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Spiders and their seasonal dynamics in transgenic Bt- vs. conventionally managed cotton fields in north-central China

WAN-XUE LIU[1], FANG-HAO WAN[1], JIAN-YING GUO[1,2] & GÁBOR L. LÖVEI[2]
[1] *Institute of Biological Control, Chinese Academy of Agriculture Sciences, Beijing 100081, P. R. China*
[2] *Danish Institute of Agricultural Sciences, Flakkebjerg Research Centre, DK-4200, Slagelse, Denmark.*
(gabor.lovei@agrsci.dk)

Abstract
The spider fauna in two transgenic Bt-cotton fields was studied by visual inspection and compared to non-Bt cotton fields under conventional or IPM management. We inspected 50 - 100 plants per field for spiders every 5 days between early June and late September 1998, at Nan-Pi Agricultural Station, Hebei Province, near Beijing, P. R. China. The highest number of families (10) and species (18-24) were found on plants in pesticide-free Bt-cotton fields. Plants in the conventionally pesticide-treated field had 11 species of 7 families, and in the IPM field had 13 species in 8 families. The most common species on the plants were *Achaearanea tepidariorum* (Koch), *Hylyphantes graminicola* (Sundevall), and *Dictyna arundinacea* (L.) that accounted for 52%, 23% and 10% of the total spider numbers, respectively. The spider population was small in the early season (until late July) and built up quickly to high densities (max. 18.4 individuals / 10 plants) in August. The build-up was faster in Bt-cotton than in the IPM field. The conventionally managed field only had a small increase in September.

Key words: Bt-cotton, pesticides, spiders, seasonal dynamics, P. R. China

INTRODUCTION

Insect-resistant transgenic cotton (Bt-cotton) has been grown in China, the largest cotton producer of the world, since 1997. In 2001, Bt-cotton was grown in China on an estimated total area of 1.5 million ha (James 2002). There are several transgenic lines in cultivation, which are either of Chinese development, or lines developed by the international corporation Monsanto (Pray et al. 2001). All of them contain different versions of the toxin gene from the insect pathogenic bacterium *Bacillus thuringiensis*.

Transgenic crops can have potentially significant environmental impacts such as prey depletion for predatory arthropods (Wolfenbarger & Phifer 2000). Consequently, biodiversity in cultivated areas can be further depleted. Agricultural habitats can also be significant in supporting biodiversity, especially in heavily cultivated areas. In spite of several detailed faunistic studies of agricultural fields (see, for example, Duelli et al. 1999; Mészáros 1984), we neither know what level of biodiversity can be supported by an agricultural landscape, nor how does this relate to the ' total' biodiversity in a region (Daily 1999).

Our aim in the present project was to study cotton fields under different management regimes, including transgenic Bt-cotton, and compare their spider fauna, its seasonal dynamics under these different conditions. Here we report on the first year of monitoring, considering species richness patterns, and seasonal dynamics of the most common species. Further, we report on the correlation between the seasonal dynamics of the eggs of the most significant pest, the cotton bollworm (*Helicoverpa armigera*) and spider activity in different plant parts.

MATERIAL AND METHODS

Study area

The work was done at Nan-Pi Agricultural Research Station, Hebei Province, north central China (38°00'N, 116°70'E). This station has several experimental fields of cotton (a total of 15 ha) as well as a range of other cultivated crops and trees. Cotton was planted in early May (except for Monsanto 33B that was sown one week later, on 15 May). The bolls were hand-harvested several times between late August and early October. The field census was done on 3000 m^2 cotton plots separated by non-cultivated strips of 10-50 m. The fields were neighbouring each other, on the same soil, under the same cultivation and management, except the experimental treatments (see below). Planting density was the same on all plots, with both row and interplant distance being 50 cm. Four different management regimes were compared:

1. Conventionally managed non-transgenic cotton. The Chinese cv. 82-Xinxi was planted, and the plot was regularly treated with pesticides according to the usual practice of farmers in the region. There were 5 insecticide treatments per season, on 25 June, 3, 7, 25 July and 6 August 1998). For sprayings, a mixture containing equal portions of the insecticides methamidophos EC, parathion-methyl EC, esfenvalerate EC, and cypermethrin EC was used at the recommended application rate.

