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Co-efficacy of a Trap Crop, *Colocasia esculenta* (L.) Schott and a Biological Agent, *Spodoptera litura* Nuclear Polyhedral Virus on the Tobacco Caterpillar, *Spodoptera litura* (Fabricius) in the Tobacco Field

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Abstract.- The tobacco caterpillar, *Spodoptera litura* (Fabricius) is a serious agricultural insect pest that is increasingly difficult to control in tobacco fields of Southern China. Trap crop plus biological control management system that assembles *Colocasia esculenta* trap plants and *Spodoptera litura* nuclear polyhedral virus (SlNPV) is a biologically-based pest management strategy that may effectively manage *S. litura*. Therefore, studies were conducted to evaluate three management strategies including trap crop plus biological control management system, chemical control and natural control against this pest on tobacco in South China. The results showed that the indices of population trend of 2nd and 3rd generations of *S. litura* were significantly lower in trap crop plus biological control management system than in natural or chemical control. Additionally, parasitization of *S. litura* larvae and density of several important predators were higher in trap crop plus biological control management system compared to chemical or natural control Overall, our findings suggest that the combination of trap crop plants plus biological control management system will manage effectively *S. litura* on tobacco, and we advocate the use of such ecologically-sound management practices to reduce pesticides use in Southern China.

Key words: Biological agent, life table, *Spodoptera litura*, tobacco, trap crop, trap crop plus biological control management system, pesticide application.

INTRODUCTION

Tobacco is still one of the major economic crops in China, and the tobacco caterpillar, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) is an important insect pest on tobacco causing serious damage by defoliation. Chemical control is the most common method of *S. litura* management in the fields because of easy use and dependability (Peter and David, 1988; Kumar and Parmar, 1996). However, chemical control has led to many populations of *S. litura* developing resistance to many of the traditional insecticides (Kranthi *et al.*, 2002). Control failures of *S. litura* have become common in many parts of the world, especially in Southeast Asia, India and China, and novel measures are sorely needed. One such measure is the use of trap crops. There has been a recent resurgence of interest in trap cropping as an IPM tool because of concerns about the potential negative effects of pesticides on human health and environment, pesticide resistance and general economic considerations of agricultural production (Barari *et al.*, 2005; Shelton and Badenes-Perez, 2006). Trap crops are an alternative method of control in which plants are deployed to attract, intercept, retain and/or reduce targeted insects or the pathogens they vector in order to reduce damage to the main crops (Hokkanen, 1991; Shelton and Badenes-Perez, 2006; Shelton *et al.*, 2008).

Many studies revealed that a few agricultural insect pests might be attracted by the trap crops and therefore they were less likely to leave the trap crops and attack the main crops (Vandermeer, 1989; Åsman, 2002; Barari *et al.*, 2005; Hannunen, 2005; Khan *et al.*, 2006; Shelton and Badenes-Perez, 2006;

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Shelton *et al.*, 2008). At present, many trap crops have been treated as novel control measures against some agricultural insect pests in the practical pest management (Sequeira *et al.*, 2001; Haile and Hofsvang, 2002a; Rousse *et al.*, 2003; Castle, 2006; Cárcamo *et al.*, 2007; Cook *et al.*, 2007; Bensen and Temple, 2008; Shelton *et al.*, 2008). Several of these strategies exploit the differential preferences for host plants shown by most herbivorous insects. The trap crop, which comprises highly attractive host plants of a growth stage, cultivar or species preferred by the pest, is planted near to the main crop to be protected (Hokkanen, 1991). For example, Haile and Hofsvang (2002b) investigated the preference of the feeding and oviposition of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) on 9 species of crops and weeds in the fields, which revealed this pest preferred to damage and lay eggs on *Sorghum vulgare* Pers. var. *sudanense* (Piper) Hitche (Poales: Gramineae). Srinivasan and Moorthy (1991) suggested that *Brassica juncea* was considered as a trap crop for control of the major lepidopterous pests in the vegetable fields. Talekar and Shelton (1993) and Mitchell *et al.* (2000) revealed that trap crop maintained a sustainable control of *Plutella xylostella* L. (Lepidoptera: Plutellidae) in the fields. Åsman (2002) and Shelton *et al.* (2008) reported that *B. juncea* and colewort plants revealed a strong attraction to *P. xylostella* in the vegetable fields. Hoy *et al.* (2000) proposed that the trap plants which were planted in the circumambience of crop fields might act as a significant physical barrier for the dispersal of *Lepinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae), thus the damage of potato might decrease in the plant trap system. Additionally, generalist insect herbivores are good candidates for management strategies that involve such host-plant choice in practical pest management (Bensen and Temple, 2008).

