The Great Lakes Entomologist

Volume 38
Numbers 3 & 4 - Fall/Winter 2005 *Numbers 3 & 4 - Fall/Winter 2005*

Article 5

October 2005

Evaluation of Lucerne Cover Crop for Improving Biological Control of *Lyonetia Clerkella* (Lepidoptera: Lyonetiidae) by Means of Augmenting Its Predators in Peach Orchards

Jie Dong
Beijing Plant Protection Station

Xiaoyun Wu
China Agricultural University

Changxin Xu
China Agricultural University

Qingwen Zhang
China Agricultural University

Xiaohua Jin
Beijing Plant Protection Station

See next page for additional authors

EVALUATION OF LUCERNE COVER CROP FOR IMPROVING BIOLOGICAL CONTROL OF *LYONETIA CLERKELLA* (LEPIDOPTERA: LYONETIIDAE) BY MEANS OF AUGMENTING ITS PREDATORS IN PEACH ORCHARDS

Jie Dong[1,2], Xiaoyun Wu[1], Changxin Xu[1], Qingwen Zhang[1]*, Xiaohua Jin[2], Jianyun Ding[2], Sufeng Liu[3], Yongxiang Wang[3]

ABSTRACT

The impact of cover crop manipulation on reducing reliance upon insecticides to control *Lyonetia clerkella* (L.) (Lepidoptera: Lyonetiidae), a major insect pest on peach trees, was assessed in two-year field experiments in China. Studies were conducted in three peach orchards, each with four treatments. The treatments were lucerne cover crop (L), lucerne cover crop plus limited applications of chlorbenzuron on the trees (L+L), natural ground vegetation (NG), and natural ground vegetation plus conventional applications of chlorbenzuron (NG+C). Densities of *L. clerkella* and predators were assessed for all treatments. *L. clerkella* densities were significantly lower in the two insecticide treatments (L+L, NG+C) than densities in the two treatments without insecticide applied (L, NG) in both 2003 and 2004. Densities of *L. clerkella* in the L+L treatment were significantly lower than densities in the NG+C treatment. Annual abundance of *L. clerkella* was also significantly lower in the L treatment than in the NG treatment, indicating that Lucerne ground cover led to reduced *L. clerkella* abundance. Predator densities in both the ground vegetation and tree canopy were significantly higher in the two lucerne-sown treatments (L, L+L) than in the two natural ground vegetation treatments (NG, NG+C). We conclude that decreased *L. clerkella* abundance in the lucerne-sown treatments was mainly due to an increase in predator densities. Spiders were the dominant predators and Thomisidae (hunting spiders) was the most important family. The results indicate that maintaining lucerne ground cover can attract and propagate beneficial arthropods, which in turn may lead to decreased reliance on insecticides.

Peach production in China has risen rapidly in recent years; however, yields are influenced by insect pests, with the peach leafminer, *Lyonetia clerkella* (L.) (Lepidoptera: Lyonetiidae), being one of the major insect pests in commercial peach orchards. *L. clerkella* is a multivoltine species that has three stadia. Females insert single eggs into leaves. After hatching, larvae penetrate into the mesophyll and form spiral mines in the upper half of the leaves; thereafter, they form serpentine and/or linear mines as they grow. Mature third instars leave their mines and pupate in silken cocoons under the leaves or on the trunks (Adachi 2002). The leafminer has 6 generations per year in Beijing. The pest is particularly destructive and has the potential to destroy entire leaves and cause heavy defoliation prior to harvest if not controlled (Wang et al. 1999, Yang et al. 2000).

In commercial peach orchards in China, the common strategy for controlling *L. clerkella* is to spray insecticides after eggs hatch. However, it is difficult to time sprays accurately because *L. clerkella* generations overlap extensively.

[1] Department of Entomology, College of Agronomy and Biotechnology, China Agricultural University. Beijing 100094 China.
[2] Beijing Plant Protection Station. Beijing 100029 China.
[3] Pinggu Plant Protection Station. Pinggu, Beijing 101200 China.
*Correspondence author. (email: zhangqingwen@263.net).

Moreover, intensive spraying of insecticides is not economically viable and may lead to the development of resistance. Therefore, improved control strategies are being sought, including cover crop manipulation.

Cover crop manipulation is one tactic of integrated pest management (IPM) practices used to enhance beneficial arthropod numbers in agroecosystems (Ali and Reagan 1985, Altieri and Schmidt 1985, Nentwig 1988, House and Alzugaray 1989, Bugg and Waddington 1994). This method, which includes temporary ground cover planting and mixed hedgerow planting, emphasizes use of plant species likely to be used as reservoirs of predators and parasitoids. Cover crops tend to preserve or increase plant diversity and favor natural antagonists of pests, thus, it is a method of biological control (Altieri and Letourneau 1982).

Ground cover crops in orchards have proved useful in enriching natural enemies of insect pests, as shown in a number of studies (Muma 1961; Stern et al. 1969; Koptur 1979; Altieri and Letourneau 1982; Banerjee 1983; Fye 1983; Altieri and Schmidt 1985, 1986; Andow et al. 1986; Rusell 1989; Bugg and Dutcher 1989; Bugg et al. 1989; Bugg and Ellis 1990; Tao and Luo 1992; Haley and Hogue 1990; Wyss 1996; Du and Yan 1998; Rieux et al. 1999). Many studies have indicated that orchards with rich floral vegetation exhibit a significantly lower incidence of insect pests than clean cultivated orchards, mainly because of an increased abundance of predators and parasitoids (Leius 1967, Haynes 1980, Liang and Huang 1994, Wyss 1995, Wyss et al. 1995). Thus, cover crops possibly could enhance *L. clerkella* management in peach orchards.

Lucerne (*Medicago sativa* L.) has been suggested as an ideal refuge habitat in IPM programs because it harbors high numbers of beneficial arthropods (Pearce and Zalucki 2005). The role of lucerne in managing insect pests in cotton fields (Mensah 1997, 1999, 2002a, b; Zhang et al. 2000; Lin et al. 2003) and apple orchards (Shi 1988, Yan et al. 1997, Yu and Yan 1998) has been investigated. However, the effects of lucerne on *L. clerkella* and its predators in peach orchards have not been studied.

The objectives of this study were (1) to investigate whether lucerne cover enhances populations of beneficial predators, leading to reduced *L. clerkella* density; and (2) to assess whether cover crops can allow reduced reliance upon insecticides for *L. clerkella* control.

