

The Effect of Organic Fertilizers and Flowering Plants on Sheet-Web and Wolf Spider Populations (Araneae: Lycosidae and Linyphiidae) and Its Importance for Pest Control

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Abstract

The main goal of this study was to identify the treatment that increases the populations of spiders, which are effective predators in agroecosystems. In 2013 and 2014 the experimental eggplant (*Solanum melongena* L.) field was two different treatments, organic fertilizers and chemical fertilizer treatment, and in 2014 we surrounded organic fertilizer plots with the flowering plants mealy cup sage (*Salvia farinacea* Benth.), spearmint (*Mentha spicata* L.), and basil (*Ocimum basilicum* L.). Analysis using repeated measures ANOVA revealed significant influences of fertilizer type on the numbers of linyphiid spiders and Collembola in 2013. In 2014, the numbers of Collembola, thrips, and lycosid and linyphiid spider were higher in organic fertilizer with flowering plants treatment comparing with the chemical fertilizer treatment. Moreover, the numbers of *Henosepilachna vigintioctopunctata* (F.) were significantly lower in the organic fertilizer with flowering plants treatment than in chemical fertilizers treatment. Finally, we expect that Thysanoptera and Collembola were important alternative prey for linyphiid and lycosid spiders and the use of organic fertilizer and flowering plants enhanced the density of these spiders, and may increase their effectiveness in suppressing the populations of *H. vigintioctopunctata* (F.).

Key words: farming system, organic farming, predator, spider, beneficial insectary plant

To produce organic vegetables and other crops, it is essential to utilize indigenous natural enemies of pests in combination with strategic cultivation techniques, such as planting flowering plants that attract beneficial insects and applying organic fertilizers. True spiders are effective natural predators in field crops, but their effects depend on their densities in agroecosystems (Riechert and Lawrence 1997, Marc et al. 1999, Landis et al. 2000, Symondson et al. 2002, Schmidt et al. 2003). They kill and consume a large number of prey daily (Riechert and Lawrence 1997, Riechert and Maupin 1998). Hunting spiders decreased numbers of herbivorous Coleoptera in an old field in Tennessee (Riechert and Lawrence 1997).

The quality of organic materials and the plant structure are very important to increase the soil organism densities (Yeates et al. 1997). Besides, the diet for most Collembola species is soil fungus or decaying material of plant (Verma and Paliwal 2010). Also, organic fertilization by manure application improves soil quality and structure, and it enhanced the population of saprophagous insects such as springtails (Collembola) and midges (Diptera). These prey are very important for the survival of their predators (Alderweireldt 1994, Chen and Wise

1999, Nyffeler 1999, Axelsen and Kristensen 2000). Hendawy and Abul-Fadl (2004) have reported greater densities of lycosid and linyphiid spiders in organic fertilization fields than in chemical fertilization fields. Also, Birkhofer et al. (2008) indicated that organic fertilizer had a positive effect on the ground-dwelling spiders. Additionally, numbers of sheet-web weavers spiders (Linyphiidae) had a positive respond to Collembola (Birkhofer 2007). The organic fertilizers treatment supported species richness of weeds, numbers of earthworm, and density and diversity of some invertebrates higher than mineral fertilizers treatment (Dicks et al. 2013). Öberg (2007) reported that the densities of lycosid and linyphiid spiders increased in response to organic treatment. Lycosid and linyphiid (Araneae) spiders are commonly found in arable land in central and northwestern Europe (Toft 1989, Feber et al. 1998, Samu and Szinetár 2002, Pfiffner and Luka 2003, Clough et al. 2005, Öberg and Ekblom 2006), and play an essential role in suppressing aphid populations (Luczak 1979, Nyffeler and Benz 1987, Mansour and Heimbach 1993, Lang 2003, Öberg and Ekblom 2006). On the other hand, Linyphiid spiders can be dispersed by the wind, whereas lycosid spiders walk (Luczak 1979, Weyman et al. 2002).

Linyphiid spiders occasional caught Coleoptera as a prey (Nentwig 1983). Alderweireldt (1994) indicated that sheet-web weavers depend on web captured prey or from time to time by the direct hunt.

