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Diversity of predatory arthropod communities in tobacco-garlic eco-system

Rongquan Lai[1,2]*, Jianbao Bai[3], Gang Gu[4], Changming Liu[1,2] and Xiujin Zhong[5]

[1]College of Plant Protection, Fujian Agriculture and Forestry University, Fuzhou 350002, China.
[2]State Key Laboratory of Ecological Pest Control for Fujian and Taiwan Crops, Fuzhou 350002, China.
[3]Staff Development Institute of CNTC, Zhengzhou 450008, China.
[4]Fujian Science and Research Institute of Tobacco Farming, Fuzhou 350002, China.
[5]Longyan Substation of Fujian Science and Research Institute of Tobacco Farming, Fujian, Longyan 364000, China.

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Predatory arthropods, especially spiders, play a vital role in the control of insect pests in agro-ecosystems. Accordingly, two year field study was conducted at the Longyan Substation of Fujian Institute of Tobacco Agricultural Sciences in China to determine the effects of garlic and tobacco intercropping system on spiders and predatory arthropods. A total of 545 and 860 (in 2011 and 2012, respectively) individuals of predatory arthropods representing 14 families and 16 species were collected in the fields. The diversity indices of the predatory arthropod communities were obviously higher in tobacco-garlic intercropping system than in tobacco fields. The species richness and species abundance of the predatory arthropods collected in tobacco-garlic fields were significantly higher than that of the predatory arthropods collected in tobacco fields in both study years. Moreover, the values of these indices were obviously higher for spider abundance in tobacco-garlic fields than in tobacco fields during the middle stages of tobacco growth. Intercropping garlic in tobacco fields can increase the abundance of spiders and predatory arthropods, and this approach may be useful to control pests in tobacco fields.

Key words: Tobacco-garlic, intercropping system, spider, predator arthropod, diversity.

INTRODUCTION

The presence, abundance and diversity of the predator community have significant impacts on ecosystem functions (Snyder et al., 2006; Schmitz, 2007; Bruno and Cardinale, 2008; Letourneau et al., 2009). The natural enemy hypothesis predicts that predators are more abundant and more diverse in species-rich plant communities because these communities offer a greater variety of microhabitats as well as a broader spectrum and a more stable temporal availability of prey than low diverse communities (Strong and Southwood, 1984; Srivastava and Lawton, 1998; Jactel and Duelli, 2005). With greater diversity of predators, lower trophic levels such as herbivoures can thus more effectively be regulated allowing producers to also thrive. Many studies

*Corresponding author. E-mail: lrq305@sina.com.

have compared predator diversity and abundance relative to plant diversity in monocultures to mixtures of a few plant species and most found that the polyculture system effectively influenced the pests in those systems (Pierre et al., 2011; Lin et al., 2011; Habib, 2012).

There are examples of predators, and among them predatory arthropods, that can exert strong top-down control on the food web (Bell, 2007; Schuldt et al., 2011). In agricultural ecosystems, they are a major component of the natural enemy community, predating mainly on crop pests (Pang and You, 1996; You et al., 2004; Dwyer et al., 2011). Within the predatory arthropod group, spiders are important in agroecosystems and may be a good example for the natural enemy hypothesis. For instance, Cai and You (2007) found that, throughout the growing season, the abundance of spiders from the family Theridiidae, an important group of predators, was greater in garlic (*Allium sativum*)-Chinese cabbage (*Brassica chinensis*) fields than in Chinese cabbage monocultures (Cai and You, 2007). Wu et al. (2011a) have reported that spider diversity and community stability were higher in rice fields adjacent to flue-cured tobacco fields than in the rice fields or flue-cured tobacco fields alone (Wu et al., 2011a).

