collected from the rhizosphere of seven different fruit crops, namely apricot (*Armeniaca vulgaris*), grape (*Vitis vinifera*), jujube (*Ziziphus jujuba*), apple (*Malus pumila*), pear (*Pyrus* sp.), peach (*Prunus persica*) and walnut (*Juglans regia*). Soil samples were collected using the five-point sampling method with a cylinder driller. The rhizosphere of the fruit trees was sampled at a depth of 5–30 cm. For each tree, 100 g of soil was taken in four directions. These soil samples were mixed, and 500 g of soil was selected as the final sample. The sampling site, data, and host plant were marked. The specimens were then brought back to the lab for further treatment. In each sample plot, three samples were taken, resulting in a total of 189 soil samples collected in three replicates. The Shanxi Fruit Research Institute conducted vertical distribution plots of soil nematodes

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in the rhizosphere of fruit trees. The soil depth was divided into six levels: 0–10 cm, >10–20 cm, >20–30 cm, >30–40 cm, >40–50 cm and >50–60 cm. The five-point sampling method was used to select soil samples from the same layer and fruit tree. A sample of 500 g of mixed soil was taken and three samples were collected from each sample plot. In total, 126 soil samples were collected in three replicates, resulting in a total of 315 soil samples for the experiment. The collected samples were promptly stored in a 4 °C refrigerator upon arrival at the laboratory. Nematode populations in a 100 g soil sample were extracted using the Whitehead tray method. The abundance of nematodes was determined by counting the quantity of nematodes per 100 g of dry soil. The nematodes were then authenticated and counted under a microscope. The soil nematode communities were classified into four trophic groups based on their feeding habits and esophageal characteristics: plant-parasitic nematodes, fungivore, bacterivore and omnivore-predator feeders. They were further classified into three groups based on the number of individuals in each genus. The genus with more than 10% of the total of individuals was considered dominant, those with 1% to 10% were considered common, and those with less than 1% were considered rare. 【Results】 The study identified a total of 26 genera of nematodes belonging to two classes, four orders and 15 families. Among these, 15 genera were identified as plant-parasitic nematodes, 6 genera as bacterivores, 3 genera as fungivores and 2 genera as omnivore-predator feeders. In the soil surrounding various fruit trees, the dominant genera were *Filenchus* and *Mesorhabditis*, which accounted for 36.32% of the total population. *Filenchus* was classified as a plant-parasitic trophic nematode, while *Mesorhabditis* was classified as a bacterivore. Common genera included *Aphelenchoides*, *Aphelenchus*, *Rhabditis*, *Cephalobus*, *Ditylenchus*, *Mesodorylaimus*, *Dorylaimus*, *Protorhabditis*, *Eucephalobus*, *Alaimus*, *Tylenchus*, *Paratylenchus*, *Pratylenchus*, *Tylenchorhynchus*, *Criconemella*, *Xiphinema*, *Longidorus*, *Dorylillum*, *Eudorylaimus* and *Aporcelaimus*, accounting for 61.58% of the total population. Rare genera including *Psilenchus*, *Helicotylenchus* and *Rotylenchus* accounted for 2.1% of the total population. The investigation and analysis conducted at Shanxi Agricultural University orchard focused on the total number of soil nematodes present in the rhizosphere soil of fruit trees. The findings revealed that the range of nematodes varied from 530 to 940 per 100 g of dry soil, with an average of 684 nematodes per 100 g of dry soil. However, the number differed in the other two sites. The study also observed variations in the total number of soil nematodes among different host species and geographical environments. The dominant trophic group was bacterivore, followed by plant-parasitic nematodes, while fungivores and omnivore-predators were present in lower quantities. Nematodes were distributed throughout the 0–60 cm soil layer, with the highest number observed at a depth of >20–30 cm. Among the fruit species, apple and pear exhibited the highest number of nematodes in each soil layer, followed by grape vines. Jujube and peach trees had a lower number of soil nematodes. 【Conclusion】 The study revealed that the highest abundance of nematodes was primarily concentrated in the >20–30 cm soil layer within the rhizosphere soil of fruit trees. Additionally, the study conducted has identified 26 genera of soil nematodes belonging to two classes, four orders, and 15 families. The dominant trophic group observed was bacterivore or bacteria-feeding nematodes, which indicated that the soil was in a healthy state. The study is of great significance for monitoring soil environment and improving management of orchards in Shanxi province. At present, the soil environment in orchards of Shanxi province is healthy, but it is advisable to regularly monitor plant-parasitic nematodes in orchards to ensure timely detection.

