

RESEARCH LETTER

Interaction of organic nitrogen and C/N ratio enhances soil microarthropod abundance

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[Correction added on [27 October 2025], after first online publication: The third author's first name spelling was incorrect as "Kazuo" and has been corrected to "Kazuto" in both the byline and the Author Contributions section and also in the ORCID list at the end of the article.]

Abstract

Organic management is widely regarded as an effective strategy to prevent soil degradation in agroecosystems. In this study, we investigated the abundance of soil microarthropods in a multi-cropping system by comparing organic and conventional management practices. A total of 189 soil samples were collected from 63 agricultural sites cultivating three crops: paddy rice (*Oryza sativa* L.), soybeans [*Glycine max* (L.) Merrill], and vegetables [*Cucurbita moschata* (Duch.) Poir., *Solanum melongena* L., etc.]. An averaged generalized linear mixed model revealed that both organic management and vegetable cropping were associated with significantly higher microarthropod abundance. We also detected a positive interaction between the soil carbon-to-nitrogen ratio and organic nitrogen content, indicating that organically enriched soils provide favorable conditions for microarthropods. Our findings demonstrate that agricultural management practices, cropping systems, and soil nutrient profiles collectively shape the abundance of soil microarthropods.

Plain Language Summary

Recently, chemical fertilizers and pesticides have been used on agricultural lands to achieve higher crop production, which could have negative impacts on the agroecosystem. Organic farming uses organic fertilizers and avoids chemical inputs. Microarthropods ecologically play a vital role and can be affected by inputs into the agricultural soil. As the abundance of soil microarthropods determines soil functionality, we wanted to investigate how the abundance differs according to agricultural practice as well as in major crop types like paddy, soybean, and vegetable. We examined how microarthropods respond to chemical properties whose content is influenced by agricultural inputs. We found higher microarthropod abundance in the organic management and the vegetable crop field, and their abundance is responsive

Abbreviations: CN, carbon-to-nitrogen; EC, electrical conductivity; GLMM, generalized linear mixed model; IN, inorganic nitrogen; ON, organic nitrogen.

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to carbon and organic nitrogen content in the soil. We concluded that microarthropod abundance was promoted by organic farming and cropping system also had an impact on it.

1 | INTRODUCTION

The use of chemical fertilizers and pesticides has not only enabled the supply of sufficient food to sustain a growing population (Stewart et al., 2005) but has also helped reduce the conversion of natural ecosystems to agricultural land (Jiang & Li, 2016). However, their excessive use can degrade agroecosystems and cause nitrogen (N) loading in watersheds (Kanter, 2018). Therefore, reducing their use has become an important goal (e.g., Fan et al., 2023). In this context, organic management offers a promising alternative. It relies on locally available organic inputs (Klaus et al., 2013) while restricting synthetic fertilizers and pesticides (Geiger et al., 2010; Ponce et al., 2011).

Soil quality and functionality are determined by both biological (microorganisms, mesofauna, and macrofauna) and chemical properties, including nutrient levels (N, phosphorus [P], potassium [K]) and related indicators such as pH, electrical conductivity (EC), and the carbon-to-nitrogen (CN) ratio (Iqbal et al., 2021; Liu et al., 2017; Riches et al., 2013; Schoenholtz et al., 2000). Soil microarthropods (0.2–2 mm) are key members of the mesofauna, occupying different trophic levels (Reilly et al., 2023). They contribute to soil structure, aeration, organic matter transformation, and interact closely with microbial communities through burrowing, feeding, and habitation activities (Gergőcs et al., 2022; Menta & Remelli, 2020; Tóth et al., 2025). Microarthropods respond in complex ways to agricultural inputs, depending on their feeding habits and habitat preferences (Bardgett & Cook, 1998; Russell et al., 2014). For example, mite populations can increase when habitats become more favorable, while springtails rely on young carbon (C) sources such as living roots and algae (Fujii et al., 2021; Shen et al., 2021). Since microbes are a key food source for microarthropods, and microbial activity is higher in organic matter-rich soils (Chahartaghi et al., 2005; Kundel et al., 2020; Schneider et al., 2004), high organic matter content can promote microarthropod abundance (Vreeken-Buijs et al., 1998). Previous studies have reported higher microarthropod abundance under organic management (Meyer et al., 2021; Reilly et al., 2023). For instance, Ostandie et al. (2021) found a 31.6% increase in Collembola in organically managed vineyards (*Vitis* spp.). Crop type also influences microarthropod numbers (Gergőcs et al., 2022). Peredo et al. (2009) reported densities of 23,540 individuals/m² in conventional fields versus 24,170 individuals/m² in an organic cranberry (*Vaccinium*

