Published with Open Access at Journal BiNET
Vol. 06, Issue 01: 221-232

Asian Journal of Crop, Soil Science and Plant Nutrition

Journal Home: https://www.journalbinet.com/ajcsp-journal.html

How short-term residue management and tillage impacts nematodes in tropical agricultural soils

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Article received: 26.08.2021; Revised: 12.10.2021; First published online: 15 November, 2021.

ABSTRACT

Rapid population growth and ever-increasing food demand have compelled land transformation for crop production, especially in humid tropical regions. Most of the agricultural practices in this region greatly rely on the soil organic matter (SOM) content. Among those practices, tillage and residue management are most common throughout the region. Nematode composition and diversity provide essential information on SOM decomposition status and nutrient cycling in soil. To highlight the impacts of these two management practices on nematodes in tropical agricultural soils, relevant peer-reviewed literature of the past 17 years (until 2017) was searched and compiled. This review revealed that intense application of those agricultural practices changes the composition of nematodes without essentially reducing the trophic groups. Short-term residue management surpassed the impacts of tillage operation, while no residue management changes the population dynamics of nematodes. Quality and placement of residues significantly affect nematode abundance as well as diversity. Residues with a high C:N ratio showed higher fungivore abundance, and buried residue application showed higher bacterivore abundance. Tillage intensity rapidly depletes both organic matter (OM) and water in soil, and detrimental to soil aggregate stability and nematode diversity. Therefore, zero tillage has been suggested for the recovery of soil microfauna. Future research can focus on restoring a disturbed soil ecosystem faster with appropriate residue management.

Key Words: *Tillage, Residue management, Soil microfauna, Nematode, Fungivore, Bacterivore and Parasite.*

Cite Article: Miah, I. (2021). How short-term residue management and tillage impacts nematodes in tropical agricultural soils. Asian Journal of Crop, Soil Science and Plant Nutrition, 06(01), 221-232.
Crossref: https://doi.org/10.18801/ajcsp.060121.27

I. Introduction

Humid tropic soils have a faster turnover rate of organic matter (OM) due to higher temperatures. Compared to temperate-climate zone soils, the rate of soil carbon turnover is almost double in tropical soils (Six et al., 2002). From a radiocarbon experiment, Trumbore (1993) reported mean residence time of 990 and 470 years for temperate and tropical soil, respectively. As a result, response time of ecosystems is relatively shorter for any change in management practices, rendering it vulnerable to permanent damage (Dion, 2010).

According to USDA (1978), soils are classified into ten orders. This classification is based on rough morphological processes involving soil formation. The orders with their gross characteristics and occurrences are given in Table 01 and Table 02, respectively. Oxisols and Ultisols are the two most abundant soils in the humid tropics (Table 03) and these soils make up 63% of the total soil in the humid tropics that are highly dependent on OM as a nutrient source. Therefore, OM input plays a vital role in maintaining productivity of tropical cropping systems. Traditional sources like crop residues, tree litters, farmyards and green manures supply both short-term nutrients by decomposition and OM substrate in the tropics (Palm et al., 2001).

Table 01. Brief descriptions of the ten soil orders according to soil taxonomy (adapted from Tripathi and Kang, 1992).

Soil orders	Description
ALFISOLS	- Soils with a clayey B horizon and exchangeable cation (Ca + Mg + K + Na) saturation greater than 50% calculated from NH_4OAc-CEC at pH 7.
ULTISOLS	- Soils with a clayey B horizon and base saturation less than 50%. They are acidic, leached soils from humid areas of the tropics and subtropics.
OXISOLS	- Oxisols are strongly weathered soils but have minimal variation in texture with depth. Some strongly weathered, red, deep, porous oxisols contain large amounts of clay-sized Fe and Al oxides.
VERTISOLS	- Dark clay soils containing large amounts of swelling clay minerals (smectite). The soils crack widely during the dry season and become very sticky in the wet season.
MOLLISOLS	- Prairie soils formed from colluvial materials with dark surface horizon and base saturation greater than 50%, dominating exchangeable Ca.
INCEPTISOLS	- Young soils with limited profile development. They are mainly formed from colluvial and alluvial materials. Soils derived from volcanic ash are considered a special group of Inceptisols, presently classified under the Andept suborder (also known as Andosols).
ENTISOLS	- Soils with little or no horizon development in the profile. They are mainly derived from alluvial materials.
ARIDISOLS	- Soils of arid region, such as desert soils. Some are saline.
SPODOSOLS	- Soils with a bleached surface layer (A2 horizon) and an alluvial accumulation of sesquioxides and OM in the B horizon. These soils are mainly formed under humid conditions and coniferous forests in the temperate region.
HISTOSOLS	- Soils rich in OM such as peat and muck.

Table 02. Occurrence of major soils in the humid and subhumid tropics (adapted from Tripathi and Kang, 1992).

Classification (USDA)	Occurrence
1. Alfisols	Savanna and drier forest zones
2. Hydromorphic Soils	Valley bottom of a rolling topography
3. Vertisols	Alluvial plains in savanna
4. Ultisols	Rain forest zone and derived savanna
5. Oxisols	Rain forest and savanna
6. Inceptisols	All regions
7. Andepts (suborder of Inceptisols)	Limited and localized distribution relating to present and past volcanic activities

Table 03. Geographical distribution of soils in the humid tropics (millions of hectares) (adapted from Tripathi and Kang, 1992).

Soil order	Tropical Africa	Tropical Asia	Tropical America	Total	Percent
Oxisols	179	14	332	525	35
Ultisols	69	131	213	413	28
Alfisols	21	15	18	54	4
Others	176	219	103	498	33
Total	445	379	666	1490	100

Specific management practices like slash-and-burn or shifting cultivation adversely change soil properties in this region. In slush-and-burn system, a forest area is cut and burned, and then crops are planted for several consecutive years before abandoning that area. About 60% food of Africa is grown following slash-and-burn method (Nwaga et al., 2010). In shifting agriculture, the forest land is burned and cleared. After cropping the area for few years, the land is fallowed for an extended period before continuing cropping again. The success of shifting agriculture depends mainly on the length of fallow period and population density (Christanty, 1986). Only at low population density, these practices are viable land management options. Overall, both slash-and-burn and shifting cultivation are subsistence farming practices, which are primitive and threaten the conservation of the ecosystem, especially in the humid tropics. These practices increase the soil temperature, degradation of soils, severely decrease the OM, biomass, and diversity of macro-and microfauna; ultimately decrease the productivity of the soils (Kleinman et al., 1995; Ribeiro Filho et al., 2013).

