

Nematode Community Structure Changes in Relation to Tillage Systems and Cover Crop Management in Field Rice Cultivation

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This paper discusses the use of nematode community indices for evaluating the health of agroecosystems and the effects of farming practices such as tillage and cover crop management on nematode community structure. Nematodes can be used as bioindicators of soil health because they are ubiquitous and have diverse feeding behaviors and life-history strategies, ranging from colonizers to persisters. By combining the assessment of nematode feeding groups with colonizer-persister (c-p) scaling of functional guilds, nematode faunal analysis has become a more powerful tool, allowing this phylum to be used as a bioindicator of soil health and food web condition. In a 9-year study conducted on the Kanto Plain of Japan, tillage disturbance showed a significant negative correlation with the structure index (SI) that is an indicator of food web state affected by stress or disturbance. Although cover cropping and nitrogen fertilization did not affect pathogenic nematode densities during the experimental period, cover cropping did significantly reduce the proportion of pathogenic nematodes in the total nematode abundance, and nitrogen fertilization increased the degree of rice yield reduction with greater pathogenic nematode density. Our findings suggest that no-tillage (NT) and crop rotation will be effective for controlling pathogenic nematode densities, because NT reduced their numbers and increased soil ecological diversity. Over the experimental period, SI increased not only in NT plots but also in those treated with a moldboard plow or rotary cultivator. These results suggest that increases in soil carbon foster a more diverse nematode community structure. Long-term nematode community changes will be an important focus of future research, and this information will be helpful for developing more sustainable agriculture in Japan.

Key words: agroecosystem, nematode faunal analysis, soil food web, soil health, sustainable agriculture

Introduction

Soil sustains agricultural production and easily deteriorate by mismanagement. Farmers became too dependent on chemical fertilizers to replace or enhance soil nutrients, which also degraded soil and water quality (Stamatiadis *et al.*, 1999). As local environmental quality becomes increasingly deteriorated due to soil degradation and water pollution by agricultural practices, agricultural sustainability became an important issue for discussion in the latter half of twentieth century due to concerns about the long-term productivity (Lal, 1998, 2001; Barford *et al.*, 2001).

Sustainable agriculture received strong support from some international treaties and conventions, such as the Rio Summit in 1992 as well as in Agenda 21 (UNCED, 1992), the United Nations Framework Convention on Climate Change (UNFCCC, 1992), articles 3.3 and 3.4 of the Kyoto Protocol (UNFCCC, 1997), and elsewhere. These conventions are indicative of the recognition that agricultural sustainability has become an essential component of the agricultural policies of the world.

No-tillage (NT) system is an alternative management that has spread on a global scale during the past decade because of its significant environmental ad-

Received: October 21, 2014, Accepted: January 23, 2015

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vantage over moldboard plow. In East Asian countries, including Japan and China, that have just started to adopt NT farming, the combination of cover crops and NT practice increased the environmental benefits such as reduced nitrogen leaching, soil organic matter increases, and soil biological diversity improvements (Komatsuzaki and Ohta, 2007).

Soil health is defined as a stable system with resilience to stress, high activity of soil organisms, high levels of internal nutrient cycling (Van Bruggen and Semenov, 2000). The major activities of soil microbes include maintaining soil structure, mineralization of nutrients, fixating nitrogen, and minimizing pest and disease outbreaks. However, there are occasions when they can also be parasitic and harm to plants. Thus, an important component of agricultural sustainability is a deep understanding of NT practice, cover crop management, and basic biology and ecosystem ecology.

In this paper, I discuss the use of nematode community indices for evaluating the health of agroecosystems and the effects of farming practices such as tillage systems and cover crop management on nematode community structure. This information will be helpful for developing more sustainable agriculture in Japan.

Soil nematode community as a bioindicator

The soil food webs play a critical role in many fundamentally processes associated with maintaining and improving soil health, especially by enhancing soil nutrients. Most direct mineralization of nutrients is performed by bacteria and fungi. Because these basal decomposers are affected by soil animals of higher trophic levels (e.g., protozoa, nematodes, mites, springtails, millipedes, and earthworms), these animals have indirect effects on soil nutrients.

