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Strip cropping wheat and alfalfa to improve the biological control of the wheat aphid *Macrosiphum avenae* by the mite *Allothrombium ovatum*

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Abstract

Strip cropping of wheat (*Triticum aestivum*) and alfalfa (*Medicago sativa*) as a mechanism for improving the effectiveness of biological control of the wheat aphid (*Macrosiphum avenae*) by the mite (*Allothrombium ovatum*) was studied from 2002 to 2004 in Luancheng County, Hebei Province, China. Results showed that the strip cropping of wheat and alfalfa significantly increased the egg and larval densities of *A. ovatum* and the percentage of *M. avenae* parasitized by larval mites compared with the monoculture of wheat. The mean number of mites per parasitized aphid was also significantly higher in strip cropping than in wheat monoculture. The percentage of parasitized aphids was shown as a negative and logarithmical function of the mean population growth rate of wheat aphid, however such a relationship was statistically significant only in the strip cropping plots. The higher incidence of parasitism on alate than on apterous aphids indicated that parasitism of alate aphids by *A. ovatum* play an important role in facilitating *A. ovatum* dispersal and limiting wheat aphid population increase.

Keywords: Strip cropping; Wheat; Alfalfa; Biological control; *Allothrombium ovatum*; *Macrosiphum avenae*

1. Introduction

Intercropping is a traditional agricultural technique for reducing crop losses by pathogens and insects infections, especially in the tropics (Theunissen and Den Ouden, 1980; Trenbath, 1993). Among the various methods of intercropping commonly practiced, strip cropping has been described as having the most potential to increase crop yields by suppressing pest outbreaks (Capinera et al., 1985; Hickman and Wratten, 1996; Rämert et al., 2002).

The trombidiid mite, *Allothrombium ovatum* Zhang & Xin (Acari: Trombidiidae), is a large, red, univoltine mite commonly found in soil, litter and other terrestrial habitats as an important polyphagous natural enemy of aphids and other small arthropods in North China (Dong et al., 1996; Zhang and Li, 1996; Gerson et al., 2003). The mite goes through seven developmental stages: egg, pre-larva, larva, protonymph, deutonymph, tritonymph, and adult. Adult females lay eggs in autumn and the eggs usually overwinter in the soil (Dong et al., 1996). Because the eggs of trombidiid mite hatch in early spring, larval emergence of the mite is well synchronized with the life-cycle of their aphid hosts, which typically begin to migrate into fields of crops at that time (Dong et al., 1996; Zhang, 1998; Zhang et al., 1999). Zhang and Li (1996) found that cotton monoculture had significantly more aphids and mites than intercropped fields of cotton (*Gossypium hirsutum* L.) and wheat (*Triticum aestivum* L.), and suggested that it was because the intercropping reduced aphid migration.

Wheat is cultivated over large areas of northern China, and the wheat aphid, *Macrosiphum avenae* (Fabricius), is a major pest on wheat crops in these areas. In recent years the strip cropping of wheat and alfalfa (*Medicago sativa* L.) has

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been widely practiced for improving the wheat yields. In this study, population dynamics of *A. ovatum* and *M. avenae* were investigated in wheat monoculture and strip cropping of wheat and alfalfa. The main objective was to examine the effects of wheat–alfalfa strip cropping on the abundance of *A. ovatum* and the percentage of *M. avenae* parasitized by *A. ovatum* larvae, and to answer the following questions:

(1) Can strip cropping of wheat and alfalfa decrease the density of *M. avenae* in wheat crops?
(2) Can strip cropping of wheat and alfalfa increase *A. ovatum* density in wheat fields?

2. Materials and methods

Field experiments were conducted over 3 years (2002–2004) at the Experimental Agricultural Ecosystem Station of Chinese Academy of Sciences (37°53′N, 114°41′E), located in Luancheng County, Hebei Province, northern China. The experimental field for this study was 195 m × 30 m in size, which was divided into three treatment blocks: wheat–alfalfa strip cropping, wheat monoculture, and alfalfa monoculture. Each block had three replicate plots (65 m × 10 m) that were arranged randomly within the field. All plots were 0.5 m apart and separated by bare ground. The strip cropping was planted as 10 alternating 1 m wide strips of wheat and alfalfa. Each strip was comprised of five rows spaced 20 cm apart. The monoculture plots were planted in similar strips but with only one plant species, either wheat or alfalfa. Alfalfa was sown once on March 10, 2002, and wheat on March 10 every year.

