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Abundance of Soil Arthropods under Reduced Tillage and Bagasse Mulching in a Sugarcane Plantation in Central Lampung, Indonesia

Fransiscus Xaverius Susilo[1], I Gede Swibawa[1], Nobuhiro Kaneko[2], Anastasia Kristina[1], Muhammad Badrus Sholih[1], Muhamad Jaya Saputra[1], Fazri Firdaus[1], Sri Haryani[3], Heru Gunito[3], Saefudin[3]

[1]*Faculty of Agriculture, Universitas Lampung, Jl. Prof. Sumantri Brojonegoro No. 1 BandarLampung-Indonesia, e-mail: fx.susilo@fp.unila.ac.id,* [2]*Yokohama National University-JAPAN,* [3]*PT Gunung Madu Plantations, Central Lampung- Indonesia*

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ABSTRACT

This study was aimed to show whether conservation effort through reduced tillage or mulching can promote soil zoological benefits, especially to the soil arthropods in sugarcane plantations area, Central Lampung, Indonesia. Twenty sugarcane plots of 25 m × 25 m size each were prepared in the area and treated with two combined treatments *i.e.* tillage (no tillage and full tillage) and mulching (without bagasse and with bagasse mulch). Tillage and planting were done in July 2010 while mulching was conducted in August 2010. The arthropods were sampled using pitfall traps (mouth diameter = 13.5 cm), each was set per plot for 24 hours. Specimens were identified at least to order level. Sampling was done in September 2010 (1 month after mulch treatment, MAT), January 2011 (4 MAT), and July 2011 (10 MAT). We found four major arthropod orders, namely Araneae (spiders, predator), Coleoptera (beetles, mostly non predator), Collembola (springtails, fungal feeder), and Hymenoptera (ants, mostly forager). The last two groups were the most dominant (contributing to > 90 % of the total abundance). Tillage affected the abundance of overall soil arthropods at 1 MAT and 4 MAT but the effect disappeared at 10 MAT. Reduced tillage can conserve, or does not harm, some soil arthropod groups (ants, predatory ants, beetles, springtails, spiders) in sugarcane agroecosystem.

Keywords: Lampung-Indonesia, mulch, soil arthropods, sugarcane, tillage

ABSTRAK

Penelitian ini menunjukkan bahwa upaya konservasi dengan budidaya pertanian tanpa olah tanah atau pemulsaan memberikan manfaat bagi artropoda tanah di lahan perkebunan tebu di Lampung Tengah, Indonesia. Dua puluh petak pertanaman tebu, masing-masing berukuran 25 m x 25 m, disiapkan kemudian diperlakukan dengan kombinasi olah tanah (tanpa olah tanah dan olah tanah penuh) dan pemulsaan (tanpa mulsa bagas dan dengan mulsa bagas). Pengolahan tanah dan penanaman tebu dilaksanakan pada bulan Juli 2010 sedangkan pemulsaan dilaksanakan pada bulan Agustus 2010. Pengambilan sampel arthropoda pada petak percobaan menggunakan perangkap sumuran (diameter = 13,5 cm); satu perangkap per petak dan perangkap dipasang selama 24 jam di lapangan. Spesimen arthropoda yang tertangkap diidentifikasi sampai taraf ordo. Pengambilan sampel arthropoda dilakukan pada bulan September 2010 (1 bulan setelah perlakuan, BSP), Januari 2011 (4 BSP), dan Juli 2011 (10 BSP). Arthropoda yang tertangkap terdiri atas empat ordo, yaitu Araneae (laba-laba, predator), Coleoptera (kumbang, pada umumnya bukan predator), Collembola (ekor pegas), dan Hymenoptera (semut, sebagian besar pesaba). Collembola dan Hymenoptera mendominasi hasil tangkapan ini (> 90% dari kelimpahan total arthropoda). Pengolahan tanah mempengaruhi kelimpahan arthropoda tanah pada 1 BSP dan 4 BSP tetapi pengaruh tersebut memudar pada 10 BSP. Budidaya pertanian tanpa olah tanah mengkonservasi atau tidak berdampak buruk terhadap arthropoda-arthropoda tanah tertentu (semut, semut predator, kumbang, ekorpegas, dan laba-laba) pada agroekosistem tebu.

Kata kunci: Arthropoda tanah, Lampung-Indonesia, mulsa, tanpa olah tanah, tebu

INTRODUCTION

Soil-dwelling arthropods are important animals (Lavelle and Spain 2001). They associate with plants, plant residue, microbes, and other animals in soil. These associations lead to various types of predation including herbivory, detritivory, fungivory, bacteriovory, and carnivory which form soil food-webs (Susilo *et al*. 2004). Some of these arthropod groups also mediate soil bioturbation (Jones 2003). The working of ecological processes mediated by arthropods indicates the contribution of these animals (edaphic biodiversity) to the functioning of soil ecosystems and in turn to the lives supported thereon (above-ground biodiversity).

In agroecosystem, some groups of these animals may be sensitive to changes in the soil environment due to agronomic activities including tillage. Tillage tends to suppress abundance of mites (Acari) and springtails (Collembola) in corn fields in USA (Stinner *et al*. 1988); predatory arthropods in wheat fields in Argentina (Marasas *et al*. 2001); spiders (Araneae) in corn fields in Spain (Rodriguez *et al*. 2006); and microarthropods in sorghum fields in India (Reddy *et al*. 1994). Degrees of soil disturbance, mulch coverage and decomposition, and weed coverage due to tillage-mulch combination may determine the level of their effects on these biota (Stinner and House 1990). Reduced tillage and mulching using crop residue are therefore expected to improve soil function and conserve soil biota including arthropods.

