Journal of Entomological Society of Iran
2010, 30(1), 13-28

A survey of alfalfa aphids and their natural enemies in Isfahan, Iran, and the effect of alfalfa strip-harvesting on their populations

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Abstract

During a two-year (2004-2005) survey of alfalfa aphids and their natural enemies in Isfahan, a total of four aphid species and 58 species of their natural enemies comprised of 45 predatory species, 11 parasitoid species and two species of parasitic mites were collected and identified. Moreover, five hyperparasitoid species were collected. On each sampling date, six 20-sweep samples were taken using a 38cm-diameter sweep-net and also six 20-stem were sampled. The results showed that the mean percent of *Hippodamia variegata* Goeze, *Nabis* spp., *Deraeocoris* spp., *Orius* spp., *Geocoris* spp. and aphid parasitoids in strip-harvested field were 38%, 95%, 119%, 57%, 100% and 122%, respectively; higher than those in conventionally-harvested field. In contrast, the mean percent of *Acyrthosiphon pisum* (Harris) and *Therioaphis trifolii* (Monell) forma *maculata* (Buckton) were 24% and 28%, respectively; lower in strip-harvested field than in conventionally-harvested field.
Key words: alfalfa aphids, aphid predators, aphid parasitoids, natural enemies, strip-harvesting

چکیده

در طی دو سال (۱۳۸٤-۱۳۸۳) نمونه‌برداری از جمعیت شته‌های یونجه و دشمنان طبیعی آن‌ها در اصفهان، در مجموع ٤ گونه شته و ۵۸ گونه از دشمنان طبیعی آن‌ها شامل ٤۵ گونه شکارگر، ۱۱ گونه پارازیتوئید و ۲ گونه کنه‌ی پارازیت جمع‌آوری و شناسایی شد. علاوه بر این، ۵ گونه هیپرپارازیتوئید نیز جمع‌آوری گردید. در هر روز نمونه‌برداری، شش نمونه هر کدام شامل ۲۰ بار توزدن به وسیله‌ی یک تور حشره‌گیری با قطر ۳۸ سانتی‌متر برداشته شد و همچنین شش نمونه هر کدام شامل ۲۰ ساقه‌ی یونجه برداشت شد. نتایج حاصل از برداشت نواری یونجه نشان داد که درصد *Hippodamia variegata* Goeze، *Nabis* spp.، *Deraeocoris* spp.، *Orius* spp.، *Geocoris* spp. و پارازیتوئیدهای شته‌ها در مزرعه برداشت نواری یونجه به ترتیب ۳۸٪، ۹۵٪، ۱۱۹٪، ۵۷٪، ۱۰۰٪ و ۱۲۲٪ بیشتر از تعداد آن‌ها در مزرعه برداشت کامل یونجه بود و برعکس، درصد *Acyrthosiphon pisum* (Harris) و *Therioaphis trifolii* (Monell) forma *maculat* (Buckton) در مزرعه برداشت نواری یونجه به ترتیب ۲٤٪ و ۲۸٪ کمتر از تعداد آن‌ها در مزرعه برداشت کامل یونجه بود.
واژگان کلیدی: شته‌های یونجه، شکارگرهای شته‌ها، پارازیتوئیدهای شته‌ها، دشمنان طبیعی، برداشت نواری

Introduction

Alfalfa (*Medicago sativa* L.) is the most widely used forage (Walton, 1983) with highest feeding value within the entire commonly grown hay crops and more protein producing per hectare than any other crops for livestock (Hanson & Barnes, 1988). More than half a million hectare of alfalfa hay is grown in Iran, of which about 26 thousand hectare is located in Isfahan province (Anonymous, 2006).

The aphids that attack to alfalfa are well-known in Iran and some other countries (Neuenschwander *et al*., 1975; Harper, 1978; Aeschlimann, 1981; Monajemi & Esmaili,

1981; Takahashi & Naito, 1984; Rasoulian, 1985). The *Therioaphis trifolii* (Monell), *Acyrthosiphon pisum* (Harris) and *A. kondoi* Shinji have been recorded as the major pests of alfalfa in Australia (Grimm, 1972) and New Zealand (Rohitha *et al*., 1985). The *Aphis craccivora* Koch, *A. pisum* and *T. trifolii* were the aphid species recorded each year in Spain (Pons & Lloveras, 1999). Two aphids, *A. pisum* and *A. kondoi*, were recorded as the most abundant alfalfa aphids in Japan (Takahashi & Naito, 1984). Grigorov (1982) noted that the main aphids of alfalfa in Bulgaria were *A. pisum* and *T. trifolii*. Rasoulian (1985) and Monajemi & Esmaili (1981) recorded *A. pisum, A. komdoi*, *A. craccivora* and *T. trifolii* as major pests of alfalfa in Karaj, Iran.

