Research Article

The Effects of Conservation Agriculture Practices on the Population Density of Fungivorous and Free-Living Nematodes in Different Crop Rotation Patterns

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Abstract | Conservation agriculture (CA) has been widely adopted in many regions of the world; however, the effect of CA practices on non-plant pathogenic nematodes is not well understood. This study was carried out to determine the effect of CA on population density of fungivorous (*Aphelenchus avenae*) and free-living nematodes under four crop rotation patterns. The experiment was arranged as a split plot in randomized complete block design with three tillage systems (conventional tillage, minimum tillage and no-tillage) as the main plots and three level of crop residue retention (no-residue, 30%, and 60% of residue retention) as the sub-plots that replicated three times during five consecutive cropping seasons. The results showed that fungivorous and free living nematodes exhibited differential responses to tillage and residue retention under different rotation patterns. Analysis of variance showed that the effect of tillage, residue retention and their interaction effect on population of fungivorous and free-living nematodes in the 1st (wheat, barley, cotton, wheat) and the 2nd (wheat, sugar beet, wheat, sugar beet and wheat) rotation patterns were not statistically significant. In the 3rd rotation pattern (wheat, maize, wheat, melon and wheat) interaction of tillage × residue retention had a significant effect on the population of fungivorous and free-living nematodes. In the 4th rotation pattern (wheat, canola, wheat, Persian clover, tomato and wheat), tillage intensity influenced the population density of fungivorous and free-living nematodes significantly. Long-term experiments are necessary to determine the capacity of non-pathogenic nematodes in suppression of soil-borne pathogens including the fungal and pathogenic nematodes.

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Introduction

During the last century, modern agriculture had a remarkable progress in hunger and poverty reduction, achievement of food security and improvement of nutrition for the growing world population, although this resources intensive-based production systems, generally had many negative effect on the natural resources such as soil, water and biodiversity (Kassam *et al*., 2013). To meet the world's future food security, however, the agriculture sector in 21 century pose a series of big challenges including declining availability of water resources, decreasing agricultural soil quality due to soil erosion and soil organic matter decline, high levels of greenhouse gas emissions and the negative impact from global warming and climate change (Abumhadi *et al*., 2012; FAO, 2017; Thornton *et al*., 2018). Conservation agriculture (CA), as a new paradigm of sustainable intensification of agriculture and an alternative to high-input and resource-intensive conventional farming systems has been emerged in recent decades (Hobbs *et al*., 2008; Pretty and Bharucha, 2014). This farming systems have been widely adopted in many regions of the world to improve crop productivity and soil fertility and to enhance the natural resource with minimal effects on the environment (Kassam *et al*., 2015; Paulitz, 2006; Derpsch and Friedrich, 2010; Wall *et al*., 2013). CA cropping systems comprising three inter-linked components including minimal mechanical disturbance of the soil by reduced or no-tillage, maintaining a permanent soil cover through crop residues or cover crops and crop rotation (Hobbs *et al*., 2008; Verhulst *et al*., 2010).

Crop rotation is an important agronomical practice that is associated with enhanced soil fertility, weeds control, improvement of chemical and physical soil properties, good soil water management, control of soil erosion, improvement of soil health and biological activity that is widely used around the world to avoid the inoculum buildup of the soil-borne pathogens (Nusbaum and Ferris, 1973; McLaughlin and Mineau, 1995; Florentín *et al*., 2010; Duiker and Myers, 2006; Hobbs *et al*., 2008; Ehrmann and Ritz, 2014; Panth *et al*., 2020), although crop rotation is not very successful in controlling some plant-parasitic nematodes due to their large host range (Abawi and Widmer, 2000). Most studies on the role of crop rotation in disease control have looked at its effect on reducing the population density of soil-borne pathogens in conventional agricultural systems.

Retention of crop residues on the soil surface is reported to have many benefits including formation of soil organic carbon, improvement of soil structure, increasing the soil microorganism biodiversity and microbial antagonists activities, prevention of erosion and maintaining soil moisture (Govaerts *et al*., 2007; Perez *et al*., 2008; Stagnari *et al*., 2009). However, crop residue retention may increase the risk of inoculum build-up of residue-borne pathogens (Bailey, 1996; Bailey and Lazarovits, 2003; Bockus and Shroyer, 1998). On the other hand, increased soil microbial biomass due to increased level of crop residues can potentially discourage pathogen development as increased numbers of microorganisms compete for resources or cause inhibition through antagonism or release of antibiotic (Weller *et al*., 2002).

The role of reduced tillage practices on reduction of plant pathogenic nematodes e.g. cereal cyst nematode, *Heterodera avenae*, (Roget, 1988) and soybean cyst nematode, *Heterodera glycines* (Edwards *et al*., 1988) are reported by some researcher. López-Fando and Bello (1995) studied the effect of tillage and crop rotation on diversity and population density of soil nematode fauna and reported that the populations of endo-parasitic nematodes including *Heterodera avenae* and *Pratylenchus* spp. decreased in no-tillage systems compared to conventional tillage but the greatest density and diversity of the bacterivorous, and fungivorous nematode occurred in the no-tillage system. Habig and Swanepoel (2015) reported that the microbial diversity and activity were higher in no-tillage than conventional tillage. Sharma *et al*. (2004) compared the effect of minimum and conventional tillage systems on the nematode population in rice and wheat fields in Nepal and reported that in rice fields the population of bacterivorous and omnivorous nematodes were higher in the conventional tillage than the minimal tillage but in the wheat fields the population of fungivorous nematodes were more in the conventional tillage than minimal tillage and concluded that different nematode species and trophic groups have a variable response to conventional and minimum tillage practices. Increased soil fauna including microorganisms, earthworms and nematodes is reported under no-till and residue retention practices compared to conventional tillage practices (Dick, 1992).

Soil-inhabiting nematodes are an important part of soil biological communities with particular importance in agricultural systems. They play important roles in nutrient cycling of soil by feeding on bacteria, fungi and microfauna (Overstreet *et al*., 2010). The majority of soil nematodes are free-living that obtain their food from microorganisms including bacteria, fungi and other nematodes and play an important role in decomposition and organic nutrients recycling in soil ecosystem (Hailu and Hailu, 2020). Despite the important ecological value of the free-living nematodes in agricultural soils, only a few studies have examined the influence of different cropping systems on the community of this group of nematodes (Govaerts *et al*., 2006; Rahman *et al*., 2007; Briar *et al*., 2012; Djigal *et al*., 2012). The main objective of the present study was to determine and evaluate the influence of conservation agriculture compared with the conventional practices under different crop rotation sequences on the population density of fungivorous and free-living nematodes in soil.

Materials and Methods

Experimental sites

This study was carried out at three Agricultural research stations located in the Khorasan Razavi province, northeastern Iran. Brief information of the experimental sites are presented in Table 1.

Experimental design

The impacts of tillage and cop residue retention were determined on the population density of free-living nematodes under four different crop rotation sequences at three experimental sites. The experimental design was a randomized complete split-plot with three replications. Three tillage systems, conventional tillage (CT), minimum tillage (MT) and no-tillage (NT) were assigned as main plots and three level of residue retention, (no-residue, 30% residue, and 60% residue) as subplots. The planting area of each subplot was 150 m^2 (15m ×10 m) and planting area of each main plot was 450 m^2 (3×150 m^2). The planting area of each replication of the experiment was 4050 m^2 (9×450 m^2) and the total planting area of each rotation experiment was 12150 m^2 (3×4050 m^2). The field experiments arranged under four rotation patterns. All rotation patterns were based on the wheat and are considered as the most predominant rotation patterns in the region. The first crop rotation pattern includes wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), cotton (*Gossypium hirsutum* L.), fallow and wheat was conducted at the Gonabad agricultural research station. The second crop rotation pattern includes wheat, sugar beet (*Beta vulgaris* L.), wheat, Sugar beet and wheat was conducted at the Jolge-Rokh agricultural research station. The third (wheat, maize (*Zea mays* L.), wheat, melon (*Cucumis melo* L.) and wheat) and the fourth (wheat, canola (*Brassica napus* L.), wheat, white clover (*Trifolium repens* L.), tomato (*Solanum lycopersicum* L.) and wheat) crop rotation patterns were conducted at the Torogh agricultural research station. Details of crop rotation sequences at each experimental site are provided in Table 2.

Table 1: *Brief description of experimental sites.*

Trail site	Global position		Altitude (m)	Annual mean temperature (°C)	Min. temperature (°C)	Max. temperature (°C)	Average annual rainfall (mm)
	Latitude (N)	Longitude (E)					
Gonabad agricultural research station	34° 37'	58° 76'	1060	17.3	-1.6	37.1	160
Jolge-rokh agricultural research station	35° 34'	59° 23'	1710	10.7	-23	36.5	225
Torogh agricultural research station	36° 13'	59° 40'	985	14.5	-27.8	43.4	214

Table 2: *Details of the different cropping patterns at the different experimental sites.*

1st Rotation pattern		2nd Rotation pattern		3rd Rotation pattern		4th Rotation pattern	
Growing season	Crop (cultivar)	Growing season	Crop (cultivar)	Growing season	Crop (cultivar)	Growing season	Crop (cultivar)
Oct. 2012-June 2013	Wheat (Parsi)	Sep. 2011-July 2012	Wheat (Pishgam)	Oct. 2011-July 2012	Wheat (Parsi)	Oct. 2011-July 2012	Wheat (Parsi)
Oct. 2013-June 2014	Barley (Nosrat)	May 2013-Sep. 2013	Sugar beet (Brigita)	June 2013-Sep. 2013	Maize (Single cross 704)	Oct. 2012-June 2013	Canola (Hyola401)
July 2014- Oct. 2014	Cotton (Khordad)	Sep. 2013-July 2014	Wheat (Pishgam)	Oct. 2013-June 2014	Wheat (Parsi)	Oct. 2013-June 2014	Wheat (Parsi)
Oct. 2014- Oct. 2015	fallow	May 2015-Sep. 2015	Sugar beet (Brigita)	June 2015-Sep. 2015	Melon (Khatouni)	Sep. 2014-May 2015	White Clover[1] (Harati local population)
Oct. 2015- june 2016	Wheat (Parsi)	Sep. 2015-July 2016	Wheat (Pishgam)	Oct. 2015-June 2016	Wheat (Parsi)	June 2015-Sep. 2015	Tomato (Petoearly CH)
						Oct. 2015-June 2016	Wheat (Parsi)

Tillage and residue retention treatments

In the intensive, conventional tillage practice, a moldboard plow was used followed by an offset disc plough and then a leveler. Depending on the crop, a furrower was used to complete the seedbed preparation practices and then a seeding machine was used for planting. In the minimum tillage treatment, a single furrow, one-way disc plough or a chisel plough and then a furrower and finally a seeding machine was used. In the no-tillage treatment, depending on the crop and soil conditions a chisel plough or other tined implement followed by a light trailing cover harrow or a no-tillage direct seeding machine was used. In the no-residue retained treatment, the entire surface residue from the former crop was removed just after the harvest, leaving a bare soil surface. In the other two residue management treatments, 30% and 60 % of plant residues were left on the soil surface (Erenstein, 2002; Giller *et al*., 2009; Mazvimavi and Twomlow, 2009).

Soil sampling and nematode population density analysis

Ten soil subsamples were collected in zig zag pattern from each experimental plot in the 5 to 30 cm depth, after removing the 0-5 cm top soil layer, using an auger of 2.5 cm in diameter at the end of the last growing season. The subsamples from each plot were thoroughly mixed together and compiled into one bulk sample (approximately 1 Kg). In the laboratory, nematodes were extracted from 250 ml of each combined soil sample using sieving and centrifugal-flotation technique (Jenkins, 1964). In the final washing step, each sieve was washed carefully with 200 ml of water and the final volume of suspension was adjusted to 250 ml using extra water. One ml out of the 10 ml of the resulting suspension was used for measuring the population density of nematodes in 250 ml of soil samples using counting slides under the compound light microscope (10x). The extracted nematodes were classified as the fungivorous nematode, *Aphelenchus avenae* and other free-living nematodes including predators and omnivores nematodes, based on the mouth cavity (presence or absence of a stylet), the morphology of oesophagus, especially the median bulb, without further assignment to taxonomic groups (Hunt, 1993; Nickle, 1991). Data were analysed with MSTAT-C statistical software package (MSTAT-C, 1989). Means were compared using Duncan's Multiple Range Test (MRT) (Shaffer, 1999).

Results and Discussion

Population densities of non-plant pathogenic nematodes

The population densities of non-plant pathogenic nematodes were analyzed in one hundred and eight soil samples (27 from each crop rotation sequence). Except the fungivorous nematode, *Aphelenchus avenae* Bastian, 1865, other non-plant pathogenic nematodes were grouped as free-living nematodes.