Recently, nematode community structure has been used as a means of evaluating the soil ecosystem and soil health. Changes in the nematode community structure reflect structural alterations of the soil food web (Bongers, 1990; Bongers and Ferris, 1999; Ferris *et al.*, 2001; Ferris and Matute, 2003). Most obligatory root-feeding nematodes live in the soil and feed on plant roots, thereby reducing the plant's uptake of water and nutrients and decreasing its tolerance to other stresses, such as drought. Most species of nematodes are free-living in soil, and they have no direct effect on crop production. Free-living nematodes feed on bacteria, fungi, protozoans, and even other nematodes, and they play an important role in nutrient cycling and the release of nutrients for plant growth (Fig. 1). Nematodes can be used as bioindicators of soil health because they are ubiquitous and have diverse feeding behaviors and life-history strategies, ranging from colonizers to persistent species. Nematode classification, based on the feeding groups and cp-scaling of functional guilds, has become a more useful tool as a bioindicator of soil health and food web condition (Bongers and Ferris, 1999; Ferris *et al.*, 2001; Ferris and Matute, 2003).

The development of a complex soil nematode community under agricultural practices can be monitored by nematode community indices (Bongers and Bongers, 1998; Neher, 1999; Yeates and Bongers, 1999; Ferris *et al.*, 2001; Berkelmans *et al.*, 2003). These indices have been used successfully to distinguish well-functioning ecosystems from those that are heavily disturbed or stressed (Neher, 1999; Yeates and Bongers, 1999; Berkelmans *et al.*, 2003), as well as to detect more subtle differences among agricultural practices, including tillage systems and cover crop species. However, few studies have examined the interactive effects of tillage systems and cover crop

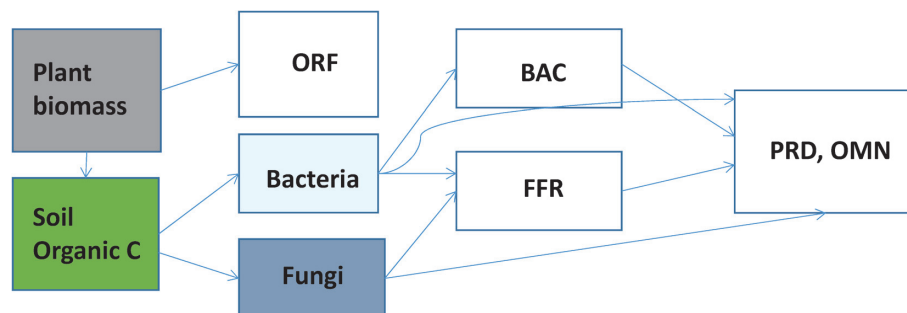


Fig. 1. Soil nematode community structure as related to plant biomass, soil carbon, and microbial biomass.

species on the nematode community, particularly in Asia.

Tillage systems and the nematode community

Soil tillage is aimed at improving soil structure and quality. One conventional tillage system uses a mold-board plow coupled with a rotary harrow for seedbed preparation (MP). The MP system moves the surface soil into the deep layer and thoroughly incorporates surface crop residues into the lower layers of the tilled area, removing crop residues from the soil surface. In Japan, more than 80% of cultivated cropland is tilled using rotary cultivators (RC) (Moriizumi *et al.*, 1995). Soil is tilled with a rotary blade and crop residues are mixed with the soil, although not completely turned into the soil. This simple system is easy to use by farmers, particularly on small to medium-scale Asian farms, and it enhances the seedbed while reducing weed occurrence. However, intensive tillage, including the use of MP and RC, is also associated with great disturbances to soil ecosystems.

Tillage strongly influences the location and degree of fragmentation of crop residues and soils. In NT systems, crop residues and surface soil remain on the surface, whereas they are fully incorporated into the lower soil in MP systems and partially fragmented and incorporated into the lower soil in RC systems. In order to maintain the natural stability of soil ecosystems, farmers are encouraged to leave crop residues in place and preserve a stable surface soil.

Fu *et al.* (2000) showed that soil nematodes are more abundant in NT than in MP systems. In particular, bacteria-feeding nematodes responded to the addition of crop residue faster than fungal and facultative root feeders (FFR) under both MP and NT. The vertical distribution of crop residues has been shown to influence nematode abundance and community structure (Fu *et al.*, 2000). Another study showed that cover cropping increased bacterial feeder abundance by two-fold, which actively influenced nitrogen mineralization (DuPont *et al.*, 2009).

We used the degree of surface soil translocation (DSST) as a proxy to measure the degree of soil disturbance by tillage and its effect on soil nematode community structure (Ito *et al.*, 2014). We used ^{137}Cs fallout from the Fukushima Daiichi Nuclear Power Plant accident as a tracer to detect the DSST in the experimental field at the Field Science Center, Ibaraki

University, but our results agreed with those of previous studies that used small pieces of chalk (Kawashima and Komori, 1962) or rock fragments (Zhang *et al.*, 2004) as a tracer. Tillage significantly influenced DSST. Overall, NT plots showed a lower DSST than other tillage systems: DSST values were 29.6–30.9% for NT plots, 49.1–72.3% for MP plots, and 43.9–50.8% for RC plots (Fig. 2).