Alfalfa aphid natural enemies have been studied by some other research workers (Wheeler, 1974, 1977, 1978; Neuenschwander *et al*., 1975; Summers, 1976; Harper, 1978; Aeschlimann, 1981; Monajemi & Esmaili, 1981; Takahashi & Naito, 1984; Rasoulian, 1985; Nakashima & Akashi, 2005; Rakhshani *et al*., 2006). Abdulmadzhid (1973) recorded 11 species of Coccinellidae, six species of Syrphidae, four species of Chrysopidae and one species of Nabidae and Aphidiinae that attack alfalfa aphids in Bulgaria. Takahashi & Naito (1984) recorded *Coccinella septempunctata* L., *Harmonia axyridis* (Pallas) and *Propylea japonica* (Thunberg) as the main coccinellid predators of alfalfa aphids in Japan. *Coccinella transversoguttata richardsoni* Brown, *Hippodamia parenthesis* (Say), *H. quinquesignata* (Kby), *H. tredecimpunctata tibialis* (Say), *H. sinuata disjuncta* Timb (Col.: Coccinellidae), *Scavea pyrastri* (L.) (Dip.: Syrphidae), *Nabis alternatus* Parshley (Hem.: Nabidae), *Orius tristicolor* (White) (Hem.: Anthocoridae), *Aeolothrips fasciatus* (L.) (Thys.: Aeolothripidae) and *Chrysopa oculata* Say were recorded as important predators of alfalfa aphids in Canada (Harper, 1978). Monajemi & Esmaili (1981) and Rasoulian (1985) recorded 18 and 19 species of alfalfa aphid natural enemies, respectively in Karaj, Iran. Aeschlimann (1981) found seven primary and 12 secondary parasites associated with alfalfa aphids in the Mediterranean region. Rakhshani *et al*. (2006) recorded 11 aphid parasitoid species in alfalfa fields in different parts of Iran.

Many agroecosystems are unfavorable environments for natural enemies due to high level of disturbance. Habitat management, a form of conservation biological control, is an ecologically based approach aimed at favouring natural enemies and enhancing biological control in agricultural systems (Landis & Wratten, 2000). Vegetation diversity augments natural enemies by providing supplemental resources, such as pollen, nectar, or other prey species, additional shelter and improved microclimate for the natural enemies (Kogan *et al*.,

1998). A form of conservation biological control involving modified harvesting patterns of alfalfa as strip-harvesting system was developed by Stern *et al*. (1964). Their method provided two growth stages of alfalfa in the same field at all times, which resulted in significant reduction of *Lygus* spp. emigration. Strip-harvesting also has a marked influence on a variety of other insects. It produces greater stability in the alfalfa ecosystem and prevents emigration of many natural enemy species at harvest (Summers, 1976). In this system, as the populations of natural enemies increase, those of insect pests, especially aphids, decrease (Anonymous, 1981). Strip-harvesting has been used to manage many insect pests (Rakickas & Watson, 1974; Summers, 1976; Hossain *et al*., 2001; Weiser *et al*., 2003).

In this study we attempted to identify the alfalfa aphids and their associated natural enemies in Isfahan and study the effect of strip-harvesting on population density of two alfalfa aphid species: *A. pisum* and *T. trifolii* and some of their natural enemies such as *Hippodamia variegata* Goeze, *Nabis* spp., *Deraeocoris* spp., *Orius* spp., *Geocoris* spp. and also aphid parasitoids.