Spodoptera litura is a generalist polyphagous insect pest, feeding on more than 290 species of host plants belonging to 99 families (Wu *et al.*, 2004). The difference in the preference of *S. litura* was found to be significant among different host plants. Balasubramanian *et al.* (1984) and Chhibber *et al.* (1985) revealed that castor, *Ricinus communis* L. (Euphorbiales: Euphorbiaceae) was the most suitable plant in supporting the development of *S. litura* among several different host plants. Balasubramanian *et al.* (1984) suggested that castor might be applied to attract *S. litura* and then destroy this pest. Additionally, Wu *et al.* (2004) reported that *Colocasia esculenta* (L.) Schott (Alismatales: Araceae) could work to attract *S. litura* from the main crops in the vegetable fields. In our early survey, *C. esculenta* hosted more *S. litura* than did castor in the tobacco fields (Zhou *et al.*, 2010).

Biological control, which is the augmentation or facilitation of natural enemies of the pest in crop fields, is also an ecologically-sound alternative control practice of insect pests. For example, *Spodoptera litura* nuclear polyhedral virus (SlNPV) is a potential effective biological control agent for managing *S. litura* (Maeda *et al.*, 1990; Monobrullah and Nagata, 2000, 2001; Zhang *et al.*, 2002). In China, SlNPV had been adequately researched, and a biological control agent (SlNPV) had been manufactured by Institute of Entomology, Zhongshan University. SlNPV has been accepted as a significant effective biological agent of *S. litura* management in the fields.

Our survey indicated that the fast-growing plants of *C. esculenta* could attract *S. litura* adults, but its seedlings could not. *C. esculenta* was at the seedling stage when 2nd generation of *S. litura* adults laid eggs on tobacco, thus *C. esculenta* could not attract 2nd generation of *S. litura* adults in the tobacco fields. However, tobacco was mainly damaged by 2nd and 3rd generations of *S. litura*, thus other innoxious control methods must be recommended for managing 2nd generation of *S. litura* in the tobacco fields in South China. SlNPV is an effective ecologically-sound biological agent for *S. litura* management (Monobrullah and Nagata, 2001; Zhang *et al.*, 2002).

With this study we aimed to measure the combined efficacy of *C. esculenta* and SlNPV virus in reducing *S. litura* in tobacco fields. Therefore, *C. esculenta* was intercropped with tobacco, and SlNPV was sprayed during the second generation of *S. litura* larvae infestation on tobacco. . We then integrated the life table analyses to evaluate the natural population dynamics of *S. litura* under two additional management practices; untreated fields, and chemical pesticide treated fields.

MATERIALS AND METHODS

Study site and plants

This study was conducted at the experimental farm of Nanxiong Research Institute of Tobacco, Nanxiong, Guangdong Province, China. There were 300 ha of tobacco fields in the research farm. Three tobacco fields (*Nicotiana tabacum* 9601) where *S. litura* caused serious damage were used in this study. The total areas of three experimental fields were about 0.27 ha.

Plants were planted on 20 February in 2006 and the density was about 1.7-1.8 plants/m^2.

Experimental set-up

Three experimental fields arranged from east to west, each containing three treatment plots in our design, and adjacent fields were separated by an unplanted ridge (0.80 m wide). Each treatment plot was about 0.03 ha. These repeat plots were randomly arranged, adjacent plots were separated by a row of unplanted ground (5 m wide). This study included three control measures, *i.e.* trap crop plus biological control management system, chemical control and natural control. The experiment was replicated three times; one replicate in each experimental field.

In trap crop plus biological control management system, a row of *C. esculenta* was planted for 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, these dults laid eggs on tobacco in the tobacco fields in South China. In this study, the larvae of 2nd generation *S. litura* were managed by SlNPV in order to avoid the loss yield of tobacco. When the larvae of 2nd generation *S. litura* were at second instars stage on 6 May 2006, the 4.0×10^{10} PIB/ha solution of SlNPV was sprayed for suppressing 2nd generation of *S. litura*. *C. esculenta* has been at the fast-growing stage and it hosted large numbers of *S. litura* when the adults of 2nd generation *S. litura* emerged from pupae in the tobaaco fields, thus any other control methods were not carried out in late stages.

In chemical control, tobacco was only planted. The 450 g/ha solutions of 50 % methamidophos (a synthetic insecticide) were sprayed at the 2nd instar stages of 1st, 2nd and 3rd generations of *S. litura* larvae on 20 April, 6 May and 30 May in 2006, respectively. Then any other measures were not used.

