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Original Article

Soil macrofauna communities under plant cover in a no-till system in Thailand

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ABSTRACT

The impact of no-till cropping systems with plant cover on soil macrofauna communities was assessed according to their abundance and biomass. The study was carried out in northeastern Thailand under a conventional cropping system (plow-based tillage), no-till cropping systems with plant cover (*Brachiaria ruziziensis*, *Stylosanthes guianensis*, *S. guianensis* associated with *B. ruziziensis*, rice straw) and under a natural dipterocarp forest. Soil macrofauna populations were sampled in 2007 (June and October) during the rainy season and at a beginning of the dry season, respectively. The results revealed that in the short term, the biological compartment responded quickly to the presence of plant cover, as shown by a significant increase in soil macrofauna abundance and total biomass. The highest mean total abundance (MTA) of 4224 individuals/m^2 at the end of planting period (October 2007) was observed under *S. guianensis* cover and also the highest mean total soil macrofauna biomass (MTB) of 14.63 g/m^2 was observed in the forest system in the same period. However, in the system of cultivation, the highest MTB of 11.33 g/m^2 was observed under *S. guianensis* cover. Moreover, the change rate of soil macrofauna MTA was the highest under *S. guianensis* cover (+751.61%) and the change rate of soil macrofauna MTB revealed that this change rate was highest in forest (+430.07%). However, in the other systems of cultivation, the highest change rate of MTB was under *S. guianensis* cover (+12.96%).

Introduction

Soil macrofauna include invertebrates over 2 mm in length, such as ants, beetles, spiders, earthworms, millipedes and termites (Blanchart et al., 2004). These organisms are the main causal function in the fragmentation and incorporation of organic matter (OM) in the soil, to make the favorable conditions for activity of soil microorganism and distribution and their activities lead to the formation of biogenic structures (galleries, chambers, faecal pellets and casts), thus influencing soil aggregation, water properties and OM assimilation (Lavelle et al., 1997). Among soil macrofauna, soil ecosystem engineers (earthworms, ants and termites) are of particular interest (Jones et al., 1994) as they have a major role in soil functioning. Through their impacts on soil physical and chemical changes, soil ecosystem engineers are directly or indirectly involved in enhancing the availability of resources for other species (Jones et al., 1994, 1997; Lavelle et al., 1997). Through their construction activities (biogenic structures), soil ecosystem engineers have an impact on soil porosity and aggregation associated with the soil water properties regarding soil organic matter (SOM), and in turn on the resources available for soil microorganisms (Decaëns et al., 2001; Sá et al., 2001). Soil macrofauna thus influence the soil physical and chemical properties related to soil fertility (Lobry de Bruyn and Conacher, 1990; Lavelle et al., 1997; Six et al., 2004; Barrios, 2007).

The adoption of no-till (NT) cropping systems with plant cover has beneficial impacts on the soil chemical, physical and biological properties, and therefore can enhance the sustainability of the

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systems (Séguy et al., 2006). These systems are designed to maintain permanent soil cover with mulch formed from organic residue (Séguy et al., 2006). A mulch layer on the soil surface helps control weeds, preserve soil humidity, minimize temperature fluctuations at the soil surface, reduce pests and diseases (Hoitink and Boehm, 1999; Locke et al., 2002, 2006), improve soil structure and aggregation (Tivet et al., 2013) and contribute to soil organic carbon (SOC) sequestration (Tivet et al., 2013). From an agronomic standpoint, it is now recognized that different cropping practices have a marked impact on soil fauna, especially on the abundance, biomass, diversity and structure of soil macrofauna populations (Boyer et al., 1999; Blanchart et al., 2007; de Aquino et al., 2008). Therefore, soil macrofauna abundance and diversity (general or functional) are important factors according to the sustainability of primary production in natural or cultivated ecosystems.

In light of the key role played by macrofauna in soil fertility processes, the main aim of this study was to assess the effects of no-till (NT) cropping systems associated with plant cover diversity on invertebrate soil macrofauna populations, especially soil ecosystem engineers (ants, termites and earthworms), and their population dynamics according to the seasons.