Materials and methods

Alfalfa aphids and their natural enemies

In order to collect alfalfa aphids and their natural enemies, sampling was done from approximately 30 alfalfa fields in Isfahan province in different intervals for two years from 24 May till 22 November 2004 and 28 February till 21 November 2005. The sampling was carried out weekly at the Isfahan University of Technology Experiment Station (Lavark), 40 km west of Isfahan, Iran. At Borkhar region, 30 km north of Isfahan, and Ziar region, 50 km southeast of Isfahan, samples were taken fortnightly, while in the other regions samples were collected monthly. On each sampling date, six 20-sweep samples were taken using a 38cm-diameter sweep-net and also six 20-stem were sampled. Samples were labelled, placed in plastic bags and transported to the laboratory for separating and counting. Also, during these sampling programmes, mummified aphids and predatory larvae were collected and reared in the laboratory until the adult insects emerged. Mounted specimens were sent to specialists for identification.

Experimental site and design for alfalfa strip-harvesting

This study was conducted at the Isfahan University of Technology Experiment Station (32° 32′ N, 51° 23′ E), 40 km southwest of Isfahan, Iran, in an alfalfa field of 12 irrigated

strips, each 4 × 200 m. In June 2005 half of the area of the field was converted to a strip-cut regime and a randomised complete block design comprising harvested and unharvested strips of alfalfa with three replications was performed on it by allowing all strips to grow and then three strips of them cut approximately one week before normal harvesting would have occurred. The alternate strips were cut some two weeks later to give time to strips that were out of phase to grow by approximately two weeks. The strips in each of the two treatments were subsequently cut at the appropriate growth stage (approximately 10% flowering) to maintain their asynchronous growth. Also, the other half of the field was cut conventionally (non strip) at the same time as three strips in strip-harvesting area of the field with no replication used in comparison. Twenty alfalfa stems in each strip were randomly sampled weekly, from 23 of June till 10 of October 2005 (18 weeks), to assess aphid population density. Also, twenty standard (15 inch) 180° sweep samples in each strip were taken randomly to assess aphid natural enemies. Samples were placed in bags, labelled and then transported to the laboratory for counting.

Statistical analyses

The data from every of three sites in each of two years were analyzed via ANOVA. Similarly, the dataset of strip-harvested field conducted in a randomised block design comprising harvested and unharvested strips of alfalfa was analysed by way of ANOVA. Additionally, the combined analysis of variance was used for the data obtained from strip-harvested and conventionally-harvested alfalfa fields. Statistical significance at $P < 0.05$ between the numbers of insects in each treatment was determined by using LSD method (SAS Institute, 1998).

Results

Alfalfa aphids and their natural enemies

In the present work a total of four aphid species and 58 species of their natural enemies including 45 predators (table 1), 11 parasitoids (table 2) and two parasitic mites were collected and identified. In all of three main sites studied, the dominant aphid was *T. trifolii* forma *maculata* (Buckton) (with more than 60% out of all aphid species) followed by *A. pisum* on the basis of their densities. The latter species was comprised of two distinct biotypes (green and red). The *A. craccivora* and also *A. kondoi* were found in low densities (table 3).

Table 1. Alfalfa aphid predators collected in Isfahan, Iran.

Coleoptera	**Chamaemyiidae**
Coccinellidae	*Leucopis annulipes* Zetterstedt
Adalia bipunctata L.	*L. glyphinivora* Tanasijtshuk
Coccinella septempunctata L.	**Neuroptera**
C. undecimpunctata L.	**Chrysopidae**
Exochomus nigromaculatus Goeze	*Chrysopa dubitans* (McLachlan)
Hippodamia tredecimpunctata L.	*Chrysoperla* sp.
H. variegata Goeze	**Hemiptera**
Hyperaspis sp.	**Anthocoridae**
Oenopia conglobata L.	*Anthocoris pilosus* (Jak.)
Propylea quatourdecimpunctata L.	*Orius niger* Wolff
Scymnus aptezi Mulsant	*O. albidipennis* (Rt.)
S. flavicollis Redtenbacher	**Lygaeidae**
S. mongolicus (Weise)	*Geocoris acutipes* Signoret
S. pallipes Mulsant	*G. ater* (Fabricius)
Diptera	*G. megacephalus* Rossi
Syrphidae	*G. pallidipennis* (Costa)
Episyrphus balteatus (De Geer)	*G. pubescens* (Jak.)
Eristalis arbustorum L.	**Miridae**
Eupeodes corollae (Fabricius)	*Campylomma diversicornis* Rt.
E. nuba (Wiedemann)	*Deraeocoris pilipes* Rt.
Ischiodon scutellaris (Fabricius)	*D. punctulatus* (Fallen)
Melanostoma mellinum L.	*D. serenus* Dgl.
Paragus bicolor (Fabricus)	**Nabidae**
P. compeditus Wiedemann	*Nabis capsiformis* Germ.
P. heamorrhous Meigen	*N. punctatus* A. Costa
Sphaerophoria rueppelli (Wied.)	**Reduviidae**
S. scripta L.	*Nagusta goedelii* (Kolenati)
S. turkmenica Bankowska	**Thysanoptera**
	Aeolothripidae
	Aeolothrips intermedius Bagnall