The study site was historically used for growing agricultural crops. Before 1995, cotton and wheat were intercropped on the site, and insecticides (mainly Deltamethrin) were used three or four times yearly for controlling cotton worms. From 1995 to 2002, wheat and corn were rotationally planted, and insecticide and herbicide were rarely used. During the experiment, insecticides and herbicides were not used on the experimental and surrounding fields. All plots were kept nearly weed-free by hand-weeding and were routinely spray irrigated during periods of low rainfall. Organic fertilizer and NH_4HCO_3 (about 350 kg/ha) were applied when seed was sown.

The numbers of alate, apterous, parasitized, and unparasitized aphids were recorded weekly on wheat stems from April 25 to July 4 in 2003, and from April 23 to July 2 in 2004. Non-destructive samplings were made from 15 random locations on each plot. In the early sampling period when aphid density was low (<200 aphids/100 stems) the aphids were counted on all wheat stems within a 0.5 m^2 sub-plot at each location. When aphid density was >200 aphids/100 stems, the aphids were counted on a random sample of 10 wheat stems at each location.

The mean number of mites per parasitized aphid (MNM) was estimated by recording the numbers of mites attached to 50 randomly selected parasitized alate and apterous aphids. All data were expressed as the density of aphids and mites per 100 wheat stems. In order to investigate a potential cause of differences in mite density between wheat monoculture and strip cropping of wheat and alfalfa, the density of mite egg pods 5–15 cm below the soil surface was measured in a 30 cm × 30 cm quadrate at five random locations on each plot.

Differences in the abundance of aphids and mites and the percentage of aphids parasitized by mites between treatments were analyzed using an independent-samples *t*-test. Kendall's nonparametric correlation method was used for testing the temporal synchrony of mite and aphid abundance. The relationship between the aphid population growth rate and the percentage of aphids parasitized by mites was examined using curvilinear regression. All statistical analyses were performed using SPSS 10.0 software. For meeting the assumptions of the independent-samples *t*-test, abundance data were first square root transformed and percentage data transformed by arc-sin square root.

3. Results

The abundance of mites was significantly higher in strip cropping than in wheat monoculture in 2003 ($t = 2.968$, d.f. = 4, $P = 0.041$) and 2004 ($t = 8.313$, d.f. = 4, $P < 0.001$). The trends of the mite population dynamics were similar between the two planting regimes, but the mite density peaked earlier in wheat monoculture than in strip cropping. There was no significant difference in the mite density between the two planting regimes either early or late in the sampling period (Fig. 1). Significantly more mite egg pods were found in strip cropping (>8 pods/m^2) than in wheat monoculture (<1 pods/m^2) ($t = 7.771$, d.f. = 4, $P < 0.001$). The wheat monoculture had significantly more aphids than

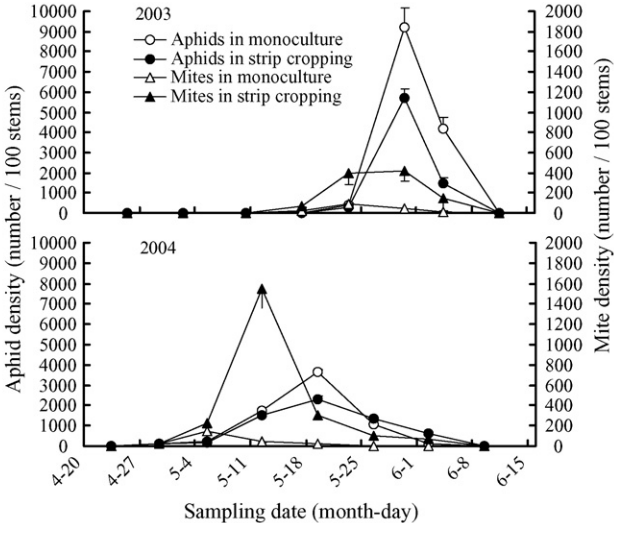

Fig. 1. Population dynamics of *Allothrombium ovatum* and *Macrosiphum avenae* in the wheat monoculture and the wheat–alfalfa strip cropping.

the strip cropping in 2003 (9119/100 stems versus 5634/100 stems) and 2004 (3610/100 stems versus 2265/100 stems).

Abundance of *A. ovatum* peaked in the early period of aphid population growth and close synchronization of mite and aphid densities was apparent in both wheat monoculture ($r = 0.714$, $n = 7$, $P = 0.012$) and strip cropping ($r = 0.810$, $n = 7$, $P = 0.005$).

In 2003, the peak of aphid parasitization was recorded on the May 22 sampling session, with a significantly higher parasitization rate in strip cropping (40.7%) than in wheat monoculture (7.3%) ($t = 5.488$, d.f. = 4, $P = 0.005$). Parasitization rates of both alate and apterous aphids were significantly higher in strip cropping than in wheat monoculture, i.e. 54.0% versus 14.7% for alate aphids ($t = 2.346$, d.f. = 4, $P = 0.003$), and 36.3% versus 6.0% for apterous aphids ($t = 4.435$, d.f. = 4, $P = 0.011$) (Fig. 2).