sp.) plantation after 6 years of management. Similarly, Scheunemann et al. (2015) observed abundances below 5000 individuals/m² in maize (*Zea mays* L.) fields but between 6000 and 20,000 individuals/m² in wheat (*Triticum aestivum* L.) fields, depending on the sampling period.

Agricultural management practices also differ in their effects on soil chemical properties, including carbon (C), nitrogen (N), and phosphorus (P) contents (Clark et al., 1998; Glisic et al., 2009; Poudel et al., 2002). While many studies have examined links between soil chemistry and microbial communities (Nautiyal et al., 2010; Page et al., 2020) or compared chemical properties alone (Aranda et al., 2011; Hou et al., 2025), few have compared microarthropod abundance under different management types in multi-cropping systems while also considering key nutrients such as organic nitrogen (ON), inorganic nitrogen (IN), and P₂O₅.

In this study, we examined soil microarthropod abundance in agricultural fields under organic and conventional managements across multiple cropping systems. We tested two hypotheses: (1) agricultural management and cropping system significantly influence microarthropod abundance by creating different environmental conditions across crop types; and (2) soil microarthropod abundance is affected by soil chemical properties, particularly organic nutrient content.

2 | MATERIALS AND METHODS

2.1 | Study sites and sampling design

The study was conducted in the Toyama prefecture, located in central Japan (36°43'25.20" N, 137°10'50.38" E), which features plains, hills, and mountains. Excluding mountainous areas, the area has an annual average temperature of 13°C–14°C, with August averaging 26.8°C, January averaging −1°C–2°C, and annual precipitation around 2300 mm (Aiura et al., 2018). The agricultural plain is predominantly composed of Gleysols, Fluvisols, and Andosols (Yanai et al., 2012).

A total of 63 fields were investigated (Figure S1), categorized into two management types, organic and conventional, and three crop types: paddy (*Oryza sativa* L.), soybean [*Glycine max* (L.) Merrill], and vegetable [*Cucurbita moschata* (Duch.) Poir., *Solanum melongena* L., etc.] (Table 1). Organically managed fields (both certified and noncertified) farmers acknowledged based restricted

pesticides, herbicides, and synthetic fertilizers, but used organic inputs. Additionally, conventional management uses market-available NPK fertilizer, pesticides, and chemical and mechanical weed treatment. Soil samples were collected between August and November in 2022 and 2023: soybean and vegetable soil samples were collected in crop situations, but paddy soil samples were collected in nonirrigated and dry conditions after harvesting. For each field, three soil samples were collected—two from the edge portion and one from the center, maintaining a minimum distance of 5 m between samples—at a depth of 0–5 cm. Each sample was collected using a sealed stainless-steel core ($\varnothing$ 5 cm $\times$ 5.1 cm; 100 cm³) and was processed for laboratory analysis on the same day as collection.

2.2 | Laboratory analysis

Berlese–Tullgren funnel was used to extract microarthropods, which were collected to be preserved in previously arranged 70% ethanol in a glass bottle. A stereomicroscope (Carton, Japan DSZT-70IFL, MS-7833) was used to identify the arthropods less than 2 mm in size, and all the identified individuals were counted (Briones, 2014; Dombos et al., 2017).