Information about soil arthropods as related to tillage in sugarcane agroecosystem is limited. Investigations on soil-dwelling arthropods in the agroecosystem have so far been mostly focussed on their pest control aspects including studies on predatory arthropods as affected by chemical control (Hensley *et al*. 1961; Reagan *et al*. 1972), on the effectiveness of biological control against the sugarcane borer (Negm and Hensley 1969), on integrated control against the sugarcane pest and disease (Bessin and Reagan 1993), on the root-feeding scarabaeidae grubs (Logan 1999), on predatory arthropods as affected by harvesting and replanting (Cherry 2003), and on the sugarcane spittlebugs that were parasitized by two species of entomopathogenic nematodes (Tonelli *et al*. 2016). None of those studies were related directly to tillage or mulching. Only recently, the study by Sandhu and Cherry (2014), has begun to link predatory arthropods (ants, beetles, spiders) in sugarcane field to tillage. It is necessary, however, to gather information on other groups of soil arthropods (springtails, mites, and others) as related to tillage.

The objective of our present study was to study the effect of reduced tillage and use of bagasse mulching on the abundance of major groups of soil arthropods in the sugarcane plantation in Central Lampung, Indonesia.

MATERIALS AND METHODS

Study Site

A field experiment was setup in Gunung Madu Plantations, Lampung. The sugarcane plantation is located at Gunung Batin Village of Terusan Nunyai Sub-district, Central Lampung District (4°40’46" S, 105°13’38" E). The site is 95 km north of Bandarlampung City, Lampung Province, Indonesia.

Experimental Setup

Twenty experimental plots of 25 m × 25 m size each were prepared and planted in the area, stretching in a north-south direction. The experiment consisted of two factors (tillage as mainplots and mulch as subplots) giving four treatment combinations, *i.e.* full tillage with mulch (TM), full tillage without mulch (T), no tillage with mulch (NM), and no tillage without mulch (N). Each treatment combination was setup in five replications. The full tillage was done in triple-plows using a tractor equipped with disks and harrows that resulted in 20 cm-deep plows (disking), 40 cm-deep plows (disking), and 20 cm-deep plows (harrowing), respectively. All plots were fertilized with urea, triple superphosphate (TSP), and Muriate of potash (MOP) at rates of 120 kg N ha^{-1}, 80 kg P ha^{-1}, and 180 kg K ha^{-1}, respectively. In addition, BBA (a mixture of decomposed bagasse, filter cake mud, and bagasse boiler ash with a ratio of 5:3:3) was also applied to all plots at a rate of 80 Mg ha^{-1}. In TM and T plots, BBA was applied into and mixed with the soil during the plowing process while in NM and N plots BBA was spread over the soil surface. Fresh bagasse was spread over as mulch on TM and NM plots (at rates of 80 Mg bagasse ha^{-1}). That way, the fresh bagasse mulch was placed on top of the BBA in NM plots. Planting was done by serially placing the sugarcane stem cuttings (variety RGM 2000-838) along double-furrows of 80 cm and 130 cm. The furrows under full tillage (TM and T) were prepared mechanically while those under no tillage (NM and N) were prepared manually. Tillage and planting were done in July 2010 while mulching was done in August

2010 (Miura *et al*. 2013; Kristina 2011; Firdaus 2012; Saputra 2012, Sholih 2012).

Arthropod Sampling

The arthropods were sampled using pitfall traps (Susilo and Karyanto, 2005). The traps made from small-sized plastic buckets (mouth or top diameter = 13.5 cm) were each placed in the center of the plot and set for 24 hours. Each trap was roofed with transparent acetic plastic to avoid rain drops from filling into the pit. Twenty ml of diluted (1%) detergent solution was poured into the bucket pits to facilitate random plunging of the passing-by arthropods into the pits. Arthropods were sampled at three sampling dates, *i.e.* September 2010 (wet season, first month after treatment, 1 MAT), January 2011 (wet season, 4 MAT), and July 2011 (dry season, 10 MAT). Arthropod specimens were sorted into major orders (groups), *i.e.* ants (Hymenoptera: Formicidae), beetles (Coleoptera), springtails (Collembola), spiders (Araneae), and others (the pool of Orthoptera and Diplopoda). Ant specimens were further identified up to generic level (Hashimoto, 2003) and then were split into predatory and non-predatory subgroups. The other groups were identified up to families using Borror *et al.* (1981) (beetles, springtails, spiders) and Chung (2003) (beetles). The abundance of each group was recorded under a dissecting microscope (Model LEICA EZ4HD) and tabulated by treatment (TM, T, NM, N) and sampling date (1 MAT, 4 MAT, 10 MAT).

Statistical Analysis

All statistical analyses were performed using R software version 3.3.2 (R Development Core Team 2016). The effects of tillage and mulching on the composition of arthropods were tested using permutational multivariate analysis of variance (PERMANOVA) using the 'vegan' package (Oksanen *et al*. 2016). Bray-Curtis dissimilarity (permutated for 9999 times) was used with the block as a random effect. The effects on arthropod abundance were tested using a generalized linear model distribution using the GLM function of the stats package. Relationships between predator (predatory ants, spiders) and prey (collembolas, beetles) were determined using structural equation modeling (SEM) using lavaan, quantreg, and semPlot packages.

RESULTS AND DISCUSSION

Soil Arthropods

Abundance of soil arthropods in the sugarcane field varies with treatments and sampling dates (Table 1). Abundance of at least four main groups of the arthropods was documented, *i.e.* ant (Hymenoptera: Formicidae), beetle (Coleoptera), springtail (Collembola), spider (Araneae), and

Table 1. Number of main groups of soil arthropods under four treatment combinations of tillage and mulch in the sugarcane fields.