In 2004, the peak of aphid parasitization was recorded on the May 5 sampling session with comparable parasitization rates of 34.0% in strip cropping and 28.6% in wheat monoculture. However, on the subsequent sampling sessions, the parasitization rate in wheat monoculture was significantly lower than in strip cropping ($t = 18.950$, d.f. = 4, $P < 0.0001$) (Fig. 2). After the third sampling session, a significantly higher percentage of alate than apterous aphids was parasitized by *A. ovatum* in both planting regimes.

The mean numbers of mites attached to individual aphids (MNM) was significantly higher in strip cropping than in wheat monoculture during the entire experimental period. Peak MNM of alate and apterous aphids (3.1 and 3.2, respectively) was recorded on May 12, 2004, at which time mites were most abundant. The maximum MNM recorded in wheat monoculture was 6 compared to 10 in strip cropping. Furthermore, the percentage of individual aphids with four or six mites was significantly lower in wheat monoculture (3.3 and 0.7%) compared to that in strip cropping (11.7 and 6.0%) ($t = 3.222$, d.f. = 10, $P = 0.009$; $t = 5.394$, d.f. = 10, $P < 0.0001$).

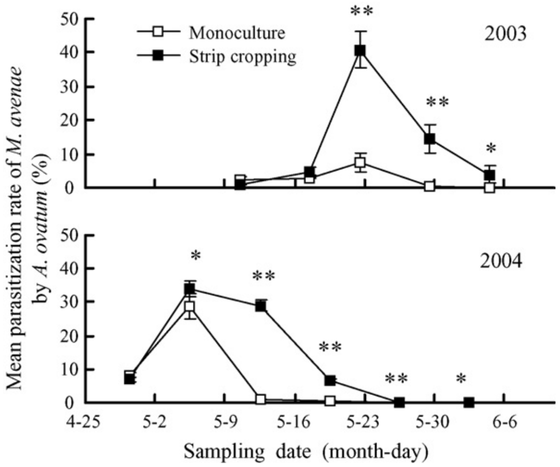

Fig. 2. Mean parasitization rate of *Macrosiphum avenae* by *Allothrombium ovatum* in the wheat monoculture and the wheat–alfalfa strip cropping. Asterisks (* and **) indicate statistical significance at 0.05 and 0.01 level (two-tailed *t*-test).

4. Discussion

Results of this study provided evidence that strongly supported the ‘‘enemies hypotheses’’ (Andow, 1991) and the conclusion of Khan et al. (1997). That is intercropping changes the environmental condition, in such a way to increase natural enemy activity. The wheat–alfalfa strip cropping significantly increases both the abundance of *A. ovatum* larvae and the parasitization rate of *M. avenae* compared to the wheat monoculture. It could be explained by the fact that the strip cropping resulted in a moister, shadier soil surface microclimate which caused adult female mites to lay more egg pods (Brust et al., 1986; Zhang and Li, 1996), and that the non-furrowed areas of the intercropped fields could provide a more suitable habitat for mites overwintering (Zhang et al., 1994).

Our results were inconsistent with the reports of Chen et al. (1994) and Zhang and Li (1996), who found that the intercropped sites of wheat and cotton had fewer mites compared to the monocultures. They postulated that such intercropping hampered the migration of mites and their alate hosts. The inconsistence might result from differences in emergence times of the aphid, mite species, and the type of intercropping.

A higher incidence of parasitism on alate than apterous aphids was consistent with Zhang (1998). Preference of mites to parasite alate aphids is an adaptation that benefits the mites for extending distribution and reducing risks of host changes during the larval stage. *A. ovatum* is a protelean parasitoid with two free-living stages: deutonymph and adult. The relatively short attachment time of larval stages limits their effectiveness as a biological control agent for host aphids (Zhang, 1998). In this study, the percentage of parasitized aphids was a negative and logarithmical function of mean population growth rate of the aphids, but such a relationship was statistically significant only in the strip cropping ($r = 0.837$, $F = 20.983$, $P = 0.0013$). The correlation between aphid population growth and the parasitization rate of alate aphids was higher than that of aphid population growth and the parasitization rate of apterous aphids in strip cropping plots. It implies that the parasitism of *A. ovatum* on alate aphids can significantly control the population increase of wheat aphids. In the wheat monoculture, there is no significant coefficient of regression between aphid population growth rate and percentage of aphids parasitized by mites, which probably suggests that the parasitism role of mites is one of the factors restricting the abundance of aphid populations. Because of the greater time-lag between the peak abundance of aphids and their other natural enemies such as ladybeetles and wasps, more accurate measurement of the quantitative relationship between these two parameters is required.