In natural control, tobacco was only planted. Any factitious measures were all avoided, and suppression of *S. litura* resulted from natural factors.

Data collection

Investigations were conducted from 26 April to 16 June in 2006 at the experimental farm of Nanxiong Research Institute of Tobacco. In tobacco, the life cycle of *S. litura* was divided into six stages: 1st instar larvae, 2nd-3rd instar larvae, 4th-5th instar larvae, 6th-7th instar larvae, pupae and adults. Approximately 9 weeks after planting tobacco, when the adults of the first generation of *S. litura* were at outbreak stages, visual sampling was begun and continued every three days. 180 plants of tobacco were surveyed by checkerboard sample in each plot at each survey stage. The egg masses that were found in tobacco in different plots at each survey stage were marked, one day after marking, the marked egg masses were observed hourly in the daytime (from 7:30 to 18:30). The number of newly-hatched larvae was recorded. The number of eggs in each plot at each survey stage could be calculated by integrating the number of 1st instar larvae with the hatching ratio of eggs. The number of larvae was directly recorded according to the findings of investigation in each plot. The pupae located in 50 cm extent nearby a sampling plant were collected and taken to the laboratory. The pupae were raised in 12 cm diameter glass incubators containing 11 % moisture content of silver sand in laboratory, and the number of pupae was recorded in each plot at each survey stage. The number of adults were recorded when the adults emerged from the pupae that were collected in different plots.

In addition, thirty egg masses, eighty larvae per instar and sixty pupae were randomly collected in each plot at each survey stage, and then they were raised in laboratory. The mortalities of different developmental stages of *S. litura* were recorded and their mortal factors described daily. When the adults emerged from pupae (these pupae were all collected in the tobacco fields), virgin female and virgin male were matched and put into a cage with a plant of tobacco. Then the cages with adults were place in the tobacco fields. 20 pairs of mating adults were observed and the number of eggs laid per female was recorded daily. Finally, the average number of eggs laid per female was calculated.

Statistical analyses

According to the principle of natural population life table suggested by Pang (2001), the parameters of life table were calculated by the following three formulae.

$N_{im}=(N_{is}\times D) / T_i$, where *Nim* is the mid-value of the number of *S. litura* which belongs to stage *i*, N_{is} is a cumulative amount of *S. litura* which belongs to stage *i* in different survey dates, *D* is a interval from the current survey date to the next survey date (*i.e.* *D*=2 in this study) and T_i is longevity of *S. litura* which belongs to stage *i*.

$N_{ib}=T_{(i\text{-}1)} \times N_{im}+T_i\times N_{(i\text{-}1)m} / T_i+T_{i\text{-}1}$, where N_{ib} is the original number of *S. litura* which belongs to stage *i*, $N_{(i\text{-}1)m}$ is the mid-value of the number of *S. litura* which belongs to stage *i*-1 and $T_{i\text{-}1}$is longevity of *S. litura* which belongs to stage *i*-1.

$S_i=N_{(i+1)\text{b}} / \text{N}_{\text{ib}}$, where S_i is survival rate of *S. litura* which belongs to stage *i* and $N_{(i+1)\text{b}}$ is the original number of *S. litura* which belongs to stage *i*+1.

The effects of control methods and mortality factors on *S. litura* were estimated by the index of population trend (*I*) and the exclusion index of population control (*EIPC*), respectively. An effective control method maintained an index of population trend of a target insect pest of less than 1 (Pang, 2001), thus the more *I* was small, the more the control method was effective. *EIPC* directly revealed that the effects of mortality factors on *S. litura*, the more *EIPC* was high, the more the effect of the mortality factor on target insect pest was significant. Hence *EIPC* could be used for evaluating the important mortality factors of a target insect pest in the fields (Pang, 2001). The two indices were calculated by the following two formulae.

$I=N_1 / N_0=S_1S_2S_3\ldots S_i\ldots S_kFP_FP_♀$, where *I* is the index of population trend, N_0 and N_1 are the populations of current and next generation of *S. litura*, respectively, *F* is the standard number of eggs laid per female, P_F is the fraction of individuals belonging to normal females (*i.e*. the females which attained the standard number of eggs laid) in total females, and $P_♀$ is the fraction of individuals belonging to females in total adults.

$EIPC=I_E / I=1/S_E$, where *EIPC* is the exclusion index of population control and S_E is survival ratio of stage *E*. When *n* factors are excluded, this formula is expressed as $EIPC\ (S_1, S_2, S_3\ldots S_n)=1/\ (S_1)\ (S_2)\ (S_3)\ldots(S_n)$.