Table 2. Alfalfa aphid parasitoids (Hym.: Braconidae: Aphidiinae) collected in Isfahan, Iran; and their hosts.

Parasitoid species	**Host aphid**
Aphidius colemani Viereck	*Aphis craccivora*
A. eadyi Stary	*Acyrthosiphon pisum*
A. ervi Haliday	*Acyrthosiphon* spp.
A. matricariae Haliday	*A. craccivora*
A. smithi Sharma & Subba Rao	*A. pisum*
Diaeretiella rapae (McIntosh)	*A. craccivora*
Lysiphlebus fabarum (Marshall)	*A. craccivora*
Praon barbatum Mackauer	*A. pisum*
P. exsoletum (Nees)	*Therioaphis trifolii*
P. volucre (Haliday)	*A. pisum, A. craccivora, T. trifolii*
Trioxys complanatus Quilis	*T. trifolii*

Table 3. Mean number and percentage of alfalfa aphids (per 20 stems) and aphid natural enemies (per 20 sweeps) in three regions and two years in Isfahan (Iran).

		Lavark region				Borkhar region				Ziar region			
	Taxa	**2004**	**(%)**	**2005**	**(%)**	**2004**	**(%)**	**2005**	**(%)**	**2004**	**(%)**	**2005**	**(%)**
Aphids	*T. trifolii*	21.96a*	61%	28.33a	60.3%	26.33a	65.2%	48.38a	80%	39.21a	73%	74.77a	97.9%
	A. pisum	12.20b	33.9%	17.49b	37.2%	13.78b	34.1%	11.83b	19.6%	13.83b	25.7%	0.76b	1.6%
	A. craccivora	1.83c	5.1%	2.15c	2.4%	0.29c	0.7%	0.29c	0.5%	0.69c	1.3%	0.24b	0.5%
	LSD:	1.38	-	1.35	-	1.82	-	2.24	-	2.06	-	1.95	-
Coccinellids	*H. variegata*	8.01a	85.8%	6.87a	71.7%	13.03a	88.1%	24.08a	85.5%	12.56a	87.2%	15.21a	68.4%
	C. septempunctata	0.64b	6.9%	1.33b	13.9%	0.44b	3%	1.51b,c	5.4%	0.47b	3.3%	0.43c	1.9%
	C. undecimpunctata	0.36b	3.9%	0.92c	9.6%	0.93b	6.3%	2.24b	7.9%	0.72b	5%	5.79b	26%
	Other Coccinellids	0.33b	3.5%	0.46d	4.8%	0.39b	2.6%	0.35c	1.2%	0.65b	4.5%	0.81c	3.6%
	LSD:	0.36	-	0.40	-	0.71	-	1.18	-	0.63	-	0.98	-
Hemiptera	*Orius* spp.	7.48a	47.3%	9.40b	38.5%	4.03b	30.5%	9.78b	29.5%	7.75a	53.8%	19.36a	54.3%
	Deraeocoris spp.	4.53b	28.6%	10.14a	41.6%	6.25a	47.2%	19.82a	59.8%	3.18b	22.1%	13.54b	38%
	Nabis spp.	2.37c	15%	3.19c	13.1%	2.44c	18.4%	2.75c	8.3%	2.76b	19.2%	2.51c	7%
	Geocoris spp.	1.45d	9.2%	1.67d	6.8%	0.51d	3.9%	0.79d	2.4%	0.72c	5%	0.24d	0.7%
	LSD:	0.59	-	0.64	-	0.58	-	1.28	-	0.69	-	1.37	-
Syrphids	*S. scripta*	1.77a	49.4%	0.81a	40.5%	0.65a	41.4%	0.15a	16.9%	0.47a	36.7%	0.05b	9.3%
	S. turkmenica	1.07b	29.9%	0.75a	37.5%	0.38b	24.2%	0.31a	34.8%	0.28b	21.9%	0.22a	40.7%
	S. ruepelli	0.44c	12.3%	0.12b	10.6%	0.26b	16.6%	0.15a	16.9%	0.21b	16.4%	0.13ab	24.1%
	Other Syrphids	0.30c	8.4%	0.24b	12%	0.28b	17.8%	0.28a	31.5%	0..32ab	25%	0.14ab	25.9%
	LSD:	0.21	-	0.15	-	0.16	-	0.16	-	0.18	-	0.13	-
Parasitoids	*A. ervi*	-	-	5.11a	86.6%	-	-	0.26c	13.1%	-	-	1.14c	10.7%
	P. exsoletum	-	-	0.30b	5.15	-	-	0.54b	27.3%	-	-	2.68b	25.1%
	T. complanatus	-	-	0.12b	2%	-	-	0.90a	45.5%	-	-	6.45a	60.4%
	Other Aphidiinae	-	-	0.37b	6.3%	-	-	0.28c	14.1%	-	-	0.40c	3.7%
	LSD:	-	-	0.30	-	-	-	0.21	-	-	-	0.67	-

