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RESEARCH ARTICLE

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Exploring N fertilizer reduction and organic material addition practices: An examination of their alleviating effect on the nematode food web in cropland

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Abstract

Excessive nitrogen (N) fertilization in croplands results in environmental problems, such as soil quality deterioration, water contamination, and biodiversity losses, which threaten the sustainable development of soil ecosystems. The soil nematode food web plays key roles in soil organic matter decomposition and nutrient cycling, and thus the sustainable development of cropland ecosystems. However, how the negative impact from the excessive N fertilization on the nematode food web is effectively alleviated remains uncertain. This study aimed to explore the effects of different N fertilization management practices (N fertilizer reduction or organic material addition) on alleviating the negative effects on the nematode food web in croplands. Four treatments/ management practices were examined: conventional fertilization (N control), N fertilizer reduction of 100% (N_0), N fertilizer reduction of 50% (N_1), and conventional fertilization with organic material addition (N_{+S}). The results showed that the abundance of nematodes and microbial phospholipid fatty acids (PLFAs) both increased in the treatments of N_0, N_1, and N_{+S} compared with N. Besides, N_{+S} also increased the nematodes' biomass, diversity, and metabolic footprint, which correspondingly strengthened the nutrient turnover through the nematode food web. Overall, two management practices 1)N fertilizer reduction and 2) organic material addition, differ in the abiotic or biotic process in alleviating the negative effects of N fertilization on the nematode food web. The reducing N fertilization can directly alleviate the negative effect of fertilizer on soil acidification and then benefit for the growth of microorganisms and nematodes. The exogenous carbon input from organic material addition might promote carbon flowing and immobilization into nematode food web, and ultimately enhance the stability of soil food web.

KEYWORDS
carbon flow, N fertilizer reduction, nematode community, organic material addition, soil food web

1 | INTRODUCTION

Nitrogen (N) fertilizers are often applied to croplands to relieve N limitation and give the benefit of relatively high yields (Zhang et al., 2007). However, excessive N application can also lead to seriously harmful or negative effects, such as soil quality deterioration, water contamination, and biodiversity losses (Bai et al., 2010; Shahbaz et al., 2016). Numerous previous studies focus on the responses of

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crops aboveground to N fertilization (Becker, 1996; Qiao et al., 2012). However, increasing studies have paid attention to the ecological effect on belowground ecosystems in recent years. Soil faunas play key roles in soil nutrient availability and soil multifunctionality (Liang et al., 2005; Okada & Harada, 2007; Zhang et al., 2020), and are regarded as the guarantee of the sustainable development of cropland ecosystems (Cusack et al., 2011; Leininger et al., 2006; Neher, 2001; Wang et al., 2019; Yeates, 2003). In previous studies, it is inferred that the N fertilization influenced soil nematode abundance and diversity by changing soil conditions and N availability, and this then impacted the structure of nematode food webs through trophic interactions (Bardgett & Wardle, 2010; de Ruiter et al., 1998; Ferris et al., 2001; Okada & Harada, 2007; Zhao et al., 2014). Lenoir et al. (2007) suggested that fungivorous nematodes significantly reduced fungal biomass with top–down control within the soil food web after N fertilization. However, the opposite result was proposed by Li et al. (2010), who found that fungal decomposition channel was degraded due to the lower soil pH and high electrical conductivity induced by N fertilization. Additionally, Okada and Harada (2007) reported that the abundances of total nematodes, fungivores, bacterivores, and omnivores were lower in unfertilized plots than in chemical fertilized plots in a conventional tillage system. The previously-mentioned inconsistent results probably depend on the application amounts of the N fertilizers. It is generally thought that low amount of N fertilization has a positive and high or excessive one has a negative effect on soil nematodes (Li et al., 2009; Thakur et al., 2019). To relieve the negative effects of excessive N fertilization on soil fauna, the management practices mainly including N fertilizer reduction or organic material addition were proposed (Gao et al., 2020; Huang et al., 2015; Wile et al., 2014).

Reducing N fertilization as a direct method fundamentally solved some negative effects of excessive N fertilizer, but crop yields may not be guaranteed (Liang et al., 2015; Liang et al., 2018; Thorp et al., 2007; Wile et al., 2014). Organic materials containing large portions of labile carbon (C) (Metay et al., 2007; Ogle et al., 2003; West & Post, 2002) provide an essential source of C and energy for soil microorganisms and nematodes (Chivenge et al., 2007; Zhang et al., 2015). It was also observed that organic material addition increased the activities of most hydrolytic enzymes excreted by soil microbes and was significantly linked to the rates of nutrient mineralization (Liang et al., 2018; Zhao et al., 2016). Therefore, this was proposed as one possible effective practice to both maintain yields and alleviate the negative effects of excessive N fertilizer on the food web (Lu, 2015; Metay et al., 2007). Recent evidence indicated that organic material input with a higher ratio of carbon to nitrogen leads to competition between microorganisms and crops for N, which leds to reduction in crop production (Fontaine et al., 2004; Fontaine et al., 2003; Pan et al., 2016). Therefore, the combined application of organic material with chemical fertilizers was encouraged in sustainable and environmental-friendly agriculture to maintain production (Cai et al., 2019). However, its feasibility is still to be proved from the view of belowground biodiversity maintenance. Above-all, N fertilizer reduction and organic material addition both have their advantages and disadvantages, and there are urgent needs to fill the knowledge gap about which practice has a better alleviative/negative effect on biodiversity maintenance within the soil food web.