Sampling date	Treatment	Ant	Predatory ant	Beetle	Springtail	Spider	Other
10-Sep	TM	14.2 (2.8)	-	3.0	68.6 (7.8)	2.6 (0.4)	0.6 (0.1)
(wet season,	T	11.4 (1.2)	-	1.2	38.4 (6.0)	3.6 (0.5)	1.6 (0.4)
1 MAT)	NM	50.0 (5.3)	-	8.8	63.2 (11.2)	2.0 (0.5)	2.8 (1.0)
	N	57.0 (11.2)	-	5.0	61.4 (10.6)	2.2 (0.4)	2.2 (0.6)
11-Jan	TM	17.0 (2.9)	1.0 (0.4)	1.2	28.8 (3.9)	2.0 (0.5)	2.6 (0.3)
(wet season,	T	33.8 (3.4)	0.0 (-)	1.4	28.4 (5.3)	2.8 (0.4)	5.8 (1.1)
4 MAT)	NM	48.0 (4.5)	2.0 (0.4)	3.4	48.6 (11.4)	2.4 (0.7)	4.2 (1.0)
	N	63.6 (6.5)	4.2 (0.8)	2.8	32.8 (7.3)	3.0 (0.2)	5.8 (0.9)
11-Jul	TM	41.4 (12.9)	1.8 (0.3)	0.8	16.0 (3.0)	1.0 (0.3)	4.0 (0.6)
(dry season,	T	28.0 (3.5)	2.2 (0.6)	0.4	27.6 (6.6)	1.6 (0.4)	2.0 (0.3)
10 MAT)	NM	49.4 (5.1)	5.0 (1.3)	0.4	52.6 (10.1)	2.6 (0.8)	6.8 (0.9)
	N	67.2 (15.3)	3.2 (0.4)	0.6	97.0 (40.4)	2.8 (0.5)	3.8 (0.5)

Note: MAT = month(s) after treatment, ant specimens that were collected at 1 MAT could not be identified to genus because were badly damaged, Other = other arthropod (Orthoptera, Diplopoda), TM = full tillage with bagasse mulch, T = full tillage without bagasse mulch, NM = no tillage with bagasse mulch, N = no tillage without bagasse mulch. Numbers without parentheses are means, numbers in parentheses are standard errors.

others. The caught spiders consist of several identified families as Agelenidae, Amaurobiidae, Dictynidae, Dysderidae, Gnaphosidae, Lycosidae, Oxyopidae, Pisauridae, Salticidae, Selenopidae, and Thomisidae. Beetle families identified are Anthicidae, Carabidae, Chrysomelidae, Cicindelidae, Coccinellidae, Curculionidae, Dytiscidae, Elateridae, Eucnemidae, Hydrophilidae, Nitidulidae, Pselaphidae, Ptilidae, Scaphidiidae, Scarabaeidae, Scydmaenidae, Staphylinidae, and Tenebrionidae. The collected springtails are from single family Entomobryidae. Ant specimens consist of 13 identified genera of four subfamilies (Dolichoderinae, Formicinae, Myrmicinae, and Ponerinae), including the predatory genus *Gnamptogenys* (Formicidae: Ponerinae). Springtails and ants contribute to the bulk (> 90%) of the total arthropod catched in this study.

PERMANOVA results showed overall tillage effect on soil arthropod abundance. Tillage effect was significant at 1 MAT ($F = 6.072^{**}$, $p = 0.001$) and 4 MAT ($F = 4.640^{**}$, $p = 0.005$) but no longer significant at 10 MAT ($F = 1.474^{ns}$, $p = 0.212$). Meanwhile, mulching did not affect soil arthropod abundance (1 MAT: $F = 1.335^{ns}$, $p = 0.276$, 4 MAT: $F = 2.076^{ns}$, $p = 0.118$, 10 MAT: $F = 0.087^{ns}$, $p = 0.985$). Interaction effects between tillage and mulch on overall arthropod abundance were not detected either (1 MAT: $F = 0.996^{ns}$, $p = 0.398$; 4 MAT: $F = 0.410^{ns}$, $p = 0.760$, 10 MAT: $F = 0.981^{ns}$, $p = 0.395$). In some cases, however, the effect of tillage or mulch on the abundance of each arthropod group may not always follow that pattern.

Ants

Abundance of ants by treatment and sampling date was plotted in Figure 1. Ant abundance under no tillage (N or NM) was higher than that under full tillage (T or TM). At 1 MAT, a sharp difference in ant abundance between the two tillage methods was detected ($t = -2.813^{*}$, $p = 0.012$). At 4 MAT, the difference was still pronounced ($t = -2.523^{*}$, $p = 0.026$) but not that sharp. At 10 MAT this difference disappeared ($t = -1.476^{ns}$, $p = 0.160$). This tillage effect conforms with that on overall arthropod abundance as detected earlier. However, as shown

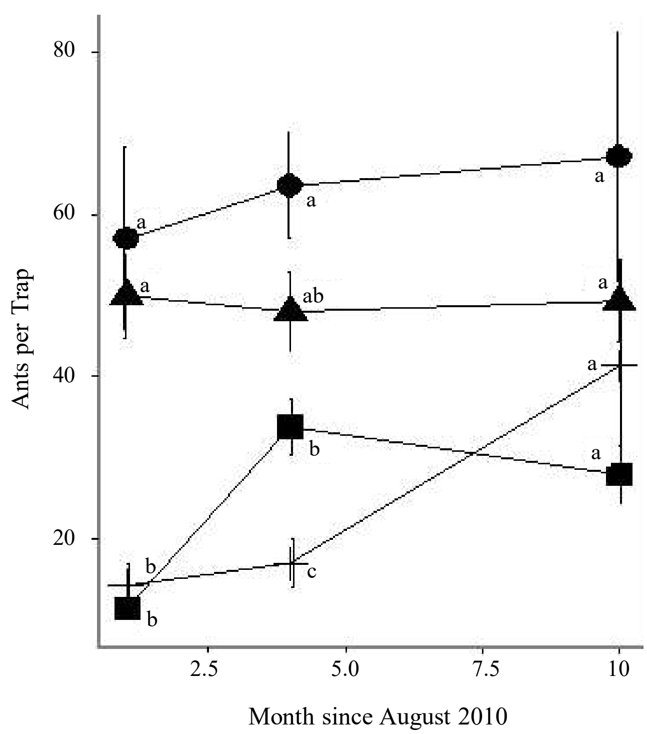

Figure 1. Means of ants obtained from three sampling dates (one month after treatment or since August 2010 (1 MAT), 4 MAT, and 10 MAT) in full tillage plots (TM = full tillage with bagasse mulching, T = full tillage without bagasse mulching) and no tillage plots (NM = no tillage with bagasse mulching, N = no tillage without bagasse mulching). Bars indicate standard errors of the means. Means in the same date followed by the same letters are not different (Tukey's test, $p > 0.05$).