Materials and methods

Field experiments

The study was conducted on the Kasetsart University campus in Sakhon Nakhon Province, northeastern Thailand (17°17′19.38″N, 104°06′ 44.54″E), at an elevation of 171 m above mean sea level. The climate in northeastern Thailand is classified according to Koppen's climatic classification (Koppen, 1948) as a tropical savanna (Aw) with 1587 mm mean annual precipitation and two distinct seasons: May–October with 1335 mm of precipitation and November–April with 252 mm of precipitation. The mean maximum and minimum temperatures are 31.4 °C and 21.2 °C, respectively.

The plant covers were sown in September 2006 consisting of a legume (*Stylosanthes guianensis* [Aubl.]), a grass (*Brachiaria ruziziensis* [R. Gem. & C.M. Evrard]) and an *S. guianensis* associated with *B. ruziziensis*. The cropping systems studied were: 1) rainfed rice (*Oriza sativa*, L.) under a conventional plow-based tillage (CT), 2) direct seeded rice in dead *S. guianensis* cover, 3) direct seeded rice in dead *B. ruziziensis* cover, 4) direct seeded rice in dead *S. guianensis* associated with *B. ruziziensis* cover, and 5) direct seeded rice in rice straw mulch. These five systems were also compared with a natural secondary forest (dipterocarp forest). In 2007, the different covers were mowed and sprayed with herbicides 1 mth before the direct seeding of rice in the covers. The rice straw treatment (imported from outside the plot) was set up at the same time as the plant covers were mowed in the other treatments. A complete randomized block design was set up, with 200 m^2 plot per treatment and per block, with five blocks.

Soil macrofauna

Soil macrofauna were sampled twice per year: 1) 4–5 wk after mowing of the plant cover (June 2007); and 2) 1 wk before the rice harvest (late October 2007). The sampling method was adopted from the Tropical Soil Biology and Fertility Programme (Anderson and Ingram, 1993). For each cropping system studied, 10 soil monoliths, measuring 25 cm × 25 cm × 30 cm (width by length by depth), were collected at 6 m intervals along a line whose origin and direction were randomly determined. A 25 cm sampling quadrat was used to mark the position of the monolith, which was then isolated by digging a 20 cm wide trench around it. After recovering the mulch, the monolith was cut into three successive 10 cm thick layers. Any invertebrates visible to the naked eye were collected and fixed in 95% alcohol. Determinations of organism identification, enumeration and biomass were carried out in the laboratory under a stereomicroscope. From identification, the main groups were earthworms (Oligochaeta), beetle larva (Coleoptera larvae), beetle (Coleoptera adults), fly larvae (Diptera larvae), fly (Diptera adults), Lepidoptera larvae, ants (Formicidae), millipedes (Diplopoda), centipedes (Chilopoda), woodlice (Isopoda), termites (Isoptera), spiders (Araneae), cockroaches (Blattidae), bedbugs (Hemiptera), earwigs (Forficulidae), mole cricket (Gryllotalpidae), two pronged bristletail (Diplura), snails and slugs (Gasteropoda), grasshoppers (Tettigoniidae), daddy longlegs (Opiliones), stick insect (Phasmatidae), Pseudoscorpionida and Symphyla. Some adult and larval organisms that were sporadically detected were classified as “other invertebrates”.

Statistical analysis

Data normality was assessed using the Shapiro–Wilk test and, when necessary, the data were log-transformed prior to analysis of variance, followed by Tukey's test for comparison of means. Non-normal data were tested using a nonparametric Kruskal–Wallis test. All statistical analyses were carried out using the XLSTAT software (version 2015.6; The Addinsoft XLSTAT company; New York, NY, United States).

Results

Soil macrofauna abundance

In June 2007, compared to the conventional tillage (CT: 250 individuals/m^2) and forest (501 individuals/m^2) systems, a significant increase ($p < 0.05$) in mean total abundance (MTA) of macrofauna was noted under all no-till (NT) cropping systems with plant cover, namely 496 individuals/m^2, 710 individuals/m^2, 787 individuals/m^2 and 1085 individuals/m^2, under *S. guianensis*, the *S. guianensis* associated with *B. ruziziensis*, rice straw and *B. ruziziensis*, respectively (Table 1).