We also measured the effect of DSST on the associated nematode community composition (Ito *et al.*, 2014). DSST was significantly negatively correlated with the abundance of bacteria-feeding, omnivorous, and obligatory root-feeding nematodes. Similarly, DSST showed a significant negative correlation with the community structure index (SI), which represents an aggregation of functional guilds with cp values ranging from 3 to 5. The SI describes whether a soil ecosystem is structured and mature (high SI) or disturbed and degraded (low SI).

Because DSST showed a significant negative correlation with the nematode community SI, DSST could be useful for evaluating the level of ecosystem disturbance not only regarding soil translocation but also in relation to soil ecosystem development.

Combining NT with cover cropping can control pathogenic nematode abundance

Cover cropping is intended to develop healthy soils in agricultural systems. Cover crops are a particularly beneficial ecosystem service in croplands because they assist in supplying soil organic matter, adding biologically fixed nitrogen, scavenging soil residual nutrients, suppressing weeds, and breaking pest cycles (Magdoff, 1993; Peet, 1996; Sarrantonio, 1998). The combinations of particular cover crops and tillage systems were shown to have strong effects on the nematode community.

The rice cyst nematode *Heterodera elachista*, previously reported only in Japan, has been detected recently in other countries in Asia and Europe. Our research team at Ibaraki University evaluated the effects of three tillage systems (MP, RC, and NT), three winter cover-cropping systems (fallow, rye [*Secale cereale*], and hairy vetch [*Vicia villosa*]), and two rates of nitrogen fertilization (0 and 100 kg N ha⁻¹ for upland rice and 0 and 20 kg N ha⁻¹ for soybean production) on population densities of *H. elachista* in 2003–2011 at an experimental site on the Kanto Plain of Japan. After 4 years of continuous upland rice

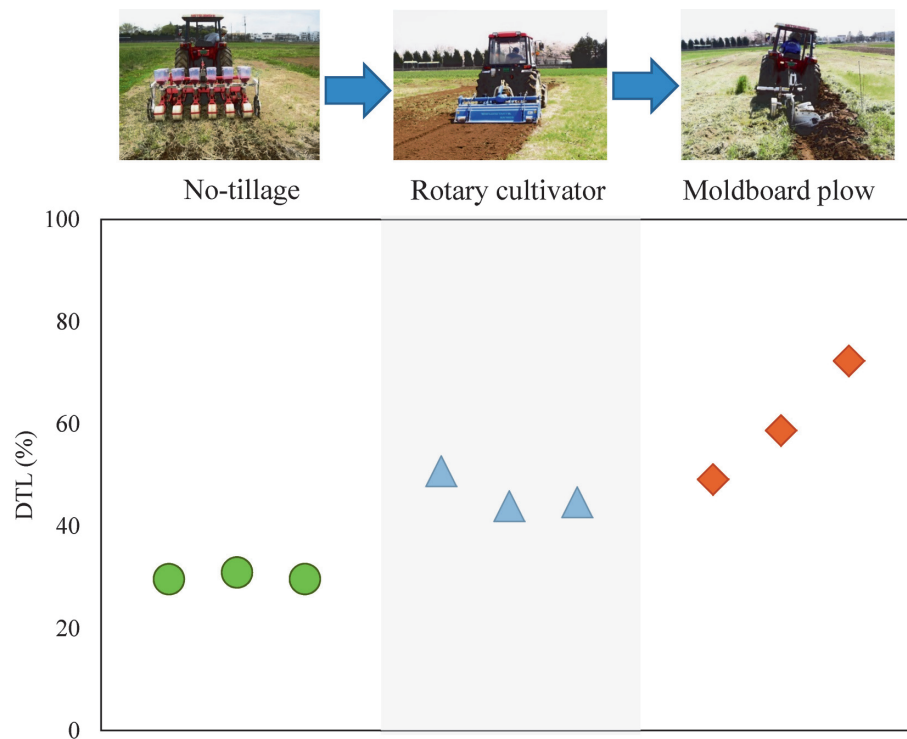


Fig. 2. The differences in the degree of surface soil translocation (DSST) among the three tillage systems.

cultivation, the population density of *H. elachista* markedly increased in MP (52.8 nematodes per 20 g fresh soil) and RC (72.7), but not in NT (2.1). However, in the fifth year of continuous cultivation of upland rice, *H. elachista* densities markedly increased in NT, such that no differences were observed between tillage systems. After conversion of the crop to soybean, *H. elachista* densities decreased in all treatments, although NT showed a more rapid decline than the other tillage systems. Cover cropping and nitrogen fertilization did not affect *H. elachista* densities during the 9 years. However, cover cropping significantly reduced the proportion of *H. elachista* in the total nematode abundance, and nitrogen fertilization increased the degree of rice yield reduction with greater *H. elachista* density. Our results suggest that NT and crop rotation will be effective for controlling *H. elachista* densities, because NT reduced their numbers and increased soil ecological diversity.