These studies tend to support the natural enemy hypothesis. However, other studies have not supported it. Lin et al. (2011) demonstrated that polycultures did not effectively optimise the structure of the spider guild nor increase its diversity in rice fields. Similarly, Chen et al. (2011) found that the use of a cover crop in tea plantations did not change spider communities. In a highly diverse forest ecosystem in subtropical China, Schuldt et al. (2011) reported that spider activities, abundance and species richness in fact decreased with increasing tree species richness.

This high variability in responses of spiders to changes in diversity underlines the need to further test this hypothesis. The main reason for the use of spiders is that they are sensitive to disturbances particularly to pesticide applications. Because of this, they have been considered as good indicators for monitoring ecological change and thus testing the natural enemy hypothesis (Pétillon et al., 2008). They have also been proposed as an ideal group for predicting the extinction debts of other taxa due to habitat destruction or disturbance.

In this study, we studied the effects of tobacco-garlic intercropping systems versus tobacco monocultures on spider and predatory arthropod communities and through this, tested the natural enemy hypothesis for predators or spiders.

MATERIALS AND METHODS

Study sites

Field experiments were conducted at the Longyan Substation of Fujian Institute of Tobacco Agricultural Sciences, Fujian Province, China (25°08'N, 116°59'E, 347.30 m altitude) from March to June in both 2011 and 2012. The climate of this area was influenced by subtropical monsoon, with an average annual temperature of 18-20°C and annual precipitation of 1600 to 1700 mm. The soil type at the study site was a red soil, and a pH of 5.2.

Experimental design

Field experiments were conducted using flue-cured tobacco (var. K326). White garlic, *Allium sativum* L., (cultivar) was planted one month before transplanting flue-cured tobacco plants. During the experiment, randomized block design was followed where three blocks and within each, four treatments plots of 12 x 11.2 m were selected as per Lai et al. (2011). Each plot was separated from each other by a flue-cured tobacco ridge. The four treatments were as follows: A) tobacco plot with two rows of garlic planted on one edge of a ridge, B) tobacco plot with two rows of garlic planted on each edge of a ridge, C) garlic planted between two individual K326 plants in a ridge, and D) monoculture of K326 tobacco. Tobacco was planted at a density of 1.80 individuals m^{-2} and garlic at a density of 5.85 individuals m^{-2}. Garlic seedlings were transplanted by hand in the tobacco fields on January 25, 2011 and January 27, 2012. After a month (on February 25, 2011 and February 27, 2012), K326 seedlings were transplanted by hand according to the density and treatments described above. Forty-five days (April 11, 2011 and April 13, 2012) after transplanting the tobacco plants, all the garlic plants were harvested by hand to avoid affecting tobacco growth. No pesticides was used during the experiment. The plants were fertilised one day before garlic transplantation and then 25 days after planting K326, using organic and chemical fertilisers for a seasonal total content for N, P, and K of 120, 20.57 and 124.47 kg ha^{-1}, respectively. The plants were furrow-irrigated five to six times during the seasons.

Sampling techniques and species identification

Thirty flue-cured tobacco plants were randomly selected from each plot with a jump spreadsheet parallel sampling method (Wu, 2000; Lai et al., 2011). The sampling started 7 days after transplanting the tobacco plants and continued until the day when all the tobacco leaves were harvested. Spiders and other arthropods from a flue-cured tobacco plant and from the 0.50-m^2 area under the plant were captured with a suction sampler (Liu et al., 1999). Sampling was performed at intervals of 7-15 days. All arthropods collected with the suction sampler were transferred and frozen in a plastic bag before identification under a microscope at the Institute of Applied Ecology, Fujian Agriculture and Forestry University, China.