Soil nematodes comprise the dominant part of microfauna in soil in terms of their abundance and interaction with soil biota at various trophic levels (Bongers and Bongers, 1998; Lenz and Eisenbeis, 2000). A wide range of life cycles (from few days to more than two years) provides the opportunity to study the integrated impacts of soil management-related stresses over various time scales (Schloter et al., 2003). Depending on the stressor, they might be suitable for biological soil quality indicators (Zhang et al., 2012). Based on feeding habits, soil nematodes are classified as plant-parasites, fungivores, bacterivores, omnivores, and predators. They provide information regarding debris decomposition pathways and nutrient cycling by feeding on the primary decomposers (bacteria and fungi), eventually, help in maintaining soil functions and remediation. Furthermore, they occupy important and diversified positions in the food web (Bongers and Ferris, 1999). A decline in nematode diversity with intensified management practices manifests both soil physical disturbance and OM quantity and quality that have changed in time (Zhang et al., 2015).

Soil biota has direct and indirect effects on production and quality of crops, pest infestation, water and nutrient cycling. Above all, their roles in diversity conservation have become an essential strategic component in sustainable agriculture (Giller et al., 2005; Swift et al., 2004). Therefore, evaluation of agricultural sustainability necessitates biological soil quality assessment employing different indicators. To detect the potential ecosystem changes physical or chemical approaches might not be sufficient (Suter, 2001). Soil biotas are too diverse to be assessed and ecologically interpreted directly. Therefore, researchers have found it effective to use a “proxy” group, a highly simplified subset that nevertheless responds similarly to the soil community as a whole. Biological indicators are also used for their ubiquity, ease of extractability, sensitivity, and predictability (Goodsell et al., 2009; Yan et al., 2012). Moreover, repeated sampling, standardized routine sampling procedure, and occurrence in all climatic conditions and environmental stresses facilitate rapid soil quality assessment (Bongers and Ferris, 1999). Thus, nematodes are more appropriate to assess soil quality. For example, Yeates and Bongers (1999) suggested that change in management practices changes the relative abundance of bacterial- and fungal-feeding nematodes as a reflection of altered primary decomposer community (bacteria and fungi). Among the agronomic practices, tillage and residue management directly affects nematode abundance (Fiscus and Neher, 2002; Mills and Adl, 2011). Hence, the response of soil nematodes to tillage and residue amendments is helpful to assess soil quality. Since most of the studies are based on short-term impacts (Bulte et al., 2005; Hooper et al., 2005; Treonis et al., 2010), this review article will focus on the short-term effects of different tillage systems and residue management on diversity and composition of soil nematode community in tropical agricultural soils.

II. Materials and Methods

Peer-reviewed scientific articles were selected from relevant journals published from 2000 to 2017. Data and main findings on the effects and residue management were screened from these selected articles to develop this compendium outlining tillage and residue management-driven alteration of nematode biodiversity in tropical agricultural soils. The criteria for selecting the articles are:

(i) Conventional tillage was the control treatment, with a minimum of one treatment of reduced tillage or no tillage. Besides a no residue application treatment, there was at least one quantitatively different residue application.

(ii) Tillage and residue treatments showed effects that differed from the impact of other treatments, for example, soil compaction, organic farming, and chemical fertilization.

EISSN 2706-5510

To assess the impact of different management practices, nematodes as bioindicators require nematode community analyses at the genus level (Yeates, 2003), which requires highly trained experts. Molecular analysis is more straightforward (Dorris et al., 1999). Agronomic practices like residue management and tillage influence soil structure, water-holding capacity, and OM content (Golabi et al., 2014). Concurrently, these practices also influence the composition and abundance of nematodes from several trophic groups. The effects of both factors will be discussed separately.

III. Effects of residue management

Experiments in tropical zone

Wang et al. (2004) conducted an experiment for five years under a tropical climate (Green Acres Agronomy Research Farm, Alachua County, Florida) in Arredondo loamy sand soil. They used two compost treatments *viz.* high-yard-waste compost (HYWC) and no yard-waste compost (NYWC), and two tillage treatments *viz*. conventional tillage and no tillage. HYWC was prepared from plant materials like clippings, sticks and wood fragments. The decomposition pathway in HYWC was dominated mainly by bacteria. Various genera of bacterivores and predators positively correlated with OM content of soil, whereas negative correlations were found for fungivores (Table 03 and Table 04). The results are consistent with Ingham et al. (1985), who reported higher N and P mineralization due to bacterivores and fungivores, respectively. Interestingly, soil texture was not a variable in their study, but it did not affect nematode density either (Table 04).

Another important determinant of bacterial community is soil pH. It is one of the most reliable predictors of diversity and composition of bacterial communities across different land management types, with the optimum growth around neutral pH values (Tripathi et al., 2012). The apparent immediate effect of pH on the diversity and composition of the bacterial community is attributed to the limited pH range for favorable growth conditions. On the other hand, fungal community can have optimal growth on broad pH range, thereby shows less susceptibility to pH change (Rousk et al., 2010).

Table 04. Correlation coefficients between population density of each nematode and soil nutrient concentration or other soil properties (adapted from Wang et al. (2004)).

Nematode genus	Correlation coefficient (r)						
	Ca	Mg	K	P	N	OM	CEC
Bacterivores							
Alaimus	0.630*	0.649*	0.663*	0.638*	0.644*	0.633*	0.630*
Cephalobus	0.702**	0.755**	0.695**	0.624*	0.737**	0.760**	0.738**
Cervidilus	0.604*	0.651*	0.583*	0.515	0.617*	0.655*	0.643*
Monhystera	0.818**	0.833**	0.774**	0.751**	0.801**	0.829**	0.845**
Plectus	0.753**	0.705**	0.754**	0.781**	0.631*	0.670*	0.728**
Rhabditidae	0.876**	0.906**	0.841**	0.792**	0.883**	0.909**	0.904**
Teratocephalus	0.622*	0.660*	0.508	0.508	0.701**	0.688**	0.652*
Wilsonema	ns	0.518	ns	ns	0.506*	0.528	0.500
Fungivore							
Diphtherophora	0.548	ns	ns	ns	ns	ns	ns
Ecphyadophora	0.922**	ns	ns	0.885**	ns	-0.672*	ns
Filenchus	0.889**	ns	ns	0.886**	0.604*	-0.573*	ns
Neotylenchidae	0.915*	ns	ns	0.717**	ns	-0.812**	-0.506
Tylenchus	0.751**	ns	ns	0.551	ns	-0.640*	-0.743**
Herbivores							
Meloidogyne	-0.703**	-0.572*	-0.712**	-0.802**	ns	-0.547*	-0.621*
Paratrichodorous	-0.505	ns	-0.507	-0.599*	ns	ns	ns
Mesocriconema	0.720**	0.680*	0.654*	0.698**	0.697**	0.691**	0.700**
Predators							
Carcharolaimus	0.589*	0.667*	0.528	ns	0.711**	0.698**	0.642*
Tobrilus	0.803**	0.805**	0.757**	0.718**	0.766**	0.809**	0.819**

OM = organic matter, CEC = cation exchange capacity; Correlation analysis based on 12 observations; * and ** signify correlation significant at $P \leq 0.05$ and $P \leq 0.01$ respectively; ns = non-significantly correlated at $P \leq 0.10$.