Proper habitat management can enhance the populations of natural enemies for biological control in agricultural ecosystems (Alomar et al. 2006, Bianchi et al. 2006). Providing good refuges can enhance the density of spiders (Sunderland and Samu 2000). Some studies demonstrated that the spider population increased and aphid population decreased when the wheat field contained strips of flowering plants (Jmhasly and Nentwig 1995). Flowering plants strips play an essential role in biological control by enhancing the predators and the alternative prey densities (Frank 2003). Furthermore, the Lycosid spiders can feed on thrips (Sahito et al. 2013). Likewise, some scientists indicated that high numbers of Thysanoptera were captured at the web of linyphiid spiders and they expected that it was a suitable prey for spiders (Harwood et al. 2003). Marc et al. (1999) indicated that it is necessary to manage the environment (i.e., habitat quality) to enhance the communities of true spiders. Spider communities are very sensitive to sources of environmental change, such as soil pollutants and chemical pesticides. Diverse habitats provide an abundance of various food sources and thus can increase the populations of natural enemies (Hatley and Macmahon 1980, Landis et al. 2000, Jonsson et al. 2008).

Flowering plants such as mealy cup sage (*Salvia farinacea*) can play an essential role in enhancing the natural enemies of crab spiders, predatory bugs, and chalcidoid wasps (El-Nabawy et al. 2015). Peterson et al. (2010) and Carrel et al. (2000) reported that Linyphiidae also feeds on pollen. Many scientists have reported the value of pollen as a food source for natural enemies (Bernardello et al. 2000, Landis et al. 2000, Jackson et al. 2001, Fiedler and Landis 2007, Lundgren 2009, Peterson et al. 2010, Messelink et al. 2014). Pollen is an excellent food source also for spiders, particularly for spiderlings, when prey populations are insufficient. Pollen increases the longevity of spiderlings (Vogelei and Greissl 1989).

Many insect pests attack family Solanaceae, *Henosepilachna vigintioctomaculata* (F.) (the large 28-spotted ladybird beetle) considered as a serious pest of eggplant in Japan (Nakamura 1987). *H. Vigintioctomaculata* (F.), this species size is greater than other ladybird beetle species and moves slowly, and when anything disturbing, it escapes to the ground surface (Kalaiyarasi and Ananthi 2015) and it can fly for just a short distance (Hao et al. 2006).

In this study, we evaluated the effects of field treatments on spider populations. We tested the effects of organic versus chemical fertilizers, and then the impact of growing flowering plants in an organic fertilizer plots to attract spiders.

Materials and Methods

Study Site

The experimental field was located in Kiire, Kagoshima prefecture, Japan, and experiments were carried out during the summers from 10 April till 19 September 2013 and from 18 April till 18 September 2014. The total area of the experimental farm was 800 m². The farm was divided into two treatment plots (treated with organic or chemical fertilizers) with two replicates. Each replicate was 150 m², consisting of five rows (10 by 1 m) in the center of the field. The rows were covered with black plastic mulch. Each row was planted with 10 eggplant (*Solanum melongena* L.) seedlings, for a total of 50 plants in each replicate. Planting occurred on 6 May 2013 and 25 May 2014. In addition, each replicate was surrounded by sorghum [*Sorghum bicolor* (L.) Moench.] as a wind buffer. An area of

Table 1. Chemical and organic fertilization

Treatment	Fertilizers type	Weight (kg)	N%	P%	K%
Chemical fertilization per 3a	Chemical fertilizers	144	48	48	48
Organic fertilization per 5a	Oilcake	200	18	8	4
	Microbe fertilizer	200	8	16	8
	Cattle manure	1,000	22	28	30
	Total	1,400	48	52	42

200 m² in the middle of the field separated the replicates. The quantities and composition of organic and chemical fertilizers are shown in Table 1.

The experimental design was similar in 2013 and 2014, except that in 2014, some flowering plants were added to the organic plots. Three species, namely, mealy cup sage (*S. farinacea*), spearmint (*Mentha spicata*), and basil (*Ocimum basilicum*), were planted in the organic plot in three alternating rows. A fourth plant species (*Cosmos bipinnatus*) was intercropped between eggplants. Weeding was done manually twice a month, using a brush cutter. No chemical pesticides were applied throughout the cultivating seasons. For meteorological data, we used the local weather data published by Japan Meteorological Agency.