*Means with different letters (a, b, c, and d) in each column indicate significant difference ($P < 0.05$) among insects in each group (e.g. Aphids).
For Lavark region: N = 162. For Borkhar and Ziar regions: N = 72.

In this survey, 13 predatory coccinellids were collected. The *H. variegata*, which comprised at least 68% of collected coccinellids, was the most abundant in all three main study regions. Afterwards, *C. septempunctata* was the second most common coccinellid in Lavark region while *C. undecimpunctata* L. was the third (table 3). However, in Borkhar and Ziar regions *C. undecimpunctata* was the second most common coccinellids and *C. septempunctata* was the third (table 3). Other coccinellids were found in lower densities.

Two syrphid species, *Sphaerophoria scripta* L. and *S. turkmenica* Bankowska, were the most abundant out of 12 syrphids bred on alfalfa in the entire regions studied, whereas *S. rueppelli* (Wied.) was the third most common syrphid. The *S. scripta* was the most abundant syrphid in Lavark region in both years followed by *S. turkmenica* and *S. ruepelli*. Similar pattern was observed in Borkhar and Ziar regions in the year 2004. Conversely, in the year 2005, *S. turkmenica* was the most abundant syrphid followed by *S. scripta* and *S. ruepelli* (table 3). The larvae of syrphids were scarce in all regions during this survey and most of syrphid larvae collected were parasitized by *Diplazon laetatorius* (Fabricius) (Hymenoptera: Ichneumonidae). It is worth mentioning that two fly species belonging to the family Chamaemyiidae, viz. *Leucopis annulipes* Zetterstedt and *L. glyphinivora* Tanasijtshuk, were collected from alfalfa fields of which the larvae of *L. annulipes* were observed to prey on cowpea aphids, *A. craccivora*.

Majority of chrysopids collected belonged to the genus *Chrysoperla* Steinmann (Neu.: Chrysopidae). Also, *Chrysopa dubitans* (McLachlan) was found in low density during this study.

Fifteen species belonging to five families were collected from the order Hemiptera (table 1). *Orius niger* Wolff and *O. albidipennis* (Rt.) were identified as the most abundant predatory anthocorids in this study while *Anthocoris pilosus* (Jak.) was observed in very low density. Five predatory lygaeid bugs from the genus *Geocoris* Fallen were collected, of which *G. pallidipennis* (Costa), and *G. megacephalus* Rossi were two most abundant species in all regions. Majority of four collected species of predatory mirids belonged to *Deraeocoris punctulatus* (Fallen) followed by *Campylomma diversicornis* Rt. Other two predatory mirid species (table 1) were less common. *Nabis punctatus* A. Costa was the most abundant predatory nabid followed by *N. capsiformis* Germ. In this survey, only one predatory reduviid was collected and identified as *Nagusta goedelii* (Kolenati) in low densities, and recorded as predator of pea aphid, *A. pisum*.