EISSN 2706-5510

Table 05. Correlation coefficients of the percentage of each nematode trophic group or other nematode community indices and soil nutrient concentrations or other soil properties (adapted from Wang et al., 2004).

Community indices	Correlation coefficient (r)			
	% bacterivores	% fungivores	% herbivores	% omnivores
Ca	0.522	-0.507	ns	ns
Mg	0.559	-0.628*	ns	ns
K	ns	ns	ns	ns
P	ns	ns	ns	ns
N	0.530	-0.691*	ns	ns
OM	0.567	-0.653*	ns	ns
CEC	0.556	-0.584*	ns	ns
% sand	ns	ns	ns	ns
% silt	ns	ns	ns	ns
% clay	ns	ns	ns	ns

OM = organic matter, CEC = cation exchange capacity. * and **Signify correlation significant at $P \leq 0.05$ and $P \leq 0.01$ respectively; ns = non-significantly correlated at $P \leq 0.10$.

Similar results were reported by Villenave et al. (2010). They conducted a 5-month mesocosm experiment in Madagascar where rice and soybean residues were used as soil amendments. No residue was applied in the control treatment. Of the total nematofauna, bacterivores represented 74.9% (12 taxa) and fungivores represented only 13.7% (5 taxa) (Table 05). Under residue treatments, they found an abundance of opportunistic nematodes like Panagrolaimidae, Rhabditidae, *Alaimus*, *Amphidelus*, *Aphelenchus*, *Ditylenehus*. Previously, in another experiment by Villenave et al. (2003) conducted in millet fields of Senegal, they used mixture of cowdung, compost, and goat faeces as organic manure and no fertilization as control. Manure treated plots showed 74% increase in nematode density at mid-cycle and 30% after harvest. Nematodes with cp-1 and cp-2 like Rhabditidae, Aphelenchina, Cephalobidae (three genera *viz. Acrobeles*, *Cephalobus* and *Zeldia*) were significantly higher. Therefore, they concluded a strong correlation between microbial biomass in soil and bacterivores, especially for the nematodes of the Cephalobidae family, considering the climatic conditions of Senegal. Overall, adding easily accessible fertilizer will result in a microbial bloom. Bacterivorous nematodes with a short life cycle (cp1-2) will benefit from this suddenly abundant food source.

Nematodes as bio-indicator / Maturity Index explained
Nematodes with low cp (colonizer–persister) value (cp-1 and cp-2) are short-lived, require more nutrients and have high fecundity and mobility rates. They are called opportunistic nematodes or r-strategists or colonize. They rapidly respond to any disturbance. On the other hand, nematodes with high cp value (cp-3 to cp-5) are long-lived, can withstand poor nutrient conditions and have low reproduction ability. They are also called persisters (K-strategists) (Bongers and Ferris, 1999).

Short-term alteration in community structure of nematodes occurs due to competition between plants and bacteria-fungi for nutrients. Such community alteration predominantly includes opportunistic nematodes (cp-1 and cp-2) (Bongers and Ferris, 1999). For instance, even after four days of manure (powdered cowdung) application, cp-1 nematodes (e.g., *Rhabditina*, *Panagrolaimus*, *Eumonhystera*) increased evidently and became dominant in 2-3 weeks. Because easily degradable substrate results in bacterial bloom, thereby causes outburst of bacterial activity. After a few weeks later, cp-2 (e.g., *Aphelenchoides*, *Eucephalobus*, *Acrobeles*, *Acrobeloides*, *Cervidellus*, *Chiloplacus*, *Cephalobidae*, *Plectus*) became dominant, whereas cp-1 nematodes decreased (Ettema and Bongers, 1993).

Experiments in temperate zone

The results discussed above are also in line with the comparable experiments in temperate regions. For example, Liang et al. (2009) conducted an experiment in a temperate climate (Northeast China) where they applied pig compost manure and urea fertilizer separately and combined with fertilizing the experimental plots. Unfertilized plots were used as control treatment. They confirmed increased number of *Aphelenchoides*, an opportunistic nematode, in OM rich conditions. Because, in stress relieving conditions in soil such as availability of OM, opportunistic nematodes thrive faster than persisters, thereby shifting towards an abundance of opportunists (Bongers, 1999). Also, decomposition rate in soil changes with temperature and amount of substrate.

Recalcitrant versus easy-to-degrade residue input effects

Different litter inputs affect the composition of soil biota, thereby changing the soil food web (Minoshima et al., 2007; Li et al., 2016). The type and localization of residue also influence the nematode composition and abundance. Fungal feeding nematodes are prominent in soils with recalcitrant OM, i.e., OM with high cellulose and lignin content (Villenave et al., 2010). During the early stages of OM decomposition, bacterivores are dominant and fungivores contribute later (Yeates and Bongers, 1999; Fu et al., 2000). Results both under tropical and temperate conditions showed consistency in case of early stage of decomposition (Villenave et al., 2010). In a residue localization effect experiment, Villenave et al. (2010) applied (soybean and rice) residues in two ways: mulching and burial. Buried application of residue showed significantly higher nematode (mostly bacterivores with cp-1 and cp-2) density than the mulched application. Because, buried application allows faster microbial growth (Djigal et al., 2004) and biomass (Yeates, 2003). Soybean residues contained more twigs than rice residues. Moreover, soybean residues contain more proteins and easily digestible sugars but less hemicellulose and cellulose. Therefore, fungivores were more abundant in soybean treatments. Among the fungivores, they found higher density of *Aphelenchus* with soybean residues and *Ditylenchus* with rice-soybean residues; whereas among the bacterivore, members of the family Panagrolaimidae were significantly more abundant in soybean residues, and *Amphidelus*, *Alaimus* and Rhabditidae were abundant in rice residues. Similarly, Zhang et al. (2015) found increased nematode abundance near soil surface (0-5cm) under corn-soybean mixed residues than under corn residues irrespective of the tillage system.