Sampling

Pitfall Traps. Pitfall traps were used to collect ground-dwelling spiders and Collembola. Each trap pot was 10 cm in diameter and 7.5 cm in depth, and was buried with its top just at the soil surface. Approximately 40 ml propylene glycol was added to trap pots to prevent dead spiders and insects from decaying. A plastic rain roof cover was placed over the trap, about 5 cm above the trap. Eight traps were used, with two in each replicate. The traps were used twice a month and the samples were emptied into plastic jars and transferred directly to the laboratory for analysis. The collected spiders and Collembola were counted and identified under a binocular microscope, and preserved in 70% alcohol in glass vials. Spiders were identified using the appropriate keys developed by Kaston (1953) and Chikuni (1989).

Population of Two Insect Pests, Aphids, and 28-Spotted Ladybird Beetles in 2014. Ten eggplant leaves were randomly collected weekly from each plot. They were preserved individually in plastic bags, and any aphids on the leaves were identified and counted. The aphid populations in this study consisted of *Myzus persicae* and *Aphis gossypii*.

We confirmed the number of 28-spotted ladybird beetles, *H. vigintioctomaculata* (F.), by a direct count in the field. Each replicate was divided into two parts, the eastern and western halves. In total, 10 leaves were selected randomly in each half of the replicate, for a total of 20 leaves per replicate. The beetles were counted and the counts were recorded.

By 10 double strokes of sweep net (36 cm in diameter and 90-cm-long handle) from each plot, we collected insect pests to measure how treatment affected by habitat structure. After collections, each catch was kept in a glass jar until identified.

Data Analysis

Repeated measures ANOVA was used to determine the effect of fertilizer type on the numbers of Lycosid and Linyphiid spiders (SPSS 2006). In addition, the correlations between spider numbers and numbers of some alternative prey were analyzed by the Spearman

Table 2. Total number of spiders (and the families to which they belong) collected during 2013 and 2014 in different treatment plots

Spider family	Total No. trapped in 2013			Total No. trapped in 2014		
	Organic	Chemical	%	Organic	Chemical	%
Lycosidae	178	161	68.76	165	113	59.4
Linyphiidae	71	47	23.94	83	52	28.85
Theridiidae	12	11	4.67	15	17	6.84
Gnaphosidae	1	2	0.61	3	1	0.86
Clubionidae	0	0	0	0	1	0.21
Ctenidae	3	1	0.81	0	0	0
Haniidae	1	0	0.2	1	0	0.21
Pisauridae	0	0	0	4	1	1.07
Salticidae	1	0	0.2	2	1	0.64
Nesticidae	0	0	0	1	0	0.21
Oxyiopiidae	1	0	0.2	2	0	0.43
Tetragnathidae	2	1	0.61	5	1	1.28
Total number	270	223	100	281	187	100

correlation coefficient. The analysis used the four pitfall traps from each treatment and served as replicates and the different dates as repeated measures to improve the significance of experimental results.

Results

Family Composition of Spiders Collected by Pitfall Traps

During the 2013 and 2014 seasons, 961 spiders, representing 12 families, were captured with pitfall traps (Table 2). Lycosidae and Linyphiidae spiders represented 68.76–59.4 and 23.94–28.85%, during the two seasons, respectively, of the total number of trapped spiders. These two spider families were the primary ground-dwelling predators in the eggplant field.

Fluctuations of Populations of Linyphiid and Lycosid Spiders, and Collembola

In 2013, the number of linyphiid spiders differed between organic and chemical fertilizer plots, particularly in mid-July, after that the population in each plot declined until the end of the season (Fig. 1a; $F_{1,6} = 6.92$, $P < 0.05$). During the seasonal transition of 2013, we identified differences in Collembola counts between the two plot types ($F_{1,6} = 87.04$, $P < 0.01$). Counts were higher in plots treated with organic fertilizer, particularly early in the season, from mid-May until mid-July. The counts were very low from the end of July to the end of summer. The fluctuations of the populations of linyphiid spiders and Collembola were very similar after mid-June. But, there were not higher numbers of lycosid spiders in organic fertilizer plots comparing with chemical fertilizer plots (Fig. 1b; $F_{1,6} = 1.66$, $P = 0.22$).

