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COMMUNITIES OF PLANT PARASITIC AND FREE-LIVING NEMATODES IN ITALIAN HOP CROPS

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Landi S., d'Errico G., Papini R., Gargani E., Simoncini S., Amoriello T., Ciccorigitti R., Carbone K. – Communities of plant parasitic and free-living nematodes in Italian hop crops.

The cultivation of hop has had a notable expansion due to growing interest of craft beer in Italy in the past few years. Thus, surveys were conducted to evaluate nematodes associated with the Italian hop cultivations. The aims of this work were to determine the occurrence of plant parasite and virus-vector nematodes and to evaluate the ecosystem services associated with the control of plant parasitic nematodes. Six different sites located in North and Central Italy were monitored to assess the structure of nematode communities. Many plant parasitic nematodes widely distributed in Italy were found in association with hop plants such as *Mesocriconema xenoplax* and *Heterodera* spp. The *Xiphinema* genus was the most abundant and ubiquitous plant parasitic nematode. The most frequent species were *X. pachtaicum* followed by *X. diversicaudatum*, the Arabis mosaic virus (ArMV)-vector. Predators were not able to regulate the ecosystem pest control service. The agronomic strategies that adopted less intensive tillage practices, such as minimum tillage or cover grass, showed the best regulation.

KEY WORDS: ecology, free-living nematodes, hop crop, North and Central Italy, plant parasitic nematodes.

INTRODUCTION

Over the last few decades, Italy has been assisting to the rise and the establishment of a new type of business in the brewing industry: the craft beer industry, which gained great success and credibility, becoming one of the most significant phenomenon of the Italian agri-food sector. The direct, indirect and induced contribution of the craft brewing sector to the Italian economy is becoming considerable, with approximately 600 microbreweries operating in the country, for an average annual beer production of 445,000 hectoliters, accounting for about 3 % of the total volume of beer produced. Besides, Italy imports almost all the brewing raw materials, especially hop cones, the inflorescences of the female plant of *Humulus lupulus* L., which play a pivotal role as flavouring/bittering and preservative agent (CARBONE *et al.*, 2017). In order to address the growing internal demand, several farmers have begun cultivating hops in different Italian regions. Currently, the hop cultivating area in Italy amounts to approximately 56 hectares with an average surface of 6351 m² (www.luppolo.crea.gov.it).

As with many crops the occurrence of infection by pathogens and the establishment of infestations by harmful organisms such as arthropods and nematodes represent a limiting factor for hop crop cultivations and cause quantitative and qualitative yield losses. This risk is seriously aggravated by the presence of several weeds that may serve as pest or pathogen sources of inoculum (D'ERRICO *et al.*, 2014). Given the recent interest in hop crop in Italy, surveys have been conducted to evaluate the phytosanitary status of the Italian hop crops (GARGANI *et al.*, 2017) and

nematode populations associated with this agroecosystem. The first records on the occurrence of nematodes in hop fields mainly showed the presence of *Heterodera humuli* Filipjev in Germany (VOIGT, 1894) and in England (PERCIVAL, 1895). Then, this species has been reported from USA, Canada, South Africa, New Zealand and in many European countries (DANILOVA YU, 1996). *H. humuli* is the obligate parasite hop cyst and represents the most common nematode species associated with hop. At present, this species has not been found in Italy (GARGANI *et al.*, 2017). In general, plant parasitic nematodes associated with hop production are considered of minor importance (HAY, 2010), except for virus-vector species of the genus *Xiphinema* (VALDEZ *et al.*, 1974). By contrast, few studies have been carried out to investigate the whole nematode community and its multiple roles within the soil food web (LIŠKOVÁ and RENČO, 2007). Several management factors still need to be addressed, such as the use of different agronomic practices, aimed to preserve biodiversity and ecosystem services with particular regard to regulative services for pest control (LANDI *et al.*, 2018a). In fact, ecosystems are strongly affected by crop management strategies, soil chemical properties and soil microbial, nematode, microarthropod and plant communities (MOCALI *et al.*, 2015a; 2015b; LAZZARO *et al.*, 2018).

The objectives of the present work were to i) determine the structure of nematode communities in Central and North Italy, the main Italian production areas, focusing on the occurrence of plant parasitic and virus-vector nematodes; ii) evaluate main ecosystem services associated with nematodes such as the control of plant parasitic nematodes.