Key words: Orchard; Soil nematodes; Diversity; Dominance; Trophic groups

线虫是土壤中最丰富的低等无脊椎动物, Van Den Hoogen 等^[1]估计地球上土壤线虫数量高达 4.4×10^{20} 头。土壤线虫的 60%~80% 是自由生活线虫, 在土壤食物网的氮矿化和有机质分解中起着重要作用, 有些因对食物链和环境反应敏感, 可根据土壤线虫种群变化用于指示土壤环境的优劣^[2-5]。还有一些植物寄生线虫可引起植物病害, 对作物造成经济损失。根据线虫的取食习性, 可将土壤线虫分为食细菌类、食真菌类、植物寄生类和捕食/杂食类 4 个营养类群^[6-7]。不同食性的营养类群, 在土壤生态系统中的角色各不相同, 尤其是在土壤生态系统稳定性方面作用重大。因此, 明确土壤线虫的营养类群及其生物多样性对于土壤健康状况和有害生物监测具有重要的意义。

山西省是我国的水果主产区之一, 果树根际土壤线虫种类丰富, 但是对其生物多样性研究方面报道较少, 因此, 笔者在本研究中选取山西省晋中市太谷区常见的杏、梨、苹果、葡萄、枣、桃、核桃等 7 种果树根际土壤线虫进行群落结构和多样性分析^[8-9], 旨在明确果树根际土壤线虫的种群数量及其分布情况, 为我国土壤动物的生物多样性研究提供丰富的资料, 揭示土壤线虫在评估土壤健康水平方面的生物指标作用, 为深入探究线虫对果树生产的危害以及控制果树线虫病害提供理论依据。

1 材料和方法

1.1 调查区自然概况

山西省晋中市太谷区($112^{\circ}28' \sim 113^{\circ}01' E$, $37^{\circ}12' \sim 37^{\circ}32' N$)位于山西省中部, 地处晋中盆地东北部, 县域地貌形态分为山地、丘陵、平原, 地势由东南向西北倾斜, 海拔 $767 \sim 1914 m$, 属暖温带大陆性气候, 四季分明。年平均气温 $9.8^{\circ}C$, 无霜期 175 d, 年平均降水量 $462.9 mm$, 地下水资源可开采量 $9600 m^3$ 。春季少雨干燥多风, 夏季暖热多雨, 秋季天晴气爽, 冬季漫长寒冷少雪。太谷区农业基础条件好, 果树产业为主要经济产业之一, 全区果树种植面积达到 $8120 hm^2$, 主要种植的果树有苹果、梨、桃、核桃、葡萄、樱桃、杏、山楂、枣等。

1.2 样品采集

选取不同管理水平的 3 个果园: 管理粗放的山西省农业科学院果树研究所、管理水平中等的山西

农业大学太谷校区果园和管理精细的山西省晋中市太谷区韩村果园为试验样地。同一样地对不同树种采用五点取样法, 用筒钻取果树根际 $5 \sim 30 cm$ 深度的土壤样本, 将采集的 5 个取样点的土壤样品充分混合作为一个土样, 3 次重复。每个重复土样按四分法保留 $500 g$ 土壤样品, 装袋封口, 并标明采样地、采样时间、寄主植物等, 带回实验室处理。共采集土样 63 个。

选取山西省农业科学院果树研究所果园作为果树根际土壤线虫垂直分布样地, 按土壤深度分为 6 个层次 ($0 \sim 10 cm, >10 \sim 20 cm, >20 \sim 30 cm, >30 \sim 40 cm, >40 \sim 50 cm, >50 \sim 60 cm$), 按五点取样法, 不同树种同一层取样土充分混合后按四分法取 $500 g$ 作为一个土样, 3 次重复, 共采集土样 126 个。本试验共采集 189 个土样, 采集的土样迅速带回实验室, 放在 $4^{\circ}C$ 冰箱中保存。

1.3 线虫分离、计数及鉴定

选用浅盘分离法^[10]在室温对线虫进行分离。每个土样用电子秤准确称取土样 $100 g$, $48 h$ 后用 $20 \mu m$ 分离筛收集线虫悬浮液, 滤去水至筛中剩余悬浮液 $30 \sim 50 mL$, 转移 $50 mL$ 的试管中, 静置 3 h, 去掉上清液, 剩下 $20 mL$ 线虫悬浮液, 备用。