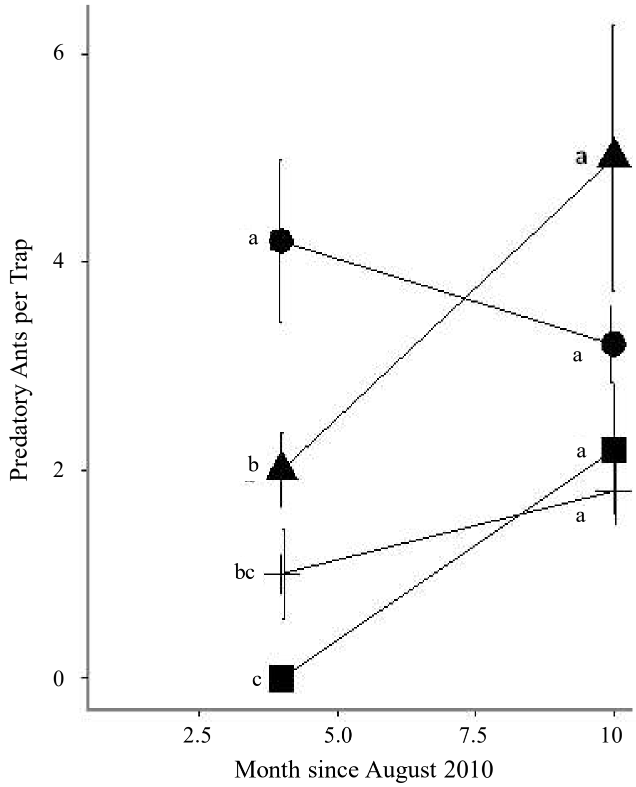

Figure 2. Means of predatory ants collected from two sampling dates (four months after treatment or since August 2010 (4 MAT) and 10 MAT in full tillage plots (TM = full tillage with bagasse mulching, T = full tillage without bagasse mulching) and no tillage plots (NM = no tillage with bagasse mulching, N = no tillage without bagasse mulching). Bars indicate standard errors of the means. Means in the same date followed by the same letters are not different (Tukey's test, $p > 0.05$). N: ●, NM: ▲ , T: ■, TM: +

in Figure 1, this tillage effect was confounded with that of mulching. Not as expected, mulching suppressed ant abundance under full tillage at 4 MAT (Z = -2.028*, p = 0.043).

Responses of the predatory ants to tillage or mulch were depicted in Figure 2. Abundance of this group was lower under no tillage at 4 MAT (t = -4211**, p = 0.003) but was not different 10 MAT (t = -0.523^{ns}, p = 0.608). The effect of mulch on this group can also be detected at 4 MAT in which mulch suppressed the abundance of predatory ants under no tillage (t = -2.593*, p = 0.032). No mulch effect was detected at 10 MAT (t = 0.941^{ns}, p = 0.361).

Soil Beetles

The abundance of soil beetles tended to decrease with time (Figure 3). The tillage effect on this group, however, was confounded with that of mulch. Combination of no tillage and mulch appeared to promote beetle abundance at the start of the sugarcane growing season (1 MAT) and at 4 MAT but had no effect later in the season (10 MAT). At 1 MAT, beetle abundance in NM plots was higher than that in TM plots (t = -1.973*, p = 0.048) or T plots (t = -2.586*, p = 0.010). The same was true at 4 MAT where beetles were more abundant in NM than in TM (t = -2.817**, p = 0.005) or T (t = -2.561*, p = 0.010). It was curious, however, that at 4 MAT beetles were also more abundant in N than in TM (t = 2.049*, p = 0.041).

Springtails

Tillage or mulch did not affect springtail abundance in the sugarcane plots (Figure 4). Springtail abundance under no tillage did not differ from that under full tillage at 1 MAT (t = -0.993^{ns}, p = 0.336), 4 MAT (t = -0.245^{ns}, p = 0.810), or 10 MAT (t = -1.336^{ns}, p = 0.206). The same was true that the abundance of this group in the sugarcane plots treated with bagasse mulch did not differ from that treated without bagasse mulch, either at 1 MAT