The data of this experiment were checked for normality and homoscedasticity as appropriate and, if needed, were log- transformed. One-way ANOVA was conducted in comparing the overall differences of the index of population trend (*I*) and the exclusion index of population control (*EIPC*) between treatments when significant treatment differences were indicated by a significant *F*-test at $P\leq0.05$ (SAS Institute Inc., 2004), and Fisher's protected LSD test was used in comparing the means between treatments.

RESULTS

Life tables of natural population of S. litura

The suppression of the 2nd generation *S. litura* mainly depended on SINPV and other natural enemies in trap crop plus biological control management system, natural factors in natural control and methamidophos in chemical control. As SINPV was a biological agent and it could not immediately kill *S. litura* larvae, SINPV mainly resulted in the death of 4th-5th instar larvae when it was sprayed at 2nd larval instars stage in trap crop plus biological control management system. Thus survival rate of 2nd instar larvae of 2nd generation *S. litura* was only 0.1902 in trap crop plus biological control management system. Methamidophos suppressed most of 2nd-3rd instar larvae and a few 4th-5th instar larvae, the survival rates of larvae of the two stages with the suppression of this pesticide were 0.3472 and 0.5306 in chemical control, respectively (Table I).

Colocasia esculenta hosted large numbers of the adults of 2nd generation *S. litura* and provided adult females for an optimal oviposition site, hence the number of egg masses on tobacco was

Table I.- Life tables of natural population of 2nd generation of *S. litura* under three control measures in the tobacco fields (Mean±SE).

Stages	Survival rates of each stage of *S. litura*			Factors	Survival rates of each factor of *S. litura*		
	Trap crop plus biological control	Chemical control	Natural control		Trap crop plus biological control	Chemical control	Natural control
Eggs	0.64±0.03	0.86±0.06	0.75±0.01	Not hatch	0.97±0.001	0.95±0.00	0.96±0.003
				Parasitoids	0.97±0.003	0.98±0.003	0.98±0.003
				Predators and others	0.67±0.02	0.91±0.06	0.79±0.009
1st instar larvae	0.59±0.02	0.69±0.04	0.63±0.01	Predators and others	0.59±0.01	0.69±0.042	0.63±0.014
2nd-3rd instar larvae	0.37±0.03	0.34±0.03	0.39±0.01	SlNPV	0.67±0.01	1.00±0.00	1.00±0.00
				Methamidophos	1.00±0.00	0.34±0.025	1.00±0.00
				M. prodeniae	0.84±0.001	0.98±0.007	0.87±0.007
				C. chlorideae	0.92±0.004	0.98±0.007	0.92±0.007
				Predators and others	0.70±0.02	0.99±0.004	0.49±0.012
4th -5th instar larvae	0.19±0.03	0.29±0.03	0.51±0.02	SlNPV	0.19±0.01	1.00±0.00	1.00±0.00
				Methamidophos	1.00±0.00	0.53±0.014	1.00±0.00
				Beauveria bassiana	0.98±0.01	0.93±0.008	0.89±0.01
				Predators and others	0.98±0.01	0.59±0.04	0.58±0.01
6th th instar larvae	0.42±0.05	0.44±0.001	0.42±0.02	SlNPV	0.74±0.01	1.00±0.00	1.00±0.00
				Methamidophos	1.00±0.00	0.93±0.01	1.00±0.00
				Predators and others	0.55±0.05	0.48±0.006	0.42±0.02
Pupae	0.49±0.07	0.61±0.02	0.63±0.01	Diseases	0.72±0.013	0.91±0.01	0.90±0.001
				Not eclosion	0.84±0.006	0.94±0.016	0.91±0.001
				V. leucaniae	0.94±0.006	1.00±0.00	1.00±0.00
				Others	0.86±0.08	0.70±0.02	0.76±0.003
Adults	0.82±0.0091	0.94±0.01	0.88±0.01	Abnormal eclosion	0.82±0.006	0.94±0.01	0.89±0.01
				Number of eggs	432.40	432.40	432.40
				Ratio of female	0.483	0.483	0.4833
Index of population trend					0.93±0.14	3.14±0.53	4.70±0.23

significantly lower in trap crop plus biological control management system than in natural or chemical control. The survival rate of 3rd generation *S. litura* eggs with the attracting of *C. esculenta* was 0.39 (Table II).

Control methods significantly affected the indices of population trend (*I*) of *S. litura* ($F_{2,6}$=181.74, P<0.0001 for 2nd generation ; $F_{2,6}$=397.26, P<0.0001 for 3rd generation). The *I*-values of 2nd or 3rd generation of *S. litura* were far lower in trap crop plus biological control management system than in natural or chemical control, which revealed the trap crop plus biological control management system gave more effective control of *S. litura* than did the other two measures (Table III). In addition, the difference in *I*- values was found to be significant between 2nd generation and 3rd generation *S. litura* in three control measures ($F_{1,4}$=12.71, P=0.0235 in trap crop plus biological control; $F_{1,4}$=22.65, P=0.0089 in chemical control; $F_{1,4}$=345.35, P<0.0001 in natural control). The *I*- value of 3rd generation *S. litura* were lower than that of 2nd generation *S. litura* in three control measures, which revealed that the three control measures more effectively suppressed 3rd generation than 2nd generation in the tobacco fields (Table III).

Analysis of important mortality factors for S. litura

The exclusive indices of population control *(EIPC)* of "not hatch", "parasitoids" and "predators and others" to eggs of 2nd or 3rd generation *S. litura* were very low in three control treatments, which meant the effects of these mortality factors on

Table II.- Life tables of natural population of 3rd generation of *S. litura* under three control measures in the tobacco fields (mean±SE).

Stages	Survival rates of each stage of *S. litura*			Factors	Survival rates of each factor of *S. litura*		
	Trap crop plus biological control	Chemical control	Natural control		Trap crop plus biological control	Chemical control	Natural control
Eggs	0.21±0.01	0.82±0.03	0.61±0.02	*C. esculenta*	0.39±0.01	1.00±0.00	1.00±0.00
				Not hatch	0.98±0.00	0.97±0.002	0.96±0.00
				Parasitoids	0.96±0.0	0.98±0.004	0.97±0.005
				Predators and others	0.56±0.01	0.86±0.035	0.65±0.02
1st instar larvae	0.43±0.01	0.66±0.01	0.50±0.01	Predators and others	0.43±0.006	0.66±0.01	0.50±0.01
2nd-3rd instar larvae	0.43±0.005	0.32±0.0	0.33±0.003	Methamidophos	1.00±0.00	0.36±0.01	1.00±0.00
				M.s prodeniae	0.58±0.004	0.98±0.01	0.58±0.01
				C. chlorideae	0.74±0.01	0.99±0.01	0.76±0.01
				Predators and others	0.991±0.00	0.90±0.029	0.76±0.01
4th-5th instar larvae	0.56±0.01	0.21±0.0	0.45±0.01	Methamidophos	1.00±0.00	0.71±0.006	1.00±0.00
				Nuclear polyhedrosis virus	0.90±0.01	0.93±0.016	0.90±0.01
				Beauveria bassiana	0.92±0.01	0.89±0.01	0.77±0.01
				Predators and others	0.67±0.02	0.36±0.03	0.66±0.03
				Nuclear polyhedrosis virus	0.61±0.01	0.83±0.01	0.67±0.01
				Beauveria bassiana	0.96±0.01	0.97±0.01	0.93±0.02
				Predators and others	0.53±0.02	0.61±0.036	0.60±0.04
Pupae	0.54±0.05	0.60±0.02	0.67±0.04	Diseases	0.73±0.01	0.92±0.01	0.80±0.01
				Not eclosion	0.89±0.01	0.90±0.02	0.95±0.01
				V. leucaniae	0.85±0.03	1.00±0.00	1.00±0.00
				Others	0.97±0.02	0.72±0.03	0.89±0.07
Adults	0.87±0.02	0.90±0.01	0.95±0.02	Abnormal eclosion	0.87±0.01	0.90±0.01	0.95±0.02
				Number of eggs (FP_F)	470.05	470.05	470.05
				Ratio of female	0.49	0.492	0.49
Index of population trend					0.72±0.04	2.08±0.13	2.57±0.15

Table III.- Comparison of indices of population trend of *S. litura* under three control measures in the tobacco fields (mean±SE).

Generations	Indices of population trend (*I*)		
	Trap crop plus biological control	Chemical control	Natural control
2nd generation	0.93±0.14 c (a)	3.14±0.53 b (a)	4.69±0.23 a (a)
3rd generation	0.71±0.03 c (b)	2.08±0.13 b (b)	2.56±0.15 a (b)

Note: The same letters out of bracket show the difference is not significant among different means on the same row, the same letters in bracket show the difference is not significant among different means on the same column (Comparing the means between treatments, $P \leq 0.05$ level, was used by one-way ANOVA: Fisher's protected LSD test).

eggs were not significant in the tobacco fields (Table IV and Table V). Although biological agent, SlNPV was sprayed on 2nd larval instars, it mainly resulted in the mortality of 4th-5th larval instars in trap crop plus biological control management system (Table IV). The *EIPC*-value of methamidophos to 2nd-3rd larval instars of *S. litura* was the highest in chemical control (Tables IV, V).

We found that the *EIPC*-values of *C. aesculenta* to eggs of 3rd generation was 2.57, which revealed *C. aesculenta* hosted large numbers of adults of 2nd generation resulted in the number of eggs laid on tobacco was significantly decreased in trap crop plus biological control management system. In addition, natural enemies (*e.g.* parasitoids) impact on the 3rd generation of *S. litura* was significantly better in trap crop plus biological control management system compared with in chemical or natural control (Table VI). The difference in the *EIPC*-values of “parasitoids”, “pathogens” and “physiological factors” to 2nd or 3rd generation of *S. litura* were significant among three control measures (Parasitoids: $F_{2,6}$=885.36, P<0.0001 in 2nd generation and $F_{2,6}$=889.90, P<0.0001 in 3rd generation; Pathogens: $F_{2,6}$=43.30, P=0.0003 in 2nd generation and $F_{2,6}$=620.05, P<0.0001 in 3rd generation; Physiological factors: $F_{2,6}$=286.18, P<0.0001 in 2nd generation and $F_{2,6}$=83.71, P<0.0001 in 3rd generation). The *EIPC*-values of “predators and others” to 2nd generation *S. litura* made a difference ($F_{2,6}$=141.62, P<0.0001), but to 3rd generation made no difference ($F_{2,6}$=2.74, P=0.1431) in three control measures. The total mortality factors significantly suppressed the populations of *S. litura* in three control measures, and the *EIPC*-values of total mortality factors to *S. litura* in three control measures also made a significant difference ($F_{2,6}$=121.90, P<0.0001 in 2nd generation and $F_{2,6}$=921.60, P<0.0001 in 3rd generation).

In the tobacco fields, predators included spiders, insect predators, frogs, toads and birds. Parasitoids emerfing from *S. litura* caterpillars and eggs were identified as being the larval parasitoids, *Microplitis prodeniae* (Viereck) (Hymenoptera: Braconidae) and *Campoletis chlorideae* Uchida (Hymenoptera: Ichneumonidae) and the egg parasitoid, *Trichogramma* sp. (Hymenoptera: Trichogrammatidae). In addition, we could identify pathogens of *S. litura*, such as the entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin. Aditional mortality factors included bacteria, and other undetermined physiological factors characterized as “not hatch” at the egg stage, “not eclosion” at the pupal stage and “abnormal eclosion” at the adult stage. The results of this study revealed that the important factors for managing 2nd generation of *S. litura* were predators both in natural and chemical control measures, but was SlNPV in trap crop plus biological control management system. The *EIPC*-value of methamidophos to 2nd generation of *S. litura* was 5.8562 in chemical control, and that of SlNPV was 10.1413 in trap crop plus biological control management system, which meant SlNPV suppressed more 2nd generation of *S. litura* than did methamidophos. The important factors for control of 3rd generation of *S. litura* under three control measures was the predator community in the tobacco fields. The *EIPC*-values of the parasitoids and predators were higher in trap crop plus biological control management system than in chemical or natural control (Table VI).

The effects of the parasitoids on S. litura

The parasitism of *S. litura* larvae by *M. prodeniae* and *C. chlorideae* was higher in trap crop plus biological control management system than in chemical or natural control with the exception of parasitism of *C. chlorideae* on 30 April and 24 May, 2006 (Fig. 1). In our investigation, *M. prodeniae* was also found to parasitize the larvae of *Theretra pinastrina* Martyn (Lepidoptera: Sphingidae), a lepidopterous pest on *C. esculenta* in trap crop plus biological control management system (Fig. 2). *M. prodeniae* continually alterned between *S. litura* and *T. pinastrina*, suggesting that trap crops, by maintaining other potential caterpillar hosts, can serve as facilitator for increasing population densities of natural enemies of pests. In addition, *Vulgichneumon leucaniae* (Uchida) (Hymenoptera: Ichneumonidae) was found to parasitize *S. litura* pupae, and the highest parasitism was 21.43 % in trap crop plus biological control management system (Fig. 2).