2. Non-transgenic cotton (cv. 82-Xinxi) under integrated pest management regime. There were only 2 insecticide treatments, using the same mixture and dosage as on the conventional field, on 30 June and 27 July 1998. In this field, the egg parasitoid *Trichogramma chilonis* was released twice during the second generation of *H. armigera*, four times during the third generation, and three times during the fourth generation. The parasitoids were released at a density of 180 000-210 000 wasps/ha at one time.

3. Bt-transgenic cotton, 33B. The plants were the " Monsanto's Event 33B", containing the Cry1A gene from the insect pathogenic bacterium *Bacillus thuringiensis* Berliner. This plot was planted one week later than the other three, and the observational data were not used for the seasonal dynamics comparisons. There was no pesticide treatment in this plot.

4. Bt-transgenic cotton, M30. Plants on this plot were the Chinese-developed Bt-cotton line Zhongmian M30, containing the same Cry1A gene of *B.thuringiensis* as the Monsanto line. There was no pesticide treatment in this plot, either.

Survey method

Starting in early June, a visual inspection of 10 (until 17 July) or 5 (22 July - end of September) plants at 10 locations per plot (total of 50 -100 plants) was done every 5 days to the end of September 1998. The observer counted and identified all spiders seen on the plants. The plant observation was stratified into top, middle, bottom part. This is not evaluated here, except when comparing the spider numbers in the top part of plants to *H. armigera* egg numbers (see later). Unidentifiable spiders were collected and taken to the laboratory for rearing and identification, at least to make sure the species in question is not a juvenile stage of a known one. The taxonomy followed Zhao (1995) and Platnick (2003). At the same time, counts of cotton bollworm (*H. armigera*) eggs were also made.

RESULTS

Species richness and density patterns

A total of 4280 individuals belonging to 15 identified and 13 unidentified species were observed during the season. At the family level, the two Bt-plots were the richest, with 10 families each. The IPM plot had 2 fewer families, and the conventionally managed plot 3 fewer families represented by at least one species (Table 1). The most species-rich was the

M30 Bt-cotton plot, followed by the Monsanto 33B plot, the IPM plot and finally, the conventionally managed plot (Table 1). The Monsanto 33B Bt-cotton plot had the highest number of spiders observed, followed by the other Bt-cotton cultivar, M30. In the conventional plot, less than one-fourth of the numbers found in the Bt-cotton plots was present (Table 1).

Species composition

The most commonly observed species was the theridiid *Achaearanea tepidariorum* Koch, 1841. This was not only overall the most common species (52% of all spiders seen belonged to this species), but ranked first in all plots except the conventionally managed one, where it was the second most common. The second-ranked species (23% of all spiders) was the linyphid *Hylyphantes graminicola* Sundevall, 1829. In the conventional plot, this was the most common species. The third one (10% of all spiders) was a dictyniid, *Dictyna arundinacea* (L.), in all plots (Table 1).

Table 1. The list of spiders observed in four different types of cotton fields at Nan-Pi Agricultural Research Station, Hebei Province, China, between June-October, 1998. * see Southwood & Henderson (2000)

Family	Species	No. of spiders in cotton fields with			
		Conventional	IPM	Bt-33B	Bt-M30
Linyphiidae	*Hylyphantes graminicola* (Sundevall, 1830)	92	179	371	331
	Ummeliata insecticeps (Bösenberg & Strand, 1906)	-	10	16	15
Dictynidae	*Dictyna arundinacea* (L., 1758)	54	66	176	135
Theridiidae	*Achaearanea tepidariorum* (C.L. Koch, 1841)	72	433	1068	658
	Coleosoma octomaculalum (Bösenberg & Strand, 1906)	-	4	-	8
	Unidentified sp1		-	-	2
	Unidentified sp2	10	7	4	9
Philodromidae	*Thanatus formicinus* (Clerck, 1757)	14	11	33	46
Araneidae	*Neoscona nautica* (L. Koch, 1875)	16	8	52	61
	Hypsosinga pygmaea (Sundevall, 1831)	-	-	-	2
	Unidentified sp3	-	-	1	-
	Unidentified sp4	4	10	3	1
	Unidentified sp5	-	-	-	2
	Unidentified sp6	-	-	3	2
	Unidentified sp7	-	3	-	-
	Unidentified sp8	2	-	-	-
Salticidae	*Evarcha albaria* (L. Koch, 1878)	-	1	15	9
	Unidentified sp9	-	1	1	-
	Unidentified sp10	-	-	-	2
	Unidentified sp11	-	-	-	2
Thomisidae	*Misumenopos tricuspidatus* (F., 1775)	18	9	21	55
	Xysticus atrimaculatus Bösenberg & Strand, 1906	2	-	40	36
	Unidentified sp 12	-	-	-	4
Gnaphosidae	Unidentified sp 13	-	-	6	4
	Gnaphosa sinensis Simon, 1880	-	-	3	2
Clubionidae	*Clubiona kurilensis* Bösenberg & Strand, 1906	10	5	15	19
Tetragnathidae	*Tetragnatha maxillosa* Thorell,1895	-	-	2	2
	Tetragnatha vermiformis Emerton, 1884	-	-	-	2
Total no. of species		**11**	**13**	**18**	**24**
Total no. of families		**7**	**8**	**10**	**10**
Berger-Parker dominance index*		**0.31**	**0.58**	**0.58**	**0.46**
Total no. of individuals		**294**	**746**	**1829**	**1411**