Among hemipterous predators, both groupings of *Orius* spp. and *Deraeocoris* spp. were the most frequent groups recorded in the entire three studied regions; though, their abundance was different. In Lavark region in 2004, the grouping of *Orius* spp. was the most abundant hemipterous predators followed by *Deraeocoris* spp.; nevertheless, in 2005, the grouping of *Deraeocoris* spp. was the most abundant followed by *Orius* spp. In Borkhar region, *Deraeocoris* spp. were the most numerous in both years while in Ziar region, *Orius* spp. were the most common hemipterous predators. The grouping of *Nabis* spp. was the third most common hemipterous predators in all studied regions for both years, followed by *Geocoris* spp. (table 3).

The *Aeolothrips intermedius* Bagnall was the most common predatory thrips. It was observed frequently in all three regions studied.

The hymenopterous parasitoids of alfalfa aphids belonged to Braconidae: Aphidiinae (table 2). A total of 11 parasitoid species were collected, of which *Aphidius ervi* Haliday (parasitoid of *Acyrthosiphon* spp.) comprised 86.6% of the collected Aphidiinae in Lavark region in 2005. In Borkhar and Ziar regions, *Trioxys complanatus* Quilis (parasitoid of *T. trifolii*) was the most abundant followed by *Praon exsoletum* (Nees) (parasitoid of *T. trifolii*) and *A. ervi* (table 3).

Additionally, five hymenopterous hyperparasitoid species were reared: *Alloxysta* sp. (Charipidae) that was reared from mummified *T. trifolii*; *Asaphes vulgaris* Walker (Pteromalidae) reared from mummified *A. pisum* and *A. craccivora*; *Dendrocerus carpenteri* (Curtis) (Megaspilidae) reared from mummified *A. craccivora* and *T. trifolii*; *Pachyneuron aphidis* (Bouché) (Pteromalidae) reared from mummified *A. craccivora*, *A. pisum* and *T. trifolii*; and *Syrphophagus aphidivorus* (Mayr) (Encyrtidae) reared from mummified *A. craccivora*.

Two aphid parasitic mites, including *Monotrombium simplicium* Zhang (Trombidiidae) and *Erythraeus hypertrichotus* Saboori, Goldarazena & Khajeali were collected. These mites were observed to feed on the aphids, *T. trifolii* and *A. craccivora*, respectively.

Alfalfa strip-harvesting

After cutting alfalfa in strips with appropriate growth stage within strip-harvested field, *H. variegata* moved to adjacent uncut strips and their numbers increased on uncut strips. In the first sampling dates after harvesting alfalfa, especially before 8th August, and also on 3rd October, the number of this predator was significantly higher in the unharvested strips than in

the harvested strips ($P < 0.05$). In the second sampling dates after harvesting alfalfa, some of these predators moved from unharvested strips to regrowth strips and their number increased because of the regrowth of the harvested strips (fig. 1-a).

The number of *Nabis* spp. on 13 sampling dates (except sampling dates in which these predators were in low densities) was significantly higher in the unharvested strips than in the harvested strips ($P < 0.05$) (fig. 1-b). Nearly similar trends were observed for *Deraeocoris* spp. as their density was significantly higher in the unharvested strips in comparison to the harvested strips on 11 sampling dates ($P < 0.05$) (fig. 1-c). The results of *Orius* spp. showed that when they were more numerous, particularly in June and July, their numbers were higher in the unharvested strips than in the harvested strips ($P < 0.05$) (fig. 1-d). Movement trend of *Geocoris* spp. from harvested strips to adjacent unharvested strips was not in a regular pattern. On five sampling dates (8 August, 22 August, 19 September, 3 October and 10 October), their numbers were significantly higher in unharvested strips than in harvested strips ($P < 0.05$). Conversely, on three sampling dates (27 June, 18 July and 29 August), their numbers were significantly higher in the harvested strips than the unharvested strips ($P < 0.05$) (fig. 1-e).