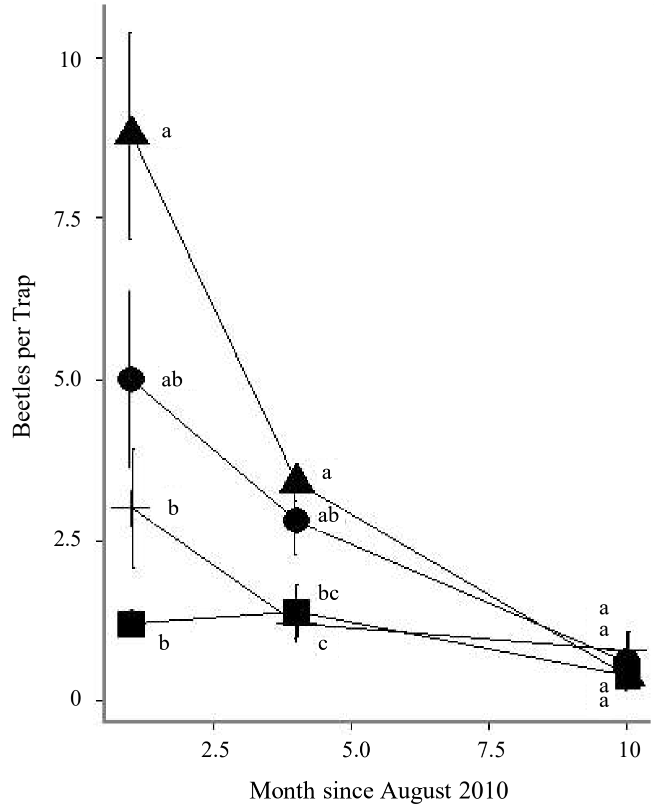

Figure 3. Means of beetles obtained from three sampling dates (one month after treatment or since August 2010 (1MAT), 4 MAT, and 10 MAT) in full tillage plots (TM = full tillage with bagasse mulching, T = full tillage without bagasse mulching) and no tillage plots (NM = no tillage with bagasse mulching, N = no tillage without bagasse mulching). Bars indicate standard errors of the means. Means in the same date followed by the same letters are not different (Tukey's test, $p > 0.05$). N: ●, NM: ▲ , T: ■, TM: +

(t = 0.078^{ns}, p = 0.939), 4 MAT (t = 0.881^{ns}, p = 0.396), or 10 MAT (t = -0.855^{ns}, p = 0.409).

Spiders

Spider abundance was not affected by tillage or mulch (Figure 5). No difference in spider abundance was evident under full tillage versus no tillage at 1 MAT (t = 1.237^{ns}, p = 0.234), 4 MAT (t = -0.166^{ns}, p = 0.870), or 10 MAT (t = -1.011^{ns}, p = 0.337). The abundance of spiders was also not different under mulch treatment at 1 MAT (t = -0.177^{ns}, p = 0.864), 4 MAT (t = -0.498^{ns}, p = 0.625), and 10 MAT (t = -0.183^{ns}, p = 0.860).

The results of structural equation modeling (SEM) analysis were depicted in Figure 6 and Figure 7. In Figure 6, the abundance of spiders (as potential predator) and predatory ants (as potential predator) were seen in connection with abundance of beetles (as potential prey). Spiders did not appear to connect with beetles (z = -0.664^{ns}, p = 0.507). Similarly, beetles did not appear to connect with predatory ants (z = 0.760^{ns}, p = 0.447). It is interesting, however, that in view of beetles as potential prey, the two potential predatory groups (spiders and predatory ants) appeared to be inter-connected.

Figure 7 illustrates the connection between collembolas (potential prey) and spiders (potential predator) and predatory ants (potential predator). No significant connection was detected between collembolas and spiders (z = 0.064^{ns}, p = 0.949) or between collembolas and predatory ants (z = 1.740^{ns}, p = 0.082). However, there was significant connection between spiders and predatory ants.

Discussion

Our data show that reduced tillage in general supports the existence of soil arthropods in sugarcane agroecosystem. Arthropod abundance under no tillage was found higher (ants and beetles at both 1 MAT and 4 MAT; springtails at 10 MAT) or not different from that under full tillage (ants and beetles at 10 MAT; springtails at both 1 MAT and 4

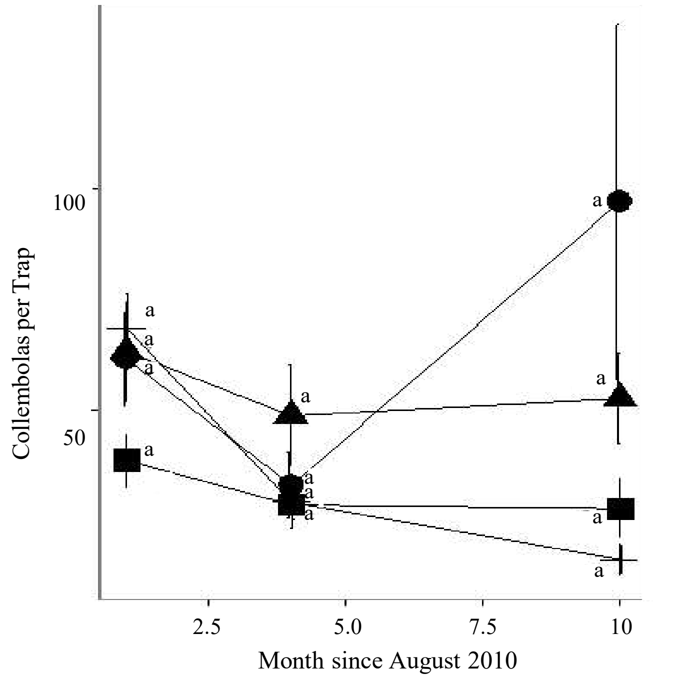

Figure 4. Means of springtails (collembolas) collected from three sampling dates (one month after treatment or since August 2010 (1MAT), 4 MAT, and 10 MAT) in full tillage plots (TM = full tillage with bagasse mulching, T = full tillage without bagasse mulching) and no tillage plots (NM = no tillage with bagasse mulching, N = no tillage without bagasse mulching). Bars = standard errors of the means. Means in the same date followed by the same letters are not different (Tukey's test, $p > 0.05$). N: ●, NM: ▲ , T: ■, TM: +