Spider seasonal dynamics
Only the data from one Bt-cotton plot (Zhongmian 30) were used for the detailed seasonal dynamics comparisons because of the difference in planting date (see under Methods). Densities started low, not reaching a mean density of 5 spiders/10 plants until early August (Fig. 1). Numbers started to increase during August, first in the Bt-cotton plot, and 5 days later, more gradually, in the IPM plot (Fig. 1). The delay in the conventional plot was nearly one month. The highest density was observed in the Bt-cotton plot, (X_{mean}± SD=18.4 spiders/10 plants ± 8.1, N=50 plants, 20 August). This density was more than three times higher than in the IPM plot (X_{mean}± SD=5.8 spiders/10 plants ± 4.2, N=50 plants), and more than eighteen times that of the density in the conventional plot (X_{mean}± SD=1.0 spiders/10 plants ± 1.2, N=50 plants, Fig. 1). The Bt-plot differed in the overall dynamics, too. Here, the peak occurred in late August, while in the IPM plot, the highest density was observed in mid-September. Densities at this time were still much lower in the conventional than the other two plots, but the values in the Bt- and the IPM plots were nearly equal. Throughout most of the season, the conventional plot had the lowest spider densities (Fig. 1).

Seasonal dynamics of the most common species
Seasonal dynamics of the most common species during the first half of the season showed inconclusive differences, but large density differences appeared from early August onwards (Fig. 2). All three of the most common species reached their highest mean densities in the Bt-plot (Fig. 2). Densities of the two common plant-living species, *A. tepidariorum* and *H. graminicola,* were the lowest in the conventional plot at any time of the year. The third one, *D. arundinacea* had similar starting densities in the three plots, but practically disappeared from the conventional plot by late July. After early July, densities in the Bt-plot were the highest, although there were fluctuations, probably caused by the low overall densities of this species (Fig. 2).

A. tepidariorum showed two density peaks in the Bt-plot, and only the second one was matched by a similar peak in the IPM plot (Fig. 2). The main density peak of *H. graminicola* was about 5 days earlier in the Bt-plot than in the other two plots (Fig. 2). The peak densities in the Bt-plot were nearly twice higher (X_{mean}± SD=7.8 spiders/10 plants ± 5.9, N=50 plants) than the later peak in IPM (X_{mean} ± SD=4.6 spiders/10 plants ± 3.4, N=50 plants). *D. arundinacea* had much lower densities (maximum X_{mean}± SD=2.0 spiders/10 plants ± 1.6, N=50 plants, on 9 September) and due to low densities and fluctuations, it is difficult to characterise the seasonal activity curve (Fig. 2).

