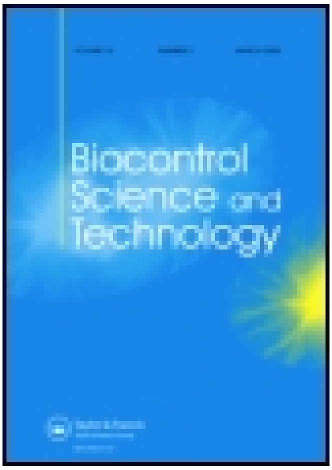

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Population dynamics of Myzus persicae on tobacco in Yunnan Province, China, before and after augmentative releases of Aphidius gifuensis

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Population dynamics of *Myzus persicae* on tobacco in Yunnan Province, China, before and after augmentative releases of *Aphidius gifuensis*

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The population dynamics of *Myzus persicae* were investigated in the field in a year without releases of *Aphidius gifuensis* (1998–1999), in a year with *A. gifuensis* releases (2000–2001) and several years later (2005–2007). The results showed that both high mean population densities and damage rates did not differ between 1998 and 1999, but were significantly lower in 2000–2001 and 2005–2007. Moreover, farmers also reported the decrease of *M. persicae* populations and attributed the declines to augmentative releases of *A. gifuensis* in their own fields, indicating farmers' recognition in the effectiveness of *A. gifuensis* for *M. persicae* control. In addition, compared with the historical data on pesticide use for *M. persicae* control, the number of insecticide applications and cost of *M. persicae* control was sustained at a low level in 2007 (several years after release of *A. gifuensis*). This suggests that the augmentative releases of *A. gifuensis* could be effective and sustainable in *M. persicae* control.

Keywords: augmentation; *Aphidius gifuensis*; *Myzus persicae*; population dynamics; pesticide use; farmer perception

Introduction

The green peach aphid (GPA), *Myzus persicae* (Sulzer), is one of the most destructive and widely distributed aphids, affecting over 400 host plants (Stary 1970). It can damage plants directly by sucking plant juices, indirectly by transmitting over 100 viral diseases and has caused large yield losses in agricultural production. Management is difficult due to its high reproductive rate and wide host range (Kulash 1949; Stary 1970; Mackauer and Way 1976; Liu 1991). In China, GPA is widely distributed and damages various crops including vegetables, fruits, ornamental plants, and tobacco (Zhao 1981; Li, Chang, and Chu 1996; Yang, Zhang, Chen, and Wang 1999). Yunnan province is the largest tobacco-producing province within China and infestations by GPA have caused economic losses (Zhao 1981). In the past, control of GPA has depended on intensive use of chemical insecticides. However, high pesticide use has caused high levels of resistance in GPA to many kinds of insecticides as well as many negative impacts on the environment and human health (Wu et al. 2004; Wu

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and Song 2007). Therefore, alternatives to pesticides for control of GPA, especially biological control, have attracted the attention of agricultural researchers in Yunnan.

Aphidius gifuensis Ashmead (Hymentoptera: Aphidiidae) is an important aphid parasitoid known to attack various aphids such as *Myzus persicae*, *Brevicoryne brassicae* (L.), *Lipaphis erysim* (Kaltenbach) and *Macrosiphum avenae* (Fabricius). This parasitoid has previously demonstrated satisfactory control of these aphid species in greenhouses and small field plots (Zhao, Din, and Zhang 1980; Xin 1986; Ohta and Ohtaishi 2005; Wei et al. 2005). *A. gifuensis* is distributed nationwide in China and its use for biological control of aphids has attracted the interest of many researchers (Chen 1979; Zhao et al. 1980; Wei et al. 2005). Although *A. gifuensis* has been used for biological control of aphids, most cases have employed small-scale releases over short intervals. Furthermore, studies on large-scale and long-term releases are limited due to lack of techniques for its mass rearing. After Wei et al. (2003) developed an economical method for mass-rearing *A. gifuensis* in the greenhouse, augmentative release of this parasitoid was considered as a potential alternative to chemical pesticides. Releases for GPA control began in tobacco fields in Hongta district, Yuxi prefecture, Yunnan province in 1998. The field studies demonstrated that *A. gifuensis* can control GPA effectively and reduce pesticide use in tobacco fields (Wu et al. 2000; Wei 2003). Since 2002, techniques for mass rearing *A. gifuensis* in small plastic greenhouses have been introduced in many rural villages (Deng et al. 2006), and sustained augmentative releases have covered all the tobacco lands (about 4000 ha) for the past 6 years in this district.