Data analysis

To perform comparisons and analyses of the predatory arthropods, the diversity index was calculated:

$$H = -\sum_{i=1}^{s} P_i \ln P_i \qquad (1)$$

Where, $P_i = n_i/N$, P_i = the proportion of the number of individuals of the *i*th species to the total number of individuals, n_i = the number of individuals of the *i*th species, N = the total number of all individuals and s = the number of species. To determine the treatment effects, the dominance index was also calculated:

$$D = N_{max}/N \qquad (2)$$

Where, N_{max} = the number of individuals in the most abundant species and N = the total number of all individuals. And the predatory arthropods were classified by the degree of dominance of the species (Liu et al., 2000), where species with $D \geq 0.1$ are considered dominant species, species with $0.05 \leq D < 0.1$ are abundant, species with $0.01 \leq D < 0.05$ are frequent, species with $0.001 \leq D < 0.01$ are occasional and species with $D < 0.001$ are rare.

The predatory arthropod or spider datasets in 2011 and 2012 were analysed separately. Statistical analyses were performed with SPSS 15.0 for Windows (Liu et al., 2008). A univariate analysis of variance was used to analyse predatory arthropod or spider community data. Prior to the univariate analysis, the data were log-transformed [$\log_{10}$ (x+1)] or log-transformed ($\log_{10}$ x) to meet the assumptions of normality and homogeneity of variance. If the *F*-statistics indicated significant effects, the means were separated with a Fisher's protected least significant difference (LSD) test with a 5% significance level.

RESULTS

A total of 545 and 860 individuals was recorded during 2011 and 2012, respectively and which represent 14 families of five orders and 16 species collected from the tobacco fields. Micryphantidae and Syrphidae families have the highest number of species (two in the first or second year). One species was collected for each of the other families in each study year. The family Theridiidae has the greatest numbers of individuals (108) in 2011, followed by Micryphantidae (103) and Staphylinidae (67). The Micryphantidae, Chrysopidae and Theridiidae has greater number of individuals, that is,149, 126 and 120, respectively in 2012 (Figure 1).

The diversity indices for the predatory arthropods did not differ significantly between the garlic-tobacco and the tobacco fields during 2011 ($F_{3,\ 80}$ = 0.675, P = 0.570) or 2012 ($F_{3,\ 92}$ = 1.976, P = 0.123). However, the diversity indices for the predatory arthropods were obviously higher in the garlic-tobacco fields than in the tobacco fields in the two years (Figure 2).

The species richness and species abundance of the predatory arthropods differed significantly between the experimental treatments during 2011 ($F_{3,\ 80}$ = 6.560, P = 0.001 and $F_{3,\ 80}$ = 3.363, P = 0.023, respectively) and 2012 ($F_{3,\ 92}$ = 7.620, P<0.001 and $F_{3,\ 92}$ = 5.221, P = 0.002, respectively) (Figures 3 and 4). The species richness of the predatory arthropods in the garlic-tobacco fields was significantly higher than in the tobacco fields (Figure 3). Moreover, the species abundance of the predatory arthropods was also significantly higher in the garlic-tobacco fields (Figure 4).

A total of 16 species of predatory arthropods were found during 2011 and 2012, including dominant species, abundant species, frequent species, occasional species and rare species. The occasional species included *Theridion octomacularum* (Boes et Str.), *Erigonidium graminicola* (Sundvall), *Coccinella septempunctata* (Wesmael), *Pardosa tinsigmita* (Boes et Str.), *Propylaea japonica* (Thungberg), *Epistrophe balteata* (De Geer), *Paederus fuscipes* (Curtis), *Misumenops tricuspidatus* (Fabricius), *Oedothorax insecticeps* (Boes et Str.) and *Sycanus croceovittatus* (Dohrn). The rare species included *Syrphus corollae* (Fab.), *Coccinella septempunctata* (Linnaeus), *Aphidoletes aphidimyza*, *Calosoma chinense* (Kirby) and *Tetragnatha maxillosa* (Thorell). In addition, *Nabis sinoferus* (Hsiao) was included in the rare species and occasional species in 2011 and 2012, respectively. However, none of the species cited above as rare or occasional was found to be dominant, abundant or frequent in this study.