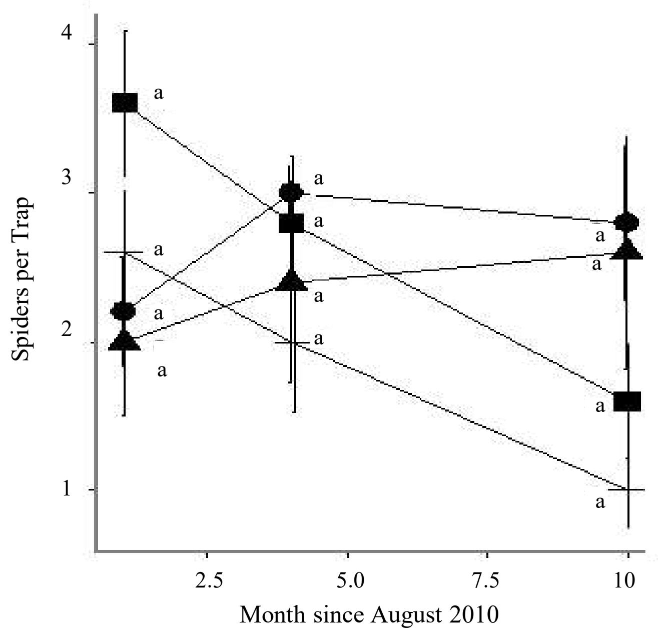

Figure 5. Means of spiders obtained from three sampling dates (one month after treatment or since August 2010 (1MAT), 4 MAT, and 10 MAT) in full tillage plots (TM = full tillage with bagasse mulching, T = full tillage without bagasse mulching) and no tillage plots (NM = no tillage with bagasse mulching, N = no tillage without bagasse mulching). Bars = standard errors of the means. Means in the same date followed by the same letters are not different (Tukey's test, $P > 0.05$). N: ●, NM: ▲ , T: ■, TM: +

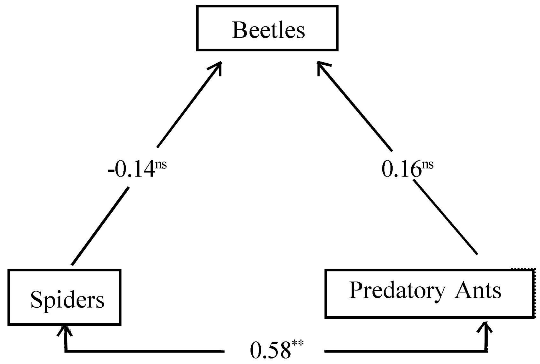

Figure 6. Structural equation model (SEM) between the number of beetles, predatory ants, and spiders. Connection coefficients followed by the sign ns are not significant ($p > 0.05$), while that followed by ** is very significant ($p < 0.01$).

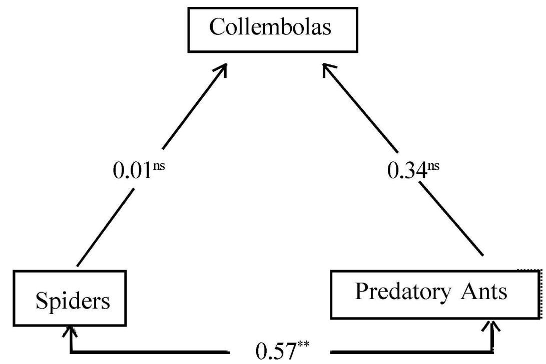

Figure 7. Structural equation model (SEM) between the number of collembolas, predatory ants, and spiders. Connection coefficients followed by the sign ns are not significant ($p > 0.05$), while that followed by ** is very significant ($p < 0.01$).

MAT; spiders at 1 MAT, 4 MAT and 10 MAT). This result is in agreement (in part) with previous results from various agroecosystems (Table 2). It clearly showed that reduced tillage either positively affected or did not harm major groups of soil arthropods in corn, sorghum, wheat, and sugarcane ecosystems. A group that is clearly and consistently affected by reduced tillage can be considered as the reliable bioindicator of the tillage effect in the particular agroecosystem; for instance springtails in the wheat field (Brennan *et al.* 2006) or spiders in the corn agroecosystem (Rodriguez *et al.* 2006).

One of major mechanisms in which soil arthropods can be affected by tillage is through mechanical disturbance (Stinner and House 1990). Tillage can affect springtails directly by crushing soil aggregates and indirectly via moisture shortage. Not being so perturbed by tillage, the soil structure under reduced tillage is more stable. According to Kladivko *et al.* (1986), reduced tillage conserves more water stable soil aggregates near the surface. Water retention in such niche is thus higher (Thomas *et al.* 1984). Springtails can take advantage of that benefits. Springtails are soft-bodied soil micro-arthropods that are prone to desiccation; so they favor to live in more moist soil. Their food items, mostly fungi (Brennan *et al.* 2006; Rickerl *et al.* 1989), are also moisture-dependent. Springtail's existence and survival are therefore dependent on moisture (Verhoef and van Selm 1983; Reddy *et al.* 1994). In dry season period (10 MAT, Figure 4), that was when water supply was short in soil, springtails needed to move into reduced tillage environment in search for moisture, and more of them stayed there in order to survive. The corollary and prior to that period is, in wet season, springtails could live practically well anywhere under either tillage regime, as was the case in this study (1 MAT and 4 MAT, Figure 4). There was no difference in soil moisture between full tillage and no tillage plots in wet season (Miura *et al.* 2013).

Ants might not be so much stressed by soil moisture but by direct disturbance of tillage. Their relatively stout-bodies seemed to be more resistant to desiccation or to water shortage. Nevertheless, ants could be sensitive to mechanical effect of plowing so that their number was lower under full tillage at a period of time not long after the plowing (1 MAT and 4 MAT, Figure 1 and 2). In later period, more ants moved in from adjacent ecosystems, continued foraging from and around no tillage plots to full tillage plots due to lack of barriers in between. That way, ant recolonization and recovery occurred under full tillage (10 MAT). In wheat agroecosystem, Marasas *et al.* (2001) recognized the occurrence of a similar phenomenon in which soil arthropods migrated between adjacent sites under differing tillage regimes.

Beetles might also be more sensitive to mechanical perturbation by tillage but their population rebound did not occur. That was shown by their lower number under full tillage at 1 MAT (and apparently so at 4 MAT) but there was no evident of recovery afterwards; instead, the overall beetle abundance under either tillage fell off to a very low level at 10 MAT (Figure 3). Beetles do not have facilities or behavior like ants that can be utilized to replenish decreasing populations. Ants build (rebuild)

Table 2. Effect of (reduced) tillage on abundance of various groups of soil arthropods in some gramineous agroecosystems.