The objectives of this study were to determine, over several years, changes in the population dynamics of GPA and document farmers' perceptions after long-term augmentative releases of *A. gifuensis* in Hongta district of Yuxi prefecture, Yunnan province.

Materials and methods

Field investigation

This study was conducted at Zhaowei Experimental Station (about 16 ha) of the Yunnan Tobacco Institute, located in Zhaowei village of Hongta district, Yunnan province. At this station, the release of the parasitoid began in 2000. Adults of *A. gifuensis* were collected after rearing in a large greenhouse, as described by Wei et al. (2003) and transferred to a nylon cylinder cage (15.0×25.0 cm; diameter $\times$ height; 100 holes per cm^2). Each cage contained about 2000 adults. After collection, parasitoids were immediately transported to the study station. Five sites (50×50 m) located in the middle and four directions (east, south, west and north) of the station were selected as the release sites. Each site was at least 200 m from the next. The releases were accomplished before noon on good weather days. Two or three releases were made annually from May to July, at a rate of $>15{,}000$ adults per ha (Wu et al. 2000; Wei 2003).

The GPA population was documented at various times: 1998–1999 (before the use of *A. gifuensis*), 2000–2001 (at the beginning of augmentative releases), and 2005–2007 (subsequent to long-term releases) at Zhaowei Experimental Station. The study sites were small plots (0.067 ha) randomly selected from locations around the station. To decrease the possible impact of insecticide sprayed in other parts of the station, study sites were separated from other fields by 3 m. Insecticides were not sprayed in the sampled fields but conventional agronomic practices were otherwise employed. Tobacco (cultivar K326) was planted in the study plots. After tobacco seedlings were transplanted to the field, five sites were randomly selected, and then 10 plants were marked and followed at each site to monitor the GPA population densities and damage rates (%) over the whole season. Observations were made once every 5 days after transplantation and ended just prior to tobacco harvest (usually from early May to the end of July). Furthermore, a control plot (0.067 ha) without insecticide and parasitoid control was also set up to investigate the population dynamics of GPA and damage rates in 2000 and 2001 following the same sampling methods mentioned above. The control field was located in the tobacco fields of Zhaowei village, where the release of the parasitoid began in 2002. The control plots and the experiment station were about 500 m apart and separated by paddy fields to decrease the possibility of parasitoid dispersion from the station. A 3-m space was also set up between adjacent fields.

Farm surveys

On-farm interviews were conducted in Hongta district in 2007 to obtain farmers' perceptions of biological control. A total of 100 farmers from five villages in Hongta district were randomly chosen from household lists where rearing and release of *A. gifuensis* was organised by villages and began in 2002. Farmers were asked via a questionnaire for their perceptions on GPA outbreaks during the past 6 years, compared with years before the release of *A. gifuensis*, and about pesticide use against GPA. Further interviews were carried out monthly (for 5 months) to collect information on pesticide use for GPA control (including spray schedules and costs) from farmers' records from May to September, 2007. Pesticide use in 2007 was compared to historical data collected by Wei (2003) in Hongta district.

Data analysis

The population densities (N) of GPA were transformed by $\mathrm{Ln}(N+1)$ before drawing population curves. Damage rates (%) = plants damaged by GPA/plants investigated. The means were analysed using a one-sample t-test ($\alpha = 0.05$) and were separated by the Least Significant Difference Test (LSD) of one-way ANOVA ($\alpha = 0.05$). All data were processed by SPSS 13.0.

Results

Population dynamics of GPA

GPA populations reached their highest density in each year 45–55 days after tobacco transplantation (in early or mid-July) and then decreased. The increase in all years appeared as a single peak. Generally, the damage rates also increased as the increase of population densities in studying years (Figures 1 and 2).

There were no significant differences in mean seasonal population densities of GPA from May to July between 1998 and 1999 (before release of *A. gifuensis*). The mean seasonal population densities of GPA in 1998 and 1999 were 2002 ± 2410 and