摇匀线虫悬浮液, 用移液枪取 $2 mL$ 液体放入表面皿中, 在体视显微镜下察看并计算线虫总数。共 3 次重复, 结果取平均值, 计算每 $100 g$ 干土壤中存在的线虫数量, 最后统计每个分离样品中线虫的数量。

用自制的睫毛挑针挑取线虫, 然后放在滴有小水滴的载玻片上, 用挑针把浮在水表面的线虫轻轻压入水中, 盖上盖玻片。在光学显微镜下观察, 并依据《An illustrated key to nematodes found in fresh water》^[11]、《植物线虫分类学》^[12] 和《植物线虫志》^[13] 将其鉴定到属。

1.4 优势度

将每个样本中线虫个体数量按照其所处属中的比例划分为 3 个优势度级别。群体中占据超过 10% 的物种可以称作优势属; 占据 1%~10% 的为常见属; 而占据不到 1% 的则属于稀有属。

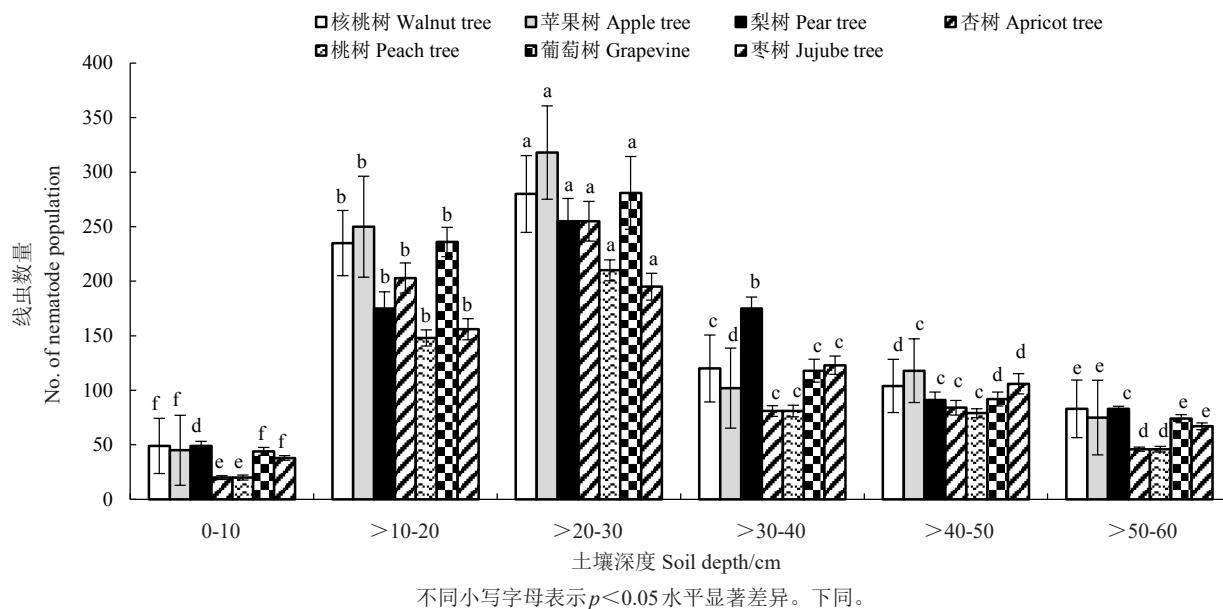
1.5 线虫营养类群的划分

通过观察线虫的摄食行为和食道结构, 笔者可以将土壤中的线虫群落分为 4 类不同的营养群^[6-7, 14]: 食细菌类群(bacterivores feeders, BF)、食真菌类群

(fungivores feeders, FF)、植物寄生类群(plant-parasites, PP)和捕食-杂食类群(omnivores-predators, OP)。

2 结果与分析

2.1 线虫在果树根际土壤中的垂直分布



不同小写字母表示 $p < 0.05$ 水平显著差异。下同。

Different small letters indicate significant differences at $p < 0.05$. The same below.