Correlation between spider density and *H. armigera* egg numbers
The main pest, the noctuid moth *H. armigera* had four generations in 1998. The correlation between *H. armigera* egg numbers and total spider numbers (r=0.093, P=0.687) or spider

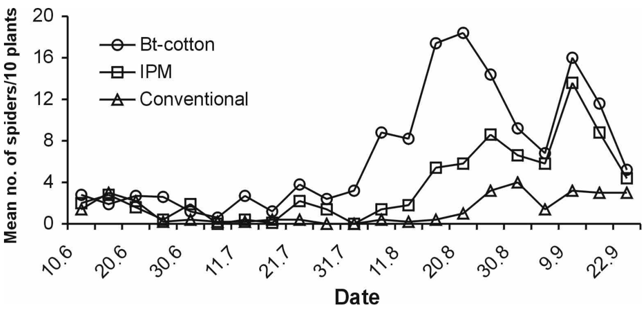

Fig. 1. Seasonal dynamics of spiders in three types of cotton fields at Nan-Pi Station, Hebei Province, north-central China, in 1998. Data are visual census results, and indicate the mean numbers observed on 10 cotton plants.

numbers on the upper plant parts only (r= -0.102, P=0.660) was not significant.

DISCUSSION

The effect of frequent pesticide spraying was evident on the density and diversity of the spider assemblage in the conventionally managed cotton. This was the only treatment where the most common species was in fact *Pardosa astrigera* L. Koch, a wolf spider active on the ground where individuals were probably more protected from the pesticide impact than plant-living species. Plant-living spider densities were drastically reduced. The early treatments seemed to exert a profound influence, setting the " starting conditions" for the spider assemblage for that season. The three most common species reached their highest densities in late August and September, and first in the Bt-plots. It is plausible to assume that the pesticide treatments in the other plots had a lasting influence on spider seasonal dynamics as they do, for example, in apple orchards in Hungary (Bogya et al. 2000).

The most species-rich and highest density assemblages were found in the two Bt-plots. In our experiment, the Bt-plots had no insecticide treatment. In China, the number of insecticide sprayings is much reduced but not completely stopped when Bt-cotton is planted (Huang et al. 2002). Such pesticide treatments are normally restricted to the second half of the growing period. Therefore we expect that the composition and dynamics of the spider assemblage in Bt-cotton would be, in today's commercial growing practice in China, closer to the " IPM assemblage" than in our experiments reported here.

It seems that Bt-cotton itself, at least at the spatial scale studied, did not prevent the de-

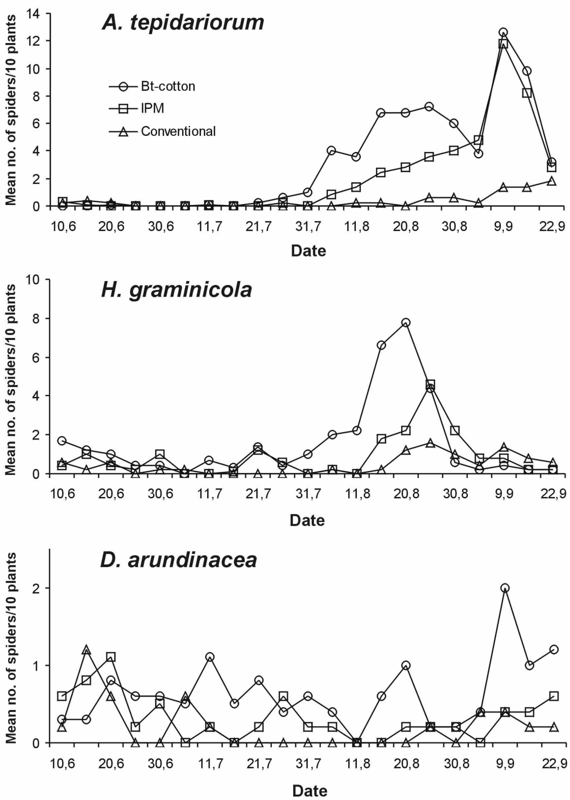

Fig. 2. Seasonal dynamics of the three most common species of spiders, *Achaearanaea tepidariorum*, *Hylyphantes graminicola*, and *Dictyna arundinacea* in three types of cotton fields, under conventional management, integrated management, or planted with Bt-cotton. Spider activity was visually censused at Nan-Pi Station, Hebei Province, north-central China, during the growing season, 1998. Data are mean numbers observed on 10 cotton plants.

velopment of a high-density spider assemblage. Our experiments were, however, restricted to just one area, and one plot per management type, even though this plot was much larger than the average cotton plot in the surrounding area (Lövei, pers. obs.). These conditions restrict the generality of our results. It is probable that the overall impact on the fauna will depend on landscape relations such as the total land surface devoted to Bt-cotton, the size and distribution of the fields, the intensity of pesticide use in the wider area, as well as the size and distribution of refuges and other habitat types.

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