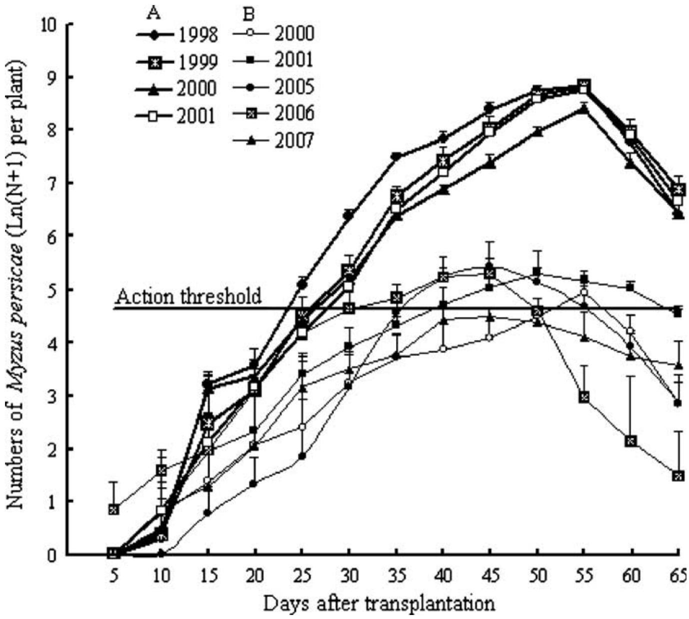

Figure 1. Population dynamics of *Myzus persicae* (Ln(N+1)+SE) on tobacco in different years (A: without *Aphidius gifuensis*; B: with *A. gifuensis*).

1743 ± 2268 per plant, respectively, significantly higher than those in 2000, 2001 and 2005 to 2007 ($P < 0.05$) (Table 1). The mean seasonal population densities of GPA in later years (after release of *A. gifuensis*) remained at relatively low levels (<85 GPA per plant) and did not differ significantly from one another ($P > 0.05$) (Table 1). Furthermore, in the years of non-adoption of *A. gifuensis* (1998–1999), the damage rates of GPA were much higher (>48%), but sustained at a lower level (<32%) in the years of parasitoid releases (Table 1, Figure 2).

Table 1. Mean seasonal population density and damage rate of *Myzus persicae* (±SD) on tobacco in the years before or after *A. gifuensis* release.

	Mean seasonal population density (per plant)	Ln(N+1) (per plant)	Damage rate (%)
Before release			
1998	2002.29(2410.16)a†	5.70(2.97)a	52.92(34.35)a
1999	1742.97(2268.25)a	5.41(2.98)a	48.92(33.64)ac
After release			
2000	41.75(44.61)b	2.93(1.63)b	23.38(15.84)b
2001	83.71(74.91)b	3.58(1.79)b	31.23(19.87)bc
2005	71.82(89.54)b	2.99(2.00)b	26.92(20.11)b
2006	66.86(73.01)b	3.30(1.62)b	31.84(18.91)bc
2007	39.91(33.65)b	3.03(1.51)b	18.31 (11.80)b
F,P,(df)	32.64,0.000 (6,448)	19.872,0.000 (6,448)	3.928,0.002 (6,84)

†Different letters in the same column indicate significant differences (LSD, $P < 0.05$) .

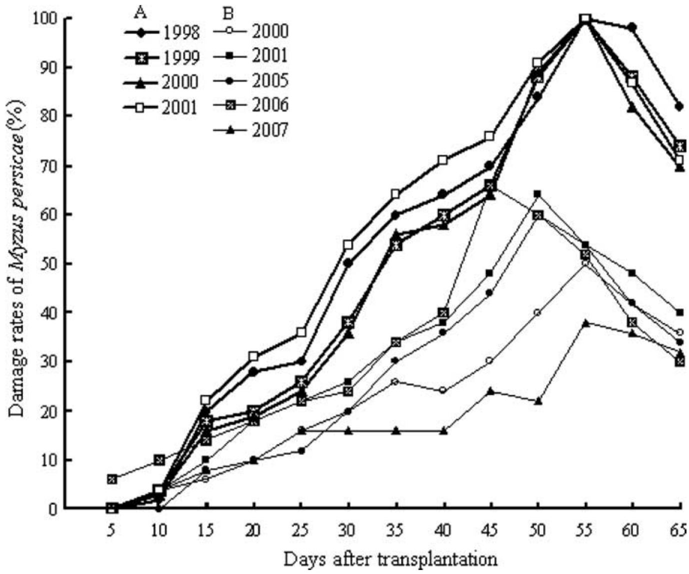

Figure 2. Damage rates of *Myzus persicae* on tobacco in different years (A: without *Aphidius gifuensis*; B: with *A. gifuensis*).

In 2000 and 2001, either the mean seasonal population densities or damage rates in the fields without *A. gifuensis* release were significantly higher ($P < 0.05$) than those in the fields with *A. gifuensis* release (Table 2, Figure 1 and 2).

Farm surveys

Farmers' perceptions of GPA population dynamics

When recalling historical information in Hongta district before 2000, 70 of 100 farmers thought GPA was a big problem in tobacco production, but only 10 still considered GPA as the key pest of tobacco in 2007. When farmers were asked about

Table 2. Mean seasonal population density and damage rate of *Myzus persicae* (±SD) on tobacco in different treatments in 2000 and 2001.

