Acta Ecologica Sinica 29 (2009) 186–191

Contents lists available at ScienceDirect

Acta Ecologica Sinica

journal homepage: www.elsevier.com/locate/chnaes

Impact of intercropping aphid-resistant wheat cultivars with oilseed rape on wheat aphid (*Sitobion avenae*) and its natural enemies

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ARTICLE INFO

Keywords:
Agrobiodiversity
Intercropping
Natural enemies
Oilseed rape
Sitobion avenae
Wheat resistance

ABSTRACT

The effects of intercropping of wheat cultivars and oilseed rape on the densities of wheat aphid, *Sitobion avenae*, and their arthropod natural enemies were evaluated. Three winter wheat cultivars with different resistant levels to *S. avenae* were used: 'KOK' (high resistance), 'Xiaobaidongmai' (low resistance) and 'Hongmanghong' (susceptible). The results showed that the densities of *S. avenae* were significantly higher on the monoculture pattern than on either the 8-2 intercropping pattern (eight rows of wheat with two rows of oilseed rape) or the 8-4 intercropping pattern (eight rows of wheat with four rows of oilseed rape). The mean number of predators and the mummy rates of *S. avenae* were significantly higher in two intercropping patterns than those in the monoculture pattern. The densities of *S. avenae*, ladybeetles, and mummy rate of *S. avenae* were significantly different among different wheat cultivars. The highest densities of *S. avenae* and ladybeetles were found on wheat cultivar Hongmanghong. The lowest densities of *S. avenae* associated with high mummy rate of *S. avenae* were found on wheat cultivar Xiaobaidongmai. The results showed that wheat-oilseed rape intercropping conserved more predators and parasitoids than in wheat monoculture fields, and partial resistance of wheat cultivar Xiaobaidongmai had complementary or even synergistic effects on parasitoid of *S. avenae*.

The English green aphid, *Sitobion avenae* Fabricius (Homoptera: Aphididae), is considered one of the most important pests of wheat in north China [1]. It can cause heavy economic damage to wheat both as a phloem feeder and as a vector of plant viruses [2,3]. Planting large monocultures of genetically homogeneous crops often lead to adaptations of herbivores to plant defences [4]. Extensive use of traditional insecticide has negative effects on the environment, natural enemies and the safety of food. To reduce insecticide inputs and minimize their negative effects on the agroecosystem, it is desirable to control pests in agroecosystem by increasing agrobiodiversity.

In a critical review of studies on herbivore population response to diversified agroecosystems, Andow [5] reported that the population density of insect pests in polycultures was lower in 52%, higher in 15%, equal in 13% and variable in 20% of the studies in comparing to monocultures. Diversified agroecosystems may be beneficial via "bottom-up" or "top-down" effects in pest suppression. The "resource concentration hypothesis" and other mechanisms are responsible for the "bottom-up" effects. The resource concentration hypothesis states that specialist herbivores are more likely to find, stay, and reproduce in pure than in diverse stands [6]. Several mechanisms are responsible for this effect such as physical obstruction, visual camouflage, masking of host plant odors, repellent chemicals, altering the profiles of the host plant odors, and reduced host plant quality [7–9]. Natural enemies play an important role in pest suppression from "top-down" effects. The "enemy hypothesis" predicts that predators and parasites are more effective in diverse systems than in simple ones [6,10]. In diverse habitats, natural enemies may benefit from improving the availability of alternative foods, providing shelter or a moderate microclimate, and providing habitat in which alternative hosts or prey are present [11].

Oilseed rape (*Brassica napus* L.) is an important economic crop in China. At the time of blooming, the flowers added valuable resources to numerous species of bees and natural enemies. In fact, adding flowers to an agroecosystem for the enhancement of beneficial insect populations has shown promise as a strategy to enhance biological control. These floral resources can provide floral nectar and pollen or extrafloral nectar which can enhance natural enemy fitness [11,12]. This can increase effectiveness of natural enemies by generating greater longevity, fecundity, parasitism for predators and parasitoids which in turn may lead to increased pest suppression [13–15]. Flower strips may increase the female-based sex ratios of parasitoid offspring [14,16]. Floral resources can also affect the spatial distribution of natural enemies in and

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doi:10.1016/j.chnaes.2009.07.009

around crops [17]. By using marking and tracking techniques, Lavandero et al. [18] found that the number of parasitoids decreased significantly with the distance from the flowers. Field experiments showed that parasitism declined exponentially with increasing distance from floral patches, reaching zero beyond 14 m [13].