Consistent significant results were not found for spider abundance in the garlic-tobacco systems during 2011 and 2012. The spider abundances did not differ significantly in 2011 ($F_{3,\ 80}$ = 2.400, P = 0.074) but differed significantly in 2012 ($F_{3,\ 92}$ = 3.016, P = 0.022). In both years, the spider abundance was similar in the garlic-tobacco fields and in the tobacco fields at the first and last stages of tobacco growth. However, the spider abundance was obviously overall higher in the garlic-tobacco fields, especially in the middle stages of tobacco growth (Figure 5).

DISCUSSION

Predatory arthropods or spiders are common and abundant in agroecosystems (Pang and You, 1996; You et al., 2004; Schmitz, 2007). Intercropping methods have been used to manipulate pests in many crop fields (Shen et al., 2007; Sohail et al., 2008; Lai et al., 2011; Lai et al., 2017). The successful use of spiders or predators for pest management provides support for the natural enemy hypothesis, which suggests that natural enemies are more abundant and diverse in diversified habitats than in monocultures. Moreover, many previous studies have shown that predatory arthropods or spiders in tobacco fields to be a key natural enemy of tobacco pests (Tao et al., 1996; Wu et al., 2005; Lai et al., 2012).

In the present study, it was found that the richness and abundance of predators and the abundance of spiders were significantly higher in the garlic-tobacco fields than in the tobacco fields (Figures 3, 4 and 5). This result is consistent with the findings of Wu et al. (2011a, b). These authors demonstrated that spider abundances and predator arthropods were higher and the abundance of *Sogatella furcifera* (Horvath) was lower in paddy fields adjacent to flue-cured tobacco fields than in paddy fields (Wu et al., 2011a, b). The natural enemy hypothesis is also clearly supported by the study.

The reason for the results cited may be that plant diversity and the stability of the arthropod communities were enhanced by intercropping garlic in tobacco fields. Intercropping garlic in tobacco fields may affect the environment. Pétillon et al. (2008) obtained results similar to these. Their study found that spiders were a suitable indicator taxon for reflecting ecological change because they were sensitive to soil moisture (Pétillon et al., 2008).