1st rotation pattern

In the 1st rotation pattern, 5268 nematode specimens were identified (440 fungivorous nematode and 4828 free-living nematodes) combined for all treatments. Based on analysis of variance, the effect of tillage, crop residue retention and the interaction between tillage and residue retention on the population density of fungivorous and other free-living nematodes and the total number of non-plant pathogenic nematodes were not statistically significant. Nematode population densities under different tillage treatments in the 1st rotation pattern were presented in Figure 1A. On average the total numbers of fungivorous nematode and other free-living nematodes were higher in conventional tillage than reduced and no-till treatments but the effect of tillage was not statistically significant. Population density of non-plant pathogenic nematodes under different crop residue treatments were presented in Figure 1B. As the results show the effect of residue retention on the population density of fungivorous, other free-living nematodes and the total number of non-plant pathogenic nematodes were not statistically significant. The population of fungivorous nematode was almost the same in all the residue retention treatments. The highest and the lowest number of free-living nematodes and the total number of non-plant pathogenic nematodes were related to the no-residue retention and 60% residue retention treatments, respectively.

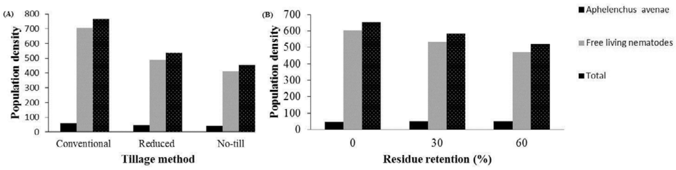

Figure 1: *Effect of different tillage methods (A) and different levels of residue retention (B) on the population of non-plant pathogenic nematodes in the 1st rotation pattern.*

The interaction effect of different tillage methods and different levels of residue retention on the population density of non-plant parasitic nematodes under the1st rotation pattern is presented in Table 3. Based on the results, the highest and lowest population density of the fungivorous nematode, *A. avenae* was related to the conventional tillage-30% residue retention and reduced tillage-30% residue retention treatments respectively. The highest and lowest population density of free-living and total population number of non-plant pathogenic nematodes were related to the conventional tillage-no-residue retention and reduced tillage-30% residue retention treatments, respectively. However, the interaction effect of tillage and residue retention on the population density of non-plant parasitic nematodes was not significant in the 1st rotation pattern.

2nd rotation pattern

In the 2nd rotation pattern, a total of 6700 nematode specimens were identified (67 fungivorous nematode and 6633 free-living nematodes) in all treatments. Based on the results from ANOVA the effect of tillage, crop residue retention and the interaction between tillage and residue retention on the population density of *A. avenae*, other free-living nematodes and the total number of non-plant pathogenic nematodes were not statistically significant. Nematode population densities under different tillage treatments in the 2nd rotation pattern were presented in Figure 2A. On average the population density of non-plant pathogenic nematodes were higher but not significant in the no-tillage than the conventional and reduced tillage treatments. The highest and the lowest number of non-plant pathogenic nematodes were related to the 30% and 60% residue retention treatments, respectively (Figure 2B). However, crop residue retention did not influence the population density of fungivorous, other free-living nematodes and the total number of non-plant pathogenic nematodes statistically.

The interaction effect of different tillage methods and different levels of residue retention on the population density of non-plant parasitic nematodes under the 2nd rotation pattern was not significant (Table 3). Based on the results, the highest and lowest population density of the fungivorous nematode was related to the conventional tillage no residue retention and reduced tillage-30% residue retention treatments respectively. The highest and lowest population density of free-living and total population number of non-plant pathogenic nematodes were related to the no-tillage-30% residue retention and reduced tillage-60% residue retention treatments, respectively.