Háněl (2003) reported that the decomposition pathway is dominated by fungi in natural fallow land of cambisol in temperate climates with pH mostly around 6-7. A higher biomass ratio of fungus: bacteria indicate a self-regulated or organic farming ecosystem (Bardgett and McAlister, 1999; Nakamoto et al., 2012). Theoretically, it represents the contribution of bacteria and fungus to SOM decomposition (Ferris et al., 2001; Vestergård, 2004). The ratio is only based on numerical abundance. It does not consider activity, body size or grazing effects of nematodes. Nakamoto et al. (2012) showed that crop residue with a higher C:N ratio (i.e., rye) enhances fungal biomass in soil than residue with a lower C:N ratio (i.e., hairy vetch). On the contrary, no residue application was found to increase plant parasitic nematodes while number of fungivores and bacterivores are decreased. For example, Zhong et al. (2017) conducted an experiment where fruit residues (chopped passion and banana fruit residues) were applied in three quantities (15, 7.5 and 0 t ha^{-1}). They reported that no residue application significantly expanded the density of plant parasites, namely *Meloidogyne* and *Rotylenchulus*. Taxa of plant parasitic nematodes decreased from 46% (for 0 t ha^{-1}) to 13.2% (for 15 t ha^{-1}). Moreover, diversity and distribution of OM increased with different residue input systems. These results were also consistent with Stirling (2013), Liang et al. (2009) and Coudrain et al. (2016). It implies that higher trophic diversity is not correlated with higher frequency of omnivores, fungivores, and predators than bacterivores and plant feeding nematodes (Háněl, 2003; Háněl, 2010).

IV. Effects of tillage

Effects of tillage on aggregate formation

Under no tillage (NT) system, soils are stratified (both physically and chemically), where concentration of nutrients is higher towards the surface (Hendrix et al., 1986). More stable soil ecosystem was observed under reduced or NT by protecting soil organic carbon (SOC) from microbial decomposition through stable aggregate (water-stable aggregates) formation. Soil macro- and micro-aggregates give physical protection to the associated soil carbon. For example, Razafimbelo et al. (2008) experimented on physical protection of SOC affected by conventional tillage (CT) and no tillage (NT) in tropical soil. A laboratory incubation experiment of 28 days was used to measure the physical protection of SOC. Under no-tillage conditions, soil carbon was found 1.8 times higher in macro-aggregates (200-2000 μm) than in tilled conditions. The management practices influenced aggregate carbon contents, and aggregates under no tillage treatment had higher SOC than ploughed condition. Another similar experiment conducted in humid tropical climate (Rondônia and Mato Grosso in western Brazil) by Maia et al. (2010). They also used CT and NT and observed its effects on SOC. No tillage increased SOC by a factor of 1.8±0.06 in their experiment. The results are also in line with Huang et al. (2015), who reported that NT in combination with organic residue enhances both formation and carbon content of macro-aggregates near the surface layer of soil. Also, Kihara et al. (2012) reported an increase in mean weight diameter of aggregates by 19 – 34% under reduced tillage compared to CT at a soil depth of 0 – 15 cm.

EISSN 2706-5510

Grandière et al. (2007) emphasized on presence of SOC as particulate organic matter (POM) form. POM is a fraction of soil OM with a size range of 2 mm to 0.053 mm (Cambardella and Elliott, 1992). Grandière et al. (2007) studied the effects of NT and CT on SOC and argued that 17-27% difference of SOC storage between NT and CT is due to its association with POM located inside (POMi) the aggregates (> 50 μm), and 46-60% difference due to association with silt+clay soil particles (< 50 μm). POM located outside the stable soil aggregates (POMe) was almost similar between the treatments (Figure 01). Castro Filho et al. (2002) conducted a similar experiment in humid subtropical climate of Brazil where NT and CT were applied for a long time (21 years) with rotations of three crops (soybean, maize, and wheat). NT showed higher aggregate stability with no overall effect of crop rotations on stability indices. The 2 mm size class of aggregates contained the highest quantities of SOC. Beare et al. (1994) collected soil samples from the separate plots used for CT and NT for a long time (13 years). Both plots were fertilized equally. Therefore, there was almost no difference in inputs except tillage. They reported fewer and unstable macro-aggregates in CT and 20% higher POM in NT treatment. Martínez et al. (2008) reported that NT treatment facilitates higher sized aggregate formation (especially in the upper layer of soils), slower soil water infiltration and higher water retention in soil (Figure 02).

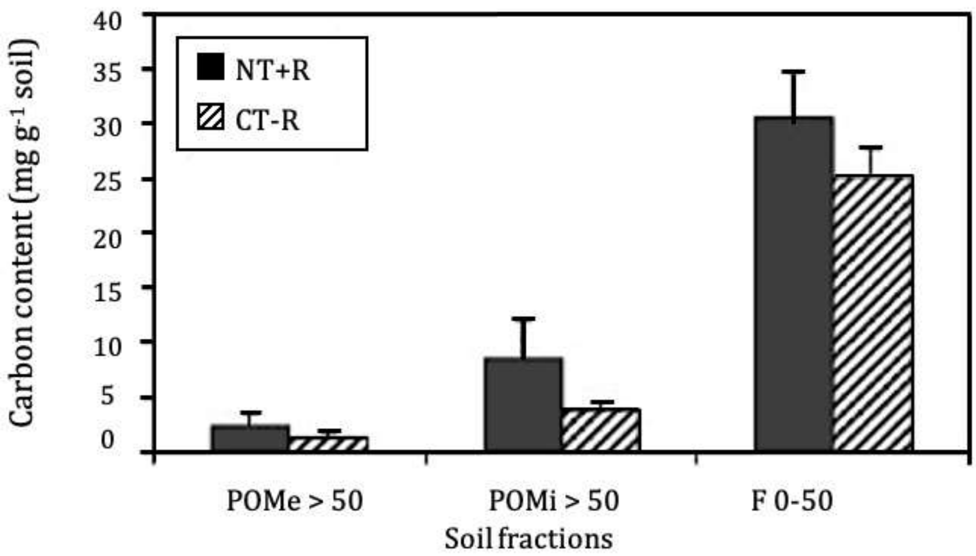

Figure 01. Carbon content (mg C g⁻¹ soil) in particulate organic matter located outside (POMe > 50 μm) and inside (POMi > 50 μm) stable soil aggregates and in silt + clay fraction (F 0–50 μm); NT+R = No-tillage with residue mulching, CT-R = Share-ploughed tillage with residue removed (from Razafimbelo et al., 2008).