Population dynamics of predators

Pirata subpiraticus (Boes. et Str.) (Araneae: Lycosidae), *Ummeliata insecticeps* Boes. et Str. (Araneae: Erigonidae), *Erigonidium graminicolum* (Sundevall) (Araneae: Erigonidae), *Oxyopes sertatus* L. Koch (Araneae: Oxyopidae), *Coleosoma octomaculatum* (Boes. et Str.) (Araneae: Tetragnathidae), *Harpactor fuscipes* (F.) (Hemiptera: Reduviidae) and *Paederus fuscipes* Curtis (Coleoptera: Staphylinidae) were several additional important predators in the tobacco fields. These predators maintained a higher population density in trap crop plus biological control management system and natural control compared with in chemical control (Fig. 3). Particulalrly, the population of *U. insecticeps* was larger in trap crop plus biological control management system than in natural control, except on 4 and 10 May, 2006. *E. graminicolum* revealed a larger population density in trap crop plus biological control management system compared with in natural control during our investigations.

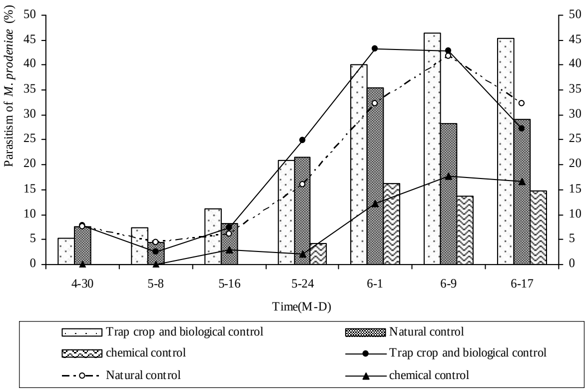

Fig. 1. Parasitism of *Microplitis prodeniae* (bar) and *Campoletis chlorideae* (line) on *S. litura* larvae under three control measures in the tobacco fields.

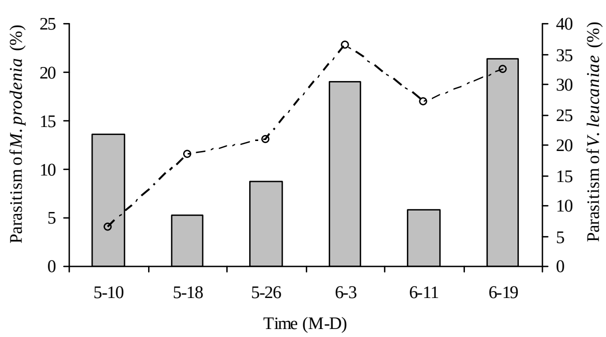

Fig. 2. Parasitism of *Microplitis prodeniae* on *Theretra pinastrina* larvae (line) and *Vulgichneumon leucaniae* on *S. litura* pupae (bar) in trap crop plus biological control management system in the tobacco fields.

DISCUSSION

In this study, life table analyses revealed that the index of population trend of 2nd or 3rd generation of *S. litura* was lower in chemical control than in natural control, but both control practices produced lower population indices than the combined trap crop plus virus application control management. Additionally, the combined trap crop plus biological control enhanced populations of natural enemies of the pest in tobacco fields.

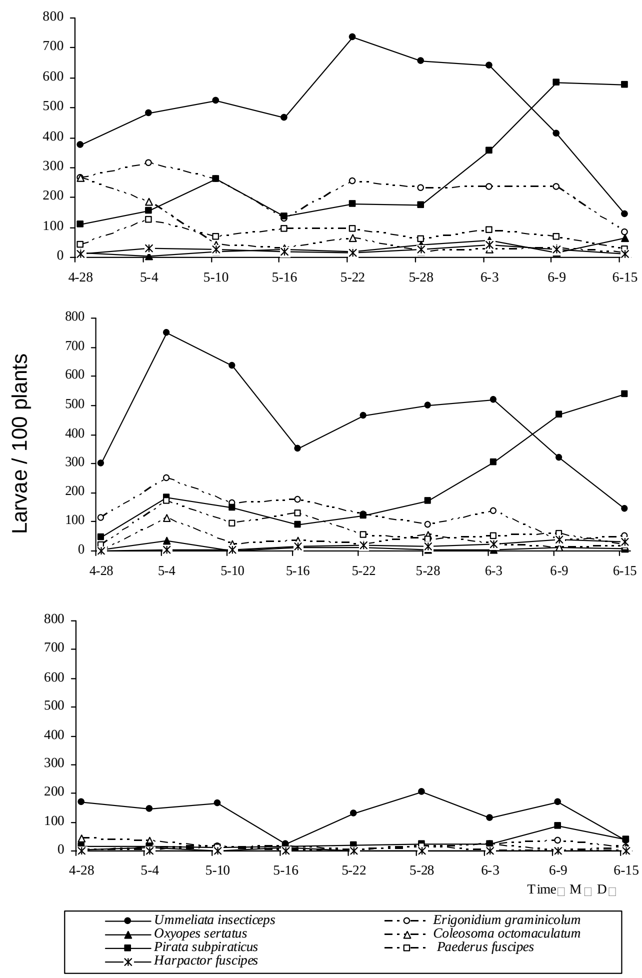

Fig. 3. Population dynamics of several major predators under three control measures in the tobacco fields. a is trap crop plus biological control, b is natural control, c is chemical control