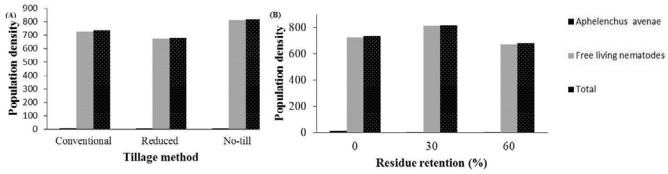

Figure 2: *Effect of different tillage methods (A) and different levels of residue retention (B) on the population of non-plant pathogenic nematodes in the 2nd rotation pattern.*

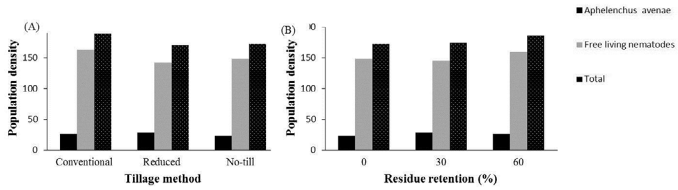

Figure 3: *Effect of different tillage methods (A) and different levels of residue retention (B) on the population of non-plant pathogenic nematodes in the 3th rotation pattern.*

3th rotation pattern

In the 3th rotation pattern, a total of 1600 nematode specimens were identified (237 fungivorous nematode and 1363 free-living nematodes) in all treatments. The results of ANOVA showed that the effect of tillage and crop residue retention on the population density of *A. avenae*, other free-living nematodes and the total number of non-plant pathogenic nematodes were not statistically significant but the interaction of tillage × residue retention influenced the population density of *A. avenae* (α=0.05), the population of free-living and total number of non-plant pathogenic nematodes (α=0.01) significantly. On average the population density of free-living and total number of non-pathogenic nematodes were higher but not significant in the conventional tillage than the reduced tillage and no-till treatments (Figure 3A). The highest number of free-living and the total non-pathogenic nematode numbers was related to 60% residue retention treatments (Figure 3B), however, residue retention did not influenced the population density of fungivorous, other free-living nematodes and the total number of non-plant pathogenic nematodes statistically.

The interaction effect of tillage and residue retention on the population density of *A. avenae*, free-living and total non-plant parasitic nematodes under the 3th rotation pattern was significant (Table 4). The difference between the highest and lowest population density of the fungivorous nematode that was related to the reduced tillage-60% residue retention and no-till-60% residue retention treatments respectively, was statistically significant. The highest and lowest population density of free-living and total number of non-plant pathogenic nematodes were related to the no-till-60% residue retention and reduced tillage-30% residue retention treatments, respectively.

4th rotation pattern

In the 4th rotation pattern, a total of 5710 nematode specimens were identified (1150 fungivorous nematode and 4560 free-living nematodes) in all treatments. Based on the ANOVA results, the effect of residue retention and the interaction of tillage × residue retention on the population density of *A. avenae*, other free-living nematodes and the total number of non-plant pathogenic nematodes were not statistically significant but tillage had a significant effect (α=0.05). On average the population density of *A. avenae*, free-living and total number of non-pathogenic nematodes was higher in the reduced tillage than the conventional and the no-till treatments. The population density of *A. avenae* in reduced tillage was significantly higher than the other tillage treatments. The population density of free-living and total number of non-pathogenic nematodes was significantly higher in reduced tillage than the no-till treatment but difference between reduced tillage and conventional tillage was not significant (Figure 4A).

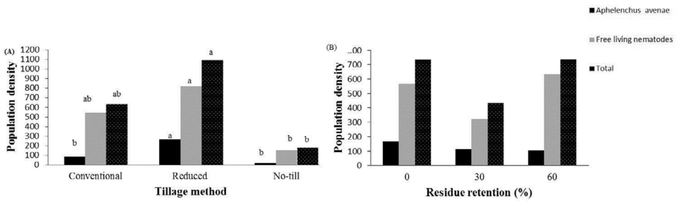

Figure 4: *Effect of different tillage methods (A) and different levels of residue retention (B) on the population of free-living nematodes in the 4th rotation pattern.*

The highest and the lowest number of free-living and the total non-pathogenic nematode was related to the 60% and 30% residue retention treatments respectively (Figure 4B), however, residue retention did not influenced the population density of fungivorous and other free-living nematodes significantly.