In October 2007, an analysis of the macrofauna MTA revealed three distinct groups. The first group, which had the lowest MTA, was noted under forest (411 individuals/m^2). The intermediate group included the CT system (1448 individuals/m^2), the NT system with the *S. guianensis* + *B. ruziziensis* association (2042 individuals/m^2) and the NT system with rice straw mulch (2126 individuals/m^2), and the third group, which had the highest MTA, was observed under NT systems with *B. ruziziensis* cover (3034 individuals/m^2) and *S. guianensis* cover (4224 individuals/m^2). The differences were significant ($p < 0.05$) as shown in Table 2.

The change rate (%) of MTA of soil macrofauna from June 2007 to October 2007 under forest, CT and NT systems with different plant cover is shown in Table 3. It can be observed that the highest percentage of change rate was under *S. guianensis* cover (+751.61%).

An analysis of soil macrofauna community structures (Fig. 1) revealed that over 50% of the macrofauna MTA was composed of soil ecosystem engineer populations—earthworms (Oligochaeta), ants (Formicidae), termites (Isoptera)—and especially social insects (ants and termites). The most important group in the soil macrofauna community with regard to the mean total soil macrofauna abundance in all systems in October 2007 was ants. In addition, soil ecosystem engineers were associated with the beetle population in the CT system in June 2007.

Soil macrofauna biomass

In June 2007, compared to the forest (2.76 g/m ^{2}) and CT (6.94 g/m^2) systems, the highest mean total biomass (MTB)

Table 1
Individual abundance (individuals/m^2) and mean total abundance (MTA) of soil macrofauna (individuals/m^2) in June 2007 under forest, conventional tillage (CT) and no-till systems (NT) with different plant cover.

Grouping	Forest	CT	NT			
			Straw	*B. ruziziensis*	*S. guianensis*	SB*
Araneae	26 (9)^{ab†}	6 (3.4)^a	26 (6.7)^b	38 (11)^b	22 (6)^{ab}	26 (7)^{ab}
Blattidae	46 (11.9)^b	2 (1.5)^a	3 (2)^a	2 (1.5)^a	6 (3.4)^a	0 (0)^a
Chilopoda	3 (2)^a	0 (0)^a	0 (0)^a	2 (1.5)^a	0 (0)^a	3 (2)^a
Coleoptera	16 (6)^a	80 (17)^b	101 (27)^b	94 (31)^b	62 (9)^{ab}	86 (17)^b
Coleoptera larvae	26 (11)^{ab}	2 (1.5)^a	18 (7.7)^{ab}	35 (10)^b	18 (11)^b	32 (11)^{ab}
Diplopoda	2 (1.5)^a	3 (2)^a	6 (3.4)^{ab}	14 (4)^b	5 (2)^{ab}	14 (4)^b
Diplura	0 (0)^a	6 (4.6)^{ab}	11 (4)^b	5 (2)^{ab}	2 (1.5)^a	6 (3)^{ab}
Diptera	0 (0)^a	0 (0)^a	0 (0)^a	3 (2)^b	0 (0)^a	0 (0)^a
Diptera larvae	2 (1.5)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Forficulidae	3 (2)^a	3 (2)^a	13 (5)^a	10 (3)^a	3 (3)^a	8 (3)^a
Formicidae	69 (15)^a	110 (49)^a	475 (170)^b	792 (514)^b	251 (82)^{ab}	416 (226)^{ab}
Gasteropoda	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Gryllotalpidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Hemiptera	5 (3)^{ab}	0 (0)^a	11 (3)^{bc}	26 (8.5)^{cd}	48 (9.6)^e	35 (9)^{de}
Isopoda	2 (1.5)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Isoptera	272 (175.5)^b	3 (3)^a	78 (45)^b	5 (2)^a	10 (4)^{ab}	18 (9.5)^{ab}
Lepidoptera larvae	2 (1.5)^a	0 (0)^a	2 (1.5)^a	2 (1.5)^a	3 (2)^a	2 (1.5)^a
Oligochaeta	24 (7)^{ab}	11 (4)^a	13 (7)^a	16 (5)^{ab}	24 (8)^{ab}	40 (10)^b
Opiliones	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Other invertebrate	2 (1.5)^{ab}	0 (0)^a	3 (2)^{ab}	5 (2)^{ab}	6 (2.5)^b	3 (2)^{ab}
Phasmatidae	0 (0)^a	0 (0)^a	2 (1.5)^a	2 (1.5)^a	0 (0)^a	0 (0)^a
Pseudoscorpionida	2 (1.5)^a	2 (1.5)^a	3 (2)^a	14 (7)^a	5 (2)^a	2 (1.5)^a
Symphyla	0 (0)^a	5 (3)^a	3 (2)^a	0 (0)^a	0 (0)^a	0 (0)^a
Tettigoniidae	2 (1.5)^a	16 (6)^{ab}	19 (6.7)^b	21 (4.5)^b	30 (12)^b	19 (7.4)^b
MTA	501 (195)^{ab}	250 (54)^a	787 (174)^b	1085 (511)^b	496 (75)^{ab}	710 (239)^b