MATERIALS AND METHODS

FIELD SITES AND SOIL SAMPLING DESIGN

Six fields of approximately half hectare each, distributed in North and Central Italy, were surveyed (Fig. 1). The characteristics of sites are reported in Table 1. Soil samples were collected from three different points of each field during summers 2017 and 2018. To determine soil texture, soil pH and Total Organic Carbon (TOC), samples were taken at 0–20 cm depth. To characterize soil nematode community, a further set of soil samples was collected close to previous ones. The sampling was carried out using a hand auger (5 cm inside diameter) from the 20 cm deep top layer of bulk soil. For each soil sample, six cores were randomly sampled and then mixed to form one composite sample. Each sample was then placed in a plastic bag, labelled and stored in a cold chamber at 4°C.

Fig. 1 – Monitored hop growing sites located in Northern and Central Italy.

SOIL PHYSICAL AND CHEMICAL ANALYSIS

The soil samples were air dried at room temperature (~20°C) and sieved through a 2 mm mesh for pH and texture, then through a 0.5 mm mesh for TOC. The texture was determined by modified pipette methods (INDORANTE *et al.*, 1990). The soil pH was measured potentiometrically in a 1:2.5 soil-water suspension. TOC was determined by hot oxidation with potassium dichromate and sulphuric acid according to SPRINGER and KLEE (1954).

SOIL NEMATODE COMMUNITY ANALYSIS

Nematodes were isolated from 100 ml of each soil sample using the cotton-wood filter extraction method. Nematodes were extracted for 48 h at room temperature, approximately 20°C. Each nematode suspension was sieved through a 25 µm mesh and the nematodes were counted under a stereomicroscope (50x magnification). Nematodes were mounted on temporary slides and identified at higher magnification to species or genus level using keys from MAI *et al.* (1962), BONGERS (1988), CORDERO *et al.* (2012), MARINARI-PALMISANO and VINCIGUERRA (2014), CROZZOLI, 2014. Taxonomic families were assigned to a trophic grouping based on YEATES *et al.* (1993) and OKADA *et al.* (2005). Nematode communities were characterised using: i) absolute abundance of individuals; ii) richness determined by counting the number of taxa; iii) the Maturity (MI) and Plant Parasitic (PPI) indices according to BONGERS (1990); iv) diversity-weighted abundance (θ) calculated using biomass values (FERRIS, 2010) as reported by FERRIS and TUOMISTO (2015) in order to evaluate the ecosystem services efficiency. In addition, plant parasitic nematode communities were characterised using the relative abundance and the distribution frequency.

STATISTICAL ANALYSIS

One-way ANOVA was performed to assess the differences of sites on nematode taxa abundance, indicators of nematode community structure and θ index. When the *F*-test was significant at $P < 0.05$, treatment means were compared using the Student-Newman-Keuls test using CoStat statistical software package (<http://www.Cohort.com/costat.html>). In addition, Canonical Correspondence Analysis (CCA) was carried out in order to link plant parasitic nematode communities (abundance of plant parasitic nematode taxa) and soil phys-

Table 1 – Characteristics of climate and management in the six selected sites.

Site ^a	Italian Province	Köppen climate types	Previous crops	Year of hops implanting	Hops varieties	Agronomic management
LAZ-1	Latina	Csa ^b	Vineyard	2014	Cascade, Chinook, Columbus, Tettnanger	Conventional tillage
LAZ-2	Roma	Csa	Uncultivated	2016	Columbus, Yeoman, Cascade	Minimum tillage
LAZ-3	Rieti	Cfa ^c	Crop rotation: wheat/corn/vegetables	2014	Hallertauer Magnum, Spalt Spalter, Hallertau Mittelfrüh, Northern Brewer, Perle, Saazer	Green cover
TOS-1	Pisa	Csa	Mother plant for vineyard	2013	Northern Brewer, Fuggle, Cascade, Perle, Centennial	Conventional tillage
EMI-2	Reggio Emilia	Cfa	Vineyard	2016	Cascade	Conventional tillage
EMI-3	Ravenna	Cfa	Nectarines	2016	Cascade, Nugget, Centennial, Sorachi Ace, Mounth Hood, Crystal, Chinook, Fuggle	Conventional tillage

^aThe geographical coordinates are not available due to the lack of the farm owners' authorisation.

^b Hot-summer Mediterranean.

ical and chemical variables (texture, soil pH and TOC) by the Past analysis package (HAMMER *et al.*, 2001) (<http://folk.uio.no/ohammer/past>). Vectors represented the environmental axes; the length of vectors indicates the importance of the environmental variable with other variables; vectors in the same direction are positively correlated, while vectors pointing in opposite directions are negatively related. The statistical significance of the relationship between community and environmental variables was assessed by permutation test of both the first ordination axis and the combination of both the first and second axes.