图1 山西省农业科学院果树研究所根际土壤线虫的垂直分布图

Fig. 1 The vertical distribution of soil nematodes in orchard of Shanxi Academy of Agricultural Sciences, Polomogy Istitute

2.2 土壤线虫多度与优势度

笔者在本试验中共分离到2纲4目15科26属线虫,如表1所示,包括15个属的植物寄生线虫、6个属的食细菌线虫、3个属的食真菌线虫以及2个属的捕食/杂食线虫。在所得到的26个属中,优势属为丝尾垫刃属和中杆属,占线虫总数的36.32%;常见属为头叶属、拟滑刃属、茎属、真滑刃属、滑刃属、中矛线属、矛线属、小杆属、原杆属、真头叶属、无咽属、垫刃属、小环属、剑属、针属、长针属、短矛属、短体属、真矛线属、孔咽属和矮化属,占线虫总数的61.58%;稀有属为平滑垫刃属、螺旋属和盘旋属,占线虫总数的2.10%。

对土壤线虫总数的调查分析(图2)发现,山西农业大学果园果树根际土壤线虫总数范围为500~950条·100 g⁻¹,平均为681条·100 g⁻¹,不同寄主之间线虫多度差异显著,杏树的线虫多度最高,其他寄主的线虫多度均显著低于杏树,其中,以苹果树线虫多度最低;韩村果园果树根际土壤线虫总数范围为

不同果树根周围土壤线虫的垂直分布情况见图1,结果显示在0~60 cm深度范围内土壤线虫均有分布,尤其是>20~30 cm深度范围内的土壤线虫数量最为丰富。各土层中核桃树、苹果树和梨树的线虫数量较多,其次是葡萄树,枣树和桃树根围土壤线虫数量较少。

80~1750条·100 g⁻¹,平均为1031条·100 g⁻¹,不同寄主之间线虫多度差异显著,以枣树的线虫多度为最高,其他寄主的线虫多度均显著低于枣树,其中部分寄主的线虫多度相互间也具有显著差异,以杏树的线虫多度为最低;山西省农业科学院果树研究所果树根际土壤线虫总数范围为400~1100条·100 g⁻¹,平均为601条·100 g⁻¹,不同寄主之间线虫多度差异显著,以苹果树的线虫多度最高,杏树和梨树次之,其他寄主的线虫多度相互间不具有显著差异。在相同地理环境下不同寄主的土壤线虫多度不同,不同地理环境下相同寄主线虫多度也不同。

2.3 土壤线虫营养类群

从土壤线虫的营养类群成分的分析结果(图3)来看,在山西农业大学果园7种果树的根际土壤中,食细菌线虫占比最高,占总体的50%以上,但枣树例外,其占比仅为22.39%,其次,植物寄生性线虫和真菌食性线虫是占据较高比例的种类,而以捕食和杂食为主的线虫占比最少,占总体的2%以下;在韩村

表1 果树根际线虫鉴定及优势度

Table 1 The identification of rhizosphere nematode in fruit trees and its dominance

线虫目 Order	线虫科 Family	线虫属 Genus	比例 Proportion/%	优势度 Dominance
垫刃目 Tylenchida	粒科 Anguinidae	茎属 <i>Ditylenchus</i>	2.49	++
	垫刃科 Tylenchidae	丝尾垫刃属 <i>Filenchus</i>	12.90	+++
		垫刃属 <i>Tylenchus</i>	1.14	++
		平滑垫刃属 <i>Psilenchus</i>	0.80	+
	纽带科 Hoplolaimidae	螺旋属 <i>Helicotylenchus</i>	0.68	+
		盘旋属 <i>Rotylenchus</i>	0.62	+
	半穿刺科 Tylenchulidae	针属 <i>Paratylenchus</i>	1.49	++
	刺科 Belonolaimidae	矮化属 <i>Tylenchorhynchus</i>	1.44	++
	短体科 Pratylenchidae	短体属 <i>Pratylenchus</i>	1.74	++
	环科 Crionematidae	小环属 <i>Criconemella</i>	1.66	++
滑刃目 Aphelenchida	真滑刃科 Aphelenchidae	拟滑刃属 <i>Aphelenchoïdes</i>	5.19	++
		真滑刃属 <i>Aphelenchus</i>	5.08	++
矛线目 Dorylaimida	滑刃科 Aphelenchoididae	滑刃属 <i>Aphelenchus</i>	4.96	++
	长针科 Longidoridae	剑属 <i>Xiphinema</i>	1.10	++
		长针属 <i>Longidorus</i>	1.49	++
	矛线科 Dorylaimidae	短矛属 <i>Dorylillum</i>	1.81	++
		中矛属 <i>Mesodorylaimus</i>	3.65	++
		真矛属 <i>Eudorylaimus</i>	1.65	++
		矛线属 <i>Dorylaimus</i>	2.08	++
	孔咽科 Aporcelaimidae	孔咽属 <i>Aporcelaimus</i>	1.15	++
	小杆目 Rhabditida	小杆属 <i>Rhabditis</i>	7.99	++
		中杆属 <i>Mesorhabditis</i>	23.42	+++
头叶科 Cephalobidae		原杆属 <i>Protorhabditis</i>	4.67	++
	头叶科 Cephalobidae	头叶属 <i>Cephalobus</i>	6.09	++
		真头叶属 <i>Eucephalobus</i>	2.71	++
		无咽属 <i>Alaimus</i>	2.01	++
	无咽科 Alaimina			

注:+++. 优势属;++. 常见属;+. 稀有属。

Notes: +++ indicated as the dominant genus; ++ indicated as the common genus; + indicated that the rare genus.