Results of aphid parasitoids showed that they were abundant merely in June and October, and in these days, their numbers were significantly higher in the unharvested strips than the harvested strips ($P < 0.05$) (fig. 1-f). The results of 18 weeks sampling dates for comparing the percentage of aphids and their natural enemies in strip-harvested field and conventionally-harvested ones showed that the mean percentage of *H. variegata*, *Nabis* spp., *Deraeocoris* spp., *Orius* spp., *Geocoris* spp. and aphid parasitoids in strip-harvested field were 38%, 95%, 119%, 57%, 100% and 122%, respectively, higher than those in conventionally-harvested field ($P < 0.05$). Conversely, the mean numbers of *A. pisum* and *T. trifolii* were 24% and 28%, respectively, lower in strip-harvested field than in conventionally-harvested field ($P < 0.05$) (table 4).

Discussion

In this study we found that *T. trifolii* forma *maculata* and *A. pisum* were the most abundant alfalfa aphids in Isfahan. These species are also reported from Australia (Grimm, 1972), New Zealand (Rohitha *et al*., 1985), Spain (Pons & Lloveras, 1999), Bulgaria (Grigorov, 1982) and other parts of Iran (Monajemi & Esmaili, 1981; Rasoulian, 1985) as major pests of alfalfa. Although alfalfa is reported to be the host of many aphid species (Pimentel & Wheeler, 1973; Rezwani, 1987; Blackman & Eastop, 2000), only four of them

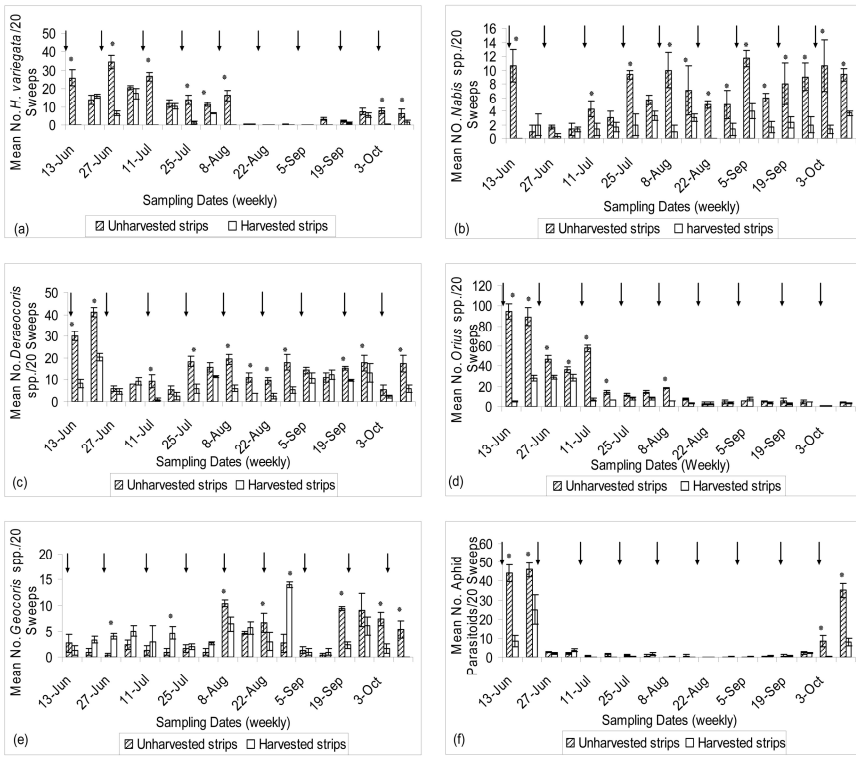

Figure 1. Comparison of mean number of aphid natural enemy densities in harvested (white) and unharvested (hatched) strips within strip-harvested field. Symbol ↓ shows harvesting date and * denote significant treatment difference within a sample date between unharvested and harvested strips at $P < 0.05$. Error bars show ± Standard Error.

Table 4. Mean number of aphids/20 stems and aphid natural enemies/20 sweeps collected from strip-harvested and conventionally-harvested alfalfa fields during 18 sampling weeks.

Taxa	Strip-harvested field	Conventionally harvested field	Difference	LSD
Hippodamia variegata	7.47	5.38	+38 % (s)	1.03
Nabis spp.	4.19	2.14	+95 % (s)	0.93
Deraeocoris spp.	11.34	5.16	+119 % (s)	3.99
Orius spp.	16.24	10.33	+57 % (s)	1.87
Geocoris spp.	3.75	1.87	+100 % (s)	1.35
Aphid parasitoids	5.65	2.54	+122 % (s)	1.78
Acyrthosiphon pisum	12.69	16.64	-24 % (s)	1.02
Therioaphis trifolii	23.43	32.57	-28 % (s)	3.13

(s): denotes significant difference between the two alfalfa fields.