RESULTS

SOIL PHYSICAL AND CHEMICAL PROPERTIES

Soil textures of sampled sites were classified according to the USDA Soil Taxonomy. EMI-2 and EMI-3, both in Emilia Romagna Region, were classified as clay loam and silty clay. The site located in Tuscany, TOS-1, was classified as sandy clay loam. Finally, in Latium Region, collected soils were classified as clay (LAZ-1 and LAZ-3) and clay loam (LAZ-2). Soil pH values ranged from 6.7 to 8.2 in Emilia Romagna and Latium, respectively, while pH was 5.1 in Tuscany. The highest TOC value was found in LAZ-2, followed by LAZ-3 and the lowest in TOS-1 (Table 2).

SOIL NEMATODE COMMUNITY STRUCTURES

Twenty-seven genera, belonging to twenty plant parasitic and free-living nematode families, were identified in soil samples collected in the six sites (Table 3). In general, the nematode population was low, only the Rhabditidae family was prominent among sites. Moreover, the abundance of Aphelenchidae and Dorilaymidae families were higher in LAZ-3 than in other sites. Conversely, the taxa richness was high in all sites except for TOS-1. Thirteen different genera of plant parasitic nematodes belonging to ten families were identified (Table 4). In general, the plant parasitic relative communities showed the absence of dominant species. *Xiphinema pachtaicum* was the most abundant species followed by *Meloidogyne incognita*, *Mesocriconema xenoplax*, and *Helicotylenchus digonicus*. *Xiphinema pachtaicum* was also the most widely distributed species among four sites, followed by *M. xenoplax* found in three sites. Finally, the species *Pratylenchus penetrans*, *Ditylenchus* sp., *Rotylenchus robustus*, *M. incognita*, and *X. diversicaudatum* were reported by less than 20% of sites. Other plant parasitic species occurred rarely.

SOIL NEMATODE INDICATORS

MI values ranged from 1.3 to 2 indicating the presence of generalist and opportunistic species (Table 3). Conversely, the PPI reached higher values (from 2.6 to 3.4) associated

with the presence of families of persistent plant parasitic nematodes like Longidoridae. The MI and PPI were significantly higher in LAZ-3 than in other sites. Average values of diversity-weighted abundance (θ) are reported in Fig. II. The nematode assemblage was arranged in three functional classes: i) detritivores (bacterial and fungal feeders); ii) plant parasitic nematodes; iii) predators (including omnivores). The biomass of plant parasitic nematodes was significantly higher in EMI-2, LAZ-1, LAZ-2 and LAZ-3 than EMI-3 and TOS-1. By contrast, no significant differences were found in the other functional classes. In general, the detritivores channel was greater than other functional classes in all sites, while predator channel was low in all sites. Therefore, the regulation functions of opportunistic and plant parasitic nematodes by predation were insufficient: the predators/preys ratio ranged from 1:6.23 in LAZ-3 to 1:17.47 in EMI-3.

RELATIONSHIP AMONG SOIL VARIABLES

AND PLANT PARASITIC NEMATODE COMMUNITY STRUCTURE

In the CCA conducted between plant parasitic nematode taxa abundance (expressed as genus) and soil variables (texture, soil pH and TOC), the total variance explained by the first two axes was 56.7% (30.7 % axis 1 and 26% axis 2). The ordination diagram in the plane defined by the first and second CCA axes were statistically significant for $P < 0.04$ and $P < 0.001$, respectively (Fig. III). Sand (0.72), TOC (-0.68), soil pH (-0.67) clay (-0.55) and silt (-0.55) are the soil variables best correlated with axis 1, whereas silt (0.52), soil pH (0.51) and sand (-0.47) are best correlated with axis 2. CCA confirmed a clear separation of sites according to soil parameters; the main parameter was represented by the texture. The community variables were considered significant if their values exceed 1. Thus, significant community variables were associated to genera: *Tylenchorhynchus* and *Ditylenchus* (dominated by sand content and inversely related to TOC), *Heterodera* (its dominant drivers were silt content and soil pH), *Paratylenchus* genus (inversely related to soil pH). By contrast, *Xiphinema* and *Mesocriconema* genera were the least influenced by the environmental gradient established within the study areas.

DISCUSSION

The selected sites were representative of different climatic areas of Italy, soil types and agronomic practices allowing a broad evaluation of soil nematode communities associated to hop crops. In fact, the monitored area corresponded to 5% of the whole extent covered by hop crops in Italy and interested two climatic zones (Csa, Hot-summer Mediterranean; Cfa, Humid subtropical). The soil textures belonged to the main soil types (silty, sandy and clay soils) and a broad vari-

Table 2 – Soil physical and chemical properties of the topsoil (0-20 cm) in the six sites.

	Sand	Silt	Clay	Soil texture classification	Soil pH	TOC (g kg ⁻¹)
LAZ-1	25.0±1.4	24.6±0.4	50.4±1.5	Clay	6.7±0.2	1.3±0.1
LAZ-2	30.8±3.0	36.7±4.4	32.5±1.4	Clay loam	7.3±0.1	1.9±0.05
LAZ-3	10.0±1.4	30.0±3.8	60.0±3.8	Clay	7.8±0.	1.5±0.03
TOS-1	73.3±1.7	4.2±4.2	22.5±2.5	Sandy clay loam	5.1±0.1	0.7±0.1
EMI-2	15.0±1.4	50.8±0.8	34.2±2.2	Silty clay loam	7.8±0.1	1.3±0.04
EMI-3	1.7±1.7	42.5±1.4	55.8±0.8	Silty clay	8.2±0.02	1.2±0.1

Table 3 – Abundance of nematode taxa (number of nematodes 100 ml⁻¹ soil). Samples were collected from the six sites during 2017 and 2018 (n=6). Standard errors are reported. Values in the row followed by different letters are significantly different at $P < 0.05$. The significant p-values are reported in bold.

	LAZ-1	LAZ-2	LAZ-3	TOS-1	EMI-2	EMI-3	P-values
Rhabditidae	45.3±4.1	49.0±7.9	33.7±7.9	36.3±12.8	44.7±3.5	48.7±6.6	0.64
Monhysteridae	0 b	0 b	0 b	0 b	0 b	1.3±1.3 a	0.02
Cephalobidae	4.0±1.5	2.0±1.0	7.0±2.3	26.3±14.4	7.0±0.6	2.3±0.7	0.11
Plectidae	0 b	1.3±0.7 a	0 b	0 b	0 b	0 b	0.02
Alaimidae	4.7±1.2 a	0 b	0 b	0 b	0 b	0 b	0.0001
Aphelenchidae	0 b	6.0±1.5	8.3±1.9 a	4.3±0.7	2.0±1.5	3.0±1.0	0.006
Discolaimidae	0 b	3.0±1.0 a	0 b	0 b	0 b	1.0±1.0 b	0.004
Dorylaimidae	5.0±2.6 b	6.0±1.5 b	13.0±1.5 a	2.7±1.8 b	10.0±1.0	2.7±1.8 b	0.004
Seinuridae	1.0±0.6	0.7±0.7	0	0.7±0.74	0.3±0.3	1.0±1.0	0.74
Mononchidae	1.7±1.7	0	1.7±0.9	0 a	1.7±0.3	0.3±0.3	0.38
Tylenchidae	0 b	12.7±4.9 a	8.3±2.3	7.0±1.2	8.7±2.6	2.0±0.6	0.04
Paratylenchidae	0.7±0.7	0	0	0	0	0	0.46
Anguinidae	0	0.7±0.7	0.7±0.7	2.0±1.0	2.3±1.5	0	0.26
Pratylenchidae	2.7±1.3	0	0.7±0.7	5.3±2.7	3.0±0	0	0.07
Hoplolaimidae	7.0±4.0	1.3±1.3	3.0±3.0	0	7.7±2.9	3.3±0.9	0.25
Cricematidae	2.7±1.8	0	1.3±0.9	0	4.0±2.1	1.3±0.7	0.21
Heteroderidae	0 b	1.7±0.9 b	0 b	0 b	1.0±1.0 b	6.0±3.2 a	0.05
Meloidogynidae	6.3±6.3	7.8±7.8	0	0	0	0	0.20
Dolichodoridae	2.3±0.3 a	0 b	0 b	0 b	0 b	0 b	0.00001
Longidoridae	6.0±1.2	7.0±0.6 a	6.7±1.3 a	0 b	6.3±1.8 a	0 b	0.0005
Total abundance	89.3±2.2	99.0±10.7	85.3±13.1	84.7±9.5	98.7±3.5	73.0±6.4	0.32
Taxa richness	9.3±0.3 a	9.0±0.6 a	9.3±0.3 a	6.7±0.7 b	11.0±0.6 a	9.0±0.6 a	0.003
<i>MI</i>	1.6±0.0	1.6±0.1	2.0±0.1 a	1.6±0.2	1.6±0.1	1.3±0.1 b	0.05
<i>PPI</i>	3.2±0.2	3.1±0.3	3.4±0.2 a	2.6±0.2 b	3.2±0.2	2.8±0.1	0.05

ability was also revealed in soil pH values, from acid to sub alkaline to alkaline. Being recent hop plants (established from 2013 to 2016 in all sites), soil organic carbon content was affected both by previous managements and current agronomic practices. LAZ-2 and LAZ-3 showed the highest organic matter content close to 2%, which is considered as the critical threshold for soil quality in temperate region (LOVELAND and LEGENDRE, 1988). In these sites, conservative agronomic techniques have been applied both before and after hop planting. LAZ-2 was uncultivated since 2016 and then the hop cultivation was managed by minimum tillage, LAZ-3 was managed by crop rotation since 2014 and then by green cover. By contrast, the traditional tillage has caused low content of organic matter. In particular, the sandy soil with acid pH showed the lowest values.

SOIL NEMATODE STRUCTURE

A great variability in soil nematode community was found among different climatic areas, soil types and agronomic managements, according to NEHER *et al.* (1995).

Many plant parasitic nematodes widely distributed in Italy were also found associated with hop plants such as the ring nematode *M. xenoplax* common on fruit trees in Europe and reported associated with hop only in South Africa (NYCZEPIR and HALBRENDT, 1993; CROZZOLI, 2014; GARGANI *et al.*, 2017). This species is known to occur, also, in grape-growing areas in Italy (MALOSSINI *et al.*, 2008; MALOSSINI *et al.*, 2011) and it often causes significant economic losses in the grape wine areas of the world (TÉLIZ *et al.*, 2007). The ring nematode is often occurring in association with *Xiphinema* spp. (AMBROGIONI and D'ERRICO, 1980). *H. humuli*, the most

common species infesting hop in Europe, was not found during this survey, but other species belonging to *Heterodera* genera were found: *H. carotae*, *H. schachtii* and *H. cruciferae* were detected in LAZ-2, EMI-2 and EMI-3, respectively. No dominant plant parasitic nematode species have been found in any site, however the species belonging to *Xiphinema* genus were widely distributed in the study areas and some of them could transmit plant virus. The most frequent species were *X. pachtaicum* followed by *X. diversicaudatum*. The Arabis mosaic virus (ArMV), the most common nepovirus identified in hop and transmitted by *X. diversicaudatum* has not been found yet in Italy (GARGANI *et al.*, 2017), but the presence of this virus-vector nematodes *X. diversicaudatum* is of particular concern. Multiple plant parasitic nematode association and/or their interaction with virus or fungi may also constitute a problem because this can cause synergistic damages to plants (RAGOZZINO and D'ERRICO, 2011; ANWAR and MCKENRY, 2012).

Several genera of plant parasitic nematodes were affected by soil parameters. CCA suggested that edaphic variables soil texture, pH and organic carbon, are the primary determinants that influence the structure and diversity of plant parasitic nematode community. The texture influenced three genera: *Heterodera* was favoured by silt content, while genera *Ditylenchus* and *Tylenchorhynchus* increased with high sand content. As reported by PEDERSEN *et al.* (2010), *Heterodera* genus was also influenced by soil pH. In fact, the population density was associated with high soil pH. In accordance with BARKER and KOENING (1998), BIRD (2000) and LANDI *et al.* (2016), the increase of organic matter content was negatively correlated with plant parasitic nematodes

Table 4 – Specific structure of plant parasitic nematode communities in hop sites.

Nematode species	Mean value X±SE	Relative abundance %	Distribution frequency %
Tylenchidae			
<i>Tylenchorhynchus</i> sp.	0.4±0.4	2.3	5.6
Paratylenchidae			
<i>Paratylenchus</i> sp.	0.1±0.1	0.6	5.6
Anguinidae			
<i>Ditylenchus dipsaci</i> (Kühn) Filipjev	0.4±0.3	2.3	11.1
<i>Ditylenchus</i> sp.	0.6±0.3	3.2	22.2
Pratylenchidae			
<i>Pratylenchus penetrans</i> (Cobb) Filipjev and Schuurmans Stekhoven	0.8±0.3	4.5	27.8
<i>Pratylenchus vulnus</i> Allen and Jensen	0.2±0.2	1.3	5.6
<i>Pratylenchus</i> sp.	1.0±0.6	5.8	16.7
Hoplolaimidae			
<i>Helicotylenchus digonicus</i> Perry in Perry, Darling and Thorne	1.4±0.6	8.4	27.8
<i>Helicotylenchus</i> sp.	0.3±0.2	1.9	11.1
<i>Rotylenchus robustus</i> (de Man) Filipjev	0.7±0.3	3.9	22.2
<i>Rotylenchus</i> sp.	1.3±0.8	7.4	16.7
Criconeematidae			
<i>Mesocriconeema xenoplax</i> (Raski) Loof and De Grosse	1.4±0.5	8.4	44.4
<i>Criconeema</i> sp.	0.1±0.1	0.6	5.6
Meloidogynae			
<i>Meloidogyne incognita</i> (Kofoid and White) Chitwood	2.3±1.2	13.5	22.2
Heteroderidae			
<i>Heterodera carotae</i> Jones	0.3±0.2	1.6	11.1
<i>Heterodera cruciferae</i> Jones	1.0±0.7	5.8	11.1
<i>Heterodera schachtii</i> Schmidt	0.2±0.2	1	5.6
Dolichodoridae			
<i>Merlinius brevidens</i> (Allen) Siddiqi	0.4±0.2	2.3	16.7
Longidoridae			
<i>Longidorus macrosoma</i> Hooper	0.2±0.1	1.3	16.7
<i>Xiphinema diversicaudatum</i> (Micoletzky) Thorne	0.9±0.4	5.2	22.2
<i>Xiphinema italiae</i> Meyl	0.4±0.2	2.3	16.7
<i>Xiphinema pachtaicum</i> (Tulaganov) Kirjanova	2.8±0.6	16.4	66.7

Fig. II – Diversity-weighted abundance (θ) expressed as biomass for functional classes of soil nematode assemblages in six sites located in three Italian regions: Lazio (LAZ-1, LAZ-2 and LAZ-3), Tuscany (TOS-1) and Emilia Romagna (EMI-1 and EMI-2).

belonging to the genera *Ditylenchus* and *Tylenchorhynchus*. By contrast, in these study areas the genera *Mesocriconeema* (harmful for vineyards) and *Xiphinema* (vector of plant virus) resulted ubiquitous. As reported by HARRISON and WINSLOW (1961) and BOAG *et al.* (1991) *Xiphinema* genus could be expected to require well-aerated soils, whereas they are also found in soil with medium or heavy texture. Moreover, the increment of native soil organic matter did not suppress larger nematodes. At this regard, PONCHILLIA (1972) found that only large additions of organic matter as much have a deleterious effect on *Xiphinema* species.

The nematode indicators showed that the nematode community composition varied as a result of the previous and current agricultural practices. In fact, the LAZ-3 site, characterized by previous crop rotation and the current cover grass management, showed the highest values in MI and PPI indices. The lack of soil tillage may have reduced the negative impact on the nematode populations, as previously reported (THOMAS, 1978; WARDE, 1995; LANDI *et al.*, 2018a; 2018b). In contrast, the lowest MI value was found where the agronomic technique included annual deep ploughing. In the context of ecosystem services, nematode community plays an important role in pest control (regulating services) and in nutrient recycling (supporting service). Nematode predators provide to regulate plant parasitic nematodes, while detritivores and predators provide nutrient recycling service. The use of diversity-weighted abundance expressed as biomass showed that the predators are unable to regulate

Fig. III – Scatter plot of CCA ordination showing relationships between soil properties and plant parasite nematode taxa abundance. Percentage of variance explained was 30.7% for axis 1 ($P < 0.04$) and 26% for axis 2 ($P < 0.001$).

the ecosystem services of plant parasitic nematodes and carbon mineralization. However, the differences among sites were relevant: the site previously managed using crop rotation and then by grass cover showed the best regulation.

CONCLUSION

By evaluating six different sites located in Northern and Central Italy, we are able to assess the structure of nematode communities. Overall, with regard to plant parasitic nematodes, the virus-vector *Xiphinema* genus is the most abundant and widely distributed and for this reason periodic soil monitoring is necessary to evaluate the phytosanitary status. Moreover, the predators were not able to regulate the ecosystem services and in particular the pest control service. At this purpose, agronomic practices that reduce tillage such as minimum tillage or, better, cover grass are recommended.

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