Therefore, the objective of this study was to explore the response of the nematode food web to management practices alleviating the negative N effects (N fertilizer reduction and organic material addition) in cropland ecosystems. We hypothesize that (a) the reduction of N fertilizer and the addition of organic material will directly or indirectly alleviate the negative N effects on the nematode food web, and (b) after alleviation, the growth of soil nematodes will be stimulated and the corresponding decomposition pathway and trophic relationship within the nematode food web will be varied with the reduction of N amount and the addition of organic material.

2 | MATERIALS AND METHODS

2.1 | Site description and experimental design

The N fertilization experiment was set up at the Tieling Agricultural Research Station of the Liaoning Academy of Agricultural Sciences (42°35′N, 123°63′E), Liaoning Province, Northeast China in 2014. The area has a temperate humid and semi-humid continental monsoon climate. The mean annual precipitation and temperature are 700 mm and 6.3°C, respectively. The soil type is Hapli-Udic Cambisol (FAO Classification). Maize (*Zea mays* L.) continuous cropping and conventional tillage were practiced before the experiment was initiated.

The experiment was a complete randomized block design with four treatments including conventional N fertilization as the control (N, 225 kg N ha^{-1} yr^{-1}), N fertilizer reduction of 100% (N_0, no N fertilization), N fertilizer reduction of 50% (N_1, 112.5 kg N ha^{-1} yr^{-1}), and combined organic material addition with conventional N fertilization (N_{+S}, 8000 kg ha^{-1} yr^{-1} straw application and 225 kg N ha^{-1} yr^{-1}; Table S1). The experiment was a completely randomized block design with three replicates plots, and the plot size was 62.1 m^2 (6 m × 10.35 m).

2.2 | Soil sampling and analysis

Soil samples were taken at a depth of 0–20 cm on July 7, 2017. In each plot, eight soil cores were randomly collected with a 2.5 cm diameter auger and then uniformly mixed as a composite sample for each replicate. In total, 12 soil samples (4 treatments × 3 replicates) were collected. A total of 10 g fresh soil was taken from each composite sample, and then frozen at −20°C for extracting microbial phospholipid fatty acids (PLFAs). Another subsample of the soil was air-dried in a dark condition for the analysis of soil properties. Then soil pH, total carbon and soil total nitrogen were measured using standard methods, and detailed description in Cui et al. (2018). A total of 5 g fresh soil was used for NH_4^+-N and NO_3^--N extraction with 50 ml 2 M KCL solution (Su et al., 2017).

2.3 | Soil enzyme activities

Soil enzyme activities were used to measure the functions of relevant microbial communities and significantly link to the rates of nutrient mineralization and organic matter decomposition (Carreiro et al., 2000; Saiya-Cork et al., 2002; Sinsabaugh et al., 2008). The activities of β-glucosidase (BG) and Leucine aminopeptidase (LAP) enzymes were quantified based on Saiya-Cork et al. (2002). Briefly, total 2 g fresh soils were placed in 500 mL container, add sodium acetate buffer, and the buffer keep a pH of 5.0, and blend on high speed for 1 min to make a slurry. Subsequently, 200 μl of slurry was added into the 96-well plates, and, then, added 50 μl of 5 mM substrate in each plate. The mixture was then incubated at 25°C for 2 hr, and the absorbance of spectrophotometer was determined using at 450 nm.

2.4 | Analysis of soil PLFAs

Soil microorganism composition was characterized using PLFA analysis according to Bossio et al. (1998). Detailed extraction processes were description in our previous studies (Cui et al., 2018; Guan et al., 2018; Kou et al., 2018; Zhang et al., 2015). The following PLFAs biomarkers were used: gram-positive (G^+) PLFAs (i15:1ω6c, i15:0, a15:0, i16:0, i17:1ω9c, i17:0, a17:0), gram-negative (G^-) PLFAs (16:1ω6c, 16:1ω7c, 16:1ω9c, 17:1ω8c, cy17:0ω7c, 18:1ω6c, 18:1ω7c, cy19:0ω7c), fungal PLFAs (18:2ω6c, 18:1ω9c), arbuscular mycorrhizal fungi (AMF) PLFAs (16:1ω5c), and actinomycete PLFAs (10MeC16:0, 10MeC17:0, 10MeC17:1ω7c, 10MeC18:0, 10MeC18:1ω7c) (Briar et al., 2011; Cui et al. 2018; Dempsey et al., 2013; McKinley et al., 2005). Fatty acids were converted into microbial biomass carbon according to de Vries et al. (2013) and Guan et al. (2018).