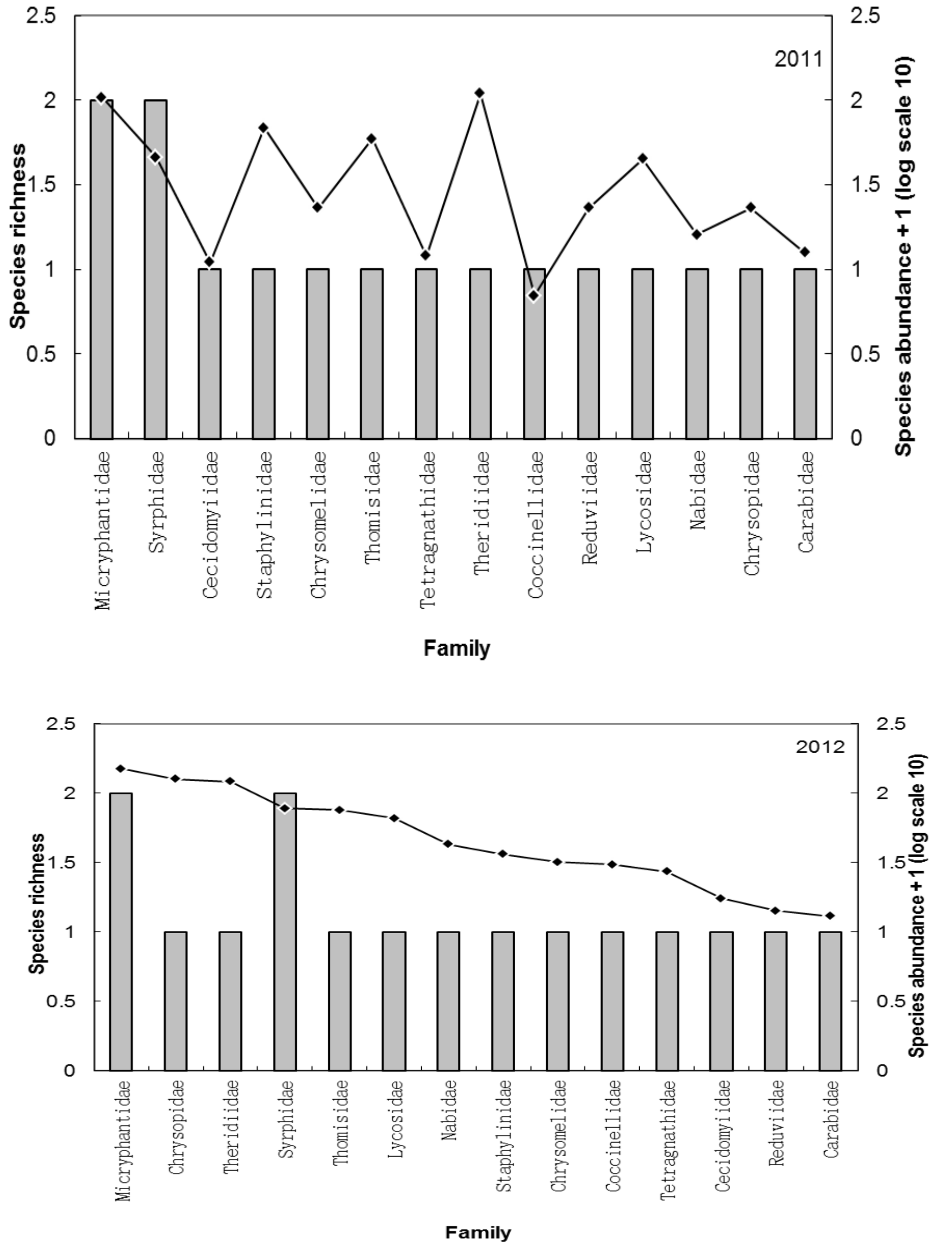

Figure 1. Species richness (bar graphs) and species abundance (line plots) distributes within families for predatory arthropod in garlic-tobacco systems in Longyan during 2011 and 2012.

In addition, Andow (1991) and Cai and Youl (2007) have found that the richness and abundance of natural enemies were higher in intercropping-multiculture fields than in monoculture fields (Andow, 1991; Cai and You, 2007). These findings imply that a higher diversity in tobacco fields may result in higher abundances of spiders or predators. Such results suggest that it may be difficult to control crop pests or to maintain the stability of arthropod community in a monoculture agro-ecosystem.

In this study, it was also found that the abundance of spiders decreased gradually during the middle stage of tobacco growth in garlic-tobacco fields (Figure 5). Two reasons may help to explain this finding. First, the diversity of the garlic-tobacco ecosystems decreased because all the garlic plants were removed forty-five days after transplanting the tobacco plants (see “experimental design”). Second, the changes in the populations of natural enemies may follow the changes in the populations of the pests (fewer enemies result from fewer pests). The latter reason is consistent with the findings of Shi (2000) and Cai et al. (2007). Shi (2000) have demonstrated that changes in *Myzus persicae* (Sulzer)