In 2014, there were large differences in the numbers of both spider families and Collembola between the two types of plot (Fig. 2; Linyphiidae, $F_{1,6} = 31.68$, $P < 0.01$; Lycosidae, $F_{1,6} = 10.82$, $P < 0.05$; Collembola, $F_{1,6} = 41.36$, $P < 0.01$). The number of Linyphiid spiders was higher in organic plots than in chemical plots from mid-June to mid-July, and then the population in each plot declined until the end of the season. The counts of Collembola were similarly high in organic plots from early June to mid-July. Clear differences between organic and chemical treatments were observed during June, and from late July to late August. The seasonal fluctuations of lycosid spider counts differed from Collembola counts.

Fluctuations of the Populations of Aphids, 28 Spotted Ladybird Beetles, Collembola, and Thrips coloratus Schmutz in 2014

An acute outbreak of aphids was observed during June in the plot treated with chemical fertilizers while the differences between the two treatments were not significant (Fig. 3a, $F_{1,2} = 1.66$, $P = 0.33$). In addition, there were fewer 28-spotted ladybird beetles in organic fertilizer with flowering plants plots than in chemical plots, especially in July and the early part of September (Fig. 3b, $F_{1,6} = 8.45$, $P < 0.05$). The population density of pests in the organic treatment remained low, compared with the chemical treatment, throughout the season. On the other hand, the numbers of nonpest *Thrips coloratus* Schmutz were significantly higher in the organic fertilizers with flowering plants plot than the chemical fertilizer plot especially during August (Fig. 3c, $F_{1,2} = 169.92$, $P < 0.01$).

Correlation Between the Numbers of Lycosid and Linyphiid Spiders and Insects

To identify different factors fluctuating spider population density, we studied the Pearson correlation coefficient between spiders and prey insects. In 2013, linyphiid spider counts were positively influenced by Collembola ($r = 0.48$, $P < 0.01$). Additionally, the correlation between lycosid spider and Collembola is significantly positive ($r = 0.26$, $P < 0.05$). Similarly, in 2014 Collembola affected the numbers of Lycosidae ($r = 0.34$, $P < 0.01$), and thrips positively affected numbers of Linyphiidae ($r = 0.35$, $P < 0.5$).

Discussion

Factors Contributing to Increase the Linyphiid and Lycosid Spiders Densities

Various factors can contribute to increases in spider population density (Piffner and Luka 2003). We compared spider and some insect populations between organic and chemically treated field plots in 2013 and 2014 separately. The chemical treatments were the same in both years, whereas the organic treatments differed. In 2013, the organic plot was treated solely with organic fertilizer, whereas in 2014 it was treated with the organic fertilizer and we also added flowering plants to the plot.

In 2013, organic fertilizer treatment enhanced the density of Linyphiidae spiders and Collembola, and there was a significant positive correlation between linyphiid spiders and Collembola counts. Birkhofer (2007) showed that sheet-web weavers spiders, Linyphiidae, had a positive relationship with alternative or nonpest prey (Collembola), and Piffner and Luka (2003) found the numbers of saprophagous insects such as the Collembola increased by using organic fertilizer. Moreover, Collembola species feed on soil fungus or some of the plant decaying material (Verma and Paliwal 2010) and the organic fertilizers are very essential to rise the soil organism densities (Yeates et al. 1997).

In 2014, differences in lycosid and linyphiid spider counts for the two treatments were evident, there are many reasons that may be responsible for boosted spider density in the organic fertilizers and flowering plants treatment; 1) organic fertilizers can have indirect effects to enhance the spider population by increasing the alternative prey density. Moreover, organic fertilization can improve the soil structure and microclimate, which is very important for saprophagous insects such as Collembola (Alderweireldt 1994; Chen and Wise 1999; Nyffeler 1999; Axelsen and Kristensen 2000; Piffner and Luka 2003). Our results are consistent with these previous studies because we found a positive relationship between the numbers of