For ecological control of wheat aphids, an understanding of the population dynamics of wheat aphids and natural enemies on different wheat cultivars that are resistant or susceptible to *S. avenae* is necessary for maximizing the effectiveness of the wheat-oilseed rape intercropping system. The objectives of this study were to compare the effects of wheat monoculture and wheat-oilseed rape intercropping on wheat aphids and natural enemies, and to estimate the abundance of wheat aphids and natural enemies in intercropped wheat cultivars with different resistant levels to wheat aphids.

1. Materials and methods

1.1. Wheat and oilseed rape cultivars

Three wheat cultivars with different resistant levels to *S. avenae* were provided by Institute of Plant Protection Chinese Academy of Agricultural Science at Beijing: 'KOK' (high resistance), 'Xiaobaidongmai' (low resistance) and 'Hongmanghong' (susceptible). Oilseed rape variety 'Yuyou 5' was provided by Cotton and Oil Crops Institute of Henan Academy of Agricultural Sciences at Zhengzhou, Henan, and this variety is currently used commercially in Henan and some other provinces in China.

1.2. Field experimental design

Field studies were conducted at the experimental farm of Shandong Agricultural University, Shandong Province of China (36°09′N, 117°09′E). The experimental plot was a rectangular north south trending field. North of the experimental plot was an alley, and the other three directions were all wheat fields. The experiment included three wheat cultivars, one oilseed rape and two intercropping patterns for each wheat cultivar and the oilseed rape (Fig. 1). The intercropping patterns were 8-2 pattern – eight rows of wheat with two rows of oilseed rape, and 8-4 pattern – eight rows of wheat with four rows of oilseed rape. Wheat monoculture plots were used as untreated controls. The experiment had a total of nine treatments including six wheat-oilseed rape intercropping treatments and three wheat monoculture treatments. All treatments were arranged in a completely randomized design, and each treatment was replicated three times. Each treatment plot was 80 m^2, and a 4-m-wide alley was established around plots to decrease the possibility of natural enemy dispersion among treatments. The row space of wheat was 20 cm. A 40 cm interval was left between oilseed rape and wheat rows. Oilseed rape was planted in 40 cm row spacing and 15 cm plant spacing. Oilseed rape and wheat were sown on 8 October, 2006, and the wheat was harvested on Jun. 3, 2007. All treatments were fertilized with 150–50–25 (N–P–K) kg/ha and furrow irrigated four times in 2006 and 2007. No pesticides and herbicides were used during the experiment.

1.3. Sampling of wheat aphids and natural enemies

Aphids and all predatory and parasitiod natural enemies were sampled from each plot. Ladybeetles (all stage) and syrphid flies (larval stage only) on all wheat plants within a 1-m^2 square covering six rows of wheat were counted and identified. Sampling of *S. avenae* was adopted a "Z" sampling pattern. Ten sampling sites