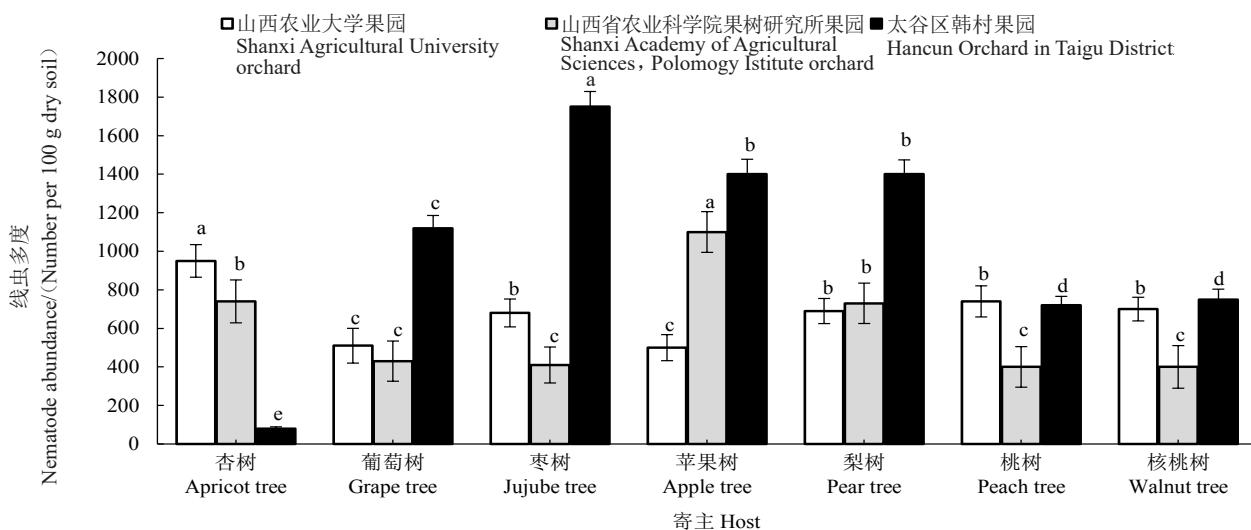


图2 山西省7种果树根际土壤线虫的多度

Fig. 2 The abundance of the rhizosphere soil nematodes in orchards of Shanxi province