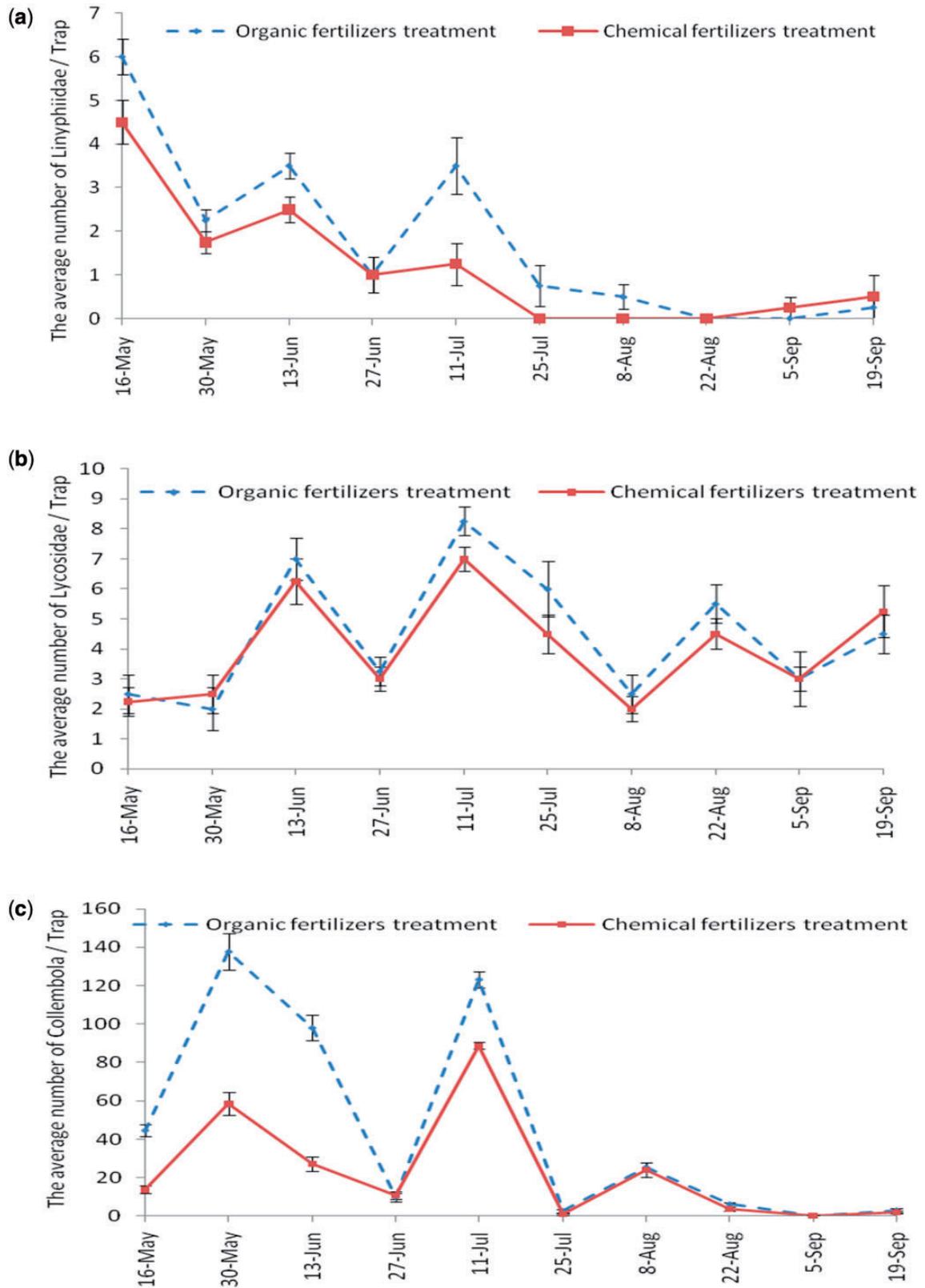


Fig. 1. Fluctuations of the populations of Linyphiidae (a) and Lycosidae spiders (b) and Collembola (c) captured by pitfall traps, according to plot type in 2013.