2.5 | Soil nematode extraction and identification

The modified cotton-wool filter method was used to extract soil nematodes with 100 g fresh soil (Liang et al., 2009). In each sample, nematodes were counted under stereoscope (OLYMPUS CX41), and then at least 100 nematodes were identified to genus level according to Bongers (1994), Ahmad and Jairjpuri (2010) and Liet al. (2017). Then the nematodes were divided into the following four trophic groups according to their morphological characteristics: bacterivores, plant parasites, fungivores, and predators-omnivores (Yeates, 2003).

The average fresh body weight (W) of each nematodes genus was defined based on http://nemaplex.ucdavis.edu. The nematode biomass carbon is calculated according to the following formula:

$$\mathrm{Ne}_{\mathrm{carbon}} = 20\% \times W_{\mathrm{f}} \times 52\%/100\,(\mu\mathrm{g\,g}^{-1})$$

where $\mathrm{Ne}_{\mathrm{carbon}}$ = nematode biomass carbon, W_{f} = nematode fresh weight (Ferris, 2010).

Nematode metabolic footprints values were calculated using the Nematode Indicator Joint Analysis (NINJA) (Sieriebriennikov et al., 2014). Nematode species abundance (number of nematode 100 g^{-1} dry soil) and Shannon–Wiener diversity (H') were calculated for each plot. Following equations were used to calculate the indices:

$$H' = -\sum_{i=1}^{S} n_i/N \times \ln(n_i/N) \tag{1}$$

where H'= Shannon–Wiener diversity, S = number of species, n_i = each genus individual number in identified samples, N = total individual number in identified samples.

2.6 | Statistical analysis

Data analysis was calculated using SPSS19 statistical software (SPSS Inc., Chicago, IL). One-way analysis of variance (ANOVA) was performed to assess the effects of N fertilization treatments on soil properties, microbial PLFAs, nematode biomass, and enzyme activities. The LSD test was used if the main effect was significant, and the differences at the $p < .05$ level were considered statistically significant. The effect of N fertilization treatments and types of microbial PLFAs (bacteria or fungi) or nematode trophic groups on biomass and biomass carbon were determined using two-way ANOVA. A Tukey's HSD test was used to permit pairwise comparisons of means.

Functional metabolic footprints of nematode communities under different N fertilization treatments were calculated using the NINJA application (Sieriebriennikov et al., 2014). The vertical axis represents the enrichment footprint and the horizontal axis represents the structural footprint. The x-axis coordinates of the metabolic footprints are calculated as SI-0.5F_s/k and SI + 0.5F_s/k, and the y-axis coordinates as EI-0.5F_e/k and EI + 0.5F_e/k. The functional metabolic footprint is depicted by sequentially joining points: SI-0.5F_s/k, EI; SI, EI + 0.5F_e/k; SI + 0.5F_s/k, EI; SI, EI-0.5F_e/k; and SI, EI (central point). F_s (structure footprint) is the sum of the standardized C utilization from the structural indicator taxa and F_e (enrichment footprint) from the enrichment indicator taxa, and the k value is 2. The total nematode metabolic footprint defined as the total area of the enrichment and structure footprints (Ferris, 2010).

We analyzed the correlations between soil properties and soil microbial and nematode biomass carbon using the 'Corrplot' function in R studio software (version 3.1.2). In order to determine the effects of the management practices on soil nematode food web associations, Spearman's rank correlation matrix based on biomass carbon data of microorganisms and nematodes were depicted graphically through network analysis using the CYTOSCAPE software, version 3.7.1 (Kou et al., 2020; Morriën et al., 2017; Shannon et al., 2003).

3 | RESULTS

3.1 | Soil physiochemical properties

Reducing N fertilizer application treatments including N_0 and N_1 all significantly influenced the soil pH and moisture ($p < .05$), with the highest values in N_0. Compared with the control (N), N_0 and N_1 significantly decreased the soil NO_3^--N. No significant differences were found in the measured soil physiochemical properties between N and N_{+S} treatments (Table 1).

3.2 | Soil enzyme activities

The values of enzyme activities ranged from 6.59 to 10.81 μ mol hr^{-1} g^{-1} dry soil for BG, and from 0.41 to 1.47 μ mol hr^{-1} g^{-1} dry soil for LAP. The organic material addition (N_{+S}) had a significant effect on the enzyme activities of both BG and LAP ($p < .05$; Figure 1). For BG activity, a significant higher value was observed in N_{+S} than in other treatments ($p < .05$). The activity of LAP was significantly higher in N_1 and N_{+S} than in N_0 and N ($p < .05$; Figure 1).

TABLE 2 Two-way ANOVA on the effect of N fertilization treatments and types of microbial PLFAs and nematode trophic groups on biomass

F values of ANOVA	Microbial biomass	Nematode biomass
Nitrogen (N)	9.93**	3.11*
Type (T)	238.32**	18.68**
N × T	1.09	1.76

*$p < .05$.
**$p < .01$.