Year	Indicator	Without *A. gifuensis* release	With *A. gifuensis* release	*F*, *P* (df)
2000	Mean seasonal population density (per plant)	1029.76(1349.65)a†	41.75(44.61)b	34.769, 0.000 (1,128)
	Ln(N+1)(per plant)	5.19(2.69)a	2.93(1.63)b	33.995, 0.000 (1,128)
	Damage rate (%)	47.46(33.36)a	23.38(15.84)b	5.526, 0.027 (1,24)
2001	Mean seasonal population density (per plant)	1579.51(2109.56)a	83.71(74.91)b	32.639, 0.000 (1,128)
	Ln(N+1)(per plant)	5.31(2.93)a	3.58(1.79)b	16.406, 0.000 (1,128)
	Damage rate (%)	54.38(32.94)a	31.23(19.87)b	4.707, 0.04 (1,24)

†Different letters in the same row indicate significant differences (ANOVA, $P < 0.05$).

changes in GPA populations over the past 6 years, 86 reported that the population had decreased and remained at a low level. In identifying the reasons for decreasing GPA populations, 80 farmers among 86 respondents in Hongta district attributed declines to the use of *A. gifuensis* in their villages. Seventy-eight and 13 of 100 respondents reported a large and a slight reduction, respectively, and only nine farmers reported no obvious change in pesticide use for GPA control after the release of *A. gifuensis*.

Pesticide use

In Hongta district, farmers sprayed pesticides to control GPA on tobacco 2.14 times on average during the 2007 season, within a range of 0–5. The average insecticide cost for GPA control was $25.25 per ha. With the cost of parasitoid at $4.29–6.43 per ha, the total cost for GPA ranged $29.54–31.68 per ha (Table 3). Compared with historical data, the spraying times of insecticide against GPA was sustained at a low level after release of parasitoids. Moreover, the control cost for GPA was also largely reduced in 2007 (after release of parasitoids) (Table 3).

Discussion

Population dynamics of GPA in different years

GPA populations were very high and damaged tobacco severely in the years prior to the adoption of *A. gifuensis* releases (1998–1999), but both populations and damage rates of GPA largely decreased and remained at relatively low levels after releases of *A. gifuensis* (2000–2001, 2005–2007) (Figure 1 and 2, Table 1). These results agree with farmers' perceptions of GPA populations during these years. Moreover, in 2000 and 2001, GPA populations were significantly higher in the fields without releases of *A. gifuensis* than in fields with *A. gifuensis* releases (Figure 1), demonstrating the

Table 3. Insecticide use and control cost ($ per ha) for *Myzus persicae* control in different years.

Year	Average spraying times (per season)	Average cost of insecticides	Cost of parasitoids[1]	Total cost
Without release of *A. gifuensis*				
1998[2]	6.15 (0.17)*	–	–	–
1999	5.0–6.0	–	–	–
2000	5.0–6.0	–	–	–
2001	5.0–6.0	83.94	–	83.94
With release of *A. gifuensis*				
2000	2.8	–	4.29–6.43	–
2001	1.5–2.0	–	4.29–6.43	–
2002	1.45 (0.17)	–	4.29–6.43	–
2007[3]	2.14 (1.54)	25.25 (19.47)	4.29–6.43	29.54–31.68

*The number in parentheses indicates ±S.D. [1]About 15,000 parasitoids per ha, 2–3 releases per year and about $0.143 (recurring cost) for 1000 parasitoids in small plastic house (Wei 2003). [2]The data source of 1998–2002 is from Wei (2003). [3]Data were collected in 2007 with the total of 100 respondents.

effectiveness of *A. gifuensis* in suppressing GPA populations and supporting previous field studies (Wu et al. 2000; Wei 2003).

We compared population densities in different years with the action threshold of 100 individuals per plant (Li et al. 1992; Chen, Tu, Bai, and Li 1994). During years of non-adoption of *A. gifuensis*, GPA increased quickly and the population densities exceeded the action threshold during most of the growing season. However, during the years of parasitoid releases, the increase of GPA was relatively low and the population density was much closer to the action threshold even at their highest population densities (Figure 1). Furthermore, during the entire growing season the population densities of GPA exceeded the action threshold fewer times in the years of releases of *A. gifuensis* than in the years of non-adoption (Figure 1). The action threshold for GPA on tobacco may differ among varieties or within growth stages (Li et al. 1992; Chen et al. 1994) and the action threshold we refer to may not be suitable due to control costs for GPA. Nevertheless, our results show that augmentative releases of *A. gifuensis* can provide an economic benefit for GPA control. In addition, there is strong evidence that GPA can transmit many kinds of viruses (e.g. mosaic virus), which can cause diseases and decrease the quality of tobacco (Kulash 1949; Lojek and Orlob 1972; Kanavaki, Margaritopoulos, Katis, Skouras, and Tsitsipis 2006). Undoubtedly, the lower populations and damage rates of GPA after release of *A. gifuensis* can reduce the likelihood of virus transmission.

Pesticide use and control cost for GPA

One of the major stimuli for augmentative biological control has been the drive to reduce reliance on chemical pesticides (Collier and Van Steenwyk 2004). Farmers sprayed pesticides 5–6 times annually to control GPA without *A. gifuensis* releases, but only 1.45–2.8 times with releases of *A. gifuensis* (Wei 2003). In this study, the average number of pesticide applications for GPA control was 2.1 and the average cost was only $29–32 per ha in Hongta district in 2007, which was much lower than that of $84 per ha in the fields without *A. gifuensis* releases in 2001 (Table 3), further suggesting that adopting augmentative releases of *A. gifuensis* can effectively control GPA and sustain pesticide usage at a lower levels. Moreover, the reduction of pesticides in GPA control may also benefit farmers by less exposure to chemicals.

Farmers' perception and recognition

Evaluation of farmers' perception and practices was widely applied in many pest management systems and is essential for the development, evaluation and promotion of a pest control technique (Van Mele and Cuc 2001; Yang, Iles, Yan, and Jolliffe 2005). Although the interviews with farmers did not generate specific data on GPA populations, they provided important insights into their experiences with GPA outbreaks and their control. In Hongta district, 86% of farmers considered that GPA populations had decreased, had remained at low levels, and that GPA was no longer the key pest on tobacco following the releases of *A. gifuensis*. Eighty (93%) of these 86 respondents attributed the decrease of GPA populations in recent years to the adoption of *A. gifuensis* releases in their communities. Moreover, 91 of 100 respondents reported a decrease in pesticide usage for GPA control after the release of *A. gifuensis* since 2002. These results indicate that most farmers recognised the effectiveness of *A. gifuensis* for GPA control, and this recognition has played a role in adoption of this biological control strategy in this region of China.

Farmers in Yunnan province are typical small-scale producers. They are independent decision makers with respect to farming practices, and have relied heavily on pesticides (Yang et al. 2007). It is difficult to organise or persuade them to adopt new pest control methods (Yang, Tu, Liu, Xiang, and Kuang 2007). The augmentative release of natural enemies involves costs that are frequently higher than pesticide applications, limited releases seldom translate to economical control of pest populations, and many environmental factors can limit the effectiveness of biological control (Stiling 1993; Collier and Van Steenwyk 2004). Moreover, many farmers believed it would be more difficult to rear and release natural enemies than apply pesticides. As such, initially it was difficult to convince farmers to adopt *A. gifuensis* for GPA control. Although mass-rearing of aphids and parasitoids in a greenhouse is easy to learn and the recurring cost is relatively low (only $0.06 per 1000 mummified aphids; Wei et al. 2003), the non-recurring cost (e.g. the establishment of greenhouses etc.) is still very high for individual farmers. Thus, the releases of *A. gifuensis* were completely reliant on government support before 2002. During this period, coverage of augmentative releases was very limited and the effectiveness of *A. gifuensis* was not recognised by farmers. Later, farmers were invited to tobacco demonstration fields to observe the effect of *A. gifuensis* on GPA. Training and education events explaining biological control and pesticide risks were held in rural communities. Gradually, the farmers' desire to adopt *A. gifuensis* releases increased. Fortunately, the improvement of techniques for rearing *A. gifuensis* in small plastic greenhouses makes it possible for individual farmers or villages to rear this parasitoid themselves at low cost (Deng et al. 2006). Consequently, the mass rearing and augmentative release of *A. gifuensis* was quickly adopted by farmers and extended to all rural communities in Hongta district beginning in 2002. To our knowledge, there are few successful cases of such long-term augmentative biological control practices adopted by farmers in China or elsewhere. Moreover, augmentative release of *A. gifuensis* for GPA control in Hongta district has also aroused interest in other tobacco planting regions in Yunnan province (e.g. Chuxiong and Dali prefectures) where infestation of GPA is severe. Farmers and agricultural researchers in these regions actively go to Hongta district to learn about parasitoid rearing and release. Parasitoid rearing and release is being extended to these regions.

It can be concluded that *A. gifuensis* is an effective agent for augmentative biological control of GPA and our experiences with *A. gifuensis* releases in Hongta district may be of special interest to small-scale farmers in other countries.

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