Table 3: *Interaction between tillage and crop residue retention on the population density of non-plant pathogenic nematodes in the 1st and 2nd rotation patterns.*

Tillage methods	Residue retention (%)	1st Rotation pattern			2nd Rotation pattern		
		A. aveneae	Free living nematodes	Total	*A. aveneae*	Free living nematodes	Total
Con. tillage	0	36.67^{a}	855.00^{a}	891.7^{a}	16.8^{a}	626.7^{a}	643.3^{a}
	30	96.67^{a}	786.70^{a}	883.3^{a}	6.8^{a}	806.7^{a}	813.3^{a}
	60	43.33^{a}	480.00^{a}	523.3^{a}	3.4^{a}	750.0^{a}	753.3^{a}
Reduced tillage	0	80.03^{a}	693.30^{a}	773.3^{a}	6.8^{a}	736.7^{a}	743.3^{a}
	30	13.37^{a}	210.00^{a}	223.3^{a}	0.0^{a}	720.0^{a}	720.0^{a}
	60	50.00^{a}	563.30^{a}	613.3^{a}	10.0^{a}	563.3^{a}	573.3^{a}
No-till	0	26.67^{a}	266.70^{a}	293.4^{a}	10.0^{a}	813.3^{a}	823.3^{a}
	30	36.67^{a}	606.70^{a}	643.4^{a}	6.7^{a}	910.0^{a}	916.7^{a}
	60	56.67^{a}	366.70^{a}	423.4^{a}	6.8^{a}	706.7^{a}	713.3^{a}

Means with the same letter in each colum are not significantly different from each other at α=0.05 based on Duncan's multiple range test.

Table 4: *Interaction between tillage method and crop residue retention on the population of non-plant pathogenic nematodes in the 3rd and 4th rotation patterns.*

Tillage methods	Residue retention (%)	3rd rotation pattern			4th rotation pattern		
		A. aveneae	Free living nematodes	Total	*A. aveneae*	Free living nematodes	Total
Con. tillage	0	16.67^{ab}	160.0^{abc}	176.70^{abc}	53.33^{b}	590.0^{ab}	643.3^{ab}
	30	36.67^{ab}	230.00^{a}	266.70^{a}	86.67^{b}	423.3^{ab}	510.0^{ab}
	60	26.67^{ab}	100.00^{bc}	126.70^{bc}	130.0^{b}	616.7^{ab}	746.7^{ab}
Reduced tillage	0	26.67^{ab}	216.70^{ab}	243.30^{ab}	423.3^{a}	796.7^{ab}	1220^{ab}
	30	20.00^{ab}	70.00^{c}	90.00^{c}	223.3^{ab}	443.3^{ab}	666.7^{ab}
	60	40.00^{a}	140.00^{abc}	180.00^{abc}	163.3^{b}	1223.0^{a}	1387.^{a}
No-till	0	26.67^{ab}	70.00^{c}	96.67^{c}	26.67^{b}	310.0^{ab}	336.70^{ab}
	30	30.00^{ab}	136.70^{abc}	166.70^{abc}	26.67^{b}	96.67^{b}	123.3^{b}
	60	13.33^{b}	240.00^{a}	253.30^{a}	16.67^{b}	60.00^{b}	76.67^{b}

Means with the same letter in each Colum are not significantly different from each other at α=0.05 based on Duncan's multiple range test.

The interaction effect of tillage and residue retention on the population density of *A. avenae*, free-living and total non-plant parasitic nematodes under the 4th rotation pattern was significant (Table 4). The highest and lowest population density of *A. avenae,* free-living and total number of non-plant pathogenic nematodes were related to the reduced tillage- no residue retention and no-tillage-60% residue retention treatments, respectively.

Agronomical practices play significant roles in regulating the composition and population density of soil decomposer microflora including bacterivorous and fungivorous nematodes (López-Fando and Bello, 1995; Govaerts *et al*., 2007; Henneron *et al*., 2014). In this study there was a considerable difference in the population density of fungivorous and other free-living nematodes in different rotational sequences. The population density of non-parasitic nematodes in 2nd rotation pattern (wheat, sugar beet, wheat, sugar beet and wheat) was four times more than the 3th rotation pattern (wheat, maize, wheat, melon and wheat). In general, the population of plant parasitic nematodes is more closely related to the availability of the host plants, while the population of free-living saprophagous nematodes is more closely related to the amount of organic matter in the soil than to the type of crop.

Tillage effects on the population density of non-plant parasitic nematode was variable in different rotational sequences and different level of residue retention. Our data showed that in the 1st and 2nd rotation patterns the effect of tillage, residue retention and the interaction effect of tillage × residue retention on the population of the fungivorous nematode and other non-pathogenic nematodes were not statistically significant, however in the 3th rotation pattern the interaction of tillage × residue retention and in the 4th rotation pattern tillage intensity influenced the population density of *A. avenae*, and other non-pathogenic nematodes significantly. Mashavakure *et al*. (2018) studied the impact of conventional tillage and reduced tillage practices on the population of soil and root-borne nematodes in maize and reported that different species of plant-parasitic nematode exhibited differential responses to different tillage systems. Rahman *et al*. (2007) compared wheat monoculture and wheat-lupin annual rotation sequence under residue management and tillage treatments in a long-term experimental site in Australia and reported that the population density of free-living nematodes were higher in rotational cropping sequence than monoculture while the population density of plant-parasitic nematodes (*Pratylenchus* and *Paratylenchus*) were higher in monoculture system. Based on a long-term field trails in Mexican subtropical highlands, Govaerts *et al*. (2006) reported that the population of plant-parasitic and non-parasitic nematodes were not different in wheat monoculture and wheat-corn annual rotation cropping system. Briar *et al*. (2012) showed that the nematode community did not differ significantly in two rotational patterns after 13 years in Manitoba, Canada except a significant reduction in the population density of fungivorous nematodes. On the hand, Djigal *et al*. (2012) reported that in a long-time experiment in Madagascar, the population density of plant-parasitic nematode were significantly higher in continuous corn monoculture than different rotational sequences, tillage and residue retention practices.

Conservation agricultural practices tends to increase the microbial biomass and activity in the root zone (Sturz *et al*., 1997; Lal, 2018). Increased soil microbial biomass can potentially discourage pathogen development as increased numbers of microorganisms compete for resources or cause inhibition through antagonism or the release of antibiotic (Weller *et al*., 2002) that can lead to competition effects resulting in reducing the pathogen inoculum pressure and formation of suppressive soils. Li *et al*. (2018) performed a global meta-analysis based on the published data on the effect of CA practices on soil microbial biomass, and reported that soil microbial biomass increased in no-tillage with residue retention on global scale.

Soil is an extremely complex ecological system that serves as a home for many beneficial as well as harmful organisms including bacteria, fungi, protozoa, nematodes, algae, earthworms and soil insects Understanding the interactions between agronomical practices and the soil microbial community is very important to develop disease management strategies (Kerdraon *et al*., 2019). The results of this study showed that under the crop rotational sequences, agronomical practices and environmental conditions of our experimental sites, CA practices had a variable effect on the population density of non-parasitic nematodes, however, further research is required to determine the impact of CA practices on the abundance of non-parasitic nematode and their effect on the population density of plant-parasitic as well as antagonistic nematodes.

Conclusions and Recommendations

We conclude based on the results of this study that CA-based agricultural practices influence the population density of non-pathogenic nematodes including the fungivorous (*A. avenae*) and free-living nematodes in different crop rotation patterns. The effect of tillage intensity and crop residue retention however depends on the rotational patterns and the feeding habit of nematodes. Because the population density of soil nematodes including the free-living, non-plant pathogenic nematodes are highly influenced by different factors including environmental conditions, Physicochemical and biological properties of soil as well as the crop plants used in rotation system, any technical advice for using conservation agriculture cropping systems or introducing a new crop rotation pattern should be based on the results of local research and agroechological conditions. The soil samples in the present study were taken at the later stage of crop growth from each rotational pattern. To accurately compare the influence of crop and CA practices on the population density of non-plant pathogenic nematodes, further studies are required to consider soil sampling and nematode population analysis between different crop rotations across the entire growing season. Continuation of long-term experiments is necessary to determine the potential capacity of non-pathogenic nematodes and other members of the soil microbial community in suppression of soil-borne plant pathogens including the fungal pathogens and plant-pathogenic nematodes.

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Novelty Statement

The current study indicated the changes in the population density of fungivorous and free-living nematodes, as an important part of soil biological community, after implementation of conservation agriculture farming systems in different crop rotation sequences.

Author's Contribution

Reza Aghnoum: Conducted the experiment, data analysis and drafted the manuscript.
Hamidreza Sharifi: Contributed to the research project in the Jolge-Rokh research station.
Masoud Ghodsi: Contributed to the research project in the Gonabad research station, statistical analysis.
Ahmad Zare Fizabadi: Contributed to the research project in the Torogh research station.

Conflict of interest
The authors have declared no conflict of interest.

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