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RESEARCH ARTICLE

Abundance of *Aphis gossypii* (Homoptera; Aphididae) and its main predators in organic and conventional cotton fields in north-west China

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Abstract

Understanding how natural assemblages of predators are affected by organic agriculture, and whether these changes can contribute to biological control, is important for the design of Integrated Pest Management (IPM) strategies and sustainable agriculture. The effect of organic management practices on the abundance of the cotton aphid *Aphis gossypii* and its major predators was evaluated in northwestern China during the cotton-growing seasons of 2004–2006. The predators of *A. gossypii* in cotton fields included Coccinellidae (ladybirds), Chrysopidae (lacewings), spiders (Linyphiidae and Thomisidae) and Syrphidae (hoverflies). Higher peak densities and longer persistence of predators in organic fields were found, and the average annual densities of all predators except Chrysopidae adults were higher, on average by 200%, in organic fields than in conventional fields in all 3 years. The abundance of larvae of Coccinellidae, Chrysopidae and Syrphidae was higher in organically managed crops indicating that these predators bred more successfully in organic fields. Although there was a significant difference between *A. gossypii* abundance in organic and conventional fields each year, taken over the three-year period as a whole there was no significant difference. This suggests predation by natural enemies in organic fields can achieve the same efficacy in aphid control as pesticides used in conventional fields over the long term, but that predation does not prevent outbreaks of *A. gossypii* in some years.

Introduction

The growing need for food and fibre has contributed to the excessive use of synthetic pesticides and fertilizers over large agricultural areas (Devine & Furlong, 2007). These practices have had direct negative impacts on the health of the environment and ecosystem services such as the provision of the natural enemies of pests (Cardinale *et al.*, 2003; Furlong & Zalucki, 2010). Organic farming practices reduce the input of synthetic pesticides and fertilizers into agro-ecosystems, and are less damaging to surrounding ecosystems than conventional practices; as such they represent an alternative approach which can help balance the detrimental effects of ever-expanding intensified agriculture (Feber *et al.*, 1997; Crowder *et al.*, 2010). Generally, organic farming can benefit the environment, food quality, food security, climate change and contribute to social justice (Drinkwater *et al.*,1995; Van Elsen, 2000; Belfrage *et al.*, 2005; Badgley *et al.*, 2007), but it can also have negative effects such as reduced crop yields, biodiversity loss, and nutrient imbalance (Maeder *et al.*, 2002; Thorup-Kristensen *et al.*, 2012; Seufert *et al.*, 2012; Gabriel *et al.*, 2013). Nonetheless, organic farming is considered one way to minimize the negative impact synthetic pesticides and fertilizers have on the environment. Recently, there has been rapid growth in organic agriculture and in 2010 approximately 37.2 million ha of agricultural land was managed organically by 1.8 million farmers in 160 countries (http://www.ifoam.org).

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Moreover, organic cotton production has increased rapidly in the USA, Europe, India and other countries (Raynolds, 2004; Eyhorn *et al.*, 2007; Swezey *et al.*, 2007; Seufert *et al.*, 2012).

Several studies have shown that the abundance of various predators, including spiders, carabid beetles and parasitoids, can be greater under organic management practices than under conventional agricultural practices (Maeder *et al.*, 2002; Hole *et al.*, 2005). Zehnder *et al.* (2007) reviewed many approaches to pest management in organic farming systems (e.g. the release of biological control agents, use of natural insecticides and mating disruption techniques), and identified the lack of evidence on the effectiveness of natural enemies for reliable management of pests as one of the constraints to the adoption of organic practices.

The cotton aphid, *Aphis gossypii* Glover, is a polyphagous species and a serious pest of cotton in many countries, including northwestern China (Zhang *et al.*, 2004; Parajulee, 2007; Abney *et al.*, 2008). In conventional agricultural management, synthetic insecticides are used to suppress *A. gossypii* populations, but these insecticides often kill predators, and can lead to more severe outbreaks of *A. gossypii* and other pests (Kerns & Gaylor, 1993; Slosser *et al.*, 1998; Wilson *et al.*, 1999).