TABLE 1 Soil physichemical properties in different N fertilization treatments (means ± *SE*)

	N	N_0	N_1	N_{+S}	*F*-value	*p*-Value
Soil pH	5.07 ± 0.03c	5.37 ± 0.03a	5.26 ± 0.01b	5.13 ± 0.01bc	5.51	.02
Soil moisture (%)	11.24 ± 0.18b	12.04 ± 0.04a	11.31 ± 0.25b	10.87 ± 0.25b	6.12	.02
Total carbon (g kg^{-1})	11.70 ± 0.06	10.76 ± 0.32	11.43 ± 0.20	11.53 ± 0.33	2.58	ns
Total nitrogen (g kg^{-1})	1.60 ± 0.01	1.43 ± 0.03	1.50 ± 0.01	1.50 ± 0.01	2.43	ns
C/N	7.32 ± 0.23	7.51 ± 0.05	7.62 ± 0.14	7.70 ± 0.12	0.59	ns
NO_3^--N (mg kg^{-1})	20.83 ± 6.11a	3.66 ± 0.49b	9.39 ± 0.30b	10.28 ± 2.82ab	4.48	.04
NH_4^+-N (mg kg^{-1})	9.61 ± 1.41	2.92 ± 0.36	4.86 ± 1.49	5.67 ± 2.01	3.75	ns

Note: Different lower-case letters represent significant differences among different N fertilization treatments, as determined by LSD test.

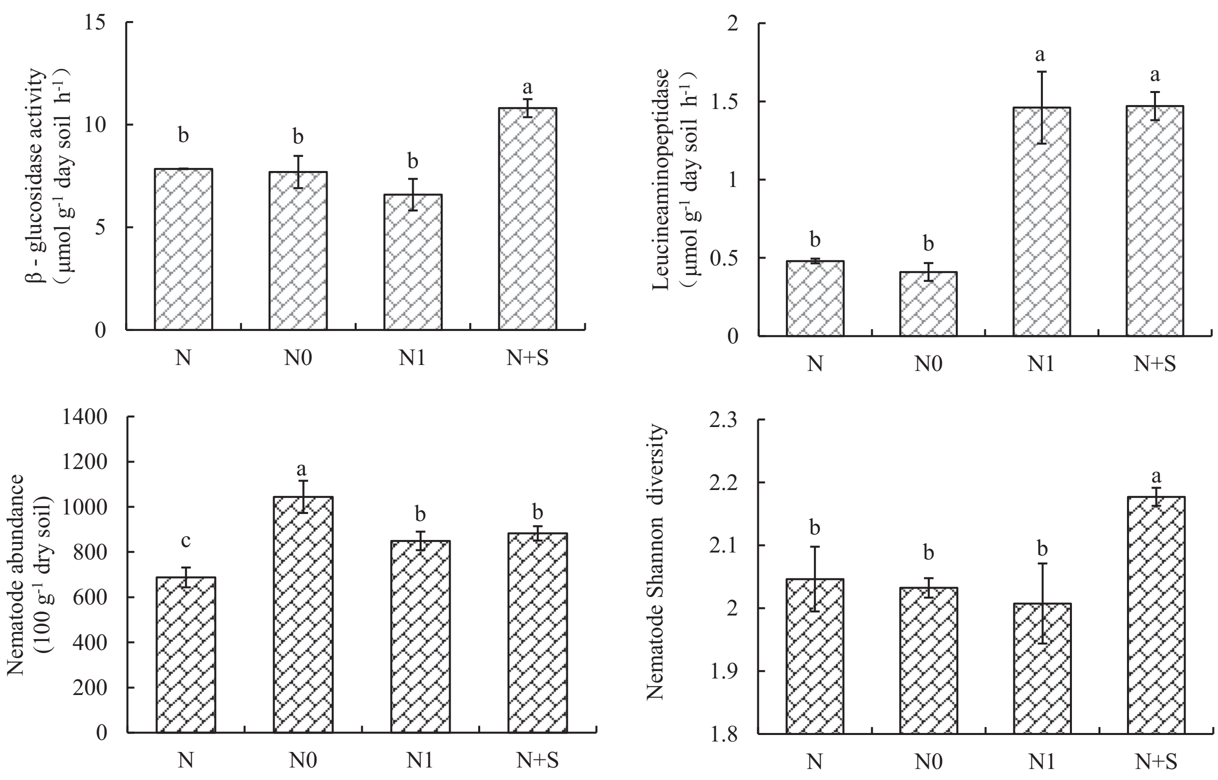

FIGURE 1 The enzyme activities and abundance and Shannon–Wiener diversity of nematodes under different N fertilization treatments. Different lower-case letters represent significant differences among different N fertilization treatments, as determined by LSD test

TABLE 3 Two-way ANOVA on the effect of N fertilization treatments and types of microbial PLFAs and nematode trophic groups on biomass carbon (means ± *SE*)