* SB = *S. guianensis* + *B. ruziziensis* association.
† Standard error in parenthesis (mean of 10 replicates) and the same lowercase superscript letter in the same row indicate that the difference is not significant (Kruskal–Wallis test, $p < 0.05$).

of soil macrofauna was noted in NT systems under plant cover, that is, with *S. guianensis* (10.03 g/m^2), *B. ruziziensis* (12.69 g/m^2), and the *S. guianensis* associated with *B. ruziziensis* (19.63 g/m^2), and these results were significant ($p < 0.05$) as shown in Table 4. Apart from the forest system, millipede (Diplopoda) and grasshopper (Tettigoniidae) biomasses had a marked impact on the soil macrofauna biomass under the other systems.

Table 2
Individual abundance (individuals/m^2) and mean total abundance (MTA) of soil macrofauna (individuals/m^2) in October 2007 under forest, conventional tillage (CT) and no-till systems (NT) with different plant cover.

Group	Forest	CT	NT			
			Straw	*B. ruziziensis*	*S. guianensis*	SB*
Araneae	32 (11)^{ab†}	34 (8)^{bc}	77 (20)^c	38 (9)^{bc}	34 (7)^{bc}	18 (10)^a
Blattidae	18 (7)^b	3 (2)^{ab}	3 (2)^{ab}	3 (2)^{ab}	5 (3)^{ab}	3 (3)^a
Chilopoda	3 (2)^a	0 (0)^a	3 (2)^a	3 (3)^a	0 (0)^a	3 (2)^a
Coleoptera	14 (9)^a	30 (10)^{ab}	40 (9)^b	42 (10)^b	34 (8)^{ab}	19 (7)^{ab}
Coleoptera larvae	30 (10)^{ab}	6 (2.5)^a	6 (2.5)^a	35 (11)^b	10 (3)^{ab}	26 (7)^b
Diplopoda	3 (2)^b	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Diplura	0 (0)^a	8 (5)^a	5 (2)^a	8 (5)^a	5 (2)^a	6 (3)^a
Diptera	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Diptera larvae	0 (0)^a	0 (0)^a	2 (1.5)^a	0 (0)^a	5 (5)^a	0 (0)^a
Forficulidae	0 (0)^a	48 (14)^b	32 (8)^b	51 (14)^b	53 (13)^b	56 (11)^b
Formicidae	237 (116)^a	1267 (295)^b	1894 (553)^b	2694 (999)^b	4030 (2444)^b	1677 (663)^b
Gasteropoda	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Gryllotalpidae	3 (3)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Hemiptera	3 (2)^a	21 (7.5)^b	14 (4)^{ab}	10 (5)^{ab}	10 (5)^{ab}	21 (5)^b
Isopoda	0 (0)^a	0 (0)^a	0 (0)^a	61 (58)^a	0 (0)^a	50 (47)^a
Isoptera	19 (7)^{bc}	5 (5)^{ab}	2 (1.5)^a	70 (37)^{abc}	2 (1.5)^a	152 (79)^c
Lepidoptera larvae	0 (0)^a	3 (2)^a	3 (2)^a	0 (0)^a	0 (0)^a	0 (0)^a
Oligochaeta	24 (10)^b	2 (1.5)^a	8 (6)^a	2 (1.5)^a	11 (2)^b	5 (3)^a
Opiliones	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	2 (1.5)^a
Other invertebrates	5 (3)^a	6 (2.5)^{ab}	19 (9)^{ab}	8 (3)^{ab}	24 (9)^b	5 (2)^a
Phasmatidae	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Pseudoscorpionida	5 (2)^b	0 (0)^a	2 (1.5)^{ab}	2 (1.5)^{ab}	2 (1.5)^{ab}	0 (0)^a
Symphyla	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a	0 (0)^a
Tettigoniidae	14 (4)^b	14 (7)^{ab}	16 (6)^b	6 (5)^{ab}	2 (1.5)^a	5 (3)^{ab}
MTA*	411 (117)^a	1448 (315)^{ab}	2126 (556)^{ab}	3034 (1014)^b	4224 (2444)^b	2042 (707)^{ab}