MATERIALS AND METHODS

Study orchards. Experiments were conducted in three peach orchards at Pinggu (117°06'E; 40°09'N), Beijing, China in both 2003 and 2004. The three orchards, owned by cooperating growers, are located at similar altitudes and have similar environmental characteristics. One or two sides of each orchard bordered crop fields; otherwise they were surrounded by other peach orchards. Factors such as slope and soil condition were homogenous over the three orchards. The orchards were all approximately 1 ha in size, and were located within 2 km of one another. The predominant peach variety in the orchards was Dajiubao. Trees were 5-6 years old and 2.5-3 m in height with a spacing of 3 – 5 m between trees. The three orchards were treated similarly with a conventional pest management program before 2003. The conventionall program included three to four aphid (Hemiptera: Aphididae) cover sprays, six to eight summer fruit tortrix moth, *Adoxophyes orana* F.R. and *Pandemis heparana* Schiff (Lepidoptera: Tortricidae), cover sprays, and seven to ten leafminer, *L. clerkella,* cover sprays per season in addition to sprays for secondary pests (e.g., mites, scale insects).

Treatments. Each orchard was divided into four discrete experimental plots, corresponding to the four treatments: lucerne cover crop (designated L), lucerne cover crop plus limited applications of chlorbenzuron on the trees (designated L+L), natural ground vegetation (designated NG), and natural ground vegetation plus conventional applications of chlorbenzuron (designated NG+C). Treatments were randomly assigned to plots. The plots were parallel to each other and were separated by 10-m wide strips of bare ground. Each plot consisted of approximately 130 trees. Lucerne seeds were sown between rows in May 2002. In the natural ground vegetation plots, *Hemistepta lyrata* Bunge, *Amaranthus retroflexus* L., *Setaria viridis* (L.) Beauv., *Digitaria sanguinalis* (L.) Scop. and *Humulus scandens* (Lour.) Merr. were the dominant grass species and ground vegetation. Nomenclature for all plant species follows Li (1988). The vegetation in all plots was mowed twice a year. No insecticide was applied in L and NG during the experiment period. The other two treatments received limited (L+L) or conventional (NG+C) applications of chlorbenzuron (Ejuemie, 25% chlorbenzuron, Huizhou Zhongxun Chemical Co. Ltd., Guangdong, China) sprayed at a label rate of 0.8 - 1.0 L/ha to control *L. clerkella* (Table 1). Moreover, in the two years, L+L and NG+C received three applications of imidacloprid (Pushiya, 10% imidacloprid, Jingpeng Biological Pharmaceutical Co. Ltd., Shandong, China) sprayed at a label rate of 0.2 - 0.3 kg/ha to control aphids and seven applications of chlorpyrifos (Gaoti, 40% chlorpyrifos, Huizhou Zhongxun Chemical Co. Ltd., Guangdong, China) sprayed at a label rate of 1.3 - 1.6 L/ha to control summer fruit tortrix moths. All three orchards received conventional fungicide sprays during the experiments including Jide (45% lime sulfur, Shuangji Chemical Co. Ltd., Hebei, China) sprayed at a label rate of 6 kg/ha once a year before sprouting, Bideli (80% Mancozeb, Shuangji Chemical Co. Ltd., Hebei, China) sprayed at a label rate of 6 kg/ha two to three times a year, and Junlimie (1.5% Benziothiazolinone, Xidahuate Technology Co. Ltd., Shanxi, China) sprayed at a label rate of 0.1 L/ha two to three times a year.

Sampling. Adults of *L. clerkella* were monitored using synthetic sex pheromone. The pheromone lures consisted of the synthetic sex pheromone 14-methyl-1-octadecane impregnated into a rubber septum and were supplied by the Institute of Zoology, Chinese Academy of Science Plastic basins (24 cm in diameter and 16 cm in height) were used as water traps. Water containing washing powder, to reduce surface tension, was placed in each basin trap to a depth of 8 cm and the pheromone lure was suspended 1 cm above the water surface. Five basin traps were deployed in each plot and each trap was set up at mid-canopy height. Traps were checked twice per week from 12 March to 29 October in 2003 and 2004. *L. clerkella* captured in traps were counted and removed following each observational period. We replaced pheromone lures every month, and added water to the traps frequently.

Predators in the ground vegetation were sampled with a sweep net (34 cm in diameter). Thirty 180°sweeps were taken per sample while walking a circuitous route through plots. Net contents were transferred to glass bottles and stored in 70% ethanol. Specimens were identified and counted in the laboratory. Samples were collected twice per month from 19 March to 25 October in 2004.

Predators in the trees were sampled by beating net and visual observations. A conical 60 mesh net (56 cm in diameter and 50 cm in height) was used for sampling. Thirty trees were chosen randomly in each plot, and on each tree five limbs (1-2 m above ground) were chosen at random from the eastern, western, northern, southern and middle parts. The net was held beneath the limb, and the limb was struck sharply three times with a stick. Dislodged leafminers and predators were transferred to glass bottles and preserved in 70% ethanol. Different trees were sampled on each sample date. Samples were collected twice per month from 14 March to 24 October in 2004. Visual observations were also made on thirty randomly selected trees in each plot twice per month from 10 March to 23 October in 2004. Tree canopies were divided into eastern, western, northern, southern and middle portions, and each portion was divided into upper, middle and lower positions. On each sampling day, one limb was sampled at random from each portion and position. Leafminers and predators were recorded in absolute numbers per tree, and identified to family, genus or species (as far as possible).

Table 1. Insecticide sprays for control of *L. clerkella* in pesticide-treated plots in 2003 and 2004.

Year	Insecticide	Dose (L /ha)	Spray date L+L	Spray date NG+C
2003	25% Chlorbenzuron1	0.8	15 May	15 May
		1	7 June	5 June
		1	15 August	2 July
		1	15 September	3 August
		1		15 August
		1		5 September
		1		16 September
		1		28 September
2004	25% Chlorbenzuron	0.8	13 May	13 May
		1	8 June	8 June
		1	4 July	3 July
		1	10 September	16 July
		1		5 August
		1		22 August
		1		10 September
		1		24 September

[1] Chlorbenzuron (Ejuemie, 25% chlorbenzuron, Huizhou Zhongxun Chemical Co. Ltd., Guangdong, China) was sprayed at a label rate of 0.8 - 1.0 L/ha.

Identification. The predators of *L. clerkella* in peach orchards include primarily green lacewings and spiders (Wang et al. 1999). In this study, green lacewing adults were identified to species; larvae and eggs were categorized only to the family Chrysopidae. The majority of spiders (93%, n=7693) were identified to family, although some common spiders were identified to species (e. g., *Misumenops tricuspidatus* (Fabricius), *Xysticus ephippiatus* Simon, *Erigonidium graminicolum* (Sundevall), and *Araneus cornutus* (Clerck). Other species, belonging to well-characterized taxa that had very similar biologies, were identified to genus (e.g., *Tetragnatha*, *Pardosa*, *Philodromus* and *Plexippus*).