Collembola and Lycosidae. Also, we found a positive relationship between the numbers of Collembola and linyphiid spider in 2013 and between Collembola and lycosid spiders in both years. Birkhofer (2007) showed the importance of Collembola to linyphiid

spider as alternative prey. In addition, Dicks et al. (2013) indicated that weeds richness and density and diversity of some invertebrates increased in the organic fertilizer treatment higher than the mineral fertilizer treatment. 2) The flowering plants may provide suitable

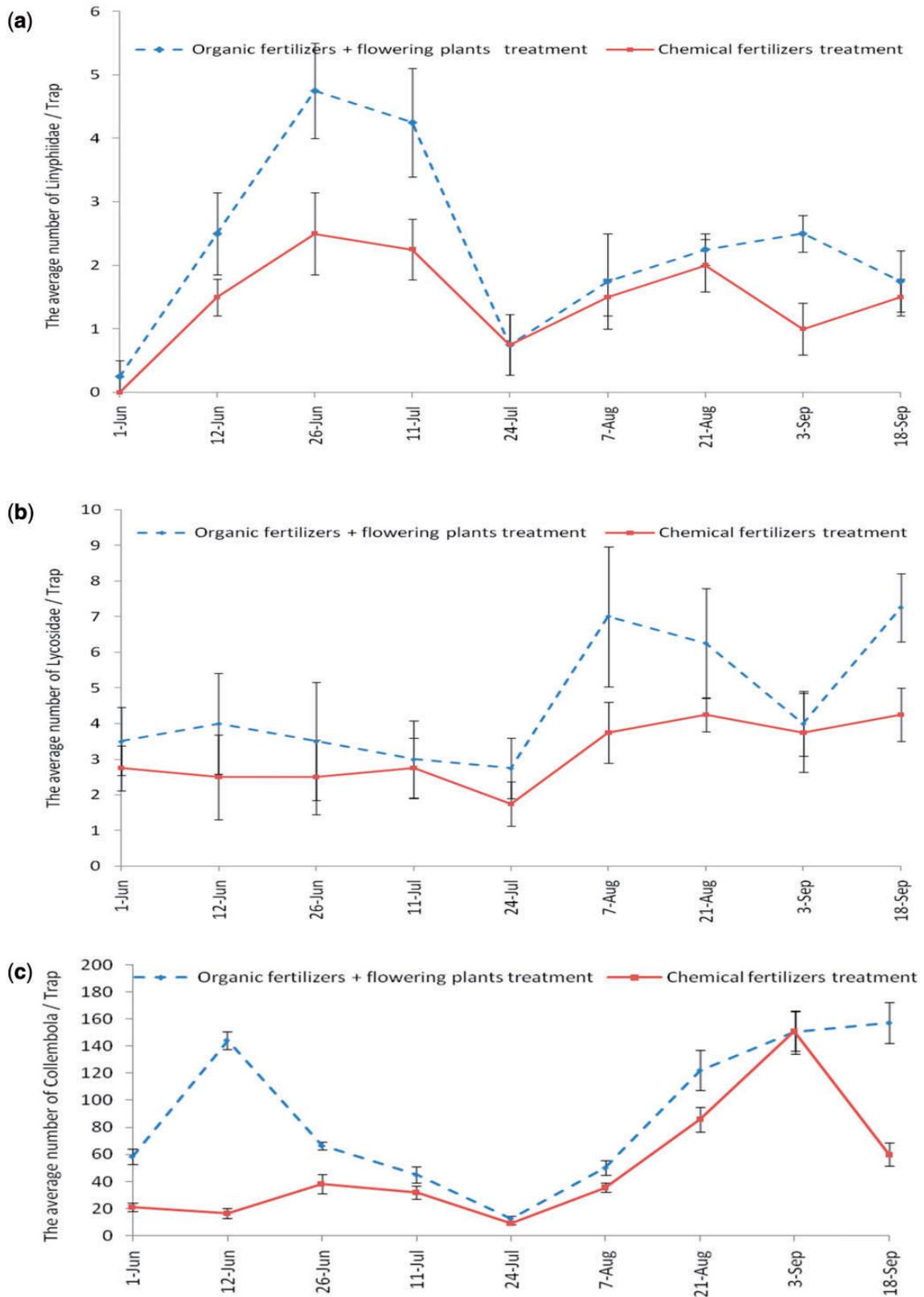


Fig. 2. Fluctuations of the populations of Linyphiidae (a) and Lycosidae spiders (b) and Collembola (c) captured by pitfall traps, according to plot type in 2014.

refuges for the lycosid and linyphiid spiders. Sunderland and Samu (2000) found the density of spiders can enhance by increasing suitable refuges. Malumbres-Olarte et al. (2012) reported a positive relationship between the number of lycosid spiders and the diversity

of plant species. 3) Flowering plants change the habitat composition or may enhance the density of alternative prey and this point was confirmed by Frank (2003) found that flowering plants strips are very important to enhance the numbers of alternative prey and also,