* SB = *S. guianensis* + *B. ruziziensis* association.
† Standard error in parenthesis (mean of 10 replicates) and the same lowercase superscript letter in the same row indicate that the difference is not significant (Kruskal–Wallis test, $p < 0.05$).

Table 3
Change rate (%) of mean total abundance (MTA) of soil macrofauna (individuals/m^2) from June 2007 to October 2007 under forest, conventional tillage (CT) and no-till systems (NT) with different plant cover.

MTA	Forest	CT	NT			
			Straw	*B. ruziziensis*	*S. guianensis*	SB*
June 2007	501 (195)^{ab}†	250 (54)^{a}	787 (174)^{b}	1085 (511)^{b}	496 (75)^{ab}	710 (239)b
October 2007	411 (117)^{a}	1448 (315)^{ab}	2126 (556)^{ab}	3034 (1014)^{b}	4224 (2444)^{b}	2042 (707)^{ab}
% Change	−17.96	+606.34	+170.14	+179.63	+751.61	+187.61

* SB = *S. guianensis* + *B. ruziziensis* association.
† Standard error in parenthesis (mean of 10 replicates) and the same lowercase superscript letter in the same row indicate that the difference is not significant (Kruskal–Wallis test, $p < 0.05$).

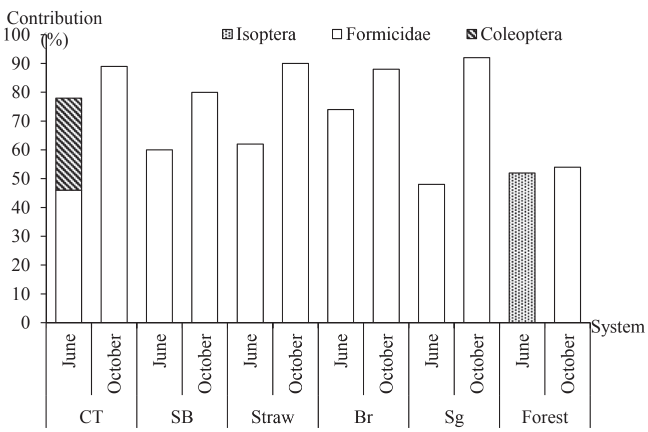

Fig. 1. Contribution of the most important groups of soil macrofauna communities to the mean total soil macrofauna abundance in the different studied systems in June and October 2007. CT (conventional tillage), Br (*Brachiaria ruziziensis*), Sg (*Stylosanthes guianensis*) and SB (*Stylosanthes guianensis* associated with *B. ruziziensis*).

In October 2007, the lowest MTB values were recorded under the CT system (4.61 g/m^2) and under the NT systems with the *S. guianensis* associated with *B. ruziziensis* (5.80 g/m^2) and with rice straw (6.59 g/m^2), and they were significantly lower ($p < 0.05$) than the levels noted in the NT system with *S. guianensis* cover (11.33 g/m^2). Intermediate values were obtained under the NT system with *B. ruziziensis* cover (5.78 g/m^2) and the forest system (14.63 g/m^2) as shown in Table 5. Earthworm biomass had a marked impact on the MTB in the forest (79.8%) and CT (44.68%) systems, as well as in the NT system with rice straw (73%) and *S. guianensis* (60%). Ants and beetle larva (Coleoptera larvae) biomass predominated under the NT systems with *B. ruziziensis* cover (35% for beetle larva and 30% for ants) and with the *S. guianensis* + *B. ruziziensis* association (29% for beetle larva and 48% for ants) as shown in Table 5.