Air-dried soil samples were sieved to $\leq$ 2-mm particle size and oven-dried (ISUZU EPN-115) at 105°C for 2 h to remove the remaining moisture from the samples. Total carbon (TC), total nitrogen (TN), NO₃, NH₄, P₂O₅, pH, and EC were analyzed with the dried samples. The content of soil TC and TN was assessed by the dry combustion method using a CN Corder MT-700 (YANACO). pH and EC were measured by a compact pH meter (Horiba LAQUAtwin compact) and an EC meter (Horiba LAQUAtwin compact conductivity), respectively. The inorganic forms of nitrogen, IN, such as NH₄ and NO₃, were quantified by a spectrophotometric method based on the indophenol blue method and naphthylethylenediamine method after zinc (Zn) reduction (Hata et al., 1992). IN and ON were expressed by $IN = (NH_4 - N + NO_3 - N)$ (Dai et al., 2016) and $ON = TN - IN$ (Jickells et al., 2013; Yang et al., 2019), respectively. P₂O₅ was calculated from PO₄²⁻ concentration determined by the molybdenum blue method (Taguchi et al., 1985).

2.3 | Statistical analysis

We conducted all data analysis in R (version 4.4.1) using packages glmmTMB, MuMIn, effects, ggplot2, DHARMA, car, dplyr, MASS, and emmeans (R Core Team, 2024). The Wilk–Shapiro test ($p < 0.05$) was performed to check the normality and homoscedasticity of the data. Generalized linear mixed models (GLMMs) were used to assess the relationship

Core ideas

- Soil microarthropod abundance differs between agricultural managements and among cropping systems.
- Organic management and carbon–nitrogen-related soil properties have a positive impact on microarthropods.

between soil microarthropod abundance as response variables, and habitat traits (agricultural management, and crop type) and chemical properties (CN, ON, IN, P₂O₅, pH, and EC) as explanatory variables. Random factor “field ID” was used to handle group-structured and nonindependent samples. Negative binomial distribution was used in the GLMMs to handle the overdispersion of data. The model with combinations of explanatory variables was executed by the dredge function from the MuMIn package. Competitive models were determined by $\Delta AICc < 2$ and AICc (where AICc indicates corrected Akaike information criterion) was used because of the small sample size (number of observations/estimated variables < 40) (Barrientos & Bolonio, 2009; Ponce et al., 2011), and the DHARMA package was used to check the model fit (Goldstein & de Valpine, 2022). Model averaging was conducted using the “model.avg” function from the MuMIn package and model-averaged coefficient value was extracted for predictor variables (Marie et al., 2018). To assess the significance of the differences in soil properties between practices and among crop types, a number of GLMMs with gamma distribution (natural logarithm link) were executed (Potapov et al., 2017; Salekin et al., 2021). The fixed factors were “agricultural management” and “crop type,” respectively. For the retrieval of the significance of soil properties, a posteriori tests were conducted using the emmeans function with Tukey’s honestly significant difference test.

3 | RESULTS

Nine groups of soil microarthropods were identified (Table S1), with Collembola being the most abundant (48.45%), followed by Acari (28.09%) and Araneae (11.74%). The mean density of total microarthropods was 6.39 individuals per 100 cm³ (range: 0–41 individuals per 100 cm³), which corresponds to an average of 3,256 individuals/m², ranging from 0 to 20,892 individuals/m².

The averaged GLMM from the five competitive GLMMs (Table S2) identified agricultural management, crop type, P₂O₅, pH, EC, CN ratio, ON, and the CN $\times$ ON interaction as explanatory variables (Table S3). Among these, agricultural management (organic), crop type (vegetable), and

TABLE 1 Soil chemical properties of agricultural lands. Mean values ($\pm$ S.E.) are shown for TC (total carbon), TN (total nitrogen), ON (organic nitrogen), IN (inorganic nitrogen), P_2O_5 (phosphorus pentoxide), carbon-to-nitrogen (CN) ratio, pH, and EC (electrical conductivity).