Organic cotton farming has been implemented in the arid region of Xinjiang Province, China, and has raised many new challenges in cotton pest management. As there was little specific information on how to manage pest problems in organic agriculture, a monitoring programme for *A. gossypii* and their predators in organic fields was conducted over 3 years (2004–2006). Our aims were to determine whether organic approaches to farming could support a greater abundance of natural enemies compared to conventional farming, and to assess the effect of organic management on *A. gossypii* populations.

Materials and methods

Experimental cotton crops and fields

The experimental site was located in Gela Kule town, AkeSu city, Xinjiang Province, China (40°21 N, 80°01 E). Large-scale agricultural land was reclaimed from the desert in this region in the 1950s, and an oasis-like agro-ecosystem of broad-acre farms surrounded by desert was established. The agro-ecosystem is relatively homogeneous with 90% of arable soil covered by cotton crops since 1995. Since 2001, a smaller area of land has been reclaimed for agricultural development and part of this was set aside for organic agriculture. The experiments reported here were conducted in this recently reclaimed area in 2004, 2005 and 2006. The experimental fields (see below) were located in an area of organically grown cotton (600 ha) and conventionally grown cotton (2000 ha) separated by 1 km of natural habitat. The size of individual fields for both organic and conventional cotton was 10 ha. Adjacent fields were separated by 8–10 m wide strips of trees to act as wind breaks.

Cotton growing practices in Xinjiang Province are distinct from those elsewhere in the world: drip irrigation, plastic mulch, high planting density (3–5 times higher than in USA and Australia) and top pruning for shortening the growth period and controlling excessive vegetative growth (Bednarz *et al.*, 2000; Wang *et al.*, 2004; Bhattarai *et al.*, 2006). All experimental crops were sown at a density of 0.24–0.27 million plants ha^{-1} between 7 and 14 April of each year (2004–2006). Seedling emergence occurred after 7–12 days. Soil was mulched within row with plastic sheet to increase soil temperature and moisture. Equal volumes of water were used to furrow irrigate crops four times (mid-June, late-June, mid-July and early-August) in each year. Organic cotton fields were treated with sheep manure (3.6 ton ha^{-1} applied as a deep dressing at the end of October in each year). No insecticide was applied to the organic cotton fields and their management was certified as organic by Organic Crop Improvement Association International (OICA, ID: 1173-03). Conventional cotton fields were treated with nitrogen fertilizer (300 kg ha^{-1} of pure nitrogen, 40% as base fertilizer, and 60% as a top dressing), and sprayed with insecticides according to the local threshold for the major pest, the moth *Helicoverpa armigera*, although on one occasion in 2004, *A. gossypii* was targeted specifically (Table 1). Temperature and rainfall were recorded throughout the growing seasons (from 1 May to 31 August) and are given in Supplementary Figure 1. The daily mean temperatures during the experimental periods (10 June to 10 August) were 24.6°C, 24.5°C and 24.4°C in 2004, 2005 and 2006, respectively. Total rainfall in the same period each year was 3.8 mm, 25.1 mm and 15.9 mm in 2004, 2005 and 2006, respectively.

Arthropod sampling

A sample site (plot) of 0.5 ha was established in the middle of each organic or conventional field in order to avoid edge effects; these plots constituted the experimental units of the study. The same numbers of organic and conventional fields were studied in each year; 4, 5 and 10 fields of each type were studied in 2004, 2005, and 2006, respectively. The central plots in individual fields were considered as replicates of each type of cotton field for data analysis. Individual plots were sampled every 5 days from mid-June to mid-August in each year. At each sampling point, 20 cotton plants were randomly selected in each plot and the number of *A. gossypii* on a bottom,

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Table 1 Insecticide schedule for *Helicoverpa armigera* and *A. gossypii* pest management in conventional cotton fields within the experimental area of Xinjiang Province, China, 2004–2006[a]

Days relative to June 10[b]	Target insects	2004	2005	2006
−30	*Helicoverpa armigera*		Endosulfan EC 35%	Endosulfan EC 35%
−5 to 10	*Aphis gossypii*	Decis EC 2.5%	Bt SC 8000 IU μL^{-1}	
	Helicoverpa armigera		Endosulfan EC 35%	
	Helicoverpa armigera			
10–35	*Helicoverpa armigera*	Endosulfan EC 35%	Endosulfan EC 35%	Endosulfan EC 35%
			Endosulfan EC 35%	Endosulfan EC 35%
45	*Helicoverpa armigera*	Endosulfan EC 35%,		
60	*Helicoverpa armigera*	Bt SC 8000 IU μL^{-1}		

[a]Rates of insecticide application: Decis 450 mL ha^{-1}, Endosulfan 1500 mL ha^{-1}, Bt 1500 g ha^{-1}. All insecticides formulated in 450 L water ha^{-1}
[b]Negative values represent days prior to June 10.

middle and top leaf of the main stem of the plant was recorded.

Predatory arthropods were sampled using sweep nets (diameter 30 cm, length 1.5 m). The terminals of cotton plants (top 10–15 cm) were swept while walking along the row, each sweep was 1.5 m wide, and 30 sweeps were done in each plot. All arthropods collected were counted and classified in the laboratory. Adult insects were classified to species. Larvae were classified to family because of the difficulties in finer level taxonomic resolution of immature stages of the Coccinellidae, Chrysopidae and Syrphidae by morphological means.

Statistical analyses

The number of adult predators captured by 30 sweeps in each plot was summed for individual families. The effect of leaf position on aphid abundance was tested by one-way analysis of variance (ANOVA). Leaf position did not affect aphid abundance and so the number of aphids on the three sampled leaves (top, middle and bottom) was averaged to calculate aphid density per leaf; this was then averaged over 20 plants to estimate aphid density per leaf for each plot. The annual mean abundance of different predators and aphids per plot was calculated by determining the mean density per plot over the sample period. A two-way ANOVA was used to determine the effects of year, cotton field type and their interaction on population densities of *A. gossypii* and predators. Where required, raw data was log transformed to normalize the residuals from the ANOVA. Fisher's protected least significant difference (LSD) was used to separate means within treatments (Bithell *et al.*, 2011).

Results

A. gossypii abundance

A. gossypii populations varied considerably between years (Fig. 1, Table 3). Aphids were most abundant in 2004 when the aphid density per leaf exceeded 500 in both field types during peak population periods. Populations were lower in 2005 when densities were less than 200 per leaf during the population peaks, and lower still in 2006 when densities did not exceed 30 aphids per leaf in peak periods (Fig. 1).

In 2004 and 2006 *A. gossypii* populations peaked in mid-July under both management regimes, while in 2005 populations peaked in mid-July in conventionally managed fields but in late August in organically managed fields (Fig. 1). The annual average *A. gossypii* density varied between organic and conventional fields between years (Table 3). Over the season, there were significantly more *A. gossypii* in conventional fields than in organic fields in both 2004 (P <0.05) and 2006 (P <0.05) but in 2005 the abundance of *A. gossypii* in organic fields was significantly greater than the abundance in conventional fields (P <0.05).

Predatory arthropod abundance

The major species of predatory arthropods collected were Coccinellidae (ladybirds) [*Hippodamia variegata* (Goeze), *Coccinella undecimpunctata* L. and *Oenopia conglobata* L.], Chrysopidae (lacewings) (*Chrysopa phyllochroma* Wesmael, *Chrysoperla carnea* Stephens and *Chrysoperla sinica* Tjeder), Syrphidae (hoverflies) (*Sphaerophoria scripta* L. and *Syrphus corollae* Fabricius), Linyphiidae (spiders) (*Erigonidium graminicolum* Sundevall) and Thomisidae (spiders) (*Misumenops tricuspidatus* Fabricius). Very few aphid parasitoids or entomophthorales-infected aphids were collected during the course of the study (data not shown).

Coccinellidae were the dominant predatory species in all 3 years of the study (Fig. 1) but population peaks occurred at different times in each year: mid-July in 2004, early August in 2005, and early July in 2006 (Fig. 1). Organic fields supported approximately threefold more adult coccinellids than conventional fields (P < 0.05 in all 3 years). Similarly, organic fields supported

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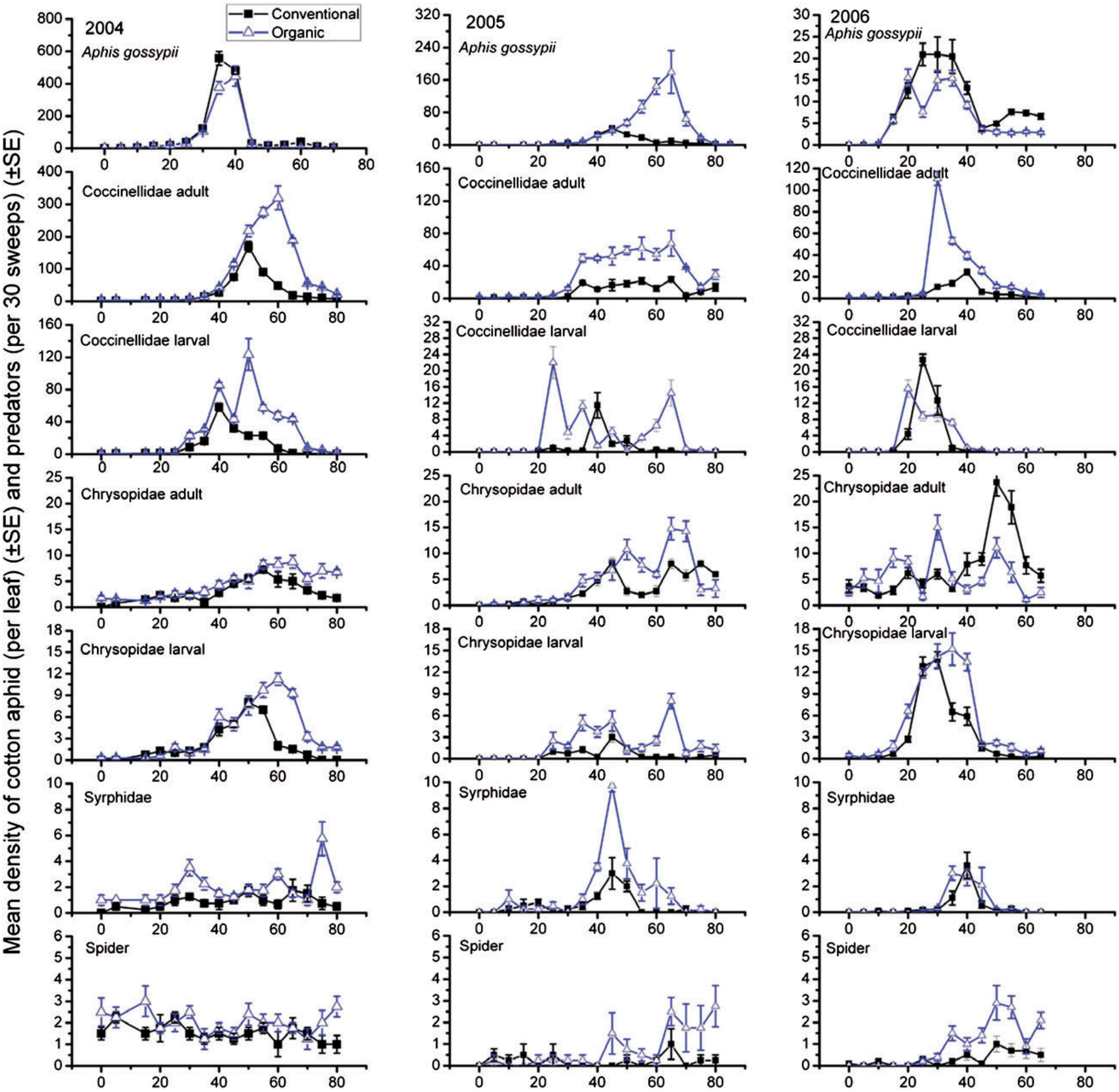

Figure 1 Population dynamics of *A. gossypii* [mean density (± SE) per leaf per plot] and its predators [mean number (± SE) per plot in 30 sweeps] in cotton fields under organic and conventional management practices in Xinjiang Province, China 2004–2006. x-axis shows the number of days from 10 June.

approximately threefold more larval coccinellids than conventional fields in 2004 and 2005 ($P < 0.05$ in both years); in 2006 there was no difference for the season long abundance of Coccinellidae larvae between organic and conventionally managed fields ($P > 0.05$).

The abundance of Chrysopidae peaked in mid-August in both organic and conventionally managed cotton fields in all 3 years of the study (Fig. 1). Overall the abundance of adult lacewings was greater in organic fields than in conventional fields in 2004 ($P < 0.05$) and 2005 ($P < 0.05$), but it was lower in organic fields than in conventional fields in 2006 ($P < 0.05$). Organic fields supported more Chrysopidae larvae than conventional fields and overall abundance of immature Chrysopidae was greater in organic fields than in conventional fields in all three years of the study ($P < 0.05$ in all 3 years).

The abundance of Syrphidae larvae was greater in organic fields than in conventional fields; the difference was significant in 2004 ($P < 0.05$) and 2005 ($P < 0.05$),

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Table 2 F-tests on effect of year, management regime and their interactions on annual mean densities of *A. gossypii* and various predators[a]

Source of variation	df	Coccinellidae Adults	Coccinellidae Larvae	Chrysopidae adults	Chrysopidae larvae	Syrphidae	Spiders	*Aphis gossypii*
Management	1	823.84***	412.69***	2.17NS	107.97***	23.71***	70.76***	0.34NS
Year	2	729.29***	930.8***	29.75***	113.72***	45.38***	38.45***	463.48***
Management*Year	2	130.15***	262.81***	12.05**	0.68NS	5.48**	2.47NS	43.24***

[a]Spiders represent Lyniphiidae and Thomisidae combined.
***$P < 0.001$.
**$P < 0.01$.
nsP > 0.05.

but not in 2006 ($P > 0.05$). In 2004 and 2005, the abundance of spiders (Lyniphiidae and Thomisidae combined) peaked late in the season but it fluctuated greatly throughout 2006 (Fig. 1). The abundance of spiders was significantly greater in organic fields when compared to conventional fields in 3 years ($P < 0.05$ in all 3 years).

Over the entire thee-year period, organic fields supported a greater abundance of Coccinellidae adult (more than 3 times greater), Coccinellidae larvae (more than 2 times greater), Chrysopidae larvae (more than 1.8 times greater), Syrphidae (more than 1.6 times greater) and spiders (Lyniphiidae and Thomisidae combined, more than 2.6 times greater) than conventional fields, but the abundance of Chrysopidae adult and *A. gossypii* was not significantly different between field types (Tables 2 and 3). Significant interactions between year and field type were detected for Coccinellidae adult, Coccinellidae larvae, Chrysopidae adults, Syrphid and *A. gossypii*, but not for spiders or Chrysopidae larvae.

Discussion

The abundance of most predators of *A. gossypii* was influenced by farming practices in cotton fields in Xinjiang Province. During this three-year study, the densities of predators in organic cotton fields were greater than in conventional cotton fields in all 3 years, with some exceptions in 2006. Our findings are consistent with reports from other organic crops in the USA and Europe. For example, there were 17–56% more natural enemies in organic cotton in California, USA, and 62% more ground-dwelling spiders in organic wheat fields than in conventional wheat fields in Germany (Purtauf *et al.*, 2005; Schmidt *et al.*, 2005; Swezey *et al.*, 2007).

Organic systems could offer refuge for beneficial insects, particularly for immature predators. Although fewer Chrysopidae adult were found in organic fields in 2006, Chrysopidae larvae were more abundant in organic fields in all 3 years, suggesting that organic cotton farming provided suitable breeding habitats for the predators of aphids (including Coccinellidae and Syrphid in this study). Swezey *et al.* (2007) also found that immature natural enemies were significantly more numerous in organic fields than in conventional or IPM fields.

The study provides some evidence, albeit indirect, that predators in organic fields suppressed aphid populations to some degree. In two of the three years of this study, the density of cotton aphid was greater in conventional fields than in organic fields. In a multi-year study (1996–2001) in California, late season infestations of *A. gossypii* in conventional fields were generally greater than in organic and IPM fields (Swezey *et al.*, 2007). This is consistent with our findings and our conclusions that predators can decrease the abundance of *A. gossypii*. This suggests that predators in organic fields, where no insecticide was used, could suppress aphid populations as effectively as chemical pesticides via a top-down effect, as has been found for other pests under a wide range of agricultural management systems (Costamagna & Landis, 2006; Hunter & Price, 1992). There remains debate over the effectiveness of top-down and bottom-up effects for pest population regulation (Walker & Jones, 2001; Denno *et al.*, 2002). Our findings suggest that the bottom-up effect of organic agricultural practices could indirectly drive the top-down effect of an increase in the abundance of predators and thereby enhance the biological control of pests.

In a critical review of the existing models of aphid population dynamics, natural enemies were found to have an effect in the early season, but were unlikely to affect aphid density in the later part of the season (Kindlmann & Dixon, 2010). Nevertheless, our study suggests that natural enemies were a vital factor in reducing *A. gossypii* abundance in late cotton-growing season. Our study surveyed the effect of organic practices on predators and cotton aphid dynamics on a field scale; the influence of landscape on these dynamics requires further research.

Our results show that organic management practices usually result in larger populations of predators in these fields, but the biological control of *A. gossypii* may not be effective in every year (e.g. in 2005 in this study). This means organic farms need additional pest management practices that comply with international organic production standards, such as cultural control practices, vegetation management to enhance biological control,

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Table 3 A comparison of the mean densities of predators (number per plot in 30 sweeps) and *A. gossypii* (number per leaf per plot) in cotton grown under conventional or organic management for the years 2004–2006[a]

		Coccinellidae adults	Coccinellidae larvae	Chrysopidae adults	Chrysopidae larvae	Syrphidae	Spiders	*Aphis gossypii*
2004	Organic	81.56	30.59	4.53	3.77	2.03	1.95	68.68
	Conventional	30.36	10.92	2.91	2.17	1.53	0.92	90.9
2005	Organic	31.16	4.41	5.06	2.20	1.58	0.81	37.0
	Conventional	9.67	1.17	3.56	0.56	0.54	0.23	8.87
2006	Organic	19.14	2.99	5.73	5.22	0.61	0.93	5.99
	Conventional	5.22	2.94	7.41	3.24	0.45	0.32	8.89
SED		0.89	0.33	0.33	0.15	0.1	0.12	2.17
$LSD_{0.05}$		1.82	0.68	0.67	0.30	0.21	0.25	4.43
d.f.		19	19	19	19	19	19	19

SEM: standard error of the difference between two means, $LSD_{0.05}$: least significant difference between two means at $P = 0.05$, d.f.: degree of freedom associated with LSDs and SEDs.
[a]Spiders represent Lyniphiidae and Thomisidae combined

releases of biological control agents, and bio-insecticides (rotenone, neem and plant oils) (Zehnder *et al.*, 2007). Natural vegetation management could easily be adopted in most cases to conserve natural enemies in agriculture (Landis *et al.*, 2000; Hossain *et al.*, 2002; Zehnder *et al.*, 2007). However, inter-cropping and trap-cropping could promote plant heterogeneity at the field and landscape scale to increase predator diversity and abundance in the cotton agro-ecosystem (Parajulee *et al.*, 1997; Slosser *et al.*, 2000). For example, strip plantings of alfalfa along the edges of conventional cotton fields has been used extensively and successfully for many years in Xinjiang Province to provide predator breeding habitat as a control measure for *A. gossypii* (Zhang *et al.*, 2004). Similar practices of habit management could be a source of predators for organic cotton cropping in Xinjiang.

We found there was a significant interaction between the year of the study and field type on the abundance of predators and aphids. Growers should consider seasonal factors when making pest control decisions in organic fields, particularly the weather conditions in different cotton-growing seasons. In our study, the average summer temperature was near to 23°C over the 3 years. In 2006, the daily temperature was lower compared to 2004 and 2005. The minimum daily temperature was below 15°C on several days of 2006 and this is a likely reason why aphid density was lower in this cotton season. In the summer of 2004 the weather conditions were warm and dry and population densities of *A. gossypii* were consequently higher. The temperatures in 2005 were very suitable for aphid population growth, but there was considerable rainfall over the summer and this resulted in lower aphid densities than in 2004. Over the study the yields from organic cotton fields were 15–20% less than yields from conventional cotton fields (data not shown), but the sale price of organic cotton was more than 1.5 times greater than that for conventional cotton, leading to greater returns from organic crops. This is leading to an increase in the adoption of organic cotton farming in this region and it is the preferred method of management by growers.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Supplementary Figure 1. Weather conditions (from 1 May to 31 August) in the experimental area over the 3 years of the study. x-Axis is the number of days since the beginning of weather recording (1 May), left and right y-axis represent temperature (°C) and rain (mm), respectively.

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