The change rates (%) of MTB of soil macrofauna from June 2007 to October 2007 under forest, CT and NT systems with different plant cover are shown in Table 6. The comparison revealed that the change rate of MTB was by far the highest under forest (+430.07%) but in the other systems of cultivation, the highest change rate of MTB was with *S. guianensis* cover (+12.96%).

Table 4
Biomass of individuals (g/m^2), and mean total biomass (MTB) of soil macrofauna (g/m^2) in June 2007 under forest, conventional tillage (CT) and no-till (NT) systems with different plant cover.

Group	Forest	CT	NT			
			Straw	*B. ruziziensis*	*S. guianensis*	SB*
Araneae	0.05 (0.03)^{a}†	0.03 (0.03)^{a}	0.05 (0.03)^{a}	0.12 (0.06)^{a}	0.03 (0.03)^{a}	0.02 (0.02)^{a}
Blattidae	0.55 (0.5)^{b}	0.004 (0)^{a}	0.002 (0)^{a}	0.01 (0.01)^{a}	0.003 (0)^{a}	0.01 (0.01)^{a}
Chilopoda	0.02 (0.01)^{a}	0 (0)^{a}	0 (0)^{a}	0.01 (0.01)^{a}	0 (0)^{a}	0.02 (0.02)^{a}
Coleoptera	0.12 (0.06)^{a}	0.067 (0.02)^{a}	0.09 (0.03)^{a}	0.09 (0.05)^{a}	0.67 (0.4)^{a}	1.66 (1.35)^{a}
Coleo larvae	0.44 (0.2)^{ab}	0.06 (0.06)^{a}	0.45 (0.4)^{a}	1.09 (0.34)^{b}	0.04 (0.03)^{a}	0.43 (0.3)^{ab}
Diplopoda	0.03 (0.03)^{a}	3.77 (2.4)^{ab}	5.32 (2.6)^{abc}	4.98 (2.5)^{bc}	1.19 (0.7)^{abc}	7.63 (3.4)^{c}
Diplura	0 (0)^{a}	0.01 (0.01)^{ab}	0.01 (0.01)^{b}	0.02 (0.02)^{ab}	0.001 (0.00)^{a}	0.002 (0.00)^{ab}
Diptera	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Diptera larvae	0.002 (0.00)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Forficulidae	0.003 (0.00)^{a}	0.01 (0.01)^{a}	0.04 (0.02)^{ab}	0.04 (0.02)^{b}	0.02 (0.02)^{ab}	0.01 (0.01)^{ab}
Formicidae	0.22 (0.11)^{a}	0.26 (0.18)^{a}	0.82 (0.18)^{b}	0.91 (0.57)^{ab}	0.19 (0.1)^{a}	0.60 (0.22)^{ab}
Gasteropoda	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Gryllotalpidae	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)a	0 (0)^{a}	0 (0)^{a}
Hemiptera	0.08 (0.05)^{a}	0 (0)^{a}	0.004 (0.00)^{a}	0.02 (0.01)^{ab}	2.4 (1.5)^{c}	0.59 (0.5)^{bc}
Isopoda	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Isoptera	0.57 (0.3)^{c}	0.001 (0)^{a}	0.26 (0.15)^{bc}	0.01 (0.00)^{a}	0.003 (0.00)^{a}	0.01 (0.01)^{ab}
Lepido larvae	0.11 (0.11)^{a}	0 (0)^{a}	0 (0)^{a}	0.71 (0.68)^{a}	0.14 (0.13)^{a}	0.12 (0.11)^{a}
Oligochaeta	0.56 (0.2)^{ab}	0.196 (0.1)^{a}	0.59 (0.47)^{a}	1.41 (0.77)^{ab}	0.8 (0.4)^{ab}	4.52 (2.25)^{b}
Opiliones	0.001 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Other invert	0 (0)^{a}	0 (0)^{a}	0.19 (0.18)^{a}	0.5 (0.33)^{a}	0.62 (0.54)^{a}	0.056 (0.04)^{a}
Phasmatidae	0 (0)^{a}	0 (0)^{a}	0.02 (0.02)^{a}	0.01 (0.01)^{a}	0 (0)^{a}	0 (0)^{a}
Pseudoscor	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0.0002 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Symphyla	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Tettigoniidae	0 (0)^{a}	2.53 (1.67)^{b}	1.60 (0.63)^{b}	2.77 (1.85)^{b}	3.93 (1.95)^{b}	3.95 (1.97)^{b}
MTB	2.76 (0.84)^{a}	6.94 (2.6)^{ab}	9.47 (2.8)^{abc}	12.69 (2.7)^{bc}	10.03 (2.7)^{bc}	19.63 (6)^{c}

* SB = *S. guianensis* + *B. ruziziensis* association.
† Standard error in parenthesis (mean of 10 replicates) and the same lowercase superscript letter in the same row indicate that the difference is not significant (Kruskal–Wallis test, $p < 0.05$).

Table 5
Biomass of individuals (g/m^2), and mean total biomass (MTB) of soil macrofauna (g/m^2) in October 2007 under forest, conventional tillage (CT) and no-till (NT) systems with different plant cover.

Group	Forest	CT	NT			
			Straw	*B. ruziziensis*	*S. guianensis*	SB*
Araneae	0.17 (0.05)^{ab†}	0.08 (0.04)^{ab}	0.26 (0.1)^{b}	0.28 (0.17)^{ab}	0.09 (0.03)^{ab}	0.1 (0.08)^{a}
Blattidae	0.21 (0.1)^{b}	0.01 (0.01)^{a}	0.1 (0.07)^{ab}	0.01 (0.01)^{ab}	0.02 (0.02)^{a}	0.01 (0.01)^{a}
Chilopoda	0.04 (0.004)^{a}	0 (0)^{a}	0 (0)^{a}	0.03 (0.03)^{a}	0 (0)^{a}	0.02 (0.02)^{a}
Coleoptera	0.05 (0.03)^{a}	0.01 (0.01)^{ab}	0.06 (0.04)^{ab}	0.17 (0.07)^{b}	0.1 (0.06)^{ab}	0.13 (0.07)^{ab}
Coleo larvae	1.77 (0.79)^{ab}	0.13 (0.08)^{a}	0.13 (0.1)^{a}	2.03 (0.77)^{b}	0.74 (0.34)^{ab}	1.71 (0.63)^{b}
Diplopoda	0.07 (0.05)^{b}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Diplura	0 (0)^{a}	0.002 (0.00)^{a}	0.005 (0.00)^{a}	0.006 (0.00)^{a}	0.007 (0.00)^{a}	0.008 (0.00)^{a}
Diptera	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Diptera larvae	0 (0)^{a}	0 (0)^{a}	0.008 (0.00)^{a}	0 (0)^{a}	0.1 (0.1)^{a}	0 (0)^{a}
Forficulidae	0 (0)^{a}	0.1 (0.03)^{b}	0.08 (0.02)^{b}	0.12 (0.04)^{b}	0.11 (0.03)^{b}	0.21 (0.05)^{b}
Formicidae	0.49 (0.24)^{a}	1.90 (1.25)^{ab}	1.03 (0.22)^{b}	1.78 (0.74)^{b}	3.28 (2.15)^{b}	2.8 (1.67)^{b}
Gasteropoda	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Gryllotalpidae	0.05 (0.05)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Hemiptera	0 (0)^{a}	0.02 (0.01)^{a}	0.01 (0.00)^{a}	0.06 (0.04)^{a}	0.02 (0.01)^{a}	0.03 (0.01)^{a}
Isopoda	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0.02 (0.02)^{a}	0 (0)^{a}	0.03 (0.03)^{a}
Isoptera	0.02 (0.01)^{bc}	0.03 (0.02)^{ab}	0.01 (0.01)^{ab}	0.08 (0.05)^{bc}	0 (0)^{a}	0.42 (0.21)^{c}
Lepido larvae	0 (0)^{a}	0.22 (0.2)^{a}	0.002 (0.00)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Oligochaeta	11.68 (5.75)^{b}	2.06 (1.95)^{a}	4.85 (4.4)^{ab}	0.96 (0.91)^{a}	6.8 (1.5)^{b}	0 (0)^{a}
Opiliones	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Other invert	0.009 (0.01)^{a}	0.02 (0.01)^{ab}	0.01 (0.01)^{ab}	0.01 (0.01)^{ab}	0.05 (0.03)^{b}	0 (0)^{a}
Phasmatidae	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Pseudoscor	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0.001 (0.00)^{a}	0 (0)^{a}
Symphyla	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}
Tettigoniidae	0.08 (0.03)^{b}	0.05 (0.03)^{ab}	0.03 (0.02)^{ab}	0.21 (0.19)^{ab}	0.01 (0.01)^{a}	0.32 (0.3)^{ab}
MTB	14.63 (5.7)^{ab}	4.61 (2.1)^{a}	6.59 (4.4)^{a}	5.78 (1.1)^{ab}	11.33 (1.9)^{b}	5.80 (2.3)^{a}