Chemical property	Agricultural management		Crop type		
	Conventional ($N = 34$) ($n = 102$)	Organic ($N = 29$) ($n = 87$)	Paddy ($N = 36$) ($n = 108$)	Soybean ($N = 15$) ($n = 45$)	Vegetable ($N = 12$) ($n = 36$)
TC (mg/g)	29.41 $\pm$ 1.32a	27.92 $\pm$ 1.15a	27.03 $\pm$ 1.15a	29.01 $\pm$ 1.15a	33.60 $\pm$ 1.49a
TN (mg/g)	2.51 $\pm$ 0.09a	2.40 $\pm$ 0.07a	2.37 $\pm$ 0.09a	2.42 $\pm$ 0.06a	2.72 $\pm$ 0.07a
ON (mg/g)	2.46 $\pm$ 0.09a	2.37 $\pm$ 0.07a	2.34 $\pm$ 0.09a	2.39 $\pm$ 0.06a	2.68 $\pm$ 0.07a
IN (mg/g)	0.04 $\pm$ 0.001a	0.03 $\pm$ 0.001b	0.03 $\pm$ 0.001a	0.03 $\pm$ 0.001a	0.04 $\pm$ 0.002a
P_2O_5 (mg/g)	0.31 $\pm$ 0.26a	0.36 $\pm$ 0.39a	0.20 $\pm$ 0.12a	0.30 $\pm$ 0.12b	0.76 $\pm$ 0.53c
CN	11.60 $\pm$ 2.02a	11.40 $\pm$ 1.58a	11.30 $\pm$ 1.07a	11.81 $\pm$ 2.08a	12.01 $\pm$ 2.93a
pH	5.88 $\pm$ 0.42a	5.73 $\pm$ 0.43a	5.67 $\pm$ 0.31a	5.75 $\pm$ 0.37a	6.32 $\pm$ 0.43b
EC (μ S/cm)	74.9 $\pm$ 26.0a	75.7 $\pm$ 29.6a	73.3 $\pm$ 23.6ab	67.8 $\pm$ 12.6a	90.4 $\pm$ 43.4b

Note: Significant differences ($p < 0.05$) among groups are indicated by different letters (Tukey's honestly significant difference [HSD] test). N and n indicate the number of fields and the number of samples, respectively.

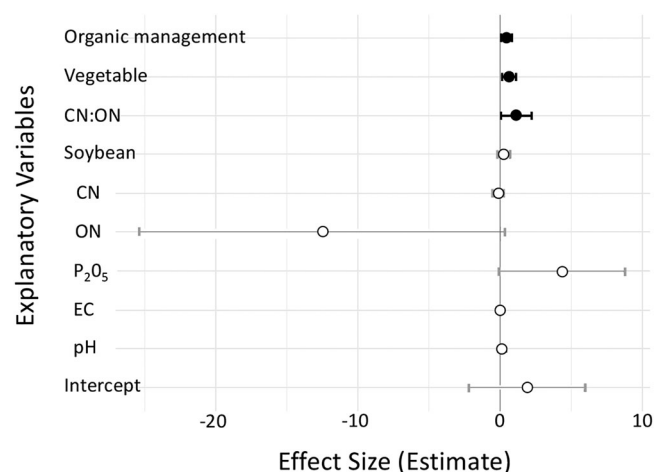


FIGURE 1 Averaged generalized linear mixed model (GLMM) results from five competing models ($\Delta AICc < 2$) showing the effects of agricultural management, crop type, and soil properties on total microarthropod abundance. Solid circles with black lines indicate significant effects ($p < 0.05$), while open circles with gray lines indicate nonsignificant effects ($p > 0.05$). Error bars represent 95% confidence intervals. CN, carbon-to-nitrogen; EC, electrical conductivity; ON, organic nitrogen.

the CN $\times$ ON interaction had significant effects ($p < 0.05$; Figure 1). Organic management was associated with higher microarthropod abundance than conventional management (estimate = 0.438). Compared with paddy fields, soybean (estimate = 0.226) and vegetable crops (estimate = 0.621) showed higher abundance, although only the vegetable effect was significant. The CN $\times$ ON interaction had the strongest positive effect (estimate = 1.135), although its relationship with management or crop type was unclear (Figure S2).