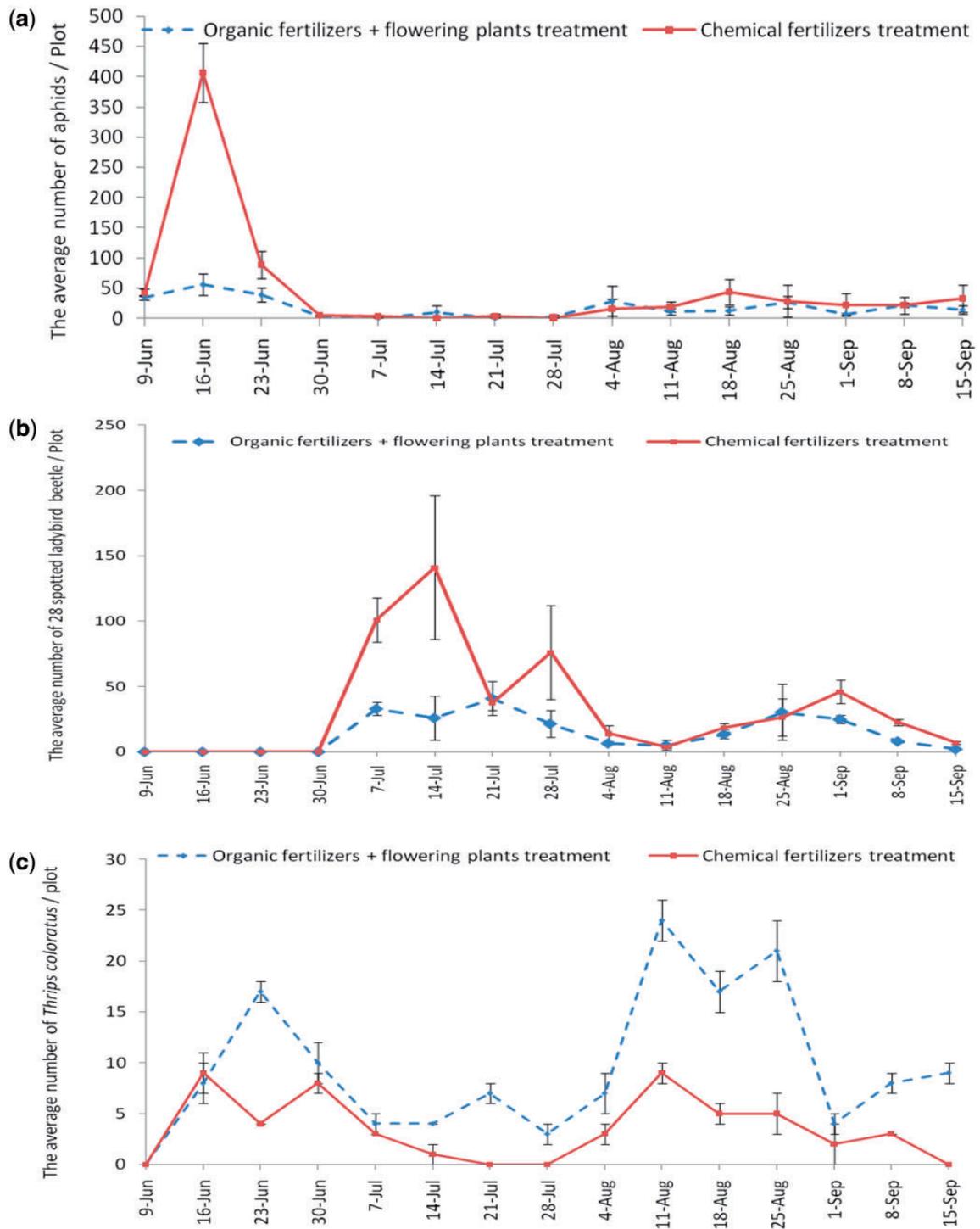


Fig. 3. Fluctuations of the populations of aphids (a) (counted by microscope), 24-spotted ladybird beetles (b) (counted directly) and *T. coloratus* Schmutz. (c) (collected by sweeping net) between the organic and chemical treatments in 2014.