The improvement of upland rice cultivation requires further research because of the projected limitations on water resources in the next decade, particularly in Asia (Tuong *et al.*, 2005). NT systems are appropriate for developing sustainable rice production because they reduce the energy needed for seedbed preparation and

enhance soil carbon sequestration (Higashi *et al.*, 2014) and soil biological diversity (Komatsuzaki and Ohta, 2007). Our results showed a significant effect of NT in *H. elachista* control both in continuous rice cultivation and after a change to soybean cultivation. These results will help us to develop appropriate farming practices for upland rice production in Japan.

Long-term effects of farming on nematode community

In the 9-year study described above, we also assessed the effects of tillage system, cover crop treatment, and nitrogen fertilization on changes in the nematode community structure. Sixty-nine taxa were encountered. The total nematode abundance and that of bacterial feeders, predators, omnivores, and obligatory root feeders were greater in NT than in MP and RC, but the abundance of FFR was greater in RC than in NT and MP. Cover cropping also influenced the nematode community structure. Plots planted with rye and hairy vetch always had higher total nematode abundance and more bacterial feeders, FFR, obligatory root feeders, and omnivores than the fallow plots. Seasonal change in nematode community structure was also significant; in particular, as soil carbon increased,

the nematode abundance also increased. The relationship between nematode indices and soil carbon was significant only in the NT system: the enrichment index (EI), as an indicator of the soil nutrient richness, and SI showed significant positive correlations with soil carbon. Soil bulk density was also significantly negatively correlated with FFR and ORF. The seasonal difference in the nematode community structure between summer and autumn was greater under rice cultivation than soybean cultivation. Over the 9-year experiment, SI increased not only for NT, but also for MP and RC. These results suggest that increasing soil carbon would have a great impact on the development of a more diverse nematode community structure.

EI and SI provide a quantitative estimate of the state of the soil food web. EI is a measure of soil nitrogen enrichment, and SI is an indicator of how the state of the food web is affected by stress or disturbance. In this research, SI values increased in all plots after converting to soybean cultivation as a summer crop, suggesting that soybean cropping fosters a more well-developed nematode community structure. Thus, future research should focus on the combined effects of tillage system, cover crop management, and summer crop on nematode community structure.

Conclusions

Our findings suggest that NT and crop rotation will be effective for controlling pathogenic nematode densities, because NT reduced their numbers and increased soil ecological diversity. During the decomposition process of organic matter, the nutrients present in residue of cover crop are transferred to decomposers and consumers in soil ecosystem. Enough supply of organic matter and stable habitat increase the biomass of soil organisms and develop the soil ecosystem. In this study, NT system combined with rye cover cropping increased the population of free-living nematode and improved the nematode diversity. In the developed nematode community, the interspecific competition may occur and prevent the population growth of pathogenic nematode.

Acknowledgments

I thank Dr. Masakazu Komatsuzaki (College of Agriculture, Ibaraki University) for constructive comments and warm encouragement. This study was supported in part by a grant from the School of Agriculture, Ibaraki University.