Effects on soil microbe types

Application of tillage leads to disturbance of ecosystem in soil and supports short-lived organism thereby increasing the abundance of bacterivores (Háněl, 2003). Bouwman and Zwart (1994) reported that during the initial, rapid phase of decomposition, nematodes, in particular, from Rhabditidae (opportunistic cp-1) family bloomed. At the further stages of decomposition, Cephalobidae (bacteria-feeding nematodes), Aphelenchoididae (fungal-feeding nematodes), and at last Tylenchidae (phytophages, also fungivore) became abundant. Fu et al. (2000) also confirmed that bacterivores were more abundant than fungivores immediately after the decomposition, particularly under the tilled condition. But with the progress of decomposition, relative abundance of fungivores increased. They attributed the rapid proliferation of nematodes as a result of fast reproduction. An increasing trend of omnivores was evident at later stage of residue incorporation, regardless of tillage treatments. Overall, under no tillage treatment, higher abundance of omnivores, predators, and phytophages was reported. This result is consistent with Zhang et al. (2012), who reported that omnivorous nematodes (e.g., *Dorylaimellus*) are benefitted under reduced tillage or conservational tillage. Also, in a temperate climate, Löbmann et al. (2016) found an explicitly higher population of omnivores-predators and fungivores in untilled apple orchards than in tilled oilseed rape fields.

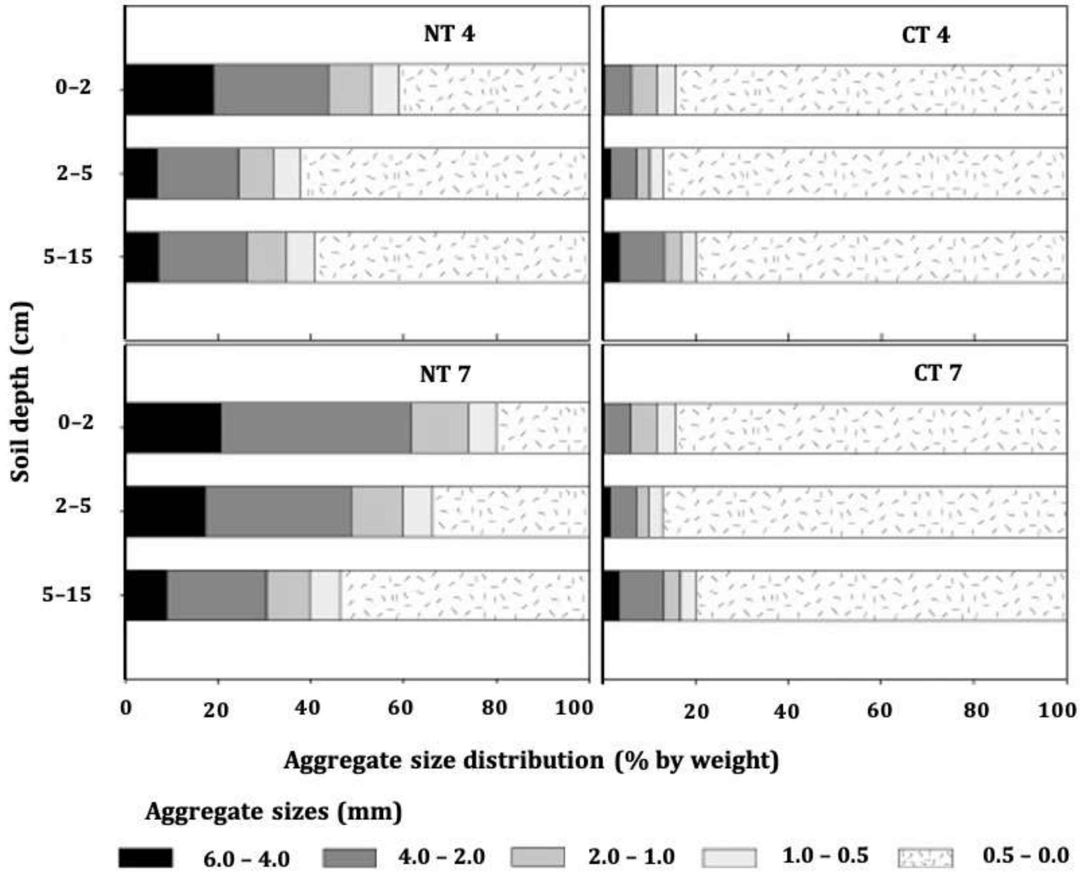

Figure 02. Aggregate size distribution under the different tillage treatments (from Martínez et al., 2008). NT 4 = No tillage for 4 years, NT 7 = No tillage for 7 years, CT 4 = Conventional tillage for 4 years, CT 7 = Conventional tillage for 4 years.

Effects on moisture retention

Tillage application changes soil surface conditions which exerts more significant influence on water accumulation. No-tillage favours water retention and eventually supports higher root growth (Lampurlanés et al., 2001). Therefore, especially root-feeding nematodes proliferate due to higher density and prolonged duration of active roots. This type of nematode is highly sensitive to tillage application regardless of tillage (deep or shallow). For example, Okada and Harada (2007) found a more diverse nematode community with significant increase in *Pratylenchus*, a root-feeding nematode (cp-3) in no-tillage treatment. *K*-strategists (cp-3 to cp-5) were found in abundance, e.g., dorylaimids, *Diphtherophora* whereas *r*-strategists had a lower density, such as *Eumonhystera*, Panagrolaimidae. They attributed these results to accumulation of OM with optimum moisture in untilled soil. Above all, absence or deficiency of physical disturbance due to no-tillage more likely paved the way for this increased diversity. The results are also consistent with that of Ferris et al. (2001), who concluded that nematodes with higher cp values (*K*-strategists) such as plant parasites, predators and omnivores are more sensitive to environmental disturbances than *r*-strategists (with lower cp values) such as bacterivores. Therefore, this transition from *r*-strategists to *K*-strategists correlates to a lower soil disturbance and higher stability in soil system (van Capelle et al., 2012; Zhong et al., 2017).

V. Conclusion

Intensified agriculture does not necessarily reduce the trophic groups of nematodes; instead, it changes the composition of trophic groups (Ferris et al., 1996). Understanding the impacts of different tillage treatments on soil biota is crucial for maintaining soil biodiversity as well as sustainable crop production. Residue management comes along as one of the main differentiating factors between tillage systems (Wardle, 1995). Under short-term application, residue management has more influence on soil nematode than no-tillage system (Zhang et al., 2012). Without residue treatment, population of fungivores surpassed the population of bacterivores. Several short-term impact studies reported remarkable responses from residue management than tillage operations (Zhang et al., 2012; Lenz and

EISSN 2706-5510

Eisenbeis, 2000). Under no-tillage system, rate of OM decomposition was found slower with more diversified soil fauna. In pursuit of sustainability, no-tillage has triggered a behavioral change among the farmers and extension workers in tropical countries. Over ten years (from 1990 to 2005/2006), no-tillage system was adopted from 1 million hectares to 25 million hectares in Brazil (Dion, 2010). Háněl (2003) thinks that recovery of nematode communities is possible within several years after cessation of intensive management practices. Though diversity restoration is a slow process, intervention in the food web by omnivorous nematodes (e.g., *Aporcelaimellus*) with their versatile feeding technique can compensate for the lack of highly sensitive species to habitat disturbance. Restoration of disturbed soil ecosystem has a huge scope for future research.