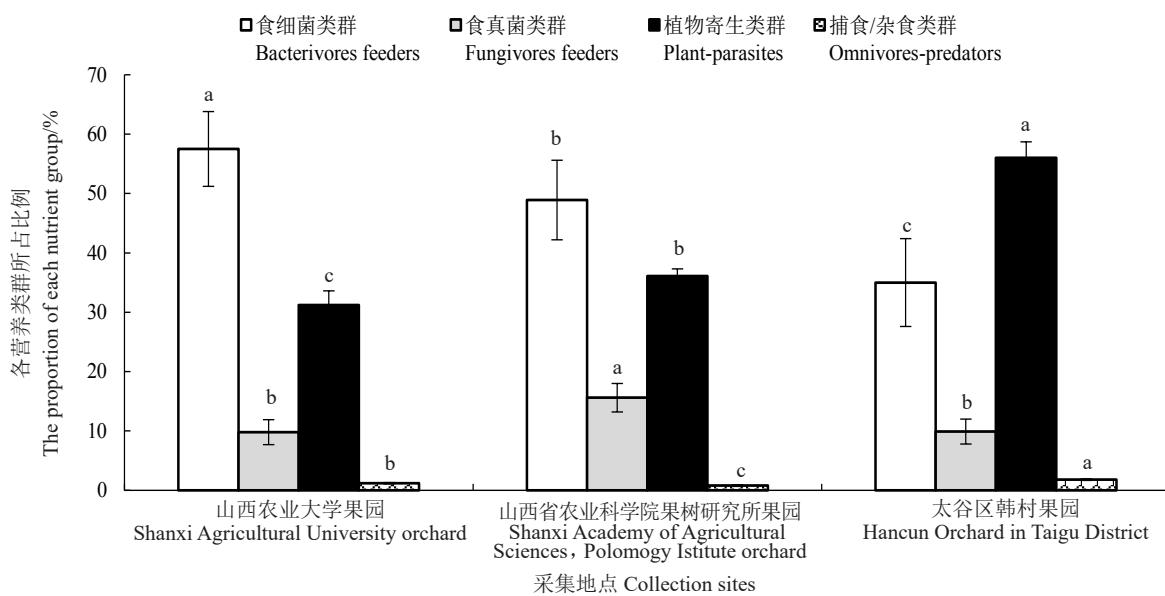


图3 山西省果树根际土壤线虫的营养类群分析

Fig. 3 The trophic groups in orchard of Shanxi province

果园7种果树的根际土壤中,植物寄生性线虫占比最高,但葡萄和桃树根际土壤中植物寄生性线虫仅占比26.79%和35.14%,食细菌线虫以及真菌食性线虫占比次之,而以捕食和杂食为主的线虫占比最少,占总体的2%以下;在山西省农业科学院果树研究所7种果树的根际土壤中,占比最高的是食细菌线虫,但枣树例外,其占比仅为27.91%,其次,植物寄生性线虫及真菌食性线虫是占据较高比例的种类,而以捕食和杂食为主的线虫占比最少,占总体的1%以下。

3 讨 论

土壤线虫是土壤食物链中重要的组成部分,对植物生长的土壤环境和地上植物具有重要影响。了解果园土壤线虫群落的分布及生物多样性,对深入认识果园土壤环境、提高果园管理水平具有重要意义。

笔者对土壤线虫垂直分布研究发现,线虫多集中于中层土壤,可能的原因是表层土壤属于砂质土,孔隙度小、水分含量不高,且线虫的繁殖数量相对较稀少,尤其是位于土壤表层的0~10 cm深度,线虫数量更是极少。线虫分布受多种因素影响,如水分、植物根分泌物、土壤质地、温度和透气状况等。线虫通常难以在浅层土壤中生存,数量也较少。相比之下,在深20~30 cm的土壤中更有利于线虫的繁殖和生存。

Viketoft等^[15-17]的试验结果表明,植物的特征和功

能类型明显地影响着线虫群落的多样性。但是,Viketoft^[16]研究了一个半自然草地的线虫群落,只用了8 g湿土进行调查,这个样本量远远少于大多数线虫学家通常使用的200 g湿土来分析线虫群落。因此,这个样本的代表性可能存在问题是。尽管各项结果有所不同,但所有这些研究都表明,植物的属性和功能类型会对线虫群落的多样性产生影响。

对线虫土壤营养类群分析发现,食细菌线虫和植物寄生线虫是山西省果树根际的主要营养类群,研究结果与樊金玲^[18]报道的山西省果树根际线虫群落结构的结果保持一致。通过比较管理模式发现,管理粗放的山西农业大学和山西省农业科学院果树研究所果园以食细菌线虫为主,而管理精细的韩村果园则以植物寄生线虫为主。食细菌线虫与土壤肥力和植物生产力密切相关,据初步统计,在1 m²森林中就有数十万头食细菌线虫存在,一条食细菌线虫可每天捕食106个细菌^[19],但是果树根际的食细菌线虫与土壤肥力的相关性还有待于进一步研究。其次,植物寄生线虫通过食道腺分泌物和口针穿刺等对植物造成直接危害,每年对全球造成的经济损失高达3582亿美元^[20]。在笔者报道的类群中,短体属(*Pratylenchus*)可引起植物根腐病害,该属中的非中国种类是我国对外有害生物检疫对象;此外,剑属(*Xiphinema*)和长针属(*Longidorus*)可通过传播植物病毒对植物造成间接伤害,这2个属线虫可在葡萄、桃树和梨树上传播葡萄铭色花叶病毒、葡萄扇叶病

毒、桃丛簇花叶病毒和梨石果病毒等^[21],因此建议在果树上定期监测植物线虫病害及植物病毒病害。

4 结 论

笔者对山西省晋中市太谷区果树根际土壤线虫的种群数量和分布情况进行研究,线虫主要分布于果树根际>20~30 cm土层中,共鉴定到2纲4目15科26个属线虫,食细菌线虫是主要的营养类群,植物寄生线虫次之。因此该地区土壤营养类群属于健康,但是应及时监测果园内植物寄生线虫的危害。

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