Type / Treatment	Microbial biomass carbon		Nematode biomass carbon			
	Bacteria	Fungi	Bacterivores	Fungivores	Plant parasites	Predator-omnivores
N	111.60 ± 4.27	601.56 ± 41.36	12.11 ± 1.09a	3.74 ± 0.11	4.08 ± 0.77	6.37 ± 2.27c
N_0	123.72 ± 0.51	715.29 ± 28.52	11.02 ± 0.96a	6.15 ± 1.16	5.91 ± 0.78	21.40 ± 3.94b
N_1	113.47 ± 0.77	678.90 ± 43.66	8.96 ± 0.80ab	6.07 ± 0.65	4.93 ± 1.46	19.13 ± 3.70bc
N_{+S}	121.63 ± 6.80	630.03 ± 22.67	6.76 ± 0.40b	4.79 ± 0.63	8.06 ± 0.46	54.92 ± 0.07a
F values of ANOVA						
Nitrogen (N)	2.22		38.89**			
Type (T)	17.28**		134.65**			
N × T	0.49		41.64**			

Note: Different lower-case letters represent significant differences among different N fertilization treatments, as determined by Tukey's test.
**$p < .01$.

3.3 | Soil microbial PLFAs and biomass carbon

Both the N fertilization and the types of microorganism have a significant effect on the microbial PLFAs (Table 2), but not on the bacterial or fungal biomass carbon (Table 3). The microbial PLFAs of actinomycete and fungi were both significantly higher in N_0 than in N ($p < .05$), and there was no significant difference in the PLFAs of G^+ and G^- among different treatments (Figure 2a). The PLFAs value of actinomycete and fungi were significantly lower than that of G^+ and G^-.

3.4 | Soil nematode communities

Nematodes' abundance was significantly higher in N_0, N_1, and N_{+S} than in N ($p < .05$). Compared with N_0, N_1, and N_{+S} significantly increased the Shannon–Wiener diversity index of nematode ($p < .05$; Figure 1). Two-way ANOVA showed that the N fertilization and types of nematode trophic groups have significant effects on the nematode biomass and biomass carbon ($p < .05$; Tables 2 and 3). The biomass value of predator-omnivores was significantly higher than other three nematode trophic groups in N_0, N_1, and N_{+S} treatments, but not in N ($p < .05$; Figure 2b). Different fertilization treatments also significantly influenced the biomass carbon of bacterivores and predator-omnivores with the higher value in N and N_{+S}, respectively, but did not impacted that of fungivores and plant parasites (Table 3). The nematode functional metabolic footprint (NMF), which is the total area of the enrichment and structure footprints, is shown in Figure 3. The total NMF was the greatest in N_{+S}, and higher structure index and a lower enrichment index were found in N_{+S} than in other treatments.

3.5 | Relationships among soil properties, microbes, and nematodes

Soil fungal and fungivores biomass carbon were all positively correlated with soil pH ($p < .05$; $p < .01$). The soil enzyme activities of BG

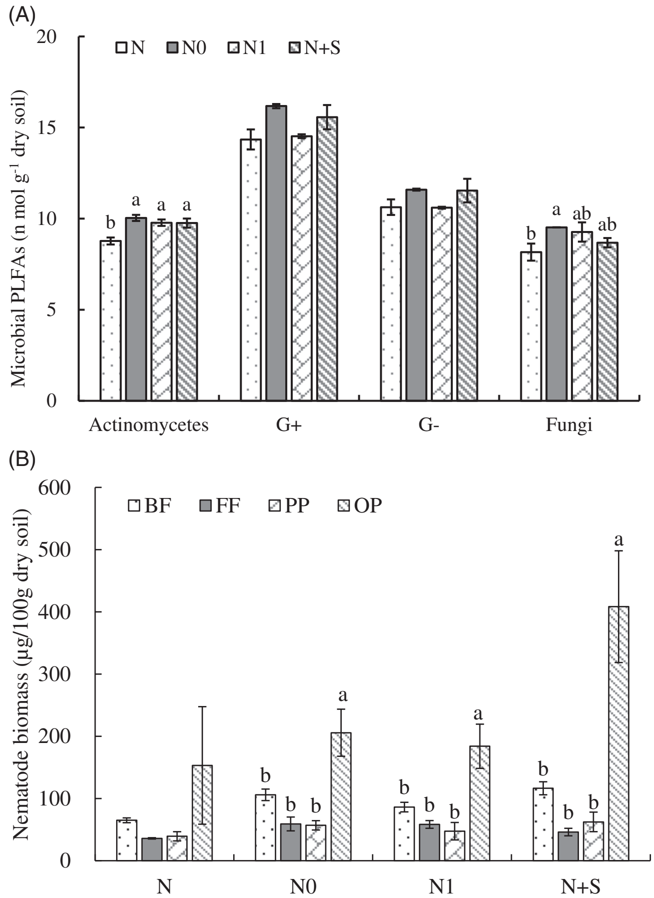

FIGURE 2 The microbial PLFAs and nematode biomass under different N fertilization treatments. Different lower-case letters in microbial community represent significant differences among different N fertilization treatments, and different lower-case letters in nematode community represent significant differences among different trophic groups, as determined by Tukey's test. PLFA, phospholipid fatty acid