References

[1]. Bardgett, R. D. and McAlister, E. (1999). The measurement of soil fungal: bacterial biomass ratios as an indicator of ecosystem self-regulation in temperate meadow grasslands. Biology and Fertility of Soils, 29(3), 282-290. https://doi.org/10.1007/s003740050554

[2]. Beare, M. H., Hendrix, P. F. and Coleman, D. C. (1994). Water-stable aggregates and organic matter fractions in conventional-and no-tillage soils. Soil Science Society of America Journal, 58(3), 777-786. https://doi.org/10.2136/sssaj1994.03615995005800030021x

[3]. Bongers, T. (1999). The maturity index, the evolution of nematode life history traits, adaptive radiation and cp-scaling. Plant and soil, 212(1), 13-22. https://doi.org/10.1023/A:1004571900425

[4]. Bongers, T. and Bongers, M. (1998). Functional diversity of nematodes. Applied Soil Ecology, 10(3), 239-251. https://doi.org/10.1016/S0929-1393(98)00123-1

[5]. Bongers, T. and Ferris, H. (1999). Nematode community structure as a bioindicator in environmental monitoring. Trends in Ecology and Evolution, 14(6), 224-228. https://doi.org/10.1016/S0169-5347(98)01583-3

[6]. Bouwman, L. A. and Zwart, K. B. (1994). The ecology of bacterivorous protozoans and nematodes in arable soil. Agriculture, ecosystems & environment, 51(1-2), 145-160. https://doi.org/10.1016/0167-8809(94)90040-X

[7]. Bulte, E., Hector, A. and Larigauderie, A. (2005). eco SERVICES: assessing the impacts of biodiversity changes on ecosystem functioning and services. Diversitas Report, 3, 40.

[8]. Cambardella, C. A. and Elliott, E. T. (1992). Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Science Society of America Journal, 56(3), 777-783. https://doi.org/10.2136/sssaj1992.03615995005600030017x

[9]. Castro Filho, C., Lourenço, A., Guimarães, M. D. F. and Fonseca, I. C. B. (2002). Aggregate stability under different soil management systems in a red latosol in the state of Parana, Brazil. Soil and Tillage Research, 65(1), 45-51. https://doi.org/10.1016/S0167-1987(01)00275-6

[10]. Christanty, L. (1986). Shifting cultivation and tropical soils: patterns, problems, and possible improvements. *Traditional agriculture in Southeast Asia. A human ecology perspective.*, 226-240.

[11]. Coudrain, V., Hedde, M., Chauvat, M., Maron, P. A., Bourgeois, E., Mary, B. and Recous, S. (2016). Temporal differentiation of soil communities in response to arable crop management strategies. Agriculture, Ecosystems & Environment, 225, 12-21. https://doi.org/10.1016/j.agee.2016.03.029

[12]. Dion, P. (Ed.). (2010). Soil biology and agriculture in the tropics. Berlin, Germany: Springer. https://doi.org/10.1007/978-3-642-05076-3

[13]. Djigal, D., Brauman, A., Diop, T. A., Chotte, J. L. and Villenave, C. (2004). Influence of bacterial-feeding nematodes (Cephalobidae) on soil microbial communities during maize growth. Soil Biology and Biochemistry, 36(2), 323-331. https://doi.org/10.1016/j.soilbio.2003.10.007

[14]. Dorris, M., De Ley, P. and Blaxter, M. L. (1999). Molecular analysis of nematode diversity and the evolution of parasitism. Parasitology today, 15(5), 188-193. https://doi.org/10.1016/S0169-4758(99)01439-8

[15]. Ettema, C. H. and Bongers, T. (1993). Characterization of nematode colonization and succession in disturbed soil using the Maturity Index. Biology and Fertility of Soils, 16(2), 79-85. https://doi.org/10.1007/BF00369407

[16]. Ferris, H., Bongers, T. and De Goede, R. G. M. (2001). A framework for soil food web diagnostics: extension of the nematode faunal analysis concept. Applied soil ecology, 18(1), 13-29. https://doi.org/10.1016/S0929-1393(01)00152-4

[17]. Ferris, H., Venette, R. C. and Lau, S. S. (1996). Dynamics of nematode communities in tomatoes grown in conventional and organic farming systems, and their impact on soil fertility. *Applied Soil Ecology*, 3(2), 161-175. https://doi.org/10.1016/0929-1393(95)00071-2

[18]. Fiscus, D. A. and Neher, D. A. (2002). Distinguishing sensitivity of free-living soil nematode genera to physical and chemical disturbances. *Ecological Applications*, *12*(2), 565-575. https://doi.org/10.1890/1051-0761(2002)012[0565:DSOFLS]2.0.CO;2

[19]. Fu, S., Coleman, D. C., Hendrix, P. F. and Crossley, D. A. (2000). Responses of trophic groups of soil nematodes to residue application under conventional tillage and no-till regimes. *Soil Biology and Biochemistry*, 32(11), 1731-1741. https://doi.org/10.1016/S0038-0717(00)00091-2

[20]. Giller, K. E., Bignell, D. E., Lavelle, P. A. T. R. I. C. K., Swift, M. J., Barrios, E. D. M. U. N. D. O., Moreira, F. A. T. I. M. A. and Huising, J. E. R. O. E. N. (2005). Soil biodiversity in rapidly changing tropical landscapes: scaling down and scaling up. *Biological Diversity and Function in Soils. Cambridge University Press, Cambridge*, 295-318. https://doi.org/10.1017/CBO9780511541926.017

[21]. Golabi, M. H., El-Swaify, S. A. and Iyekar, C. (2014). Experiment of "No-Tillage" Farming System on the Volcanic Soils of Tropical Islands of Micronesia. International Soil and Water Conservation Research, 2(2), 30-38. https://doi.org/10.1016/S2095-6339(15)30004-6

[22]. Goodsell, P. J., Underwood, A. J. and Chapman, M. G. (2009). Evidence necessary for taxa to be reliable indicators of environmental conditions or impacts. *Marine Pollution Bulletin*, 58(3), 323-331. https://doi.org/10.1016/j.marpolbul.2008.10.011

[23]. Grandière, I., Razafimbelo, T., Barthes, B., Blanchart, E., Louri, J., Ferrer, H. and Feller, C. (2007). Effet de différents systemes en semis direct avec couverture végétale (SCV) sur la distribution granulo-densimétrique de la matiere organique d'un sol argileux des Hautes Terres de Madagascar. *Etude et Gestion des Sols*, 14, 117-133.