Agro-ecosystem	Arthropod	Ant	Beetle	Mite	Spider	Springtail	References
Corn	0	?	0	0	0	0	Stinner *et al.*(1988)
Corn	+	0	0	0	+	0	Rodriguez *et al.* (2006)
Corn[a]	?	?	?	?	?	+	Rickerl *et al.* (1989)
Corn	?	?	+[b]	?	?	?	Lalonde *et al.* (2012)
Rice	?	?	?	?	?	+	Chang *et al.* (2013)
Sorghum	+	?	?	?	?	?	Blumberg and Crissley Jr. (1983)
Sorghum	0	?	?	0	?	0	Reddy *et al.* (1994)
Sugar cane	?	0	0	?	0	?	Sandhu and Cherry (2014)
Sugar cane	0	0	0	?	0	0	This study
Wheat	?	?	?	?	?	+	Brennan *et al.* (2006)
Wheat	+	?	?	0+-[c]	?	+	Dubie *et al.* (2011)
Wheat	?	?	+[b]	?	?	?	Kosewska *et al.* (2014)

+ = positive effect (higher abundance under reduced tillage), - = negative effect, 0 = no effect, ? = unknown effect because the pertinent arthropod group was not recovered under either tillage (not observed or not reported), a = in rotation with cotton, soybean, and peanuts, b = effect on Carabid beetles, c = no effect (on Astigmata), negative effect (on Prostigmatida), and positive effect (on Oribatida and Mesotigmata).

nests and other structures (roadways, trenches, arcades, tunnels, outstations, 'cowsheds', bridges, etc.) along their foraging trails that facilitate them to colonize-recolonize niches or habitats effectively and efficiently (Anderson and McShea 2001). In contrast, soil beetles do not build nests and their non-social behavior makes them difficult, if any, to reshape their populations once they have been decreased. Although colonization-recolonization by soil-dwelling beetles is possible aerially through in-flight migration (Maelfait *et al.* 2007), that phenomenon, curiously enough, did not seem to manifest in this field study.

In other agroecosystems (*e.g.* corn) spider abundance is affected by tillage while in sugarcane such effect, if any, cannot be detected (Table 2). That means, reduced tillage in sugarcane does not harm the spiders. Certainly, spiders faced similar stress under tillage but it seemed that they had a means to solve the problem. Soil-dwelling spiders are in general small-sized and they can escape from in-situ disturbance by way of ballooning. In ballooning (Suter 1992), spiders position their bodies in a certain posture then throw their silken threads up to the moving air as such that they can be aerially transported from place to place. There is great chance of dying in ballooning (Suter 1992), so this strategy is not always successful for survival. Apparently, ballooning relatively works in sugarcane agroecosystems but does not always work in corn agroecosystems (Table 2).

CONCLUSIONS

Four groups of soil arthropods were found inhabiting the sugarcane field in Terusan Nunyai area of Central Lampung-Indonesia, including ants (Hymenoptera: Formicidae, mostly foragers), springtails (Collembola), beetles (Coleoptera, mostly non-predatory), and spiders (Araneae, predators). Tillage and application of mulch (= sugarcane bagasse) affected the abundance of some of these groups. No-tillage promoted ant abundance in general but did not affect that of predatory ants. Combination of no-tillage and mulch promoted beetle abundance but tillage or mulch did not affect the abundance of springtails and spiders.

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REFERENCES

Anderson C and DW McShea. 2001. Intermediate-level parts in insect societies: adaptive structures that ants build away from the nest. *Insect Soc* 48: 291-301.

Bessin RT and TE Reagan. 1993. Cultivar resistance and arthropod predation of sugarcane borer (Lepidoptera: Pyralidae) affects incidence of deadhearts in Louisiana sugarcane. *J Econ Entomol* 86: 929-932.

Blumberg AY and DA Crossley Jr. 1983. Comparison of soil surface arthropod populations in conventional tillage, no-tillage and old field systems. *Agro-ecosystems* 8: 247-253.

Borror DJ, DM De Long and CA Triplehorn. 1981. An Introduction to the Study of Insects. 5th ed. Saunders College Publishing, Philadelphia etc.

Brennan A, T Fortune and T Bolger. 2006. Collembola abundances and assemblage structures in conventionally tilled and conservation tillage arable systems. *Pedobiologia* 50: 135-145.

Cherry R. 2003. The effect of harvesting and replanting on arthropod ground predators in Florida sugarcane. *Fla Entomol* 86: 49-52.

Chang L, H Wu, D Wu and X Sun. 2013. Effect of tillage and farming management on Collembola in marsh soils. *Appl Soil Ecol* 64: 112-117.

Chung AY. 2003. Manual for Bornean Beetle (Coleoptera) Family Identification. Darwin Initiative-Universiti Malaysia Sabah, Kota Kinabalu.

Dubie TR, CM Greenwood, C. Godsey and ME Payton. 2011. Effect of tillage on soil microarthropods in winter wheat. *Southwest Entomol* 36: 11-20.

Firdaus F. 2012. Pengaruh pemulsaan dan reduksi pengolahan tanah terhadap keanekaragaman dan populasi laba-laba tanah di lahan pertanaman tebu. Skripsi. Fakultas Pertanian Universitas Lampung. Bandarlampung (in Indonesian).

Hashimoto Y. 2003. Identification Guide to the Ant Genera of Borneo. Total Protocol for Understanding of Biodiversity. Universiti Malaysia Sabah, Kota Kinabalu.

Hensley SD, WH Long, LR Roddy, WJ McCormick and EJ Concienne. 1961. Effects of insecticides on the predaceous arthropod fauna of Louisiana sugarcane fields. *J Econ Entomol* 54: 146-149.

Jones DT (ed). 2003. Tools for the Rapid Assessment of Soil Invertebrate Biodiversity in the ASEAN Region. Handbook to Accompany the Training Course, 13-25 October 2003. Universiti Malaysia Sabah, Kota Kinabalu.