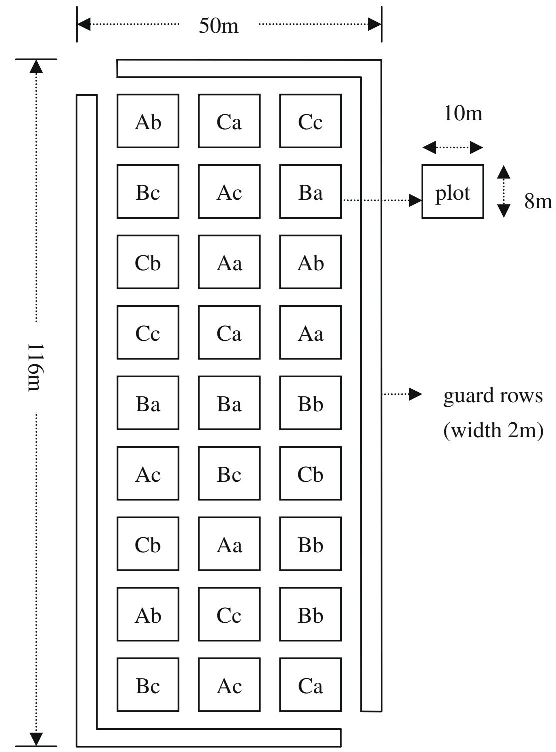

Fig. 1. Layout of experimental site. A: KOK; B: Xiaobaidongmai; C: Hongmanghong; a: 8-2 pattern; b: 8-4 pattern; c: monoculture.

were chosen from each plot. Within a sampling site, ten randomly selected wheat tillers were used as a sampling unit, 10 units or 100 wheat tillers were sampled from each plot, and number of *S. avenae* was counted from all tillers. The aphid mummies were counted on the same 100 wheat tillers on each sampling date. And mummy rate were calculated at the end of each investigation. All insect species were sampled at 3-day intervals from 11 April to 20 May in 2007, the growth and development stage of wheat was from jointing stage to mature stage during investigation.

1.4. Statistical analysis

Each date of insect species analyzed is the mean of fourteen samples during investigation. All data on population densities of insect species sampled in different treatments were analyzed using one-way analysis of variance (ANOVA) [19], and means were separated using Duncan's multiple range test. Effects of intercropping patterns and wheat cultivars were analyzed using two-way analysis of variance (ANOVA, general linear model procedure). Mummy rate of *S. avenae* used in ANOVA and GLM were transformed using $\text{Sin}^{-1}\sqrt{x}$ to meet assumptions of normality.

2. Results

2.1. Wheat aphids and their main natural enemies in different intercropping patterns

The major species of aphids and natural enemies found in the wheat fields were listed in Table 1. There were three species of aphids, *S. avenae*, *Schizaphis graminum* Rondani and *Rhopalosiphum padi* L. on wheats during the sampling period, and *S. avenae* was the most dominant species. Predators of wheat aphids belonged to two families, Coccinellidae (Coleoptera) and Syrphidae (Diptera). There were two species of aphid parasitoids, *Acidovorax*

Table 1
Aphids and major natural enemies found on wheats during the whole period of sampling under different intercropping patterns.

Insects sampled	Order: family	Species
Aphids	Homoptera: Aphididae	*Sitobion avenae* Fabricius
		Schizaphis graminum Rondani
		Rhopalosiphum padi L.
Predators	Coleoptera: Coccinellidae	*Coccinella septempunctata* L.
		Harmonia axyridis Pallas
		Propylaea japonica Thunber
	Diptera: Syrphidae	*Syrphus corollae*Fabricius
		Episyrphus balteata De Geer
Parasitoids	Hymenoptera: Aphidiidae	*Aphidius avenae* Haliday
		Aphidius gifuensis Ashmead

avenae and *Aphidius gifuensis*, and *Acidovorax avenae* was the dominant species.

2.2. Effects of wheat cultivars and intercropping patterns on the abundance of S. avenae and natural enemies on wheats

A summary of the statistical analyses on the effects of wheat cultivars and planting patterns on the mean number of *S. avenae*, ladybeetles, larvae of syrphid flies, and mummy rate of *S. avenae* on wheat are given in Table 2. There were significant differences in *S. avenae* ($P < 0.01$), ladybeetles ($P < 0.01$), and mummy rate ($P < 0.01$) among different wheat cultivars. Different intercropping patterns had significant differences on *S. avenae* ($P < 0.01$), ladybeetles ($P < 0.01$), larvae of syrphid flies ($P < 0.01$), and mummy rate ($P < 0.01$). But no significant differences were detected in the interactions of wheat cultivars and different intercropping patterns.

2.3. Effects of wheat cultivars and intercropping patterns on abundance of S. avenae

Numbers of *S. avenae* differed significantly among wheat cultivars and among the three intercropping patterns (Fig. 2). Of the three wheat cultivars, there were more *S. avenae* on Hongmanghong than on KOK and Xiaobaidongmai, but no significant difference was detected between KOK and Xiaobaidongmai (Fig. 2a; 8-2 pattern: $F_{2,6} = 13.12$, $P < 0.01$; 8-4 pattern: $F_{2,6} = 17.01$, $P < 0.01$; monoculture: $F_{2,6} = 24.07$, $P < 0.01$). Of the three different intercropping patterns, there were more *S. avenae* on monoculture pattern than on either the 8-2 or the 8-4 intercropping pattern (Fig. 2b; KOK: $F_{2,6} = 105.17$, $P < 0.01$; Xiaobaidongmai: $F_{2,6} = 122.44$, $P < 0.01$; Hongmanghong: $F_{2,6} = 194.76$, $P < 0.01$), and there were no significant difference between the two intercropping patterns.

2.4. Effects of wheat cultivars and intercropping patterns on abundance of ladybeetles

Numbers of ladybeetles (all species) on wheat plants were significantly different among the three wheat cultivars and among the three intercropping patterns (Fig. 3). Of the three wheat cultivars,

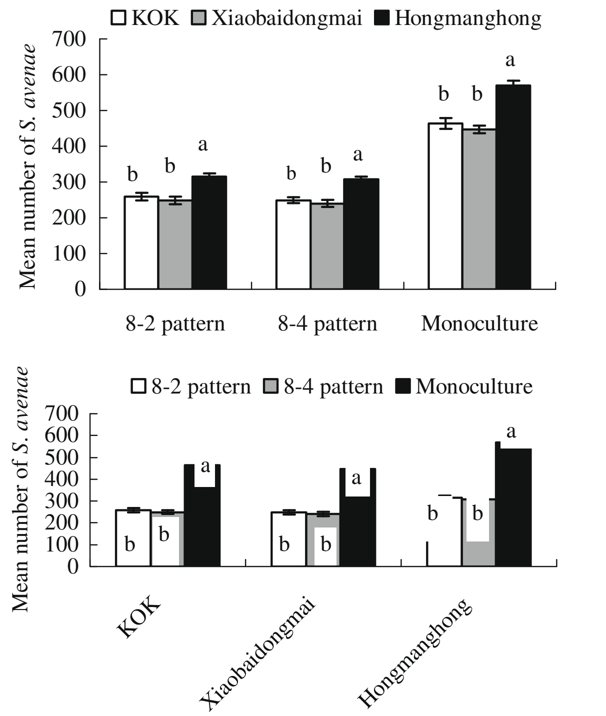

Fig. 2. Mean (±SEM) abundance of *S. avenae* (numbers/100 wheat tillers) in wheat fields with different intercropping patterns. Each histogram is the mean of fourteen samples from 11 April to 20 May in 2007. Within a intercropping pattern or wheat cultivar, different letters show statistically significant difference of individual parameters at $P < 0.05$. The same as below.

Hongmanghong had the highest number of ladybeetles, followed by Xiaobaidongmai and KOK in all three intercropping patterns (Fig. 3a; 8-2 pattern: $F_{2,6} = 23.41$, $P < 0.01$; 8-4 pattern: $F_{2,6} = 27.93$, $P < 0.01$; monoculture: $F_{2,6} = 41.93$, $P < 0.01$). Of the three intercropping patterns, numbers of lady beetles in the 8-2 and 8-4 were significantly greater than that in the monoculture pattern in all three wheat cultivars (Fig. 3b; KOK: $F_{2,6} = 74.86$, $P < 0.01$; Xiaobaidongmai: $F_{2,6} = 80.87$, $P < 0.01$; Hongmanghong: $F_{2,6} = 54.14$, $P < 0.01$).

2.5. Effects of wheat cultivars and intercropping patterns on abundance of syrphid fly larvae

Numbers of syrphid fly larvae (all species) in each of the three intercropping system were not significantly different among the three wheat cultivars (Fig. 4a; 8-2 pattern: $F_{2,6} = 0.66$, $P = 0.55$; 8-4 pattern: $F_{2,6} = 0.55$, $P = 0.60$; monoculture: $F_{2,6} = 0.73$, $P = 0.52$). Of the three intercropping patterns, numbers of syrphid fly larvae on the wheat in the 8-4 intercropping pattern were the highest, followed by those in the 8-2 intercropping pattern, and those in the monoculture pattern had the lowest (Fig. 4b; KOK: $F_{2,6} = 167.65$, $P < 0.01$; Xiaobaidongmai: $F_{2,6} = 144.58$, $P < 0.01$; Hongmanghong: $F_{2,6} = 127.72$, $P < 0.01$).

Table 2
F-test on effects of wheat cultivars and planting patterns on the abundance of *S. avenae*and natural enemies on wheat.

Source of variation	df	*F*-values[a]			
		S. avenae	Ladybeetles	Larvae of syrphid flies	Mummy rate of *S. avenae*
Wheat cultivar	3	53.551**	88.125**	0.385 NS	25.153**
Intercropping pattern	2	410.427**	203.283**	437.698**	181.439**
Wheat cultivar * Intercropping pattern	6	2.52 NS	0.018 NS	0.76 NS	0.206 NS

[a] NS: – not significantly different or $P > 0.05$.
** $P < 0.01$.

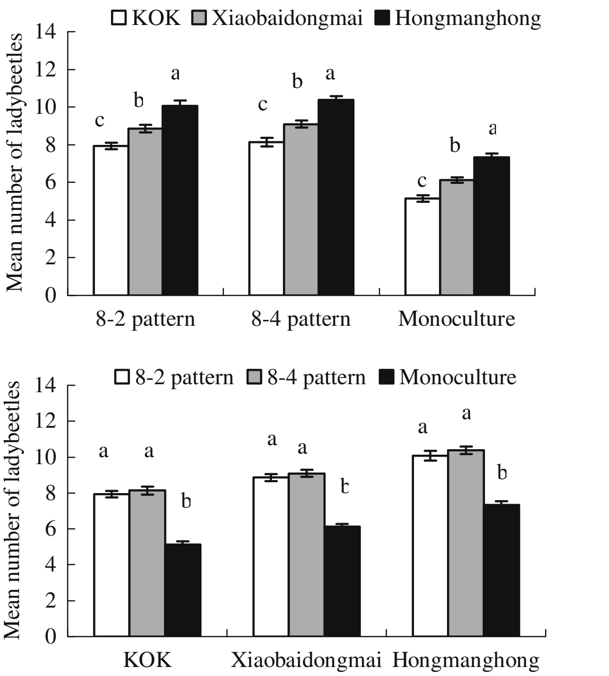

Fig. 3. Mean (±SEM) abundance of ladybeetles (numbers/m^2) in wheat fields with different intercropping patterns.

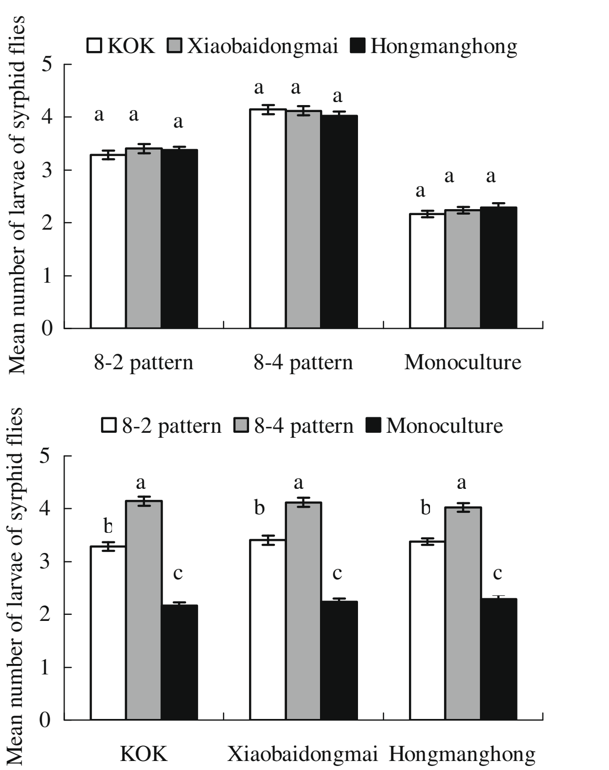

Fig. 4. Mean (±SEM) abundance of syrphid fly larvae (mean numbers/m^2) in wheat fields with different intercropping patterns.

2.6. Effects of wheat cultivars and planting patterns on mummy rate of S. avenae

Mummy rate of *S. avenae* differed significantly among the three wheat cultivars and among the three intercropping patterns (Fig. 5). Of the three wheat cultivars, mummy rate of *S. avenae*

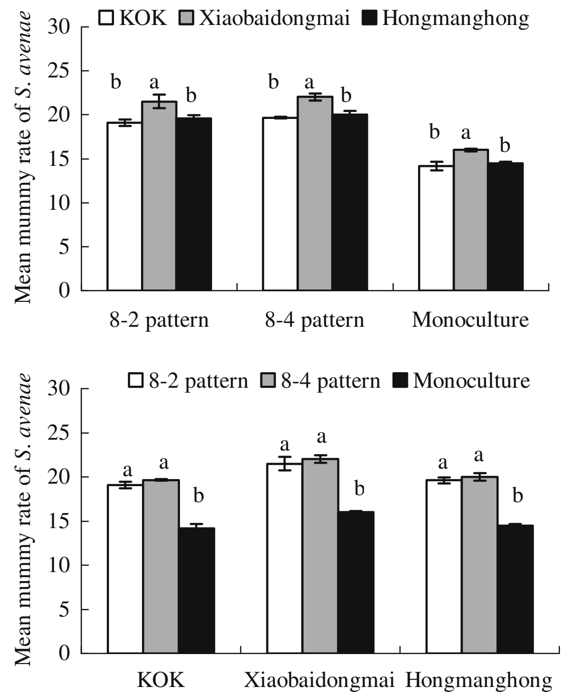

Fig. 5. Mean (±SEM) mummy rate of *S. avenae* (arcsin transformed) in wheat fields with different intercropping patterns.

were significantly higher on Xiaobaidongmai than on KOK and Hongmanghong, but no significant difference was observed between KOK and Hongmanghong (Fig. 5a; 8-2 pattern: $F_{2,6} = 5.84$, $P = 0.04$; 8-4 pattern: $F_{2,6} = 13.49$, $P < 0.01$; monoculture: $F_{2,6} = 10.00$, $P = 0.01$). Of the three intercropping patterns, mummy rate of *S. avenae* in the 8-2 and 8-4 were significantly higher than that in the monoculture in all three wheat cultivars (Fig. 5b; KOK: $F_{2,6} = 77.33$, $P < 0.01$; Xiaobaidongmai: $F_{2,6} = 42.65$, $P < 0.01$; Hongmanghong: $F_{2,6} = 85.55$, $P < 0.01$).

3. Discussion

Wheat cultivars with different resistant levels to *S. avenae* can suppress the population growth of *S. avenae* in wheat fields. Meanwhile, the fluctuation of *S. avenae*population may affect abundance of natural enemies. Increasing agrobiodiversity can lead to greater insect herbivore suppression by natural enemies [5,20]. The addition of floral resources can enhance the survival, fecundity, longevity and behavior of natural enemies in order to increase their effectiveness [11,13,14,21]. It is possible to control wheat aphids by using floral plants to design an ideal intercropping system.

Our results suggested that wheat cultivars with different resistant levels to *S. avenae* have significant effect on the abundance of *S. avenae*, ladybeetles, and mummy rate of *S. avenae*. Wheat cultivar Hongmanghong (susceptible) had more *S. avenae* compared to wheat cultivars KOK (high resistance) and Xiaobaidongmai (low resistance). The reason may attribute to the fact that nonpreference resistant cultivars KOK and Xiaobaidongmai were repellent to *S. avenae* [22]. And the population growth rates of *S. avenae* on wheat cultivar KOK and Xiaobaidongmai were significantly reduced than that on susceptible wheat cultivars [23]. We found that there were a number of wheat aphids in the early stage of growth on wheat cultivar Xiaobaidongmai, and the presence of high aphid densities could attract predators and parasitoids to the plants during the middle and late stage. On wheat cultivar Xiaobaidongmai, mummy rate of *S. avenae* were the highest. The combined effects of wheat resistance and natural enemies lead to the best suppression effects of wheat aphids on wheat cultivar Xiaobaidongmai. These results support the hypothesis that complementary or even synergistic interactions of partial resistance of the host plant and natural enemies are a common phenomenon for aphids feeding on cereals [24–26].

Our data showed that intercropping patterns that increased crop diversity in the agroecosystems significantly affected the abundance of insect herbivores and their natural enemies. Densities of wheat aphids in the two intercropping fields were significantly lower than those in the monoculture fields. There were more predators in wheat-oilseed rape intercropping fields compare to wheat monoculture. And mummy rate of *S. avenae* in the two intercropping patterns were significantly higher than that in the monoculture pattern. The same results have been reported in the literature, and are also in agreement with the natural enemies hypothesis which suggest that natural enemies are more abundant in diversity habitats where they can impose higher mortality on herbivores than in monocultures [5,6,27,28]. In diversified habitats, the presence of floral resources could benefit natural enemies in a number of ways by providing shelter, as a source of alternative hosts or prey, or by providing non-host foods such as nectar and pollen [11,29,30].

We also found that during the early stage of wheat growth, there were a number of *Myzus persicae* Sulzer and *Lipaphis erysimi* Kaltenbach on the oilseed rape in wheat-oilseed rape intercropping systems. Those aphids served as alternative hosts for parasitoids and predators. Besides, oilseed rape provides flower nectar for natural enemies to increase biological control of wheat aphids. In two intercropping fields, there were no significant differences among the densities of predators and parasitoids except for syrphid flies. There were more larvae of syrphid flies in the 8-4 pattern of intercropping compared to the 8-2 pattern of intercropping. This may attribute to the fact that there were more oilseed rapes in 8-4 pattern of intercropping which can provide floral nectar for syrphid flies.

4. Conclusion

In general, partial resistance of wheat cultivars had complementary or even synergistic effects on natural enemies of wheat aphids. Oilseed rape could provide flower nectar and alternative hosts or preys which can enhance parasitoids and predators fitness. Wheat-oilseed rape intercropping systems could obtain better effects in conserving and enhancing populations of natural enemies, and consequently reducing the chemical dependency in agroecosystems. Considering the actual situations in field application, wheat cultivar KOK or Xiaobaidongmai in combination with 8-2 pattern of intercropping was a better way to be used in fields. In designing a effective intercropping system, we should take into account the selection of main crop cultivars and intercropping crops.

Given the inherent complexity of the effects of vegetational diversity, it is necessary to understand and evaluate the effects of vegetational diversity on population dynamics of pests and natural enemies. Further research need to be done to evaluate the net effect of additional floral resources in a complex natural agroecosystem and to investigate the mechanisms how additional floral resources affect wheat aphid population dynamics.

Acknowledgements

We thank Dr. CHENG Dengfa's Research Group (Institute of Plant Protection, Chinese Academy of Agricultural Science) for providing wheat seed. We would also like to thank Dr. LIU Tongxian (Texas A&M University) for his constructive suggestions on the manuscript. The study was supported by National Basic Research Program of China (973 Program) (2006CB100204) and Key Technologies R&D Program of 11th Five-year Plan (2006BAD08A05) for financial support.

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