[24]. Háněl, L. (2003). Recovery of soil nematode populations from cropping stress by natural secondary succession to meadow land. Applied Soil Ecology, 22(3), 255-270. https://doi.org/10.1016/S0929-1393(02)00152-X

[25]. Háněl, L. (2010). An outline of soil nematode succession on abandoned fields in South Bohemia. Applied soil ecology, 46(3), 355-371. https://doi.org/10.1016/j.apsoil.2010.10.005

[26]. Hendrix, P. F., Parmelee, R. W., Crossley, D. A., Coleman, D. C., Odum, E. P. and Groffman, P. M. (1986). Detritus food webs in conventional and no-tillage agroecosystems. Bioscience, 36(6), 374-380. https://doi.org/10.2307/1310259

[27]. Hooper, D. U., Chapin, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S. and Schmid, B. (2005). Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological monographs, 75(1), 3-35. https://doi.org/10.1890/04-0922

[28]. Huang, M., Liang, T., Wang, L. and Zhou, C. (2015). Effects of no-tillage systems on soil physical properties and carbon sequestration under long-term wheat–maize double cropping system. Catena, 128, 195-202. https://doi.org/10.1016/j.catena.2015.02.010

[29]. Ingham, R. E., Trofymow, J. A., Ingham, E. R. and Coleman, D. C. (1985). Interactions of bacteria, fungi, and their nematode grazers: effects on nutrient cycling and plant growth. Ecological monographs, 55(1), 119-140. https://doi.org/10.2307/1942528

[30]. Kihara, J., Martius, C., Bationo, A., Thuita, M., Lesueur, D., Herrmann, L. and Vlek, P. L. (2012). Soil aggregation and total diversity of bacteria and fungi in various tillage systems of sub-humid and semi-arid Kenya. Applied Soil Ecology, 58, 12-20. https://doi.org/10.1016/j.apsoil.2012.03.004

[31]. Kleinman, P. J. A., Pimentel, D. and Bryant, R. B. (1995). The ecological sustainability of slash-and-burn agriculture. Agriculture, Ecosystems & Environment, 52(2-3), 235-249. https://doi.org/10.1016/0167-8809(94)00531-I

[32]. Lampurlanés, J., Angás, P. and Cantero-Martınez, C. (2001). Root growth, soil water content and yield of barley under different tillage systems on two soils in semiarid conditions. Field Crops Research, 69(1), 27-40. https://doi.org/10.1016/S0378-4290(00)00130-1

[33]. Lenz, R. and Eisenbeis, G. (2000). Short-term effects of different tillage in a sustainable farming system on nematode community structure. Biology and Fertility of Soils, 31(3), 237-244. https://doi.org/10.1007/s003740050651

[34]. Li, N., Pan, F. J., Han, X. Z. and Zhang, B. (2016). Development of soil food web of microbes and nematodes under different agricultural practices during the early stage of pedogenesis of a Mollisol. Soil Biology and Biochemistry, 98, 208-216. https://doi.org/10.1016/j.soilbio.2016.04.011

EISSN 2706-5510

[35]. Liang, W., Lou, Y., Li, Q., Zhong, S., Zhang, X. and Wang, J. (2009). Nematode faunal response to long-term application of nitrogen fertilizer and organic manure in Northeast China. Soil Biology and Biochemistry, 41(5), 883-890. https://doi.org/10.1016/j.soilbio.2008.06.018

[36]. Löbmann, M. T., Vetukuri, R. R., de Zinger, L., Alsanius, B. W., Grenville-Briggs, L. J. and Walter, A. J. (2016). The occurrence of pathogen suppressive soils in Sweden in relation to soil biota, soil properties, and farming practices. Applied Soil Ecology, 107, 57-65. https://doi.org/10.1016/j.apsoil.2016.05.011

[37]. Maia, S. M., Ogle, S. M., Cerri, C. C. and Cerri, C. E. (2010). Changes in soil organic carbon storage under different agricultural management systems in the Southwest Amazon Region of Brazil. Soil and Tillage Research, 106(2), 177-184. https://doi.org/10.1016/j.still.2009.12.005

[38]. Martínez, E., Fuentes, J. P., Silva, P., Valle, S. and Acevedo, E. (2008). Soil physical properties and wheat root growth as affected by no-tillage and conventional tillage systems in a Mediterranean environment of Chile. Soil and Tillage Research, 99(2), 232-244. https://doi.org/10.1016/j.still.2008.02.001

[39]. Mills, A. A. S. and Adl, M. S. (2011). Changes in nematode abundances and body length in response to management intensive grazing in a low-input temperate pasture. Soil Biology and Biochemistry, 43(1), 150-158. https://doi.org/10.1016/j.soilbio.2010.09.027

[40]. Minoshima, H., Jackson, L. E., Cavagnaro, T. R., Sánchez-Moreno, S., Ferris, H., Temple, S. R. and Mitchell, J. P. (2007). Soil food webs and carbon dynamics in response to conservation tillage in California. Soil Science Society of America Journal, 71(3), 952-963. https://doi.org/10.2136/sssaj2006.0174

[41]. Nakamoto, T., Komatsuzaki, M., Hirata, T. and Araki, H. (2012). Effects of tillage and winter cover cropping on microbial substrate-induced respiration and soil aggregation in two Japanese fields. Soil science and plant nutrition, 58(1), 70-82. https://doi.org/10.1080/00380768.2011.650134

[42]. Nwaga, D., Jansa, J., Angue, M. A. and Frossard, E. (2010). The Potential of Soil Beneficial Micro-Organisms for Slash-and-Burn Agriculture in the Humid Forest Zone of Sub-Saharan Africa. Soil Biology and Agriculture in the Tropics, 81–107. https://doi.org/10.1007/978-3-642-05076-3

[43]. Okada, H. and Harada, H. (2007). Effects of tillage and fertilizer on nematode communities in a Japanese soybean field. Applied Soil Ecology, 35(3), 582-598. https://doi.org/10.1016/j.apsoil.2006.09.008

[44]. Palm, C. A., Giller, K. E., Mafongoya, P. L. and Swift, M. J. (2001). Management of organic matter in the tropics: translating theory into practice. In *Managing Organic Matter in Tropical Soils: Scope and Limitations* (pp. 63-75). Springer Netherlands. https://doi.org/10.1007/978-94-017-2172-1_7

[45]. Razafimbelo, T. M., Albrecht, A., Oliver, R., Chevallier, T., Chapuis-Lardy, L. and Feller, C. (2008). Aggregate associated-C and physical protection in a tropical clayey soil under Malagasy conventional and no-tillage systems. Soil and Tillage Research, 98(2), 140-149. https://doi.org/10.1016/j.still.2007.10.012