Prey capture strategies in spiders are diverse (Nyffeler et al. 1994) and previous studies have noted differences in spider fauna in sprayed and unsprayed orchards based on prey capture strategy (Specht and Dondale 1960; Mansour et al. 1980; Bostanian et al. 1984; Wisniewska and Prokopy 1997). For some analyses of beating net, visual observation and sweep net samples in different treatments, we separated spiders into two guilds based upon hunting strategy (Nyffeler and Sunderland 2003): active hunters and web-builders.

Statistical analysis. The univariate ANOVA to assess treatment effects and correlation analysis between *L. clerkella* and its predators were performed using the SPSS statistical package (SPSS 1998). Following a significant ANOVA, treatment means were separated using the LSD test at $P = 0.05$.

RESULTS

Seasonal trends in *L. clerkella* counts. Figure 1 shows both 2003 and 2004 seasonal trap catch and mean annual catch of *L. clerkella* in pheromone-baited water traps in peach orchards treated with lucerne cover crop, lucerne cover crop plus limited applications of chlorbenzuron, natural ground vegetation, and natural ground vegetation plus conventional applications of chlorbenzuron. There were six generations of *L. clerkella*, although patterns in trap catch were different between the two years. The annual catch of *L. clerkella* adults in the two insecticide treatments (L+L, NG+C) was significantly lower than catch in the treatments that had no insecticide applied (L, NG) in both years ($P \leq 0.05$) (Fig. 1). Moreover, the annual catch of *L. clerkella* in the L+L treatment was significantly lower than catch in the NG+C treatment ($P \leq 0.05$), and the mean catch in the L treatment was significantly lower than catch in the NG treatment ($P \leq 0.05$) in both years (Fig. 1).

Data for visual observations and beating net samples are shown in figures 2 and 3. Compared with the NG+C treatment, the L+L treatment also had lower *L. clerkella* abundance. Similarly, *L. clerkella* abundance was significantly lower in the L treatment compared to the NG treatment (Figs. 2 and 3).

Seasonal trends of predator densities. There were large differences among treatments in vegetation predators (Figs. 3 and 4). Predator densities in cover crops in the two lucerne-sown treatments (L, L+L) were very low before July, and increased rapidly and remained at a high level until mid-October (Fig. 4). There was no significant difference in predator numbers ($P \geq 0.05$) between the L and L+L treatments (Fig. 3). In the two natural ground vegetation treatments (NG, NG+C), predator densities were relatively low and did not show distinct peaks throughout the sampling period (Fig. 4). On most sampling days, predator densities in the two lucerne-sown treatments were significantly higher than densities in the two natural ground vegetation treatments ($P \leq 0.05$) (Fig. 4). Annual abundance of predators in the L and L+L treatments were also significantly higher than in the NG and NG+C treatments ($P \leq 0.05$) (Fig. 3).

Data for visual observations and beating net samples are shown in figures 2 and 3. On most sampling days, due to insecticide use for control of aphids and summer fruit tortrix moths, predator densities in the lucerne cover + limited chlorbenzuron (L+L) plots were significantly lower than densities in the insecticide-free lucerne plots (L) ($P \leq 0.05$) (Fig. 2B, D). However, annual abundance in the L+L treatment was still significantly higher in comparison to densities seen in the natural ground vegetation treatment which had no insecticide applications (NG) ($P \leq 0.05$) (Fig. 3). Predator densities in the NG+C treatment were lower than densities in all other treatments (Figs. 2B, 2D, 3).

In 2004, the first predators of *L. clerkella* were recorded in mid-April (Figs. 2B, D). By then, *L. clerkella* adults had been active for three weeks. Maximal abundance of predators corresponded to peak counts of *L. clerkella*. Generally, a strong positive correlation was shown between visual counts of *L. clerkella* and its predators (L, $r = 0.74$, $P \leq 0.05$; L+L, $r = 0.80$, $P \leq 0.001$; NG, $r = 0.70$, $P \leq 0.05$; NG+C, $r = 0.66$, $P \leq 0.05$) and between counts obtained by beating net (L, $r = 0.71$, $P \leq 0.05$; L+L, $r = 0.72$, $P \leq 0.05$; NG, $r = 0.70$, $P \leq 0.05$; NG+C, $r = 0.56$, $P \leq 0.05$) (Fig. 2).

Effects of treatment on the spider fauna. Spiders were the dominant predator taxon in both the ground vegetation (sweep net samples, ≥ 94% of predators) and tree canopy (visual observations, ≥ 90% of predators; beating net samples, ≥ 91% of predators). Three characteristics in annual abundance of spiders were discerned among the four treatments, as shown in figures 5 and 6. First, hunting spiders (Thomisidae, Salticidae, Philodromidae) were dominant in both the cover crop (sweep net samples, ≥ 78%) and tree (visual observations, ≥ 84%; beating net samples, ≥ 81 %) spider communities. Second, spider densities in the two lucerne-sown treatments were significantly higher than in the two natural ground vegetation treatments in both the ground vegetation and tree canopy, irrespective of whether insecticide was applied. Third, although insecticide was used in the L+L treatment, spider density in the trees was still significantly higher in that treatment than in the NG treatment ($P \leq 0.05$).

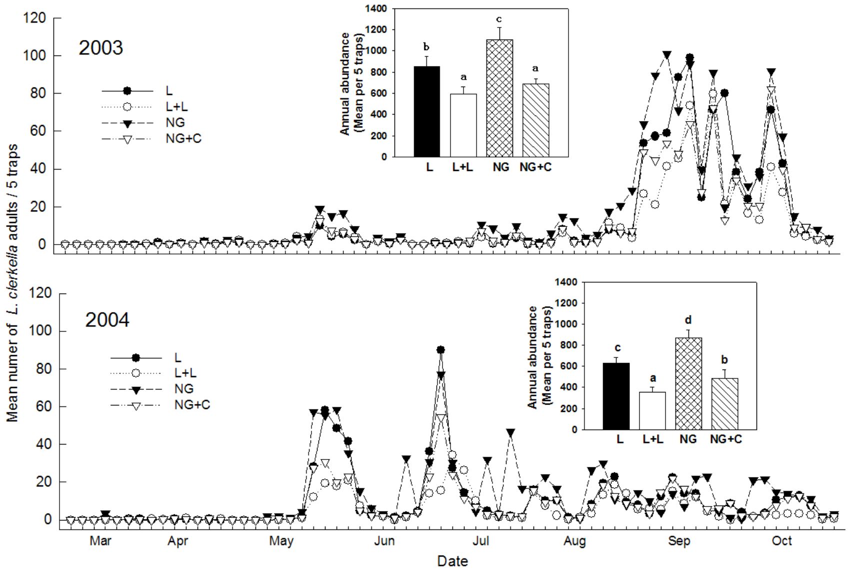

Figure 1. Seasonal trap catch of *L. clerkella* and mean (± SE) annual catch (inset) in 2003 and 2004 in three peach orchards treated with lucerne cover crop (designated L), lucerne cover crop plus limited applications of chlorbenzuron on the trees (designated L+L), natural ground vegetation (designated NG), and natural ground vegetation plus conventional applications of chlorbenzuron (designated NG+C). Means are based on the combined data from three orchards. Annual means having different letters are significantly different ($P \leq 0.05$, LSD test).

Thomisidae was the most abundant spider taxon in both the ground vegetation and tree canopy (Fig. 6). This Family accounted for 65-76% of total sweep-net-captured spiders in ground vegetation, and 68-80% of the total spiders sampled by visual observations and 66-81% sampled by beating net in the tree canopy in all treatments (Figure 6). In the family Thomisidae, the most abundant species was *Misumenops tricuspidatus* (Fabricius) followed by *Xysticus ephippiatus* Simon. Web-builders were represented mainly by Linyphiidae and Araneidae, and accounted for less than 20% of spiders (Fig. 6). *Erigonidium graminicolum* (Sundevall) and *Araneus cornutus* (Clerck) were the most abundant species.

DISCUSSION

Predator density in the lucerne cover crops was significantly higher than that in natural ground vegetation. This observation suggests that Lucerne could be a useful cover crop as a part of an integrated pest management (IPM) program (see also Zhang et al. 2000; Mensah 1997, 1999, 2002a, b; Du and Yan 1998). The number of predators collected in trees growing in orchard plots with lucerne cover crop was also significantly higher than that sampled in trees growing in orchard plots with natural ground vegetation. This can be interpreted as evidence that the Lucerne cover crop led to increased densities of predators in the tree canopy. These results are in agreement with other research results (Yan and Duan 1986, 1988; Yan et al. 1997; Yu and Yan 1998).

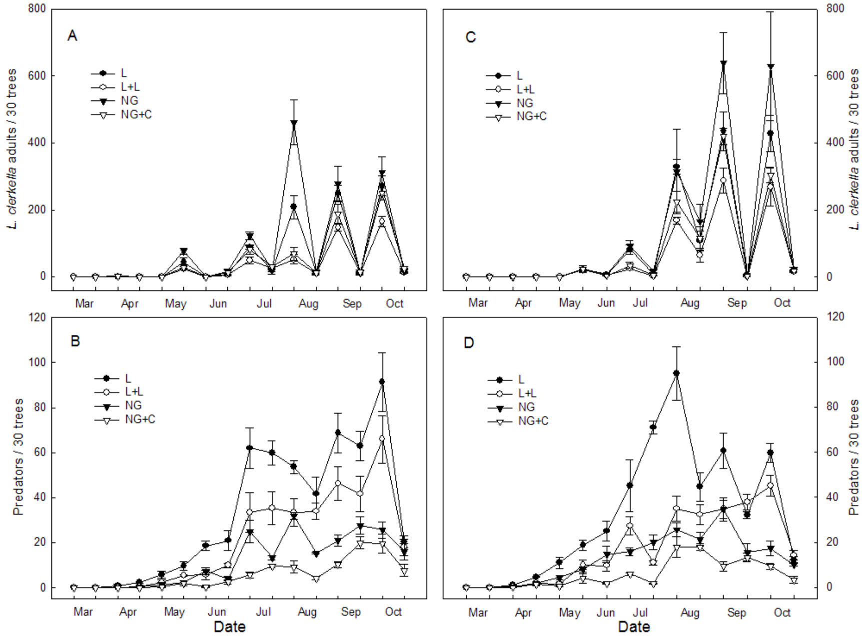

Figure 2. Counts of *L. clerkella* and predators in 2004 in the trees of three peach orchards treated with lucerne cover crop (designated L), lucerne cover crop plus limited applications of chlorbenzuron on the trees (designated L+L), natural ground vegetation (designated NG), and natural ground vegetation plus conventional applications of chlorbenzuron (designated NG+C). *L. clerkella* adults (A, visual observation; C, beating net), predators (B, visual observation, D, beating net). Means (± SE) are based on combined data for the three orchards.

Apparently due to insecticide use for control of aphids and summer fruit tortrix moths, predator density in the tree canopy in the L+L treatment was significantly lower than that in the L treatment, although there was no significant difference in predator abundance in the ground vegetation between the two treatments. Significantly more predators were captured in trees in the L+L treatment than in trees in the insecticide-free natural ground vegetation plots. This result may be attributed to the direct effects of the Lucerne cover crop.

In the two natural ground vegetation treatments, predator densities in ground vegetation were relatively low and did not show any distinct peaks throughout the sampling period. However, the abundance of predators in the tree canopy did fluctuate seasonally, and showed distinct peaks. Predaceous insects in the tree canopy had their maximal abundance at approximately the same time as peak *L. clerkella* counts were seen. Indeed, correlation analysis indicated that predator densities significantly coincided with *L. clerkella* densities not only in Lucerne sown treatments but also in natural ground vegetation treatments.

In peach orchards in Beijing, green lacewings and spiders are the main predators of *L. clerkella* (Wang et al. 1999). In our experiments, spiders were dominant in both the ground vegetation and tree canopy (see also Yan and Wang 1991). Spider density in the lucerne cover crop was significantly higher than that in natural ground vegetation. This confirms that lucerne provides a better habitat for attracting and propagating spiders than does natural ground vegetation. Spider densities in the tree canopy in Lucerne-sown treatments were

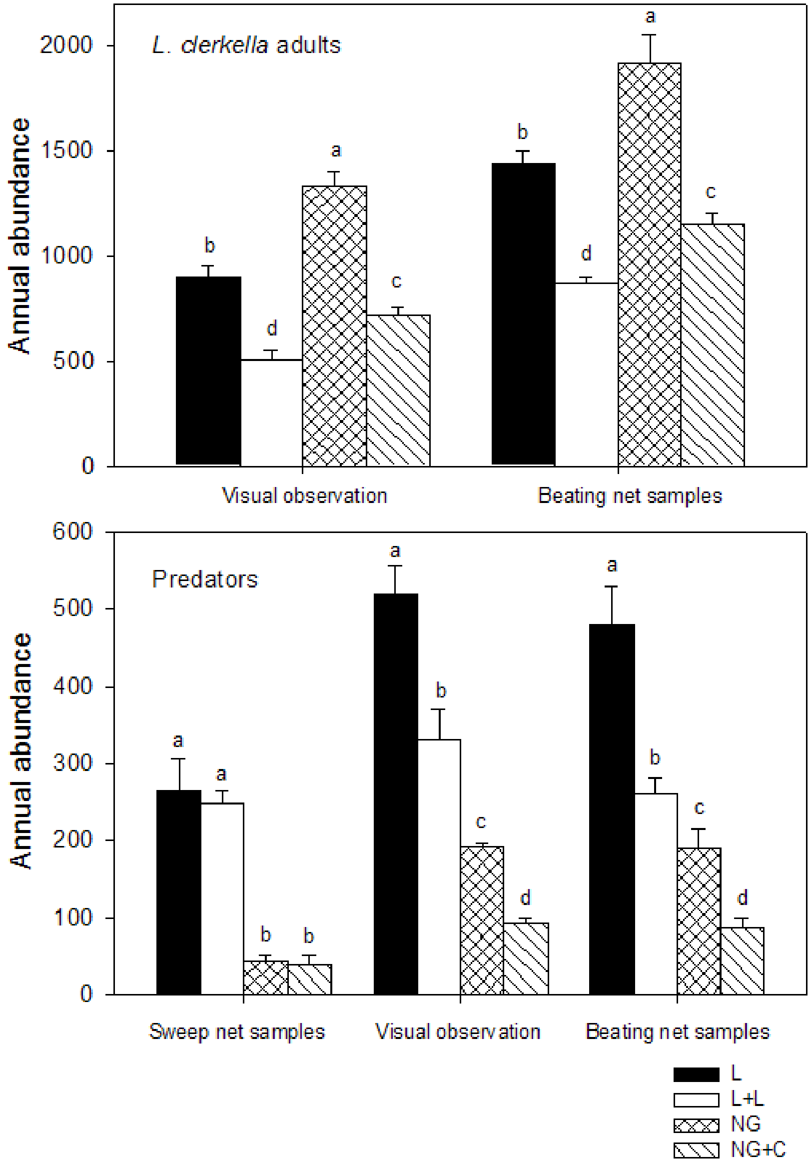

Figure 3. Mean annual abundance (±SE) in 2004 of *L. clerkella* and predators in three peach orchards treated with lucerne cover crop (designated L), lucerne cover crop plus limited applications of chlorbenzuron on the trees (designated L+L), natural ground vegetation (designated NG), and natural ground vegetation plus conventional applications of chlorbenzuron (designated NG+C) (visual observations and beating net). Means (± SE) are based on the combined data for the three orchards. For each sampling method, means not having the same letter are significantly different ($P \leq 0.05$, LSD test).

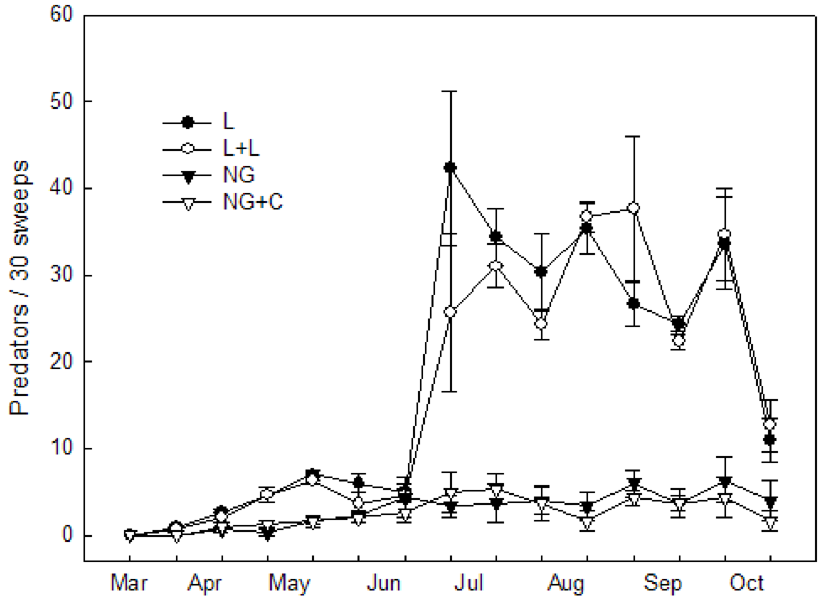

Figure 4. Predator counts in 2004 in cover crops of three peach orchards treated with lucerne cover crop (designated L), lucerne cover crop plus limited applications of chlorbenzuron on the trees (designated L+L), natural ground vegetation (designated NG), and natural ground vegetation plus conventional applications of chlorbenzuron (designated NG+C). Means (± SE) are based on combined data for the three orchards.

also significantly higher than those in natural ground vegetation treatments. Moreover, few species were exclusive inhabitants of the trees or the ground cover crops, and most occurred in both habitats, although many showed a preference for one or the other. This observation may indicate that there is movement between the two habitats (Miliczky et al. 2000).

Spider density in the tree canopy was significantly lower in the L+L treatment than in the L treatment. Similar results were shown between the NG+C and NG treatments. Although insect growth regulators (e.g., chlorbenzuron) do not harm spiders (Komorek et al. 2000), organophosphates (e.g.,chlorpyrifos) may induce moderate to high mortality rates (Komorek et al. 2000, Pekár 2002). Without exception, spider densities were lower where synthetic, broad-spectrum insecticides wereused compared to treatments receiving little or none (Chant 1956, Legner and Oatman 1964, Mansour et al. 1980, McCaffrey and Horsburgh 1980, Bostanian et al. 1984, Madsen and Madsen 1982, Miliczky et al. 2000, Pekár and Kocourek 2004).

In 2003, trap catch of *L. clerkella* in the L treatment was significantly lower than catch in the NG treatment (Fig. 1). In 2004, the other sampling methods (beating net, visual observations) also showed significant differences in *L. clerkella* counts between the two treatments (Figs. 1, 2A, 2C, 3). The earlier discussion suggested that the difference in *L. clerkella* abundance was caused by augmentation of its predators. We cannot totally exclude the parasitoids of *L. clerkella*. Adachi (1998) first identified 19 parasitoids of *L. clerkella*, which belong to the families Eulophidae, Pteromalidae, and Braconidae. In the present study, annual abundance of parasitoids belonging to these three families was

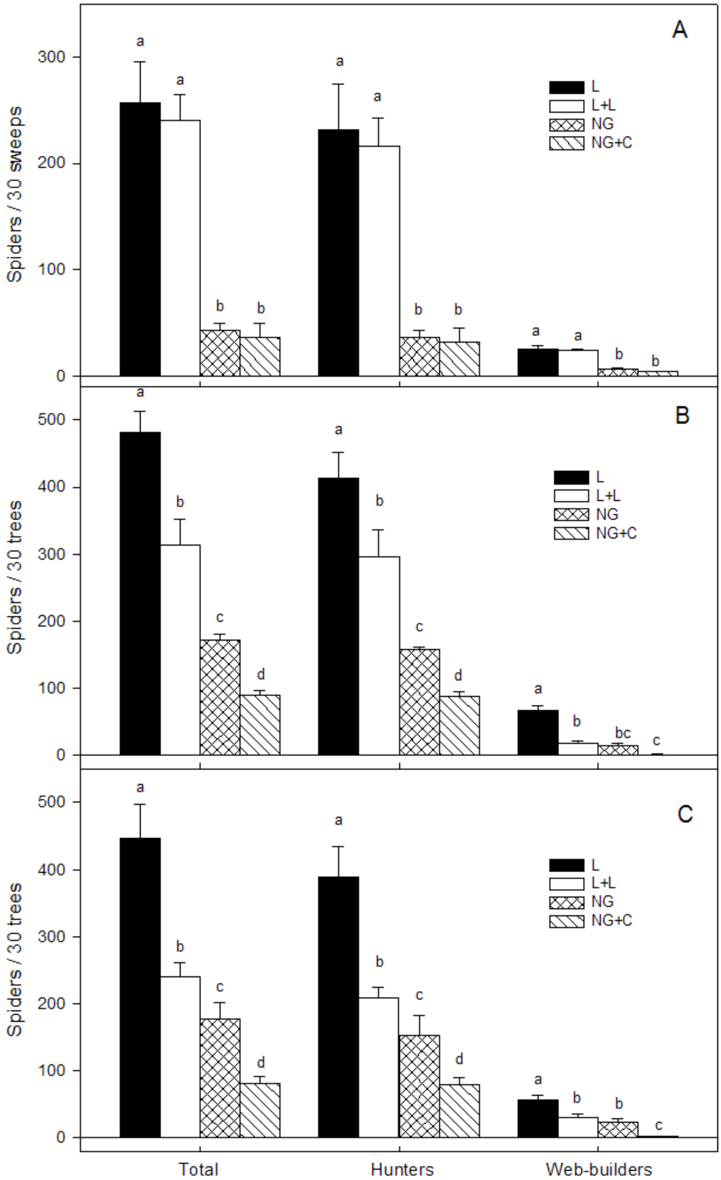

Figure 5. Mean annual abundance (± SE) in 2004 of spiders in three peach orchards treated with lucerne cover crop (designated L), lucerne cover crop plus limited applications of chlorbenzuron on the trees (designated L+L), natural ground vegetation (designated NG), and natural ground vegetation plus conventional applications of chlorbenzuron (designated NG+C). (A) cover crops (sweep net); (B) trees (visual observation); (C) trees (beating net). Means are based on the combined data for the three orchards. For each set of 4 bars, means not having the same letter are significantly different ($P \leq 0.05$, LSD test).

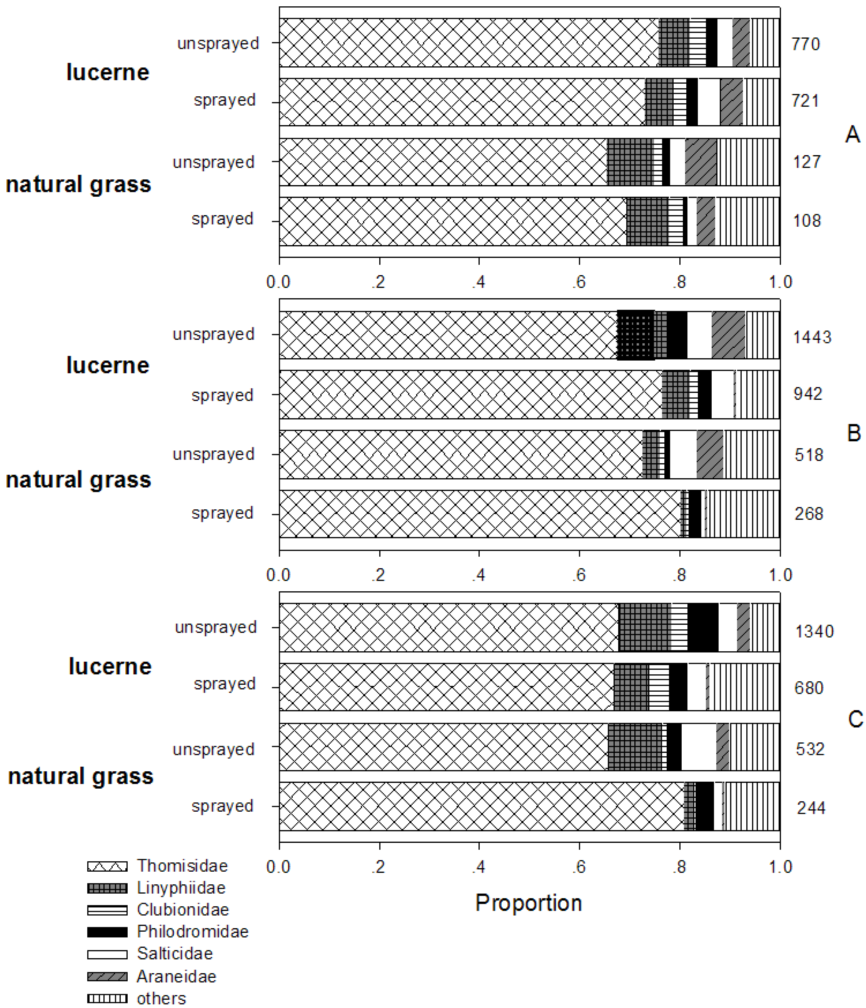

Figure 6. Family composition of the spider community in 2004 in three peach orchards treated with lucerne cover crop (designated L), lucerne cover crop plus limited applications of chlorbenzuron on the trees (designated L+L), natural ground vegetation (designated NG), and natural ground vegetation plus conventional applications of chlorbenzuron (designated NG+C). (A) cover crops (sweep net); (B) trees (visual observation); (C) trees (beating net). Values are based on combined data for the three orchards. Numbers beside each bar indicate total number captured.

also significantly higher in L than in NG in both the ground vegetation (sweep net samples, $P \leq 0.05$) and tree canopy (beating net samples, $P \leq 0.05$) (data not shown). Overall, natural enemies eventually caused a decrease in *L. clerkella* abundance.

Limited applications of chlorbenzuron for control of *L. clerkella* in the L+L treatment, despite the reduced number of applications, did not result in increased population density. In contrast, *L. clerkella* density in the L+L treatment was lower than density in the NG+C treatment, despite intensive applications of chlorbenzuron in the latter treatment (Figs. 1, 2A, 2C, 3). This result suggests that the lucerne ground cover was an effective substitute for some insecticide applications in controlling *L. clerkella*.

In summary, it can be concluded that planting lucerne in peach orchards can improve the ecological environment by increasing the diversity of bio-resources and of the arthropod community. Ground cover is an effective habitat for natural enemies, with the numbers of species and individuals being greater than in the peach canopy. Moreover, natural enemies appear to migrate from ground cover plants to the tree canopy. Maintaining ground cover can reduce insecticide use and is an important and effective technique for integrated management of *L. clerkella*. Further research and experimentation are needed to assess the effects of cover crop manipulation on other insects in peach orchards, including other major pests (aphids, summer fruit tortrix moths) and secondary pests (e.g., pest mites, scale insects). Such studies would be useful for developing an IPM strategy in peach orchards in China.

ACKNOWLEDGMENTS

We are grateful to Dr. Huanli Xu, Department of Entomology, China Agricultural University, for identifying the species and reviewing the manuscript. We thank Dr. Jianzhou Zhao and Dr. Xin Zhang, Department of Entomology, Cornell University-NYSAES, and Dr. Xiaoxia Liu, Department of Entomology, China Agricultural University, for helpful comments and revision of the manuscript. We also thank Yinping Hu, Zhijun Yu and Haili Hao, Pinggu Plant Protection Station, for assistance in collecting samples. This research was funded by "948" projects (2006-G30-05).

LITERATURE CITED

Adachi, I. 1998. Hymenopterous parasitoids of the peachleafminer, *Lyonetia clerkella* (Linnaeus) (Lepidoptera: Lyonetiidae). Appl. Entomol. Zool. 33: 299-304.

Adachi, I. 2002. Evaluation of generational percent parasitism on *Lyonetia clerkella* (Lepidoptera: Lyonetiidae) larvae in peach orchards under different management intensity. Appl. Entomol. Zool. 37(3): 347-355.

Ali, A. D., and T. E. Reagan. 1985. Vegetation manipulation impact on predator and prey populations in Louisana sugarcane ecosystems. J. Econ. Entomol. 78: 1409-1414.

Altieri, M. A., and D. K. Letourneau. 1982. Vegetation management and biological control in agroecosystems. Crop Prot. 1: 405-430.

Altieri, M. A., and L. L. Schmidt. 1985. Cover crop manipulation in Northern California orchards and vineyards: effects on arthropod communities. Biol. Agric. Hort. 3: 1-24.

Altieri, M. A., and L. L. Schmidt. 1986. Cover crops affect insect and spider populations in apple orchards. Calif. Agric. 40 (1,2): 15-17.

Andow, D. A., A. G. Nicholson, H. C. Wien, and H. R. Willson. 1986. Insect populations on cabbage grown with living mulches. Environ. Entomol. 15: 293-299.

Banerjee, B. 1983. Arthropod accumulation on tea in young and old habitats. Ecol. Entomol. 8: 117-123.

Bostanian, N. J., C. D. Dondale, M. R. Binns, and D. Pitre. 1984. Effects of pesticide use on spiders (Araneae) in Quebec apple orchards. Can. Entomol. 116: 662-675.

Bugg, R. L., and J. D. Dutcher. 1989. Warm-season cover crops for pecan orchards: horticultural and entomological implications. Biol. Agric. Hort. 6: 123-148.

Bugg, R. L., and R. T. Ellis. 1990. Insects associated with cover crops in Massachusetts. Biol. Agric. Hort. 7: 47-68.

Bugg, R. L., and C. Waddington. 1994. Using cover crops to manage arthropod pests of orchards: A review. Agric. Ecosyst. Environ. 50: 11-28.

Bugg, R. L., R. T. Ellis, and R. W. Carlson. 1989. Ichneumonidae (Hymenoptera) using extrafloral nectar of faba bean (*Vicia faba* L., Fabaceae) in Massachusetts. Biol. Agric. Hort. 6: 107-114.

Chant, D. A. 1956. Predacious spiders in orchards in south-eastern England. J. Hort. Sci. 31: 35-46.

Du, X., and Y. Yan. 1998. A study on interaction among *Lagopsis supina*, insect pests and *Orius sautori* in an apple orchard. Acta Entomologica Sinica 41: 202-204.

Fye, R. E. 1983. Cover crop manipulation for building pear Psylla (Homoptera: Psyllidae) predator populations in pear orchards. J. Econ. Entomol. 76: 306-310.

Haley, S., and E. J. Hogue. 1990. Ground cover influence on apple aphid, *Aphis pomi* DeGeer (Homoptera: Aphididae), and its predators in a young apple orchard. Crop Prot. 9: 225-230.

Haynes, R. J. 1980. Influence of soil management practice on the orchard agroecosystem. Agro-ecosystems 6: 3-32.

House, G. J., and M. D. R. Alzugaray. 1989. Influence of cover cropping and no-tillage practices on community composition of soil arthropods in a North Carolina agroecosystem. Environ. Entomol. 18: 302-307.

Komorek, M., H. Vogt, and U. Heimbach. 2000. Investigations of side-effects of two insect growth regulators and an organophosphate on dominant spiders in an apple orchard. Bull. OILB-SROP 23: 111-126.

Koptur, S. 1979. Facultative mutualism between weedy vetches bearing extrafloral nectarines and weedy ants in California. Am. J. Bot. 66: 1016-1020.

Legner, E. F., and E. R. Oatman. 1964. Spiders on apple in Wisconsin and their abundance in a natural and two artificial environments. Can. Entomol. 96: 1202-1207.

Leius, K. 1967. Influence of wild flowers on parasitism of tent caterpillar and codling moth. Can. Entomol. 94: 444-446

Li Y. 1988. Records of weeds in China. China Agricultural Press, Beijing.

Liang, W., and M. Huang. 1994. Influence of citrus orchard cover plants on arthropod communities in China: A review. Agric. Ecosyst. Environ. 50: 29-37.