(*A. pisum*, *A. kondoi*, *A. craccivora* and *T. trifolii*) are the major pests of alfalfa in the world (Neuenschwander *et al*., 1975; Aeschlimann, 1981; Monajemi & Esmaili, 1981; Takahashi & Naito, 1984; Rasoulian, 1985).

Alfalfa aphid natural enemies that we identified in this study were virtually similar to those reported from other parts of the world, at least in generic level. Alfalfa aphid parasitoids that were found in this study are similar to those reported from the Mediterranean region (Aeschlimann, 1981), Australia (Holtkamp & Bishop, 1983) and from other parts of Iran (Monajemi & Esmaili, 1981; Rasoulian, 1985; Rakhshani *et al*., 2006). Also, a similar specific or at least generic composition of aphid parasitoids has been recorded in Japan (Gonzalez *et al*., 1979), Bulgaria (Grigorov, 1982), and Ithaca, New York (Pimentel & Wheeler, 1973; Wheeler, 1978). A similar generic composition of predators such as *Coccinella* L., *Hippodamia* Dejean, *Chrysopa* Leach, *Nabis* Latreille, *Orius* Wolff and *Geocoris* has been found in Bulgaria (Abdulmadzhid, 1973), Canada (Harper, 1978; Schaber, 1992), Japan (Takahashi & Naito, 1984; Nakashima & Akashi, 2005), Berkeley, USA (Neuenschwander *et al*., 1975), Ithaca, New York (Pimentel & Wheeler, 1973; Wheeler, 1974 & 1977) and other parts of Iran (Monajemi & Esmaili, 1981; Rasoulian, 1985) too.

Although alfalfa aphid predators and parasitoids fauna of different parts of the world show a similar generic make-up, in many cases their specific composition, frequency and temporal occurrence are strongly varied in different regions (Abdulmadzhid, 1973; Aeschlimann, 1981; Monajemi & Esmaili, 1981; Grigorov, 1982; Rasoulian, 1985; Pons & Lloveras, 1999). Variations in frequency and temporal occurrence of alfalfa aphids and their natural enemies in different regions are probably due to different weather conditions, soil characteristics, alfalfa varieties and other factors that may affect alfalfa aphid populations and their natural enemies (Anonymous, 1981; Monajemi & Esmaili, 1981; Rasoulian, 1985; Dixon, 1998; Pons & Lloveras, 1999).

In alfalfa strip-harvested system, we observed that the aphid predators such as *H. variegata*, *Nabis* spp., *Deraeocoris* spp. and *Orius* spp. moved from harvested strips to adjacent unharvested strips where these unharvested strips provide refuges for them. Other researchers have reported similar results in different situations of alfalfa strip cut system. Hossain *et al*. (2001) observed higher numbers of *Coccinella transversalis* Fabricius in uncut strips compared with harvested alfalfa. Rakickas & Watson (1974) documented that *O. tristicolor* consistently migrated to the half-grown alfalfa when the fully grown alfalfa was cut. Godfrey & Leigh (1994) found that strip harvesting in alfalfa attracted adult *Orius* spp.

and *Nabis* spp. Weiser *et al*. (2003) observed higher numbers of insect predators in unharvested strips compared with harvested alfalfa. Movement trend of *Geocoris* spp. from harvested to adjacent unharvested strips was not in a regular pattern. This trend is probably due to differences in distribution patterns of this predator in different seasons that need further research.

Additionally, we found that alfalfa strip-harvested field contained more aphid predators and fewer aphids as compared with conventionally-harvested field. Probably the lower number of aphids in strip-harvested field was resulted in the greater number of aphid natural enemies in strip-harvested field and their feeding upon aphids. This is confirmed by the work of Summers (1976) who found that population levels of natural enemy species remained higher and those of *A. pisum* were lower in the border-cut than in the solid-cut field throughout the season. Hossain *et al*. (2001) noted that predator populations were higher and those of *Helicoverpa* spp. larