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Research Article

Nematode community structure in potato fields of Kurdistan province, western Iran

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Abstract: Potato is one of the most important crops produced in Kurdistan province, western Iran. Although several species of plant-parasitic nematodes have been reported in association with these potato fields, no comprehensive nematode community structure has been investigated. The present study reports the frequency, abundance and prominence value of all nematode groups from 40 potato fields across Ghurveh and Dehgolan regions. Bacterivorous nematodes showed the highest frequency, abundance and predominance in the region, followed by herbivorous (plant-parasitic nematodes), fungivorous and omnivorous nematodes. Predatory nematodes (carnivores) were not recovered probably because field soils were highly disturbed. Root-lesion nematodes were the most predominant among the identified plant-parasitic nematodes. The calculation of the indices of ecosystem function, as well as the plotting colonizer-persister (c-p) triangle, food web faunal analysis and metabolic footprint of the potato fields revealed that most of the studied fields had high proportions of c-p1 and c-p2 nematodes, but nematode individuals of c-p3-5 counted fewer in the population. According to the present study, 50% of the sampled fields represent either stressed and enriched, 30% could be considered as stable and enriched, and 20% may be described as stressed and depleted in terms of their soil nematode food webs. The current study provides the first known study in Iran on nematode assemblages and their implication in soil health.

Keywords: soil food web, colonizer-persister, metabolic footprint, plant-parasitic nematodes, bacteriovorous nematodes

Introduction

Potato, *Solanum tuberosum* L., which originated from the Andean highlands of South America, is a major food crop in 57 countries, and it is the only tuber crop produced in significant amounts in the developed countries. Of the factors which adversely influence the production of potatoes, nematodes are among the most important ones that limit the production of potatoes (Scurrah *et al.*, 2005). Out of five million tones total production of potato cultivated in 552057 hectares of potato fields in Iran, nearly 280000 tones (5.6%) are produced in the 7369 hectares of fields in Kurdistan province (Ahmadi *et al.*, 2018). The majority of potato cultivation in Kurdistan province occurs in the fields of Ghurveh and Dehgolan counties. Root-lesion nematodes (*Pratylenchus neglectus*, *P. thornei* and *P. fallax*) may be considered as the most important plant-parasitic nematodes amongst

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the 15 identified species in the studied region (Rahimi *et al.*, 2012).

Nematode communities are known to have substantial effects on soil productivity, which ultimately affects the field crops (Bello *et al.*, 2019). Because nematodes occupy key positions as primary and intermediate consumers in soil food webs, evaluation and interpretation of the abundance and function of their faunal assemblages or community structure offers a method for *in situ* assessment of impact factors (Bongers and Ferris, 1999). Functional guilds, representing the integration of nematode feeding habits (Yeates *et al.*, 1993),colonizer-persister (c-p) scales (Bongers, 1990; Bongers and Bongers, 1998), faunal food web analysis (Ferris *et al.*, 2001), and more recently, metabolic footprints (Ferris, 2010) have been developed for studying soil nematode community dynamics.

Based on life strategy, Bongers (1990) allocated terrestrial and freshwater nematodes on a continuum from colonizers to persisters (r- to K-strategists, *sensu lato*) followed by a similar proposal for marine nematodes (Bongers *et al.*, 1991). Colonizers (r-strategists, in the broad sense) produce many small eggs and exploit a nutrient-rich habitat rapidly. In contrast, persisters (K-strategists, in the broad sense) hardly react at transient conditions of high food availability. According to this classification five groups of nematodes can be distinguished on the c-p scale, including plant-parasitic nematodes (Pl), bacterial feeders (Ba), fungal feeders (Fu), carnivorous nematodes (Ca) and omnivorous nematodes (Om). An updated c-p values for terrestrial and freshwater nematodes is given in Bongers and Bongers (1998). The concept of “functional guilds” was also proposed (Bongers and Bongers, 1998) to integrate the feeding group and life strategy concepts. A functional guild is considered to be a group of organisms that have similar growth, reproductive and metabolic characteristics and perform the same ecological function. Nematologists believe, in most cases, such similarities are adequately described by categorizing nematodes with similar feeding habits at the family level (Bongers and Bongers, 1998; Bongers and Ferris, 1999). Moreover, the concepts and applications of the faunal food web plots and metabolic footprints have well been discussed (Ferris *et al.*, 2004a; Ferris, 2010; 2013).

Plant-parasitic nematodes associated with potato fields in Kurdistan province have already been identified (Rahimi *et al.*, 2012); however, there is no information on their nematode community structure not even for other potato growing zones in Iran. The present study aims to investigate nematode community structure in the potato fields of Kurdistan province as a bioindicator of soil health.

Materials and Methods

Nematode sampling and identification

Soil samples were collected from the rhizosphere of potato plants in the 40 fields of Ghurveh and Dehgolan (Kurdistan province, western Iran) during 2012-2013 (Fig. 1). At least 10 up to 20 soil subsamples per field were taken from selected fields with an approximate area of 2-5 ha at 30 cm top layer soil, and were subsequently bulked together to provide one composite soil sample per field. The samples were placed in plastic bags, labelled accordingly and transported in cool boxes to the nematology laboratory of Plant Protection Organization of Sanandej for further analyses.

Nematodes were extracted from a 200 ml subsample of each sample using the integrated method of sieving/centrifugation (Jenkins, 1964), and collected in tap water after extraction. They were killed and fixed by hot FPG (4: 1: 1, formaldehyde: propionic acid: glycerol), processed to anhydrous glycerol (de Grisse, 1969), and mounted in glycerol on permanent slides using paraffin wax to verify genus identification based on morphological characteristics using available identification keys (e.g., Siddiqi, 2000; Andrássy, 2005; 2007; 2009).

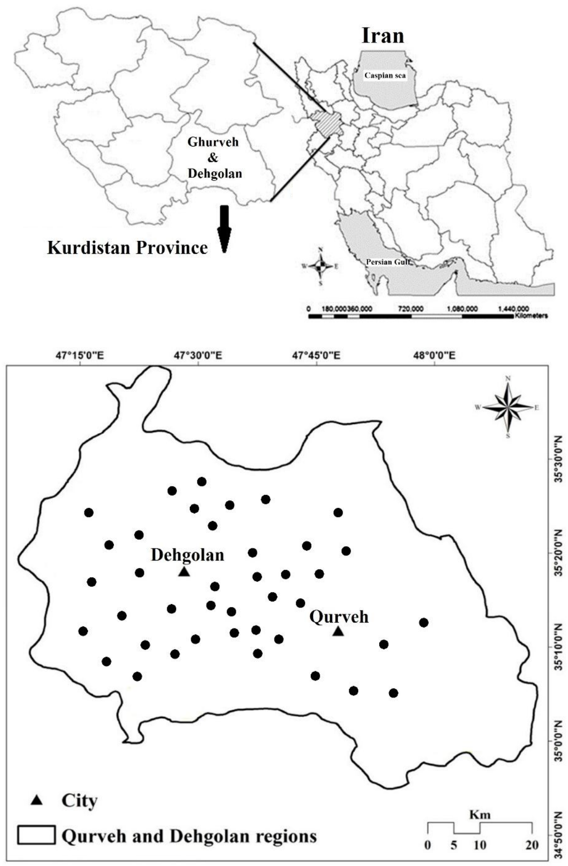

Figure 1 Sampling area and geographic location of the sampled potato fields.

Statistical analyses

Nematode absolute abundance per each field was adjusted to and expressed as nematode count per 200 gr of soil. The extraction efficiency was determined as about 50% according to the results obtained by Ghaderi *et al.* (2012). The relative frequency of a given nematode was determined based on the presence of that nematode in the infested samples (one recovered individual was considered as existence of the given genus). The prominence values (PV) for each family or genus were also calculated according to the equation: PV = absolute abundance×√relative frequency/10 (deWaele and Jordaan, 1988).

Furthermore, nematode data were subjected to faunal food web analysis for calculating function indices of ecosystem (Ferris *et al.*, 2001; Ferris, 2013). To infer ecosystem functions, indices of maturity index family (MI family) including maturity index (MI), plant-parasitic index (PPI), PPI/MI, MI2-5, and ∑MI were explored (Ferris and Bongers, 2009; Ferris, 2013). Moreover, the enrichment and structure trajectories were calculated independently from the weighted average of nematodes in functional guilds representing the basal (*b*), enrichment (*e*), and structure (*s*) of food web components according the method explained by Ferris (2013). Calculation of the three components were done as follows: the *b* component was calculated as $\sum k_b n_b$ where k_b represents the weights assigned to guilds indicating basal characteristics of the food web (Ba2, Fu2) and n_b equals nematode abundance in those guilds; the *e* and *s* components were calculated using the nematode guilds indicating enrichment (Ba1, Fu2) and structure (Ba3-Ba5, Fu3-Fu5, Om3-Om5, Ca2-Ca5), respectively. Finally, the following function indices were calculated: Enrichment index (EI) was calculated as $100 \times (e/(e + b))$, structure index (SI) as $100 \times (s/(s + b))$, basal index (BI) as $100 \times b/(e + s + b)$, and channel index (CI) as $100\ Fu2 \times W2/(Ba1 \times W1 + Fu2 \times W2)$ where W1 and W2 are constants equal to 3.2 and 0.8, respectively.

Calculations for faunal food web analysis and metabolic footprint were also done using the Nematode Indicator Joint Analysis (NINJA) online program (Sieriebriennikov *et al.*, 2014). The soil condition of each field was categorized into any of the following four quadrats: as being either stressed and enriched (Quadrat A), stable and enriched (Quadrat B), stable and depleted (Quadrat C) or stressed and depleted (Quadrat D) based on where the nematode faunal composition of each sampled field mapped in the faunal profile (Ferris, 2010; Sieriebriennikov *et al.*, 2014).

Results

Nematodes with different feeding habits including herbivorous (plant-parasitic nematodes), fungivorous, bacterivorous and omnivorous nematodes were identified in association with potato in Gurveh and Dehgolan, Kurdistan province, western Iran. No carnivorous nematodes (Mononchida, Diplogastrida or certain predatory taxa of Dorylaimida) appeared in the samples. Bacterivorous nematodes showed the highest frequency, abundance and predominance in the region, followed by herbivorous, fungivorous and omnivorous nematodes (Table 1; Fig. 2).

Pooling the data across the 40 fields sampled, indicated that among herbivores, Tylenchidae, *Pratylenchus*, *Merlinius* and *Ditylenchus* were the most frequent taxa, occurring in 90.0, 87.5, 62.5 and 50% of the samples, respectively. *Pratylenchus* showed high levels of abundance in the fields with 2-306 nematodes per 200 ml soil, therefore it can be considered as the most predominant genus (PV = 30.9) of plant-parasitic nematodes. The PV remained below 15 for other genera of plant-parasitic nematodes. Of the identified genera, *Pratylenchoides*, *Amplimerlinius* and *Mesocriconema* were the least frequent (PV under 1) with individuals being present in low numbers in only one or two fields.

Table 1 Data representing functional guilds (FG), relative frequency (RF), absolute abundance (AA), relative abundance (RA), and prominence value (PV) for nematode taxa identified from rhizosphere samples of potato plants sampled during 2014 from 40fields in Kurdistan province, Western Iran.

Feeding type\ family	Genus	FG	RF	AA[1]	RA	PV
Herbivores		Pl	97.5	66 (6-418)	32.2 (3.0-73.7)	65.2
Anguinidae	*Ditylenchus*	Pl-2	50.0	6 (2-22)	3.8 (1.3-20.4)	4.2
Criconematidae	*Mesocriconema*	Pl-3	2.5	4	3.2	0.6
Dolichodoridae	*Amplimerlinius*	Pl-3	2.5	2	0.6	0.3
Dolichodoridae	*Merlinius*	Pl-3	62.5	16 (2-93)	7.5 (0.8-30.6)	12.6
Dolichodoridae	*Scutylenchus*	Pl-3	5.0	7 (4-10)	1.3 (1.0-1.5)	1.6
Dolichodoridae	*Tylenchorhynchus*	Pl-3	17.5	8 (2-16)	4.6 (1.7-11.3)	3.3
Hoplolaimidae	*Helicotylenchus*	Pl-3	47.5	9 (2-34)	4.0 (0.6-15.9)	6.2
Hoplolaimidae	*Heterodera* (J2)	Pl-3	12.5	3 (2-4)	2.3 (0.9-3.9)	1.1
Meloidogynidae	*Meloidogyne* (J2)	Pl-3	2.5	6	4.5	0.9
Pratylenchidae	*Pratylenchoides*	Pl-3	2.5	2	0.6	0.3
Pratylenchidae	*Pratylenchus*	Pl-3	87.5	33 (2-306)	15.6 (0.9-53.7)	30.9
Pratylenchidae	*Zygotylenchus*	Pl-3	2.5	38	30.6	6.0
Tylenchidae	-	Pl-2	90.0	14 (2-60)	6.4 (0.4-17.9)	13.3
Tylenchulidae	*Paratylenchus*	Pl-2	20.0	11 (2-34)	6.3 (0.8-17.8)	4.9
Fungivores	*Aphelenchus*	Fu	95.0	20 (2-70)	11.9 (1.8-40.2)	19.5
Aphelenchidae	*Paraphelenchus*	Fu-2	90.0	15 (2-70)	9.3 (0.8-40.2)	14.2
Aphelenchidae	*Aphelenchoides*	Fu-2	5.0	5 (4-6)	2.6 (1.6-3.7)	1.1
Aphelenchoididae	*Prothalonema*	Fu-2	65.0	9 (2-26)	4.1 (0.4-13.9)	7.3
Neotylenchidae	*Aphelenchus*	Fu-2	2.5	2	0.6	0.3
Bacterivores		Ba	100.0	112 (16-750)	49.9 (14.6-98.2)	112.0
Cephalobidae	-	Ba-2	100.0	62 (6-360)	28.1 (5.0-78.2)	62.0
Panagrolaimidae	-	Ba-1	95.0	22 (2-120)	11.2 (1.2-64.2)	21.4
Plectidae	-	Ba-2	20.0	3 (2-8)	1.6 (0.6-3.4)	1.3
Rhabditidae	-	Ba-1	77.5	37 (2-300)	14.0 (1.5-77.0)	32.6
Omnivores		Om	87.5	15 (2-130)	8.2 (0.4-40.3)	14.0
Small dorylaimids	-	Om-4	67.5	12 (2-54)	7.0 (0.4-40.3)	9.9
Large dorylaimids	-	Om-5	60.0	9 (2-100)	4.1 (0.7-13.5)	7.0

[1] The number of nematodes in 200 cc soil.

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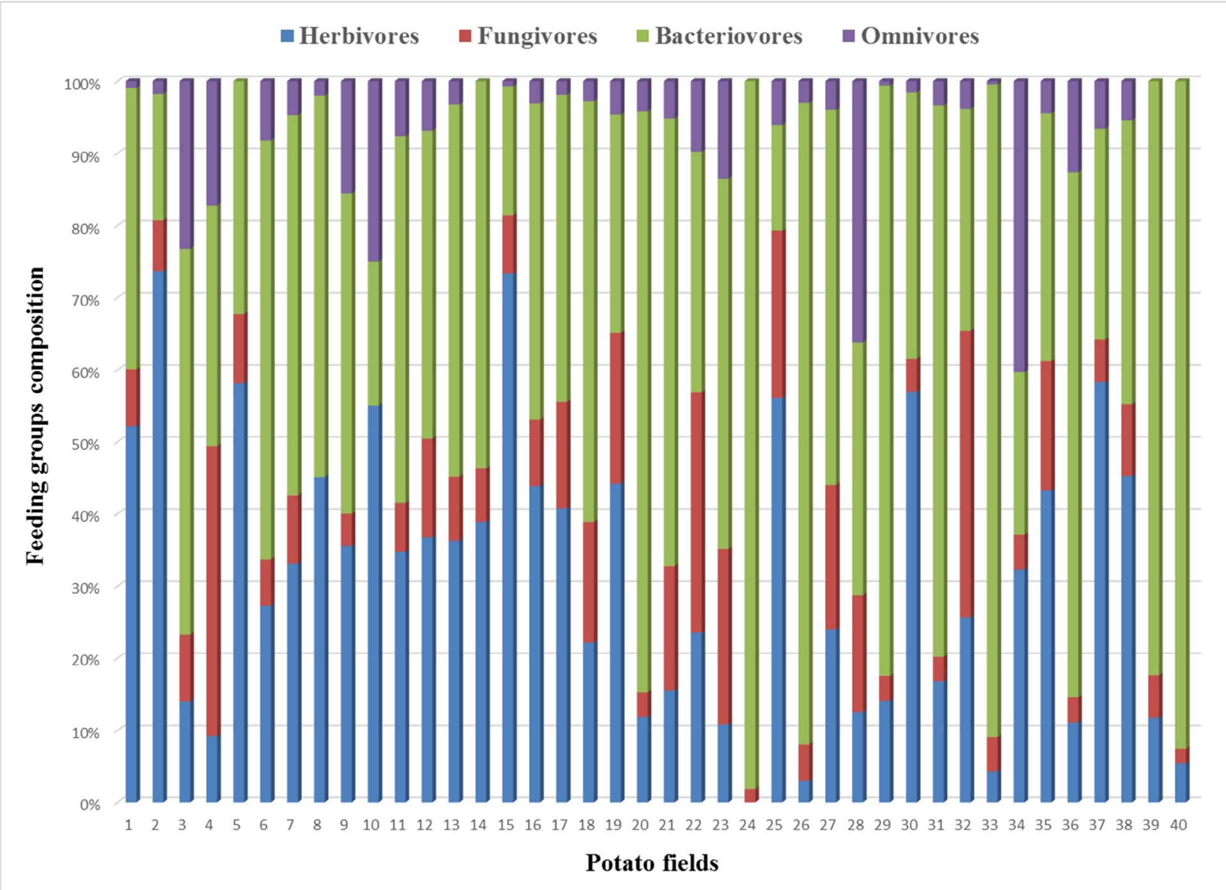

Figure 2 Feeding type composition (%) of nematode assemblages identified from 40 potato fields of Kurdistan province, western Iran, sampled during 2014.

Indices of ecosystem function were determined (Table 2) after designating recovered taxa to each c-p group. The c-p triangle, food web faunal analysis and metabolic footprint of the potato fields are plotted on the graphs (Figs. 3 and 4) that represent their soil food web status. Results indicated that most of the fields had high proportions of c-p1 and c-p2, but individuals of c-p3-5 were lower in the population. Results of the faunal analysis plot revealed further that 50% of the fields plotted in Quadrat A, representing either stressed and enriched soil food web conditions. Soils from 30% of the fields plotted in Quadrat B, which were considered as stable and enriched, and 20% of the fields plotted in quadrat D which were described as stressed and depleted in terms of their soil nematode food webs. None of the fields were plotted in quadrat C showing stable and depleted characteristics.

Table 2 Indices of ecosystem function and diversity for nematode taxa identified from rhizosphere of potato plants sampled during 2014 from 40 fields in Kurdistan province, Western Iran.

Index	Mean	SD	Min-Max
MI	1.96	0.41	1.09 - 3.22
MI2-5	2.36	0.38	2.00 - 3.50
PPI	2.70	0.24	2.00 - 3.00
PPI/MI	1.43	0.34	0.80 - 2.44
∑MI	2.19	0.40	1.18 - 3.10
EI	64.15	18.04	20.00 - 97.52
SI	41.81	24.09	2.44 - 89.09
BI	28.57	16.67	2.48 - 80.00
CI	22.39	24.31	0.59 - 100.00

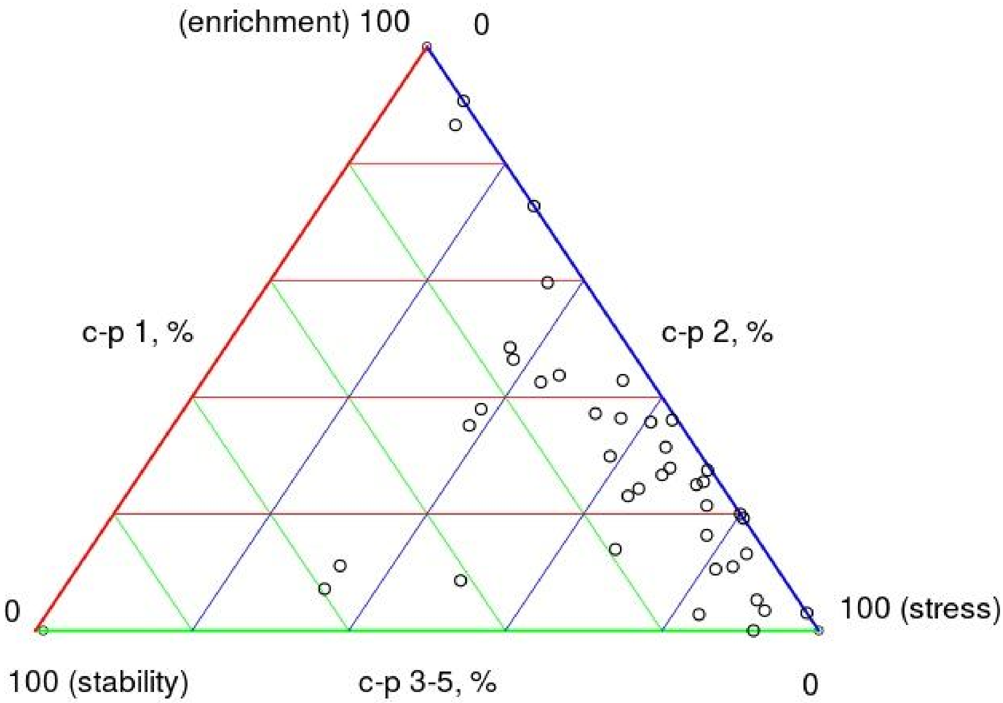

Figure 3 A c-p triangle with unweighted proportional representation of cp-1, cp-2 and cp-3-5 groups of the nematode fauna of 40 potato fields in Kurdistan province, western Iran, sampled during 2014.

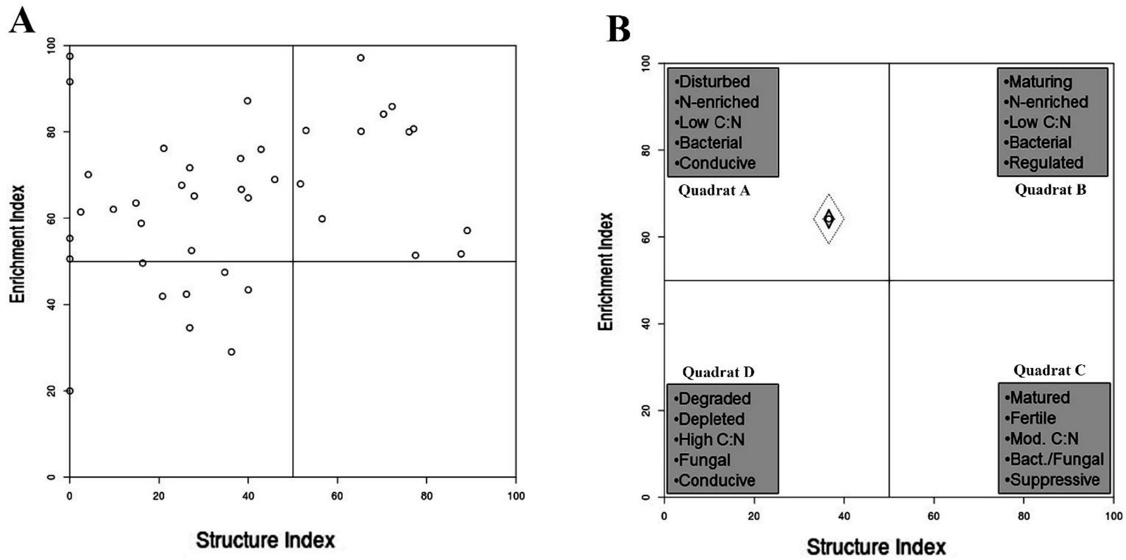

Figure 4 A faunal food web profile (A) and a metabolic footprint (B) representing the structure and enrichment conditions of the soil food web for 40 potato fields in Kurdistan province, western Iran, sampled during 2014.

Discussion

The use of nematodes as indicators of soil health has been substantially improved by allocation of nematodes into feeding groups, trophic groups, functional guilds, faunal food web analysis, and metabolic footprints of the assemblages (Yeates *et al.*, 1993; Bongers and Bongers, 1998; Ferris, 2010; van den Hoogen *et al.*, 2019). To our knowledge, there is no information available concerning nematode community structure in natural or agricultural ecosystems in Iran. Results of the present study provide an insight into the nematode community structure in potato fields and its subsequent effects on the soil food web and ecosystem diversity and functioning.

In the present study, 13 genera of plant-parasitic nematodes and four genera of fungivorous nematodes were identified along with unidentified members of Tylenchidae, bacterivorous and omnivorous nematodes. Root-lesion nematodes (*Pratylenchus* spp.) were the most dominant plant-parasitic nematodes in the studied region. These nematodes are known to damage potatoes in the temperate, tropical and subtropical regions (Scurrah *et al.*, 2005). High populations of root-lesion nematodes cause damage by not only direct feeding on cortical tissues, but interacting with a series of pathogenic organisms involved in development of some soil borne plant diseases like vascular wilts (Mai *et al.*, 1981). That is why more studies on the pathogenicity and contribution of this group of nematodes in common fungal or bacterial diseases in the region are highly recommended. Certain other important plant-parasitic nematodes (particularly *Meloidogyne* and *Ditylenchus*) occurred in the fields surveyed in this study; however, they showed much lower predominance value.

Bacterivorous nematodes showed the highest frequency (presence in the infested samples), abundance (population density) and predominance in the potato fields in the studied region, followed by herbivorous, fungivorous and omnivorous nematodes. It has already been proved that the community of soil organisms is dependent primarily on autotrophic input from plants or on subsidiary input from other sources, and this community responds in characteristic ways to enrichment of its environment by organic matter (Ferris and Bongers, 2006). Some nematodes are more responsive to resource enrichment than others. Generally, bacterivorous nematodes with short lifecycles and high reproductive potential are indicative of soil nutrient enrichment (Bongers, 1990; Ferris *et al.*, 2001). Bongers and Ferris (1999) noted an increase in the numbers of cp-1 nematodes (specialized opportunistic bacterivores) four days after manure was added to the soil and they became dominant in the community after two or three weeks; over the next few weeks, cp-1 nematodes were decreased and cp-2 species (general opportunistic bacterivores) became dominant. The MI increases during the succession and with decreasing microbial activity. Greater dominance of cp-1 nematodes indicates enrichment, increase of cp-2 nematodes (simultaneously with decrease of cp-1 and cp-3-5) indicates stress, and increase of nematodes from cp-3 to cp-5 indicates natural succession mediated by increased environmental stability (Bongers and Ferris, 1999).In other words, the most abundant nematode taxa under stressed conditions are those in cp-2, while the enrichment opportunists (cp-1) respond positively to disturbances that result in enrichment at any level of environmental quality (de Goede *et al.*, 1993; Bongers and Ferris, 1999; Ferris *et al.*, 2001). In our survey, cp-2 nematodes (Cephalobidae) were the most dominant species in the fields, but cp-1 nematodes (Rhabditidae and Panagrolaimidae) were also common, sometimes even in higher populations than the cp-1 nematodes (Table 1). Therefore, certain fields of the surveyed region may be considered as having both enriched and stressed soils, as is clearly obvious from the c-p triangle (Fig. 3).

Furthermore, the calculated maturity family indices revealed that soils of potato fields of Kurdistan province have a generally disturbed and enriched food web. The mean of Maturity Index (MI) in the surveyed area was 1.96, ranging from 1.09 to 3.22, indicating disturbed conditions and receiving chemical fertilizers or manure input in majority of the area. Plant-parasitic nematode index (PPI) was typically larger in the region, averaged 2.70 and ranged from 2.00 to 3.00 across different fields; PPI/MI ratio consequently varied from 0.80 to 2.44 reflecting a higher proportion of plant-parasitic nematodes to the other nematodes probably due to the improved plant growth after application of chemical fertilizers or manures to the soils. The MI has already been shown to decrease under the influence of N-fertilization or manuring because of higher microbial activity, but the PPI increases probably as a result of the higher carrying capacity of plants on which these nematode feed (Bongers *et al.*, 1997). The other reason for increasing of PPI/MI may be the frequently repeated tillage by farmers with the aim to stop natural succession and to keep the system in imbalance to allow the crop to compete for nutrients and light. These conditions have already been shown (Bongers *et al.*, 1997) to result in a high PPI/MI ratio.

Besides MI family, four further indices explaining more aspects of ecosystem functioning were obtained for the potato fields of Kurdistan province. The food web of soils often showed a high enrichment index (EI) but low structure index (SI), both indicating their food web has active bacterial decomposition channels, is enriched with low C/N organic materials, may be recently disturbed. The food web of the soils also lacked the appropriate proportion of the potential links among nodes in a food web that are realized in the web (also defined as connectance by Ferris *et al.*2001)). Lack of connectance makes the soil probably conducive to development of opportunistic organisms that include pest species (Ferris *et al.*, 2004a). EI is characterized by the weighted abundance of the proportion of nematodes that are cp-1 bacterivores and cp-2 fungivorous nematodes, and SI is derived from the proportional contribution of the weighted cp-3-5 nematodes to the cp-2-5 grouping (Ferris *et al.*, 2001; Ferris, 2013). The SI had lower values in the potato fields when compared to forest ecosystems (Ferris *et al.*, 2004a; Cardosso *et al.*, 2016), prune orchards (Ferris *et al.*, 2004a), watermelon fields (Bello *et al.*, 2019) or organic vegetable production systems (Ferris *et al.*, 2012), but had relatively higher values than those of the tomato fields (Ferris *et al.*, 2004b).

Ferris *et al.* (2001) described four more indices for ecosystem functioning. Enrichment index (EI) is the weighted abundance of the proportion of Ba-1 (bacterivorous nematodes of the cp-1) and Fu-2 (fungivorous nematodes of the cp-2).Structure index (SI) is derived from the proportional contribution of the weighted cp-3-5 nematodes to the cp-2-5 grouping. Basal index (BI) is the relative proportion of the basal (nematodes of cp-2) component to that of all nematodes present. Channel index (CI) which indicates the relative flow of resources into the food web through decomposition channels mediated by fungi and bacteria; higher values suggesting that fungivorous nematodes are of paramount importance in organic matter decomposition and lower values indicating dominance of bacterivorous nematodes.

Interpretation of faunal food web profile and metabolic footprint (Fig. 4) is also a very useful tool for confirming the data obtained from MI family indices or c-p triangle. Ferris *et al.* (2001) plotted a faunal food web profile including recognition of an enrichment trajectory and a structure trajectory. Each soil can be categorized into one of the quarters in terms of its food web condition. As can be observed from Fig. 4A, half of the fields sampled during this study plotted in Quadrat A, which refers to either stressed and enriched food webs in terms of soil food web, indicating that soils of such fields are highly disturbed; such soils are also N-enriched with materials having low C\Nratio while their decomposition channels are bacterial. Out of 40 sampled fields, 30% plotted in Quadrat B, which refers to stable and enriched food webs. This implies that soils of such fields have maturing food web condition characterized by low to moderate disturbance; such soils are also N-enriched with low C\N ratios while their decomposition channels are balanced. The other 20% of fields plotted in Quadrat D,

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which refers to stressed and depleted. This implies that soils of such fields show degraded food web condition, characterized by high disturbance; such soils are depleted and show low C\N ratios while they have fungal-mediated decomposition channels. A large enrichment footprint as recorded for majority of the sampled areas is indicative of a higher abundance of opportunistic nematodes (bacterivorous and fungivorous nematodes), and similarly, a small structure footprint is indicative of a lower abundance of omnivorous and carnivorous (predatory) nematodes (Ferris *et al*., 2001; Sieriebriennikov *et al*., 2014). A combination of these two footprints, functional footprint (as evidence in Fig 4B) reveals a disturbed soil food web with N-enriched system showing a low C\N ratio and bacterial-mediated decomposition channels.

The current study contributes to our knowledge of nematode community structure, and furthermore provides the first known study in Iran on nematode assemblages and their implications in soil health. A good understanding of nematode community structure within agroecosystems is important in making decisions and formulating policies that will facilitate the maintenance of soil health towards optimizing sustainable food production.

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ساختار جامعه نماتدها در مزارع سیب‌زمینی استان کردستان

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چکیده: سیب‌زمینی یکی از مهم‌ترین محصولات کشاورزی در استان کردستان محسوب می‌شود. گونه‌های مختلفی از نماتدهای انگل گیاهی در مزارع سیب‌زمینی گزارش شده‌اند، اما تاکنون مطالعه جامعی درباره ساختار جامعه نماتدهای سیب‌زمینی در ایران انجام نشده است. مطالعه حاضر فراوانی، تراکم جمعیت و شاخص غالبیت گروه‌های مختلف نماتدها را در ۴۰ مزرعه سیب‌زمینی در شهرستان‌های قروه و دهگلان گزارش نموده است. نماتدهای باکتری‌خوار بالاترین فراوانی، تراکم و غالبیت را در منطقه نشان دادند و پس از آن‌ها، نماتدهای انگل گیاهی، نماتدهای قارچ‌خوار و نماتدهای آزادزی قرار داشتند. نماتدهای شکارگر احتمالاً به‌دلیل عملیات خاک‌ورزی زیاد در مزارع یافت نشدند. نماتدهای مولد زخم ریشه غالب‌ترین نماتدهای انگل گیاهی در مزارع بودند. محاسبه شاخص‌های کارکردی زیست‌بوم، مثلث کولونیزر-پرسیستر (c-p triangle)، واکاوی فون شبکه غذایی و نگاره متابولیک مزارع سیب‌زمینی نشان داد که اغلب مزارع مورد مطالعه، نسبت بالاتری از نماتدهای گروه‌های یک و دو (c-p1 و c-p2) را دارند و نماتدهای گروه‌های سه تا پنج (c-p3-5) به تعداد کم‌تری حضور دارند. طبق نتایج مطالعه حاضر، نیمی از مزارع درحالی‌که نهاده‌های آلی و شیمیایی دریافت کرده‌اند از نظر شبکه غذایی دچار تنش هستند، ۳۰ درصد از آنها نهاده دریافت کرده‌اند اما شبکه غذایی پایدار دارند و ۲۰ درصد نیز دچار تنش بوده و شبکه غذایی تخلیه شده دارند. پژوهش حاضر نخستین مطالعه انجام شده در ایران بر روی جامعه نماتدها و کاربرد آن در سلامت خاک است.

واژگان کلیدی: شبکه غذایی خاک، کولونیزر-پرسیستر، نگاره متابولیک، نماتدهای انگل گیاهی، نماتدهای باکتری‌خوار

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