Kladivko EJ, DR Griffith and JV Mannering. 1986. Conservation tillage effects on soil properties and yield of corn and soya bean in Indiana. *Soil Till Res* 8: 277-287.

Kosewska A, T Skalski and M Nietupski. 2014. Effect of conventional and non-inversion tillage systems on the abundance and some life history traits of carabid beetles (Coleoptera: Carabidae) in winter triticale fields. *Eur J Entomol* 111: 669-676.

Kristina. 2011. Pengaruh pemulsaan dan reduksi olah tanah terhadap keragaman dan kelimpahan artropoda tanah di pertanaman tebu. Skripsi. Fakultas Pertanian Universitas Lampung. Bandarlampung (in Indonesian).

Lalonde O, A Légère, FC Stevenson, M Roy and A Vanasse. 2012. Carabid beetle communities after 18 years of conservation tillage and crop rotation in a cool humid climate. *Can Entomol* 144: 645-657.

Lavelle P and AV Spain. 2001. Soil Ecology. Kluwer Academic, Dordrecht and Boston.

Logan DP. 1999. Insect parasites of scarabs from sugarcane fields in southern Queensland (Coleoptera: Scarabaeidae). *Aus J Entomol* 38: 382-384.

Maelfait JP, K Desender and L Baert. 2007. Colonisation and source-sink dynamics in spiders and ground beetles after dry dune habitat restoration along the Belgian coast. Restoration of Coastal Ecosystems. Coastline Reports 7: 41-52.

Marasas ME, SJ Sarandon and AC Cicchino. 2001. Changes in arthropod functional group in a wheat crop under conventional and no tillage systems in Argentina. *Appl Soil Ecol* 18: 61-68.

Miura T, A Niswati, IG Swibawa, S Haryani, H Gunito and N Kaneko. 2013. No tillage and bagasse mulching alter fungal biomass and community structure during decomposition of sugarcane leaf litter in Lampung Province, Sumatra, Indonesia. *Soil Biol Biochem* 58: 27-35.

Negm AA and SD Hensley. 1969. Evaluation of certain biological control agents of the sugarcane borer in Louisiana. *J Econ Entomol* 62: 1008-1013.

OksanenJ, FG Blanchet, M Friendly, R Kindt, P Legendre, D McGlinn, PR Minchin, RB O'Hara, GL Simpson, P Solymos, MHH Stevens, E Szoecs and H Wagner. 2016. vegan: Community Ecology Package ver.2.4-1.https://CRAN.R-project.org/ package= vegan.

R Development Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Reagan TE, G Coburn and SD Hensley. 1972. Effects of Mirex on the arthropod fauna of a Louisiana sugarcane field. *Environ Entomol* 1: 588-591.

Reddy MV, VR Reddy, DF Yule, AL Cogle and PJ George. 1994. Decomposition of straw in relation to tillage, moisture, and arthropod abundance in a semi-arid tropical Alfisol. *Biol Fertil Soils* 17: 45-50.

Rickerl DH, EA Curl and JT Touchton. 1989. Tillage and rotation effects on Collembola populations and *Rhizoctonia* infestation. *Soil Till Res* 15: 41-49.

Rodriguez E, FJ Fernandez-Anero, P Ruiz and M Campos. 2006. Soil arthropod abundance under conventional and no tillage in a Mediterranian climate. *Soil Till Res* 85: 229-233.

Sandhu HS and RH Cherry. 2014. Effects of tillage practices on arthropod ground predators in Florida sugarcane. *J Entomol Sci* 49: 415-419.

Saputra, MJ. 2012. Pengaruh pemulsaan dan reduksi pengolahan tanah terhadap keanekaragaman dan populasi semut pada pertanaman tebu. Skripsi. Fakultas Pertanian Universitas Lampung. Bandarlampung (in Indonesian).

Sholih, MB. 2012. Pengaruh pemulsaan dan reduksi olah tanah terhadap keanekaragaman dan kemelimpahan kumbang tanah pada pertanaman tebu. Skripsi. Fakultas Pertanian Universitas Lampung. Bandarlampung (in Indonesian).

Stinner BR and GJ House. 1990. Arthropods and other invertebrates in conservation tillage agriculture. *Ann Rev Entomol* 35: 299-318.

Stinner BR, DA McCartney and DM van Doren Jr. 1988. Soil and foliage arthropod communities in conventional, reduced, and no-tillage corn (maize, *Zea mays* L.) systems: a comparison after 20 years of continuous cropping. *Soil Till Res* 11: 147-158.

Susilo FX and A Karyanto (Eds). 2005. Methods for Assessment of Below-ground Biodiversity in Indonesia. Universitas Lampung, Bandarlampungn (in Indonesian).

Susilo FX, AM Neutel, M van Noordwijk, K Hairiah, G Brown and MJ Swift. 2004. Soil Biodiversity and Food Webs. In: M van Noordwijk, G Cadisch and CK Ong (eds). Below-ground Interactions in Tropical Agroecosystems: Concept and Models with Multiple Plant Components. CAB International, Wallingford, pp. 285-308.

Suter RB. 1992. Ballooning: data from spiders in freefall indicate the importance of posture. *J Arachnol* 20: 107-113.

Thomas GW, RL Blevins and SH Phillips. 1984. No tillage in the tropics. In: RE Phillips and SH Phillips (eds). No Tillage Agriculture Principles and Practices. Van Nostrand Reinhold, New York etc., pp. 270-301.

Tonelli M, MFGV Peòaflor, LG Leite, WD Silva, F Martins and JMS Bento. 2016. Attraction of entomopathogenic nematodes to sugarcane root volatiles under herbivory by a sap-sucking insect. *Chemoecology* 26: 59-66.

Verhoef HA and AJ van Selm. 1983. Distribution and population dynamics of Collembola in relation to soil moisture. *Holarctic Ecol* 6: 387-394.