Soil chemical properties differed between management types and crop types (Table 1). IN content was significantly

higher under conventional management (0.04 mg/g) than organic management (0.03 mg/g). Vegetable fields had significantly higher pH (6.32) and EC (90.4 μ S/cm), and higher P_2O_5 content (0.76 mg/g), than soybean and paddy fields.

4 | DISCUSSION

Our findings align with previous studies showing that organic management positively influences soil microarthropod abundance (Coulis, 2021; Doles et al., 2001). Organic systems typically promote greater bacterial and fungal biomass and higher microbial activity (Li et al., 2017; Wen et al., 2025), providing a key food source for microarthropods (Kundel et al., 2020; Meyer et al., 2021). In addition, the incorporation of organic amendments can improve soil porosity, creating aerated microhabitats and physical refuges for these organisms (Shen et al., 2021).

Crop type also played a significant role in shaping microarthropod abundance. The long-time flooding of paddy fields creates anaerobic conditions (Sazawa et al., 2023) that are detrimental to many soil fauna (Saifutdinov et al., 2020), explaining the lower abundance observed compared with vegetable fields. Moreover, crop rotation between paddy and soybean, which is common in Japan (Nishida et al., 2013), may carry over some negative effects of anaerobic conditions from rice cultivation into soybean fields.

The positive interaction between the CN ratio and ON content supports the idea that organic matter-rich soils promote microarthropod populations. The CN ratio reflects the quality of litter inputs, which are processed by both microbes and fauna, contributing to soil carbon cycling (Alatalo et al., 2017; Chamberlain et al., 2006). Decomposition of plant- and animal-derived organic matter produces soil organic matter, including humus, which serves as a potential source of ON

(Gaskell & Smith, 2007). Microbes utilize this ON to meet metabolic demands (Séneca et al., 2021; Soong et al., 2020), indirectly supporting microarthropod feeding (Kundel et al., 2020; Meyer et al., 2021).

As expected, IN content was significantly higher in conventional than in organic systems, reflecting the frequent application of synthetic N fertilizers in conventional practices (Kwiatkowski & Harasim, 2020; Rahmawati et al., 2015). In contrast, organic systems often rely on manure and phosphorus-rich amendments (Yan et al., 2013), which may explain the observed patterns, although the difference in phosphorus content between management types was not statistically significant. The lowest phosphorus levels in paddy soils likely result from runoff and leaching under flooded conditions (Qi et al., 2020; Zhang et al., 2003). While phosphorus showed a positive effect on microarthropod abundance in our models, the relationship was only marginally significant ($p = 0.054$), suggesting the need for further investigation.

5 | CONCLUSION

Our results demonstrate that organic agricultural management promotes soil microarthropod abundance. Crop type exerted an even stronger influence, with vegetable fields supporting higher abundances than paddy or soybean fields. Moreover, microarthropod abundance was most strongly associated with the interaction between ON content and a high soil CN ratio, rather than with individual chemical nutrients alone. This suggests that organic matter-rich soils providing both carbon and nitrogen resources create optimal conditions for sustaining diverse and abundant microarthropod communities. These findings highlight the importance of integrating organic amendments and crop selection into agricultural practices to enhance soil biodiversity and to maintain healthy agroecosystems.

AUTHOR CONTRIBUTIONS

Md Ariful Haque: Data curation; formal analysis; investigation; methodology; validation; visualization; writing—original draft; writing—review and editing. **Yuto Minemura:** Data curation; investigation; visualization. **Kazuto Sazawa:** Data curation, methodology. **Hideki Kuramitz:** Methodology; validation; writing—review and editing. **Naoya Wada:** Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; supervision; validation; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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