[46]. Ribeiro Filho, A. A., Adams, C. and Murrieta, R. S. S. (2013). The impacts of shifting cultivation on tropical forest soil: a review. Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas, 8(3), 693-727. https://doi.org/10.1590/S1981-81222013000300013

[47]. Rousk, J., Bååth, E., Brookes, P. C., Lauber, C. L., Lozupone, C., Caporaso, J. G. and Fierer, N. (2010). Soil bacterial and fungal communities across a pH gradient in an arable soil. The ISME journal, 4(10), 1340. https://doi.org/10.1038/ismej.2010.58

[48]. Schloter, M., Dilly, O. and Munch, J. C. (2003). Indicators for evaluating soil quality. Agriculture, Ecosystems & Environment, 98(1), 255-262. https://doi.org/10.1016/S0167-8809(03)00085-9

[49]. Six, J., Feller, C., Denef, K., Ogle, S., de Moraes Sa, J. C. and Albrecht, A. (2002). Soil organic matter, biota and aggregation in temperate and tropical soils-Effects of no-tillage. Agronomie, 22(7-8), 755-775. https://doi.org/10.1051/agro:2002043

[50]. Stirling, G. R. (2013). Integration of organic amendments, crop rotation, residue retention and minimum tillage into a subtropical vegetable farming system enhances suppressiveness to root-knot nematode (Meloidogyne incognita). Australasian Plant Pathology, 42(6), 625-637. https://doi.org/10.1007/s13313-013-0236-9

[51]. Suter, G. W. (2001). Applicability of indicator monitoring to ecological risk assessment. Ecological Indicators, 1(2), 101-112. https://doi.org/10.1016/S1470-160X(01)00011-5

[52]. Swift, M. J., Izac, A. M. and van Noordwijk, M. (2004). Biodiversity and ecosystem services in agricultural landscapes—are we asking the right questions?. Agriculture, Ecosystems & Environment, 104(1), 113-134. https://doi.org/10.1016/j.agee.2004.01.013
[53]. Treonis, A. M., Austin, E. E., Buyer, J. S., Maul, J. E., Spicer, L. and Zasada, I. A. (2010). Effects of organic amendment and tillage on soil microorganisms and microfauna. Applied Soil Ecology, 46(1), 103-110. https://doi.org/10.1016/j.apsoil.2010.06.017
[54]. Tripathi, B. and Kang, B . (1992). THE AFNETA: Alley Farming Training Manual. Source Book For Alley Farming Research (Vol. 2). Alley Farming Network for Tropical Africa, International Institute of Tropical Agriculture, Ibadan, Addis Ababa**,** Ethiopia
[55]. Tripathi, B. M., Kim, M., Singh, D., Lee-Cruz, L., Lai-Hoe, A., Ainuddin, A. N. and Adams, J. M. (2012). Tropical soil bacterial communities in Malaysia: pH dominates in the equatorial tropics too. Microbial ecology, 64(2), 474-484. https://doi.org/10.1007/s00248-012-0028-8
[56]. Trumbore, S. E. (1993). Comparison of carbon dynamics in tropical and temperate soils using radiocarbon measurements. Global Biogeochemical Cycles, 7(2), 275-290. https://doi.org/10.1029/93GB00468
[57]. USDA (1978). Soil Taxonomy. Agriculture Handbook No. 436, USDA, Soil Conservation Service, Washington DC.
[58]. Van Capelle, C., Schrader, S. and Brunotte, J. (2012). Tillage-induced changes in the functional diversity of soil biota–A review with a focus on German data. European Journal of Soil Biology, 50, 165-181. https://doi.org/10.1016/j.ejsobi.2012.02.005
[59]. Vestergård, M. (2004). Nematode assemblages in the rhizosphere of spring barley (Hordeum vulgare L.) depended on fertilisation and plant growth phase. Pedobiologia, 48(3), 257-265. https://doi.org/10.1016/j.pedobi.2004.01.003
[60]. Villenave, C., Bongers, T., Ekschmitt, K., Fernandes, P. and Oliver, R. (2003). Changes in nematode communities after manuring in millet fields in Senegal. Nematology, 5(3), 351-358. https://doi.org/10.1163/156854103769224340
[61]. Villenave, C., Rabary, B., Kichenin, E., Djigal, D. and Blanchart, E. (2010). Earthworms and plant residues modify nematodes in tropical cropping soils (Madagascar): a mesocosm experiment. Applied and Environmental Soil Science, 323640. https://doi.org/10.1155/2010/323640
[62]. Wang, K. H., McSorley, R. and Gallaher, R. N. (2004). Relationship of soil management history and nutrient status to nematode community structure. Nematropica, 34(1), 83-96.
[63]. Wardle, D. A. (1995). Impacts of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices. Advances in ecological research, *26*, 105-185. https://doi.org/10.1016/S0065-2504(08)60065-3
[64]. Yan, S., Singh, A. N., Fu, S., Liao, C., Wang, S., Li, Y. and Hu, L. (2012). A soil fauna index for assessing soil quality. Soil Biology and Biochemistry, 47, 158-165. https://doi.org/10.1016/j.soilbio.2011.11.014
[65]. Yeates, G. W. (2003). Nematodes as soil indicators: functional and biodiversity aspects. Biology and Fertility of Soils, 37(4), 199-210. https://doi.org/10.1007/s00374-003-0586-5
[66]. Yeates, G. W. and Bongers, T. (1999). Nematode diversity in agroecosystems. Agriculture, Ecosystems and Environment, 74(1), 113-135. https://doi.org/10.1016/S0167-8809(99)00033-X
[67]. Zhang, X., Li, Q., Zhu, A., Liang, W., Zhang, J. and Steinberger, Y. (2012). Effects of tillage and residue management on soil nematode communities in North China. Ecological Indicators, 13(1), 75-81. https://doi.org/10.1016/j.ecolind.2011.05.009
[68]. Zhang, Z. Y., Zhang, X. K., Jhao, J. S., Zhang, X. P. and Liang, W. J. (2015). Tillage and rotation effects on community composition and metabolic footprints of soil nematodes in a black soil. European Journal of Soil Biology, 66, 40-48. https://doi.org/10.1016/j.ejsobi.2014.11.006
[69]. Zhong, S., Zeng, H. C. and Jin, Z. Q. (2017). Influences of different tillage and residue management systems on soil nematode community composition and diversity in the tropics. Soil Biology and Biochemistry, 107, 234-243. https://doi.org/10.1016/j.soilbio.2017.01.007

EISSN 2706-5510