Landis et al. (2000) indicated that change the habitat composition can enhance the alternative prey of spiders. Our study showed that during August high numbers of nonpest *T. coloratus* Schmutz were attracted in the organic fertilizers and flowering plants treatment and maybe they played an important role to increase the numbers of spiders. Furthermore, high numbers of nonpest thrips (*T. coloratus* Schmutz) were attracted to *S. farinacea* Bench (El-Nabawy, unpublished data). Sahito et al. (2013) found that family Lycosidae, *Hippasa agelenoides* feed on thrips. Also, Harwood et al. (2003)

reported that many individuals of Thysanoptera were found at web-sites of the linyphiid spider, and the authors expected that Thysanoptera was an efficient prey for linyphiid spider. 4) Flowering plants also can provide spiders with alternative food resources (pollen) and some previous studies have indicated the value of pollen in the good ecosystem as an alternative food resource for linyphiid spider and its role to raise the fecundity (Peterson et al. 2010). Also, Vogeley and Greissl (1989) reported that pollen can enhance the spiderlings longevity.

Populations of Insects in Organic and Chemical Plots in 2014

In June 2014, the number of Linyphiidae spiders in the organic fertilizer plots was about twice as high as that in the chemical fertilizer plots which led to the aphid counts in the chemical treatment plots were temporarily higher than those in the organic plots. While, from the end of June until the end of August the number of Collembola and linyphiid spiders had the same trend. Thus, the higher density of linyphiid spiders might be maintained by partially changing the main prey from aphids to Collembola and *T. coloratus* Schmutz. Interestingly, the numbers of aphids, no significant differences were detected between the organic fertilizers with flowering plants treatment and the chemical fertilizers treatment, indicating no direct prey-predator relationship between them. These results are not consistent with those reported by Luczak (1979), Nyffeler and Benz (1987), Mansour and Heimbach (1993), and Lang (2003), all of whom reported that lycosid and linyphiid spiders can affect aphid populations.

The numbers of 28-spotted ladybird beetles were lower in organic plots with flowering plants treatment comparing with mineral fertilizers treatment and we think the first reason is that increases in lycosid spiders may suppress populations of the beetles. Generally, most lycosid spiders dwell on the soil surface, and the 28-spotted ladybird beetle inhabits leaf surfaces. Many of the ladybird beetle were collected in our pitfall traps (unpublished data), and especially this species is bigger than other ladybird beetles and moves slowly, and if any disturbance happens, it falls to the ground (Kalaiyarasi and Ananthi 2015) and we believe that the main disturbing things were rain and wind because Japan is also the country exposed to a tropical storm (typhoon) moreover, Japan considers generally a rainy country and the rainy days numbers during this study were 10, 6, 12 and 8 d during June, July, August and September, respectively. So we think that lycosid spiders could easily feed on these beetles. Some previous studies have also indicated that lycosid spiders can feed on coleopteran insect pests. Uetz et al. (1992) reported that *Lycosa* spiders prey on *Dermestes* beetles, and Maloney (2002) found that lycosid spiders consume blueberry flea beetles (Chrysomelidae). According to Riechert and Lawrence (1997), Hunting spiders reduced phytophagous populations Coleoptera in Tennessee. Also, we think the second reason is the significant numbers of linyphiid spider in organic fertilizers and flowering plants treatment may suppress the numbers of 28-spotted ladybird beetles because they can move and spread easily by the wind (Luczak 1979, Weyman et al. 2002). Nentwig (1983) showed that Coleoptera was seldom captured by linyphiid spiders. Also, Linyphiid spiders capture prey on their web or stopping periodically to hunt prey (Alderweireldt 1994).

In conclusion, the use of organic fertilizers and predatory-attracting plants enhances the density of lycosid and linyphiid spiders and their alternative prey in Japan. And these results suggest that high densities of these spiders suppress some of the insect pests in eggplant fields.

Plan for Future

In the present study (2014), we could not determine the impact of organic fertilizers and flowering plants separately because flowering plants surrounded the organic fertilizers plots and we studied them as one treatment, so in our future study, we will compare between the mineral fertilizers, organic fertilizers, organic fertilizers with flowering plants, and flowering plants in four different treatments to determine the actual effect of each factor and the best treatment to enhance spiders populations.

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