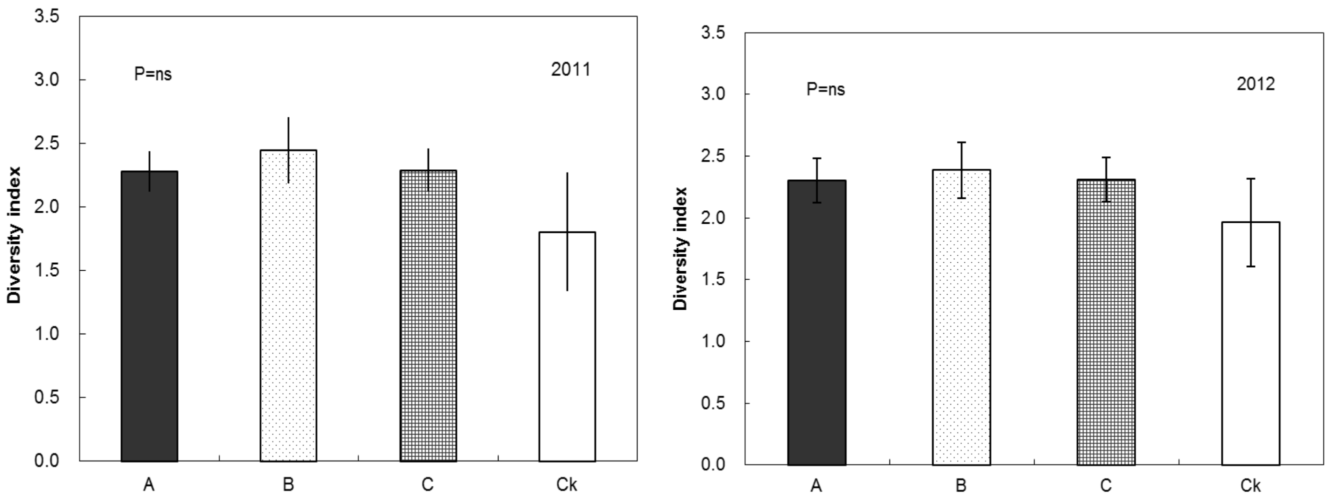

Figure 2. Diversity indexes in predatory arthropod communities in garlic-tobacco systems in Longyan during 2011 and 2012 (Mean±S.E.) Note: Treatment A consisted of two rows of garlic planted on one edge of a ridge; Treatment B consisted of two rows of garlic planted on each edge of a ridge; Treatment C consisted of garlic planted between two individual K326 tobacco plants; and the control treatment (Ck) consisted of all ridges planted with K326 only. ns is not significantly different at 5% level of significance (determined by a Fisher's protected least significant different (LSD) test for means separation) .

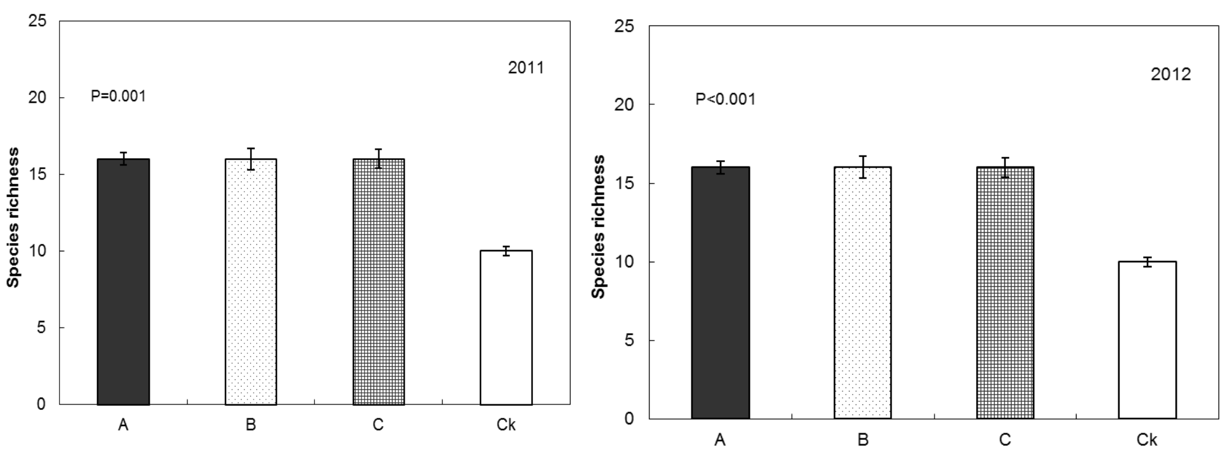

Figure 3. Species richness in predatory arthropod communities in garlic-tobacco systems in Longyan during 2011 and 2012 (Mean±S.E.). Note: Treatment A consisted of two rows of garlic planted on one edge of a ridge; Treatment B consisted of two rows of garlic planted on each edge of a ridge; Treatment C consisted of garlic planted between two individual K326 tobacco plants; and the control treatment (Ck) consisted of all ridges planted with K326 only. P value is significantly different at 5% level of significance (determined by a Fisher's protected least significant different (LSD) test for means separation).

populations in tobacco fields were followed by changes in *Aphidius gifuensis* Ashmead populations (Shi, 2000). Similarly, Cai and You (2007) found that the dynamics of the parasitoid *Diaeretiella rapae* M'Intosh population paralleled the dynamics of aphids in garlic-cabbage fields.

The Shannon-Weaner index is widely used to estimate arthropod diversity (Shannon and Weaner, 1949; Renio et al., 2008; Wu et al., 2011b). The results of this study indicated that the diversity indices for predatory arthropods did not differ significantly between intercropping tobacco fields and tobacco fields (Figure 2). This result is consistent with the findings of Lin et al. (2011), who have demonstrated the same pattern in paddy fields (Lin et al., 2011). However, the present study found that the abundances of predators or spiders were significantly higher in garlic-tobacco fields (Figures 4 and 5). These results are not consistent with the findings of Chen et al. (2011) and Lin et al. (2011). Their results showed that

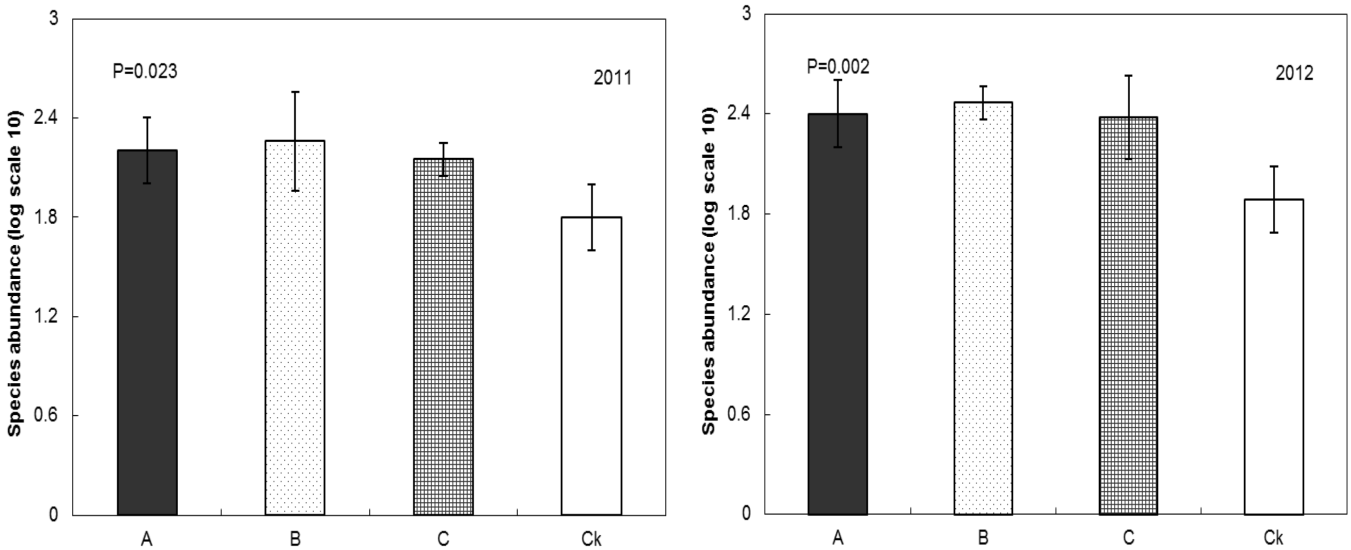

Figure 4. Species abundance in predatory arthropod communities in garlic-tobacco systems in Longyan during 2011 and 2012 (Mean±S.E.). Note: Treatment A consisted of two rows of garlic planted on one edge of a ridge; Treatment B consisted of two rows of garlic planted on each edge of a ridge; Treatment C consisted of garlic planted between two individual K326 tobacco plants; and the control treatment (Ck) consisted of all ridges planted with K326 only. P value is significantly different at 5% level of significance (determined by a Fisher's protected least significant different (LSD) test for means separation).

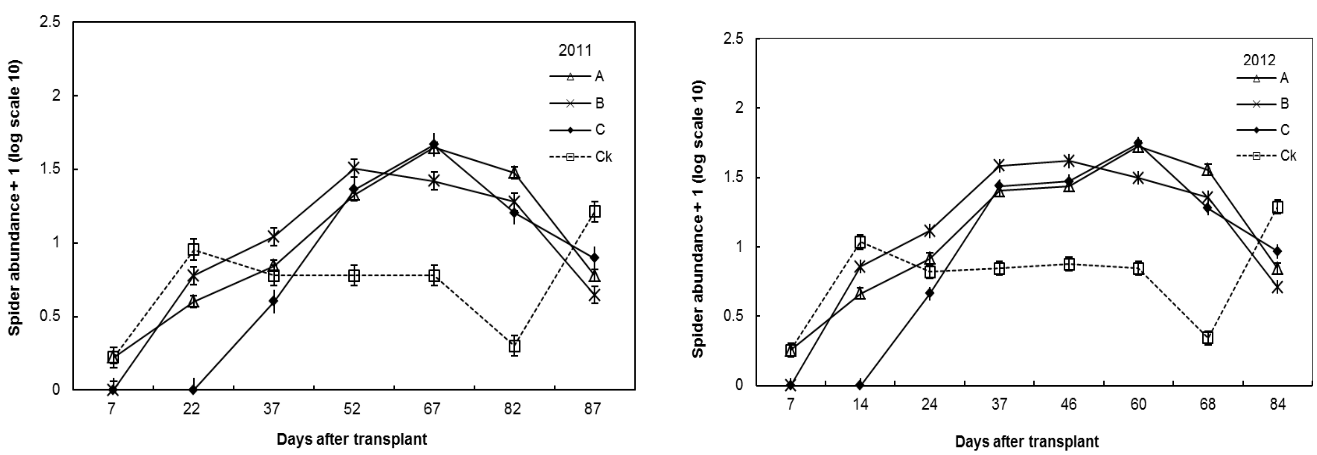

Figure 5. Spider abundance in garlic-tobacco systems in Longyan during 2011 and 2012 (Mean±S.E.). Note: Treatment A consisted of two rows of garlic planted on one edge of a ridge; Treatment B consisted of two rows of garlic planted on each edge of a ridge; Treatment C consisted of garlic planted between two individual K326 tobacco plants; and the control treatment (Ck) consisted of all ridges planted with K326 only.

spider abundances and richess were not significantly affected by a cover crop in tea plantations or by polycultural manipulation in paddy fields (Chen et al., 2011; Lin et al., 2011). The smaller number of individuals in arthropod communities may make the abundance or diversity of predators or spiders more consistent in tobacco fields than in other crop fields. Moreover, further studies are required to quantify the differences among the richness, abundance and diversity of predators or spiders in tobacco fields, and attention should be focussed on long-term studies that use larger experimental sites.

Conclusion

The results of this study show that the species richness and abundance of predator arthropods and spider abundance can be significantly enhanced by intercropping garlic in tobacco fields. The natural enemy hypothesis is clearly supported by this work. The higher abundance of predators or spiders in garlic-tobacco fields may be helpful for controlling pests.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

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