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Effects of Three *Spodoptera litura* Control Strategies on Arthropod Diversity and Abundance in Tobacco Agroecosystems in South China

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Abstract.- Effect of three *Spodoptera litura* control strategies, *viz.* use of trap crop plus biological control, chemical control only, and a-control with no intervention, on the environment, diversity and abundance of arthropods were studied in the tobacco field. Choice of *S. litura* control strategy had a significant effect on the diversity and abundance of arthropods in the tobacco agroecosystems. The results indicated that the abundance and diversity of arthropods increased significantly when tobacco was intercropped with a trap crop particularly *Colocasia esculenta.* Diversity of arthropods was significantly higher under the trap crop plus biological control strategy than under chemical, or non-control condition. In addition, trap crop plus biological control strategy increased the number of natural enemies in the field, which is possibly a reflection of higher levels of food availability (higher arthropod abundance) in these fields. Thus, the stability of arthropod community was better under trap crop plus biological control strategy than under chemical or non-control strategy. Based on the results of our study, the trap crop plus biological control strategy may give an efficient and sustainable control of tobacco pests in the field.

Key words: *Spodoptera litura*; tobacco pests, trap crop plus biological control strategy, *Colocasia esculenta.*

INTRODUCTION

Global-scale conversion of natural ecosystems to agriculture is recognized as the major cause of biodiversity loss, and threatens ecosystem functioning, sustainability and economic security (Hoekstra *et al.*, 2005). Concretely, agricultural intensification decreases arthropod predator diversity, abundance and population stability, and may affect interactions between arthropod predators and their arthropod prey –ultimately affecting ecosystem services (Philpott *et al.*, 2006). Hence, ecologists are interested not only in understanding how habitat disturbance affects biodiversity in natural ecosystems (Ricketts, 2001; Tscharntke *et al.*, 2002; Watt *et al.*, 2002), but also in agricultural ecosystems (Ricketts *et al.*, 2001; Estrada and Coates-Estrada, 2002; Siebert, 2002; Boutin *et al.*, 2009). In general, various pest control strategies have different impacts on the diversity and abundance of arthropods in agricultural ecosystems (Philpott *et al.*, 2006).

Previous studies have revealed that arthropod diversity is increased when trap crops or other plants were intercropped with, or planted in proximity to, the main economic crops or planted in circumambience of crop fields (Hokkanen, 1991; Accinelli *et al.*, 2005; Åsman, 2002; Shelton and Badenes-Perez, 2006; Song *et al.*, 2010b). Trap crops were propitious to sustainable control of the agricultural insect pests in these trap crop systems (Simon *et al.*, 2010; Song *et al.*, 2010a). For example, Åsman (2002) reported that indirect effects of vegetation diversity such as enhancement of natural enemies could potentially increase the efficacy of trap cropping.

Tobacco is one of major economic crops in China, and crop losses are mainly attributed to the tobacco caterpillar, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) causing serious damage by defoliation (Zhou *et al.*, 2011). At present, chemical control strategy is accepted as a dominant control measure for this insect pest in tobacco (Peter and David, 1988; Kumar and Parmar, 1996). However, the negative influence of insecticides on

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arthropod diversity has been reported as a major negative side effect (Kranthi *et al.*, 2002). Therefore, novel control strategies (such as control of agriculture insect pests with trap crops and biological agents) should be considered in order to reduce current dependence on synthetic insecticides. Recently, the combined application of the trap crop *Colocasia esculenta* (Araceae: Alismatales), and biological control agents such as the nuclear polyhedral virus, has been suggested as an ecologically sound strategy to reduce *S. litura* in tobacco agroecosystems (Zhou *et al.*, 2011). However, this hypothesis has yet to be tested in the field.

In this study we report the diversity and abundance of arthropods under three pest control strategies in the field, by asking whether the trap crop plus biological control against *S. litura* can be used to increase the abundance of beneficial arthropods in tobacco fields.

MATERIALS AND METHODS

Study site and plants

The study was conducted at the experimental farm of Nanxiong Research Institute of Tobacco (Nanxiong, Guangdong Province, China). Of the about 300 ha of tobacco fields (*Nicotiana tabacum* 9601) in the research farm, the present study was conducted in three experimental fields of about 0.27 ha.

Plants were planted on 20th February in 2006 at a density of about 1.7-1.8 plants/m^2.

The monthly mean temperatures were between 10.2°C and 18.4°C in the winter during 2005 and 2006, and between 14.8°C and 27.2°C during the growth season of tobacco in 2006. The monthly mean humidities ranged between 57% and 75% RH in the winter during 2005 and 2006, and between 81 % and 83 % RH during the growth season of tobacco in 2006. The monthly mean rainfalls were between 10.2 mm and 98.3 mm in the winter during 2005 and 2006, and between 158.5 mm and 242.2 mm during the growth season of tobacco in 2006.

Experimental set-up

Three experimental fields arranged from east to west, each containing three treatment plots, were separated by an unplanted ridge (0.80 m width). Each treatment plot was about 0.03 ha. These plots were randomly arranged, and adjacent plots were separated by a row of unplanted ground (5 m width). Treatments consisted of three control measures; 1) trap crop plus biological control strategy; 2) chemical control strategy; and 3) non-control strategy (no artificial control applied). The experiment was replicated three times. Each experimental field included a replicate of each.

Trap crop plus biological control strategy consisted of a row of *C. esculenta* inter-planted every four rows of tobacco. Because *C. esculenta* was still at the seedling stage and it could not attract *S. litura* when the adults of first generation *S. litura* occurred, therefore, adult females laid eggs on tobacco leaves. Along with trap crop, in this study, the larvae of 2nd generation *S. litura* were managed with the *Spodoptera litura* nuclear polyhedral virus (SlNPV). When the larvae of 2nd generation *S. litura* were at second instars stage on 6 May 2006, 4.0×10^{10} PIB (polyhedral inclusion body) /ha solution of SlNPV was sprayed for suppressing 2nd generation of *S. litura*. At the same time, *C. esculenta*, being at the fast-growing stage, attracted large number of *S. litura* adults to oviposit and hosted many *S. litura* larvae, thus any other control methods were not carried out in later stages.

Chemical control strategy consisted of 450 g/ha solutions of 50 % methamidophos (a synthetic insecticide), sprayed at the 2nd instars of 1st, 2nd and 3rd generations of *S. litura* larvae, on April 20, May 6 and May 30th in 2006, respectively.

Non-control strategy consisted of pure tobacco monoculture, and any factitious measure was avoided. Therefore, any mortality of *S. litura* was considered due to natural factors.

Data collection

Investigation was conducted from April to June in 2006, and the data were collected once every four days by checkerboard sampling in each plot. A total of 20 tobacco plants were sampled each time, and all arthropods were counted on each sampled plant, as well as in the 50 cm-radius circle nearby the investigated plants. Specimens were labeled and stored in alcohol (75%) for future identification. As there are only a few reliable identification keys for adults, and none for the early stages, arthropods were sorted initially into morphospecies. Later, some species were identified by expert taxonomists. All specimens were preserved in South China Agricultural University, Guangdong Province, China.

Statistical analyses

To understand the diversity of arthropods under three pest control strategies, Shannon-wiener's (*H'*) (Shannon and Weaver, 1949) and Hill's diversity indices (N_1 and N_2) (Hill, 1973) were calculated by the follow formulae:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i,$$

where p_i is the fraction of individuals belonging to *i*-th species.

$$N_1 = e^{H'}$$

where *H'* is Shannon-wiener's diversity index.

$$N_2 = \frac{1}{\lambda}$$

which λ is calculated as follows: $\lambda = \sum_{i=1}^{s} \frac{n_i(n_i-1)}{n(n-1)}$

where n_i is the number of individuals belonging to *i*-th species, *n* is the number of individuals of total species, and *S* is the number of species (Simpson, 1949).

The abundance of species was estimated by Margalef's index, and was calculated by

$D_{Ma} = (S-1)/\ln n$.

The evenness indices (J and Es) were determined by Pielou's index (Pielou, 1966) and Alatalo's index (Alatalo, 1981), respectively, and were calculated by $J = H'/\ln S$ and $Es = (N_2-1)/(N_1-1)$, respectively.

The dominant index was determined by Berger-parker's dominant index, and was calculated by $C = n_i/n$.

Data were checked for normality and homoscedasticity as appropriate and, if needed, were arcsine square-root or log-transformed before analysis by one-way ANOVA (SAS Institute, 2004). Fisher's protected LSD test ($P<0.05$) was used to separate treatments means.

RESULTS

Community composition of arthropod

During six weeks, we collected a total of 3943 arthropod specimens belonging to 148 species under the trap crop plus biological control strategy, 2957 specimens belonging to 95 species under the non-control strategy and 717 specimens belonging to 65 species under the chemical control strategy in the field. *Ummeliata insecticeps* was the dominant species in all arthropod communities under three control strategies (Table 1). Control strategy had a significant effect on the number of order ($F_{2,6}$=8.00, P=0.0203), family ($F_{2,6}$= 150.00, P <0.0001), species ($F_{2,6}$=2649.50, P <0.0001) and individuals ($F_{2,6}$=148165, P <0.0001) in the field.

Similarly, the number of individuals and species of natural enemies (Individuals: $F_{2,6}$=112805, P<0.0001; Species: $F_{2,6}$=255.13, P<0.0001), neutral arthropod (Individuals: $F_{2,6}$=13116.4, P <0.0001; Species: $F_{2,6}$=258.25, P<0.0001) and pest (Individuals: $F_{2,6}$=1674.14, P<0.0001; Species: $F_{2,6}$=4.50, P=0.064) were significantly affected by control strategy in the field. There were 2952 specimens of natural enemies which belonged to 91 species and 942 specimens of neutral arthropods belonged to 50 species under the trap crop plus biological control strategy. These figures appeared significantly higher than those under non-control (2106 specimens of natural enemies belonged to 51 species and 677 specimens of neutral arthropods belonged to 34 species) and chemical control (434 specimens of natural enemies belonged to 42 species and 172 specimens of neutral arthropods belonged to 12 species) strategies. There were only 49 specimens of pests belonging to 7 families under the trap crop plus biological control strategy, which were significantly lower than under non-control (174 specimens of pests belonged to 10 families) and chemical control (111 specimens of pests belonged to 10 families) strategie (Table II).

Arthropod diversities

Control strategy affected significantly dominance index (*C*) ($F_{2,6}$=140.22, P<0.0001), abundance index (D_{Ma}) ($F_{2,6}$=326.78, P<0.0001), Shannon's diversity index (λ) ($F_{2,6}$=128.87, P<0.0001), diversity index of Shannon-Wiener (H') ($F_{2,6}$= 13.41, P=0.0061), diversity index of Hill (N_1) ($F_{2,6}$=1408.55, P<0.0001) and diversity index of Hill (N_2) ($F_{2,6}$=181.32, P<0.0001), but did not affect evenness index (J') ($F_{2,6}$=0.37, P =0.7084) and evenness index (Es) ($F_{2,6}$=0.61, P=0.5743). Both diversity indices and abundance index of arthropods were the highest under the trap crop plus biological control strategy, and the lowest were observed under the chemical control strategy (Table III).

Table I.- Basical composition of arthropods under three pest control strategies in the tobacco fields.

Strategies	Trap crop plus biological control	Non-control	Chemical control
Number of classes	3	3	3
Number of orders	17a	13b	13b
Number of families	67a	47b	37c
Number of species	148a	95b	65c
Number of individuals	3943a	2957b	717c
Dominant species	*U. insecticeps* (d=0.2108)	*U. insecticeps* (d=0.2695)	*U. insecticeps* (d=0.3236)

Note: Means within the same row bearing the same letters are not significantly different (LSD, P<0.05) among treatments.

Dynamics of arthropod diversities

Shannon's diversity indices of arthropods under the trap crop plus biological control strategy were lower than those in non-control or chemical control strategy; the exceptions were noticed on May 16 and June 3 in 2006. Shannon-Wiener's diversity indices under the trap crop plus biological control strategy were higher than those in non-control or chemical control strategy during our survey stages (Fig. 1). In addition, Hill's diversity indices (N_1 and N_2) under the trap crop plus biological control strategy maintained the highest level among three control strategies during our survey stages (Fig. 2).

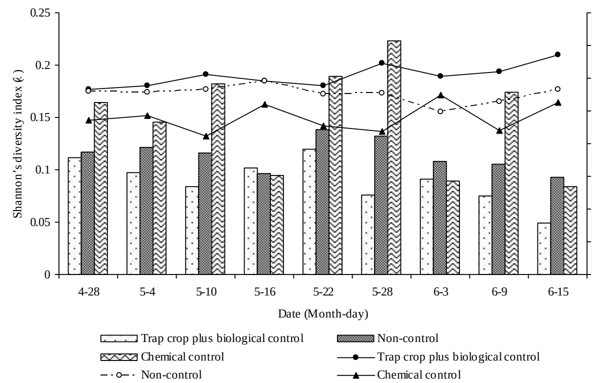

Fig. 1. Dynamics of centrality probability indices (λ) (bar) and diversity indices of Shannon-Wiener (H') (line) of arthropods under three pest control strategies in the fields.

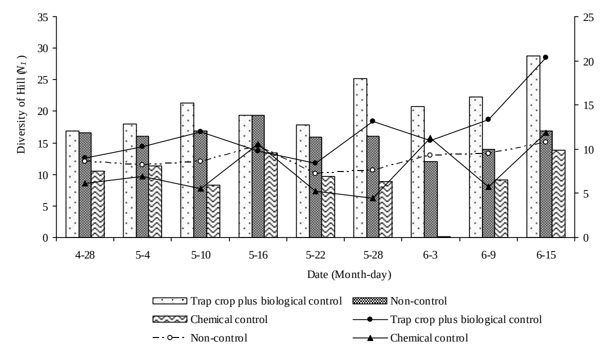

Fig. 2. Dynamics of diversity indices of Hill (N_1) (bar) and diversity indices of Hill (N_2) (line) of arthropods under three pest control strategies in the fields.

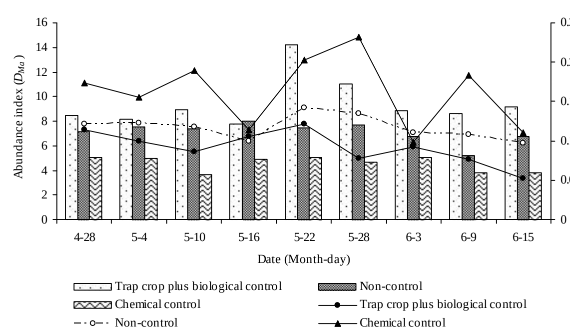

Fig. 3. Dynamics of abundance indices (D_{Ma}) (bar) and dominance indices (C) (line) of arthropods under three pest control strategies in the fields.

Table II.- Number of species and individuals of community under three pest control strategies in the tobacco fields.

Strategies	Number of individuals			Number of species		
	Natural enemies	Neutral arthropods	Insect pests	Natural enemies	Neutral arthropods	Insect Pests
Trap crop plus biological control	2952a	942a	49c	91a	50a	7b
Non-control	2106b	677b	174a	51b	34b	10a
Chemical control	434c	172c	111b	42c	13c	10a

Note: Means within the same column bearing the same letters are not significantly different (LSD, $P<0.05$) among treatments

Table III.- Diversities of arthropods under three pest control strategies in the tobacco fields.

Parameters of community	Trap crop plus biological control	Non-control	Chemical control
Dominance index (C)	0.075c	0.100b	0.140a
Abundance index (D_{Ma})	17.754a	11.762b	9.734c
Shannon's diversity index (λ)	0.074c	0.100b	0.137a
Diversity of Shannon-Wiener (H')	3.377a	3.105b	2.808c
Diversity of Hill (N_1)	29.286a	22.309b	16.570c
Diversity of Hill (N_2)	13.459a	10.010b	7.305c
Evenness index (J')	0.6768a	0.682a	0.673a
Evenness index (Es)	0.441a	0.423a	0.405a

Note: Means within the same row bearing the same letters are not significantly different (LSD, $P<0.05$) among treatments.

Dynamics of abundance and dominance indices of arthropods

The trap crop plus biological control strategy revealed a greater abundance indices (*DMa*) compared with the non-control or chemical control strategy. The dominance indices of arthropod community were the highest under the chemical control strategy and the lowest under the trap crop plus biological control strategy among the three pest control strategies during our survey stages (Fig. 3).

DISCUSSION

Previous studies have shown that the diversity of natural enemies is enhanced by high plant diversity (Norris *et al.*, 2000; Boutin *et al.*, 2009; Simon *et al.*, 2010; Song *et al.*, 2010b). Indeed, the number and species of natural enemies was increased when trap crops were intercropped with or planted in proximity to the main economic crops in the crop field (Shelton and Badenes-Perez, 2006), which appeared propitious sustainable control of insect pests on crop. In addition, insect pests on trap crops provided natural enemies for food resources, therefore increasing the diversity of natural enemies (Andow, 1991). Norris *et al.* (2000) suggested that the weeds in the circumambience of crop treatments provided beneficial arthropods for a botanic canopy and a shelter, so the diversity of beneficial arthropods (*e.g.* predators and parasitoids) increased in the crop fields. Similarly, Åsman (2002) revealed that the diversity of natural enemies was significantly promoted when colewort plants were intercropped with or planted in proximity to *Brassica juncea* in the vegetable fields.

Here we clearly show that the biodiversity and abundance of arthropods (*e.g.* spiders, predatory insect and parasitoids) is different under different pest control strategies. In general, pesticides killed large numbers of arthropods (e. g. spiders and insect), thus the diversity and abundance of arthropods revealed a lower level under chemical control strategy. For example, the detrimental impact of synthetic, broad-spectrum insecticide use on spider abundance and diversity has been clearly demonstrated (Miliczky *et al.*, 2000). Compared to those receiving little or no such insecticide input (e. g. integrated pest control, biological pest control and crop trap), habitat or agroecosystem under conventional insecticide spray strategies maintain a lower spider populations and fewer species (Chant, 1956; Legner and Oatman, 1964; Mansour *et al.*, 1980).

Based on the results of our study, we recommend the trap crop plus biological control strategy with the trap crop *C. esculenta* and the *S.*

litura nuclear polyhedral virus (SlNPV) to manage *S. litura* infestations in tobacco fields. Such strategies aim to reduce the prophylactic use of insecticides, enhance the effectiveness of parasitoids and predators and increase diversity and abundance of arthropods within trap crop systems. Our study also suggested that the number and species of natural enemies and neutral arthropods were significantly higher under the trap crop plus biological control strategy than under the natural or chemical control strategy. From a different point of view, the results suggest that the available food resources of natural enemies increased in response to the increasing number and species of neutral arthropods (*e.g.* neutral insects), thus the number of natural enemies increased as well and they had a better control effect on insect pests. In addition, the results of our investigation also showed that the arthropod diversity increased due to the planting of *C. esculenta* under the trap crop plus biological control strategy, thus the stability of arthropod community was better under the trap crop plus biological control strategy than under natural or chemical control strategy. In general, the beneficial arthropods can be efficiently used to control insect pests in a high arthropod diversity agroecosystem (Boutin *et al.*, 2009; Simon *et al.*, 2010; Song *et al.*, 2010a, b).

Finally, our results would suggest that the trap crop plus biological control strategy may be used to obtain a sustainable and ecologically-sound management practice to control *S. litura* in the tobacco field.

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