Lin, R., H. Liang, R. Zhang, C. Tian, and Y. Ma. 2003. Impact of alfalfa /cotton intercropping and management on some aphid predators in China. J. Appl. Entomol. 127: 33-36.

Madsen, H. F., and B. J. Madsen. 1982. Populations of beneficial and pest arthropods in an organic and a pesticide treated apple orchard in British Columbia. Can. Entomol. 114: 1083-1088.

Mansour, F., D. Rosen and A. Shulov. 1980. A survey of spider populations (Araneae) in sprayed and unsprayed apple orchards in Israel and their ability to feed on Larvae of *Spodoptera littoralis* (Boisd.). Acta Oecologica/Oecologia Applicata 1: 189-197.

McCaffrey, J. P., and R. L. Horsburgh. 1980. The spider fauna of apple trees in central Virginia. Environ. Entomol. 9: 247-252.

Mensah, R. K. 1997. Local density responses of predatory insects of Helicoverpa spp. to a newly developed food supplement 'Envirofeast' in commercial cotton in Australia. Int. J. Pest Manage. 43: 221-225.

Mensah, R. K. 1999. Habitat diversity: implications for the conservation and use of predatory insects of Helicoverpa spp. in cotton systems in Australia. Int. J. Pest Manage. 45: 91-100.

Mensah, R. K. 2002a. Development of an integrated pest management programme for cotton. Part 1: establishing and utilizing natural enemies. Int. J. Pest Manage. 48: 87-94.

Mensah, R. K. 2002b. Development of an integrated pest management programme for cotton. Part 2: integration of a lucerne/cotton interplant system, food supplement sprays with biological and synthetic insecticides. Int. J. Pest Manage. 48: 95-105.

Miliczky, E. R., C. O. Calkins, and D. R. Horton. 2000. Spider abundance and diversity in apple orchards under three insect pest management programmes in Washington State, U.S.A. Agric. For. Entomol. 2: 203-215.

Muma, M. H. 1961. The influence of cover crop cultivation on population of injurious insects and mites in Florida citrus groves. Flor. Entomol. 44(2): 51-68.

Nentwig, W. 1988. Augmentation of beneficial arthropods by strip-management. ?. Succession of predaceous arthropods and long-term change in the ratio of phytophagous and predaceous arthropods in a meadow. Oecologia 76: 597-606.

Nyffeler, M., and K. D. Sunderland. 2003. Composition, abundance and pest control potential of spider communities in agroecosystems: a comparison of European and US studies. Agric. Ecosyst. Environ. 95: 579-612.

Nyffeler, M., W. L. Sterling, and D. A. Dean. 1994. How spiders make a living. Environ. Entomol. 23: 1357-1367

Pearce, S., and M. P. Zalucki. 2005. Does the cutting of lucerne (*Medicago sativa*) encourage the movement of arthropod pests and predators into the adjacent crop? Aust. J. Entomol. 44: 219-225.

Pekár, S., and F. Kocourek. 2004. Spiders (Araneae) in the biological and integrated pest management of apple in the Czech Republic. J. Appl. Entomol. 128 (8): 561-566

Pekár, S. 2002. Susceptibility of the spider *Theridion impressum* to 17 pesticides. J. Pest Sci. 75: 51-55.

Rieux, R., S. Simon, and H. Defrance. 1999. Role of hedgerows and ground cover management on arthropod populations in pear orchards. Agric. Ecosyst. Environ. 73: 119-127.

Rusell, E. P. 1989. Enemies hypothesis: A review of the effect of vegetational diversity on predatory insects and parasitoids. Environ. Entomol. 18: 590-599.

Shi, Z. 1988. Vegetation diversification and its relation to the pest management in apple orchards. Master's degree thesis, China Agricultural University.

Specht, H. B., and C. D. Dondale. 1960. Spider populations in New Jersey apple orchards. J. Econ. Entomol. 53: 810-814.

SPSS. 1998. SPSS User's Guide. SPSS Inc., Chicago, IL.

Stern, V. M., A. Mueller, V. Sevacherian, and M. Way. 1969. *Lygus* bug control through alfalfa interplanting. Calif. Agric. 23 (2): 8-10.

Tao, Z., and Z. Luo. 1992. Studies on arthropod community in cover crops of citrus orchard. Acta Ecologica Sinica 12 (2): 125-134.

Wang, H., J. Jia, X. Yu, J. Feng, and F. Chen. 1999. Studies on occurrence and control techniques of *Lyonetia clerkella* Linnaeus. Plant Protection Technology and Extension 19 (4): 22-24.

Wisniewska, J., and R. J. Prokopy. 1997. Pesticide effect on faunal composition, abundance, and body length of spiders (Araneae) in apple orchards. Environ. Entomol. 26: 763-776.

Wyss, E. 1995. The effect of weed strips on aphids and aphid predators in an apple orchard. Entomol. Exp. Appl. 75: 43-49.

Wyss, E. 1996. The effects of artificial weed strips on diversity and abundance of the arthropod fauna in a Swiss experimental apple orchard. Agric. Ecosyst. Environ. 60: 47-59.

Wyss, E., U. Niggli, and W. Nentwig. 1995. The impact of spiders on aphid populations in a strip-managed apple orchard. J. Appl. Entomol. 119: 473-478.

Yan, H., and H. Wang. 1991. Control effect of spiders on citrus pests in south China. Proc. of the 1991 National Symposium on Biological Control, Beijing, pp. 113-115.

Yan, Y., and J. Duan. 1986. Some observations on biological control of apple tree spider-mites. Preliminary report on the conservation and augmentation of natural enemies by cover cropping in apple orchards. Acta Agriculturae Boreali-Sinica 1 (2): 98-104.

Yan, Y., and J. Duan. 1988. The effect of cover cropping in apple orchards on the predator community on the apple tree. Acta Phytophylacica Sinica. 15(1): 114-117.

Yan, Y., Y. Yu, X. Du and B. Zhao. 1997. Conservation and augmentation of natural enemies in pest management of Chinese apple orchards. Agric. Ecosyst. Environ. 62: 253-260.

Yang, Y., Q. Huang, X. Sun, and W. Xu. 2000. The effect of four toadstools on peachminer. Chinese Journal of Biological Control 16(4): 188-189.

Yu, Y., and Y. Yan. 1998. A study on the plant diversity in apple orchards toward sustainable pest management. Acta Entomologica Sinica. 41: 82-90 (Suppl.).

Zhang, R., H. Liang, C. Tian, and G. Zhang. 2000. The biological mechanism of controlling cotton aphid (Homoptera: Aphididae) by the marginal alfalfa zone surrounding cotton field. Chinese Science Bulletin 45: 355–357.