Remarkably up to 5–10 mites per parasitized aphids were found in the strip cropping. It has previously been found that the survival and reproductive rates of parasitized aphids decrease rapidly with increasing MNM (Dong, 2001). *A. ovatum* larvae are the most abundant natural enemies of *M. avenae* during the early growing season of wheat when other natural enemies are lacking (Zhang, 1998). Our studies revealed that coccinellid and *Aphidius* sp. population densities in the strip cropping were also low (Ma et al., unpublished data), suggesting that the lower aphid population densities were primarily due to the parasitization by *A. ovatum*. Therefore, the trombidiid mites could play an important role in suppressing aphid abundance during the early growing season of wheat in northern of China.

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References

Andow, D.A., 1991. Vegetational diversity and arthropod population response. Annu. Rev. Entomol. 36, 561–586.

Brust, G.E., Stinner, B.R., McCartney, D.A., 1986. Predation by soil inhibiting arthropods in intercropped and monoculture agroecosystems. Agric. Ecosyst. Environ. 18, 145–154.

Capinera, J.L., Weissling, T.J., Schweizer, E.E., 1985. Compatibility of intercropping with mechanized agriculture: effects of strip intercropping of pinto beans and sweet corn on insect abundance in Colorado. J. Econ. Entomol. 78, 354–357.

Chen, P.R., Zhang, Z.Q., Wang, K., Wang, X.L., Xu, W.L., Gao, Z.L., 1994. *Allothrombium pulvinum* Ewing (Acari, Trombidiidae), an important early-season natural enemy of *Aphis gossypii* Glover (Hom., Aphididae) in cotton. J. Appl. Entomol. 117, 113–121.

Dong, Y.C., 2001. Laboratory experiments on the effect of *Allothrombium ovatum* larvae (Acari: Trombidiidae) on the aphid *Rhopalosiphum padi* (Homoptera: Aphididae). Syst. Appl. Acarol. 6, 61–64.

Dong, Y.C., Ran, R.B., Xiang, J.Y., 1996. Biology of *Allothrombium ovatum* (Acari: Trombidiidae) and its controlling effect on *Aphis gossypii* (Homoptera: Aphididae). Syst. Appl. Acarol. 1, 35–40.

Gerson, U., Smiley, R.L., Ochoa, R., 2003. Mites (Acari) for Pest Control. Blackwell, Oxford, 539 pp.

Hickman, J.M., Wratten, S.D., 1996. Use of *Phacelia tanacetifolia* strips to enhance biological control of aphids by hoverfly larveae in cereal fields. J. Econ. Entomol. 89, 832–840.

Khan, Z.R., Ampong-Nyarko, K., Chiliswa, P., Hassanali, A., Kimani, S., Lwande, W., Overholt, W.A., Pickett, J.A., Smart, L.E., Wadhams, L.J., Woodcock, C.M., 1997. Intercropping increases parasitism of pests. Nature 388, 631–632.

Rämert, B., Lennartsson, M., Davies, G., 2002. The use of mixed species cropping to manage pests and disease—theory and practice. In: Powell, J., et al. (Eds.), UK Organic Research 2002: Proceedings of the COR Conference, 26–28 March 2002, Aberystwyth, pp. 207–210.

Theunissen, J., Den Ouden, H., 1980. Effects of intercropping with *Spergula arvensis* on pests of Brussels sprouts. Entomol. Exp. Appl. 27, 260–268.

Trenbath, B.R., 1993. Intercropping for the management of pests and diseases. Field Crops Res. 34, 381–405.

Zhang, H.J., Li, J.S., 1996. Sources and dispersal of *Allothrombium ovatum* larvae (Acari: Trombidiidae) in cotton fields and effects of larval mites on *Aphis gossypii* (Homoptera: Aphididae). Syst. Appl. Acarol. 1, 65–71.

Zhang, H.J., Li, J.S., Zhu, C.Q., 1994. Observation on the oviposition selectivity of *Allothrombium ignotum* to the different soil moisture content. Acta Arachnol. Sinica 3 (2), 100–103.

Zhang, H.J., Li, J.S., Liang, Y.H., 1999. Studies on aphid host selection by parasitic larvae of *Allothrombium ovatum* (Acari: Trombidiidae). Syst. Appl. Acarol. 4, 91–95.

Zhang, Z.Q., 1998. Biology and ecology of trombidiid mites (Acari: Trombidiodea). Exp. Appl. Acarol. 22, 139–155.