Life table analysis was originally applied in demography. Ecologists had begun to try to study the experimental population dynamics of *Drosophila* by life table in laboratory in the 1920's (Pearl and Parker, 1922). Morris and Miller (1954) first applied life tables to study the natural population dynamics of *Choristoneura fumiferana*

(Clem) (Lepidoptera: Tortricidae) in the fields. Pang (1979, 1990), Pang *et al.* (1981, 1984, 1995) and Pang and Liang (1982) ameliorated the research methods of life table, and suggested the life table should be assembled from different functional factors. In addition, Pang and his colleagues proposed several relevant analytical methods (*e.g.* analysis of important factors, analysis of exclusive index of population control and analysis of key factors) in order to adapt life table to the requirements of studies of pest population system. Life table analysis has been widely applied to evaluate the control effectiveness of agricultural insect pests with different control measures (Pang and Liang, 1995; Pang, 2001).

Pang (2001) suggested that an index of population trend of an insect pest of less than 1 indicated that the control method is effective. The results of this study indicated that chemical control was not a feasible control method because the indices of population trend of 2nd and 3rd generations of *S. litura* were 2.0841 and 2.567 respectively. In addition, methamidophos addition resulted in very low natural enemy species and populations, and resulted in the effects of natural enemy factors on *S. litura* decreasing significantly in chemical control.

Trap crops could be used to attract, intercept and retain insect pests, and subsequently reduce damage of insect pests to the main crops (Hokkanen, 1991). Now, trap crops have attracted more interest from entomologists in pest management. The results of our study showed that the indices of population trend of 2nd and 3rd generations of *S. litura* were far lower in trap crop plus biological control management system than in natural or chemical control, which indicated the trap crop plus biological control management system suppressed more *S. litura* than natural control or chemical control measure did. In addition, the parasitoids and predators resulted in the suppression of *S. litura* population were more significant in trap crop plus biological control management system than in chemical or natural control. Particularly, the parasitoid wasp *M. prodeniae* parasitized not only *S. litura* larvae, but also *T. pinastrina* larvae on *C. esculenta* in trap crop plus biological control management system. *M. prodeniae* maintained a high population density because a possible alternation between *S. litura* and *T. pinastrina* in trap crop plus biological control management system. Our investigation also revealed that the parasitoid *V. leucaniae* parasitized *S. litura* pupae in trap crop plus biological control management system, but this parasitoid was not found in chemical or natural control.

Trap crop plants, generally more attractive than the main crops, will recruit more insect pests. Then, because insect pests are temporarily retained in the trap crop areas, they can be destroyed with the help of insecticides or by natural enemies of the herbivore, including parasitoids, predators and pathogens (Hokkanen, 1991; Barari *et al.*, 2005). The trap crop strategies would, not only reduce the use of insecticides, but also, give effective control of the insect pests and increase the number of natural enemy species (Williams, 2004). For example, many studies showed that the abundance of natural enemies increased when trap crops were intercropped with main economic crops or planted in circumambience of crop fields (Hokkanen, 1991; Naito, 1996; Åsman, 2002; Shelton *et al.*, 2008, Andow, 1991; Khan *et al.*, 1997). For instance, Pu (1978) found that parasitism on sugarcane pests increased in fields intercropped with green manure, and suggested that green manure provides a good refuge as well as a food resource for parasitoids. Similarly, Norris and Kogan (2000) investigated interactions between weeds and arthropods, which revealed the physical habitat might be ameliorated by the presence of weeds, and the weeds provided beneficial arthropods for a shelter. All this indicating that trap crops could be considered as a breeding garden of natural enemies. Also interesting is that SlNPV did not affect the diversity and abundance of natural enemies. This is in accordance with studies showing that biological control of *S. litura* with SlNPV is safe to natural enemies (Monobrullah and Nagata, 2001). (Maeda *et al.*, 1990; Monobrullah and Nagata, 2000, 2001; Zhang *et al.*, 2002).

Our findings suggest that SINVP, combined with trap crop plants in tobacco fields is an excellent, environmental friendly, candidate control management to be implemented in IPM practices for tobacco growers.

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