and LAP showed a significantly positive relationship with predator-omnivores biomass carbon ($p < .05$). No significant relationship was found among soil moisture, TC, TN, C/N, and biomass carbon of soil microbes and nematodes (Figure 4). An obviously negative relationship between predator-omnivores and other trophic groups was found in N, which indicated a weak predator channel or predation relationship. Oppositely, N_{+S} showed a relative stronger predator relationship among predator-omnivores, fungivores, G^+, G^-, and fungi. Positive relationship between microbes (fungi, G^+ and G^-) and fungivores was found in N_0, which indicated that more carbon flow through fungal channel (Figure 5).

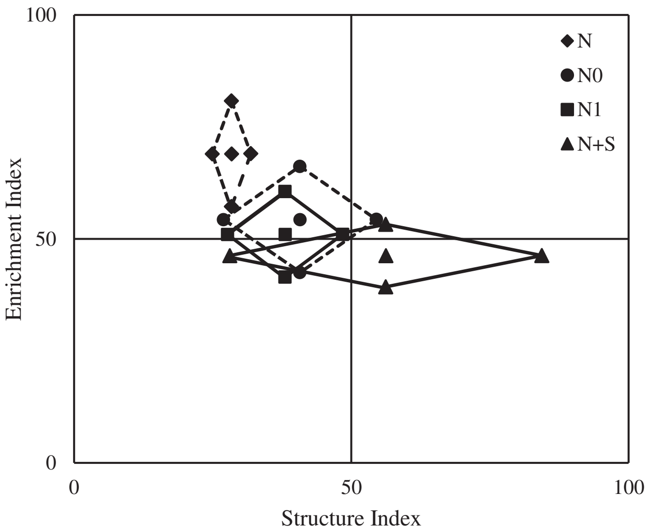

FIGURE 3 Functional metabolic footprints of nematode communities under different N fertilization treatments. The vertical axis represents the enrichment footprint and the horizontal axis represents the structural footprint (Ferris, 2010)

4 | DISCUSSION

4.1 | Effect of N fertilizer reduction and organic material addition on microbial and nematode communities

In our study, we found that N fertilization and types of soil fauna (microbial PLFAs or nematode trophic groups) have significant effects on the microbial and nematode biomass (Table 2). Among N fertilization treatments, N fertilizer reduction (N_0 and N_1) significantly increased the biomass of actinomycete and fungi (Figure 2a), and had different effect on the nematode biomass of different trophic groups with obvious response from predator-omnivores (Figure 2b). These results reflected that the susceptible response of soil biota to fertilizer reduction was in a positive way (Laliberte et al., 2017), and reduced N fertilization would be beneficial to the growth of soil biota. It was further confirmed that N fertilizer reduction directly decreased the

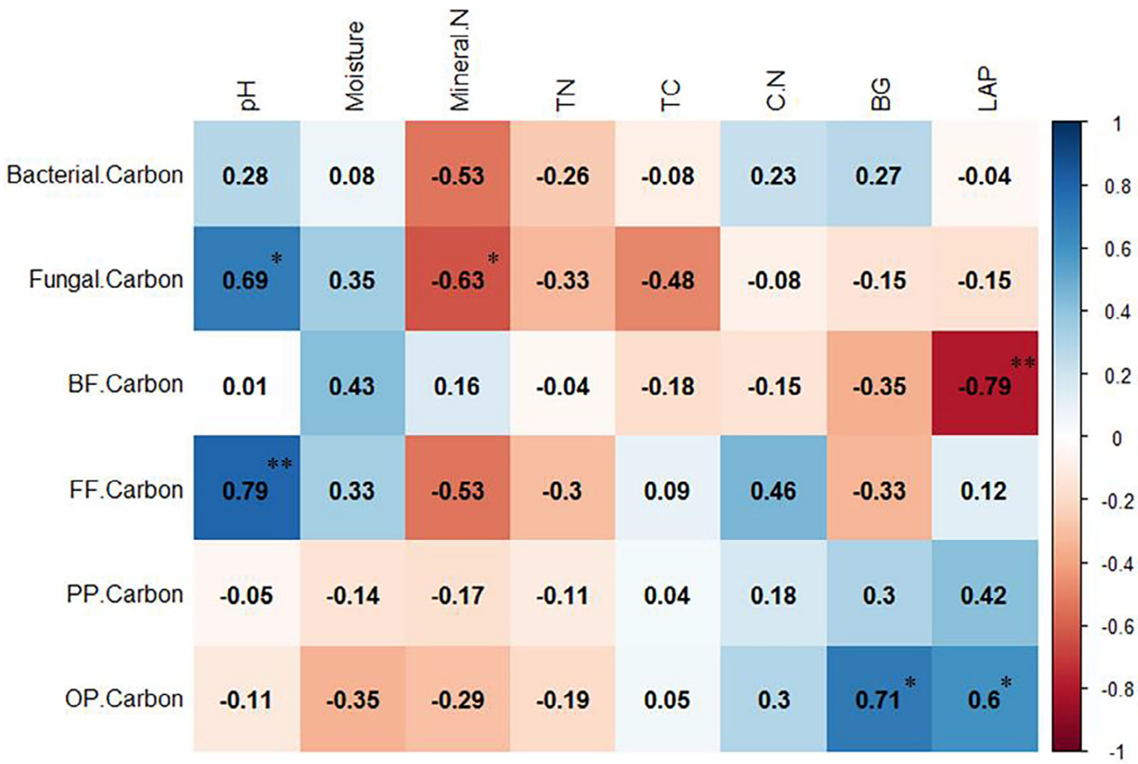

FIGURE 4 Relationships among soil properties, microbes and nematode trophic groups' biomass carbon, as determined by the Pearson test. *$p < .05$; **$p < .01$. Mineral.N, sum of NH_4^+-N and NO_3^--N; TN, total nitrogen; TC, total carbon; C.N, ratio of carbon to nitrogen; BG, β-glucosidase; LAP, leucine aminopeptidase; Bacterial.Carbon, bacteria biomass carbon; Fungal.Carbon, fungi biomass carbon; BF.Carbon, bacterivores biomass carbon; FF.Carbon, fungivores biomass carbon; PP.Carbon, plant parasites biomass carbon; OP.Carbon, predators-omnivores biomass carbon [Colour figure can be viewed at wileyonlinelibrary.com]

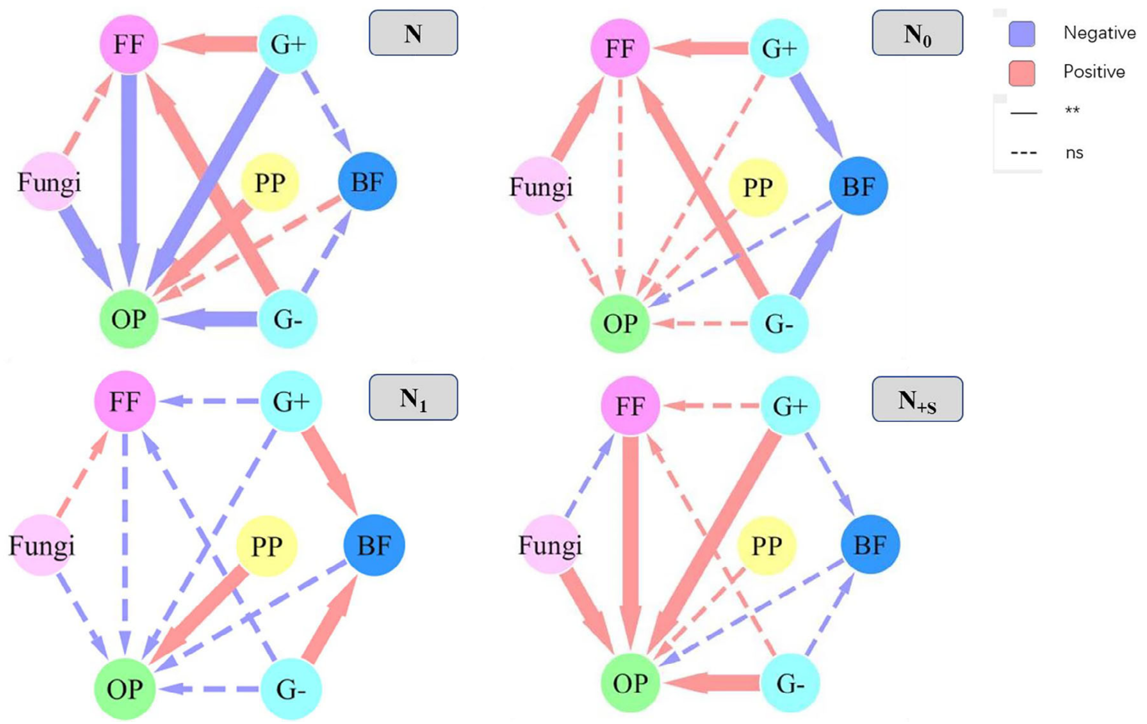

FIGURE 5 Relationship between microorganism and nematodes. The solid and dashed lines represent significant and insignificant correlations, respectively. The red and blue lines represent positive or negative correlations, respectively, as determined by the Spearman test. G^+, gram-positive biomass carbon; G^-, gram-negative biomass carbon; Fungi, fungi biomass carbon; BF, bacterivores biomass carbon; FF., fungivores biomass carbon; PP, plant parasites biomass carbon; OP, predators-omnivores biomass carbon [Colour figure can be viewed at wileyonlinelibrary.com]

amount of NO_3^--N in the soil, then alleviated the soil acidification (pH from 5.07 in N to 5.37 in N_0) caused by excessive N fertilizers (Table 1), which was one of the important reasons that promoting the growth of soil biota (Song et al., 2016). However, different from previous studies (Li et al., 2010; Okada & Harada, 2007), we did not find that soil nematode diversity increased in N fertilizer reduction treatments (N_0 and N_1) (Figure 1). It was generally considered that ecosystem multifunctionality potentially depended on diversity of soil biota (Wang et al., 2019) and soil nematode diversity was also related to a vast number of vital ecosystem functions and services (Bardgett & van der Putten, 2014). From the view of biodiversity, N fertilizer reduction contributes less to ecosystem function. Nitrogen fertilizer reduction directly alleviated the negative effect of N fertilizers on soil acidification and benefit for the growth, but not for the diversity of soil fauna.

Compared to conventional N fertilization (N), organic material addition also stimulated the biomass of soil microorganisms and nematodes. However, compared with the N fertilizer reduction (N_0 and N_1), a significant higher biomass (Figure 2b) and biomass carbon (Table 3) of predator-omnivores nematodes appeared in organic material addition. Predator-omnivores with a relatively bigger body are particularly susceptible to soil conditions, especially soil physical structure (Freckman & Caswell, 1985; Yeates et al., 2009; Zhang et al., 2013). It had been proved that organic material addition contributed to the formation of large aggregates and increased soil porosity (Chivenge et al., 2007; Liang, Cai, et al., 2018), which could provide suitable conditions and bigger space for the movement and predation of predator-omnivores, and therefore their biomass was enhanced correspondingly (Ferris, 2010). Additionally, there was a significantly higher value of nematode diversity in N_{+S} than in other treatments (Figure 1). The diversity of soil biota determines the rates and magnitudes of ecosystem services and its increase is beneficial for maintaining ecosystem functioning of the soil food web (Wang et al., 2019).

4.2 | Effect of N fertilizer reduction and organic material addition on relationships among the nematode food web

Compared with other treatments, N_{+S} showed a greater nematode metabolic footprint (Figure 3), which indicated a stronger metabolic process in the nematode food web decomposition pathway (Ferris, 2010). It can be explained by the greater predator-omnivores being fuelled by organic material addition, and then a stronger pathway through predator channel was activated. The larger predation strength may stimulate the stronger metabolic process (Ferris, 2010; Thakur & Geisen, 2019). Additionally, the main decomposition pathway within soil food web (i.e., bacterial and fungal channel) was significantly different among fertilization reduction treatments. Treatments of N_0 and N_1 showed a relatively stronger pathway through fungal and bacterial channels, respectively (Figure 5). It can be seen from this result that the dominant channel, bacterial or fungal channel, mostly depended on the amount of the reducing N fertilization (reduced 50% or 100%). Bacterial and fungal channels are, respectively, considered fast and slow decomposition pathways with regard to rates of mineralization and nutrient turnover (Chen et al., 2015; de Vries & Caruso, 2016; Fabian et al., 2017). The amount of nutrient being regulated by N fertilization application coordinated the nutrient decomposition channels and enhanced the trophic connection between soil microbes and nematodes (Kou et al., 2020).

We also observed that soil enzyme activities of BG and LAP were significantly higher in N_{+S} than that in N (Figure 1), and have a significant positive relationship with predator-omnivores biomass carbon (Figure 4). The reason for this is that the addition of organic material stimulated the microorganisms to produce more enzyme to accelerate the decomposition process and release more nutrients, which in turn promoted the microorganisms' growth and then predation strength (Ai et al., 2012; Bowles et al., 2014). Thus, it proved again that organic material addition strengthened the metabolic process within the nematode food web (Metay et al., 2007; Samahadthai et al., 2010), and even the exogenous carbon immobilization by soil biota.

In summary, N fertilization management practices significantly influenced the relationship within the soil nematode food web. Both N fertilizer reduction and organic material addition strengthened the links between different trophic groups and definitely alleviating the negative effect of N fertilizer on the nematode food web. However, compared with N fertilizer reduction treatment, organic material addition enhanced the cascade effect among trophic groups and structured the more stable nematode food web, thus exerts a better alleviation.

5 | CONCLUSIONS

In our study, two kinds of management practices, N fertilizer reduction and organic material addition, differ in how they affect the abiotic or biotic process of alleviating the negative effects of N fertilizer on the nematode food web. Reducing N fertilization alleviates the negative effect of N fertilizers through changing soil pH and available N, and then benefits the soil fauna by improving their survival conditions. Organic material addition alleviates the effects of N fertilizers by changing soil biological characteristics, for example, soil enzyme activities and predation strength of food web. Furthermore, we confirmed that organic material addition enhanced the diversity and metabolic footprint of soil nematodes, and then fuelled the energy flow through predation channel, which will promote the stability of soil food web.

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CONFLICT OF INTEREST

Authors declare no conflicts of interest.

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SUPPORTING INFORMATION

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