* SB = *S. guianensis* + *B. ruziziensis* association.
† Standard error in parenthesis (mean of 10 replicates) and the same lowercase superscript letter in the same row indicate that the difference is not significant (Kruskal–Wallis test, $p < 0.05$).

Discussion

Soil macrofauna abundance and biomass were significantly higher under no-till systems with plant cover compared to the conventional tillage after 9 mth for long cycle plant cover (*B. ruziziensis*, *S. guianensis* and the *B. ruziziensis* + *S. guianensis* association) and 4 wk for the system with rice straw. The studies of Brévault et al. (2007), which were carried out on systems that had been operational for 3 yr, also revealed that cropping systems with mulch associated with no tillage had a positive impact on soil fauna abundance.

Compared to the conventional tillage system, total soil macrofauna abundance was significantly higher under no-till cropping systems with plant cover. This total abundance was highest in the late rainy season (early dry season) due to the higher ant abundance. These results confirmed those obtained in other studies that showed a significantly higher abundance of certain macrofauna groups (ants, beetles, millipedes and earthworms) in some cropping systems with plant cover (Laossi et al., 2008; Rousseau et al., 2010; Pimentel et al., 2012). The current study found that over 50% of the total soil macrofauna abundance consisted of ecosystem engineers (ants, termites and earthworms). Additionally, for some systems, the ecosystem engineer abundance was associated with the beetle larva abundance. These results were in good agreement with other studies highlighting the predominance of the soil ecosystem engineer population in total soil macrofauna abundance (De Aquino et al., 2008; Pimentel et al., 2012). According to the plant cover used, the abundance of soil macrofauna may vary. Under *Mucuna pruriens*, Blanchart et al. (2006) observed a decrease in ant populations and Laossi et al. (2008) noted an increase under *Arachis pintoi*. These findings suggest that some macrofauna groups are more sensitive to the litter quality than other groups (Sileshi and Mafongoya, 2007).

No-till cropping systems with plant cover are more ecologically complex agrosystems than conventional systems and require long-term studies to get a clear view of their impacts on the soil biological and chemical parameters involved in overall soil fertility. The results obtained in the current study highlighted a rapid, positive and significant impact of these systems on the soil macrofauna. These short-term results would require confirmation using longer-term studies (over several years) focused on the impact of the quality and quantity of litter involved on soil macrofauna

Table 6
Change rate (%) of mean total biomass (MTB) of soil macrofauna (g/m^2) from June 2007 to October under forest, conventional tillage (CT) and no-till (NT) systems with different plant cover.

MTB	Forest	CT	NT			
			Straw	*B. ruziziensis*	*S. guianensis*	SB*
June 2007	2.76 (0.84)^{a†}	6.94 (2.6)^{ab}	9.47 (2.8)^{abc}	12.69 (2.7)^{bc}	10.03 (2.7)^{bc}	19.63 (6)^{c}
October 2007	14.63 (5.7)^{ab}	4.61 (2.1)^{a}	6.59 (4.4)^{a}	5.78 (1.1)^{ab}	11.33 (1.9)^{b}	5.80 (2.3)^{a}
% Change	+430.07	−33.57	−30.41	−54.45	+12.96	−70.45

* SB = *S. guianensis* + *B. ruziziensis* association.
† Standard error in parenthesis (mean of 10 replicates) and the same lowercase superscript letter in the same row indicate that the difference is not significant (Kruskal–Wallis test, $p < 0.05$).

population levels and their diversity and on soil chemical parameter levels (quantification).

Conflict of interest

The authors declare no conflict of interest.

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