References

- Barford, C.C., Wofsy, S.C., Goulden, M.L., Munger, J.W., Pyle, E.H., Urbanski, S.P., Hutyla, L., Saleska, S.R., Fitzjarrald, D., Moore, K., 2001. Factors controlling long-and short-term sequestration of atmospheric CO₂ in a mid-latitude forest. *Science*, 294, 1688–1691.
- Berkelmans, R., Ferris, H., Tenuta, M., Van Bruggen, A., 2003. Effects of long-term crop management on nematode trophic levels other than plant feeders disappear after 1 year of disruptive soil management. *Appl. Soil Ecol.*, 23, 223–235.
- Bongers, T., 1990. The maturity index: an ecological measure of environmental disturbance based on nematode species composition. *Oecologia*, 83, 14–19.
- Bongers, T., Bongers, M., 1998. Functional diversity of nematodes. *Appl. Soil Ecol.*, 10, 239–251.
- Bongers, T., Ferris, H., 1999. Nematode community structure as a bioindicator in environmental monitoring. *Trends in Ecol. Evol.*, 14, 224–228.
- DuPont, S.T., Ferris, H., Van Horn, M., 2009. Effects of cover crop quality and quantity on nematode-based soil food webs and nutrient cycling. *Appl. Soil Ecol.*, 41, 157–167.
- Ferris, H., Matute, M., 2003. Structural and functional succession in the nematode fauna of a soil food web. *Appl. Soil Ecol.*, 23, 93–110.
- Ferris, H., Bongers, T., De Goede, R., 2001. A framework for soil food web diagnostics: extension of the nematode faunal analysis concept. *Appl. Soil Ecol.*, 18, 13–29.
- Fu, S., Coleman, D.C., Hendrix, P.F., Crossley Jr., D., 2000. Responses of trophic groups of soil nematodes to residue application under conventional tillage and no-till regimes. *Soil Biol. Biochem.*, 32, 1731–1741.
- Higashi, T., Yunghui, M., Komatsuzaki, M., Miura, S., Hirata, T., Araki, H., Kaneko, N., Ohta, H., 2014. Tillage and cover crop species affect soil organic carbon in Andosol, Kanto, Japan. *Soil Tillage Res.*, 138, 64–72.
- Ito, T., Araki, M., Komatsuzaki, M., Nobuhiro, K., Hirayoyuki, O., 2014. Soil nematode community structure affected by tillage systems and cover crop managements in organic soybean production. *Appl. Soil Ecol.*, in press.
- Kawashima, M., Komori, S., 1962. On the displacement of soil by tillage machines. I. On the expressions of the displacement of soil. *J. Jpn. Soc. Agric. Mach.*, 24, 56–60.
- Komatsuzaki, M., Ohta, H., 2007. Soil management practices for sustainable agro-ecosystems. *Sustain. Sci.*, 2, 103–120.
- Lal, R., 1998. Soil erosion impact on agronomic productivity and environment quality. *Crit. Rev. Plant Sci.*, 17, 319–464.
- Lal, R., 2001. World cropland soils as a source or sink for atmospheric carbon. *Adv. Agron.*, 71, 145–193.
- Magdoff, F., 1993. Building soils for better crops: organic matter management. *Soil Sci.*, 156, 371.
- Moriizumi, S., Hayashi, N., Takahashi, M., Ikeda, K., Matsui, K., Kojima, K., 1995. Studies on the soil displacement by rotary tillage. IV. A method of investigation using KCl solution and analysis of soil-overturning by its method. *Jpn. J. Farm Work Res.*, 30, 207–213.
- Neher, D.A., 1999. Nematode communities in organically and

- conventionally managed agricultural soils. *J. Nematol.*, 31, 142.
- Peet, M., 1996. *Soil Management*. Focus Publishing/R. Pullins Co., Newburyport, MA.
- Sarrantonio, M., 1998. *Building Soil Fertility and Tilth with Cover Crops*, 2nd ed. Sustainable Agriculture Network, Beltsville, MD.
- Stamatiadis, S., Werner, M., Buchanan, M., 1999. Field assessment of soil quality as affected by compost and fertilizer application in a broccoli field (San Benito County, California). *Appl. Soil Ecol.*, 12, 217–225.
- Tuong, T.P., Bouman, B., Mortimer, M., 2005. More rice, less water: integrated approaches for increasing water productivity in irrigated rice-based systems in Asia. *Plant Prod. Sci.*, 8, 231–241.
- United Nations Conference on Environment and Development (UNCED), 1992. Agenda 21. Available via <https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf> (accessed January 23, 2015).
- United Nations Framework Convention on Climate Change (UNFCCC), 1992. United Nations Framework Convention on Climate Change. Available via <http://unfccc.int/resource/docs/convkp/conveng.pdf> (accessed January 23, 2015).
- United Nations Framework Convention on Climate Change (UNFCCC), 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. Available via <http://unfccc.int/resource/docs/convkp/kpeng.pdf> (accessed January 23, 2015).
- Van Bruggen, A., Semenov, A., 2000. In search of biological indicators for soil health and disease suppression. *Appl. Soil Ecol.*, 15, 13–24.
- Yeates, G., Bongers, T., 1999. Nematode diversity in agroecosystems. *Agric. Ecosyst. Environ.*, 74, 113–135.
- Zhang, J., Lobb, D., Li, Y., Liu, G., 2004. Assessment of tillage translocation and tillage erosion by hoeing on the steep land in hilly areas of Sichuan, China. *Soil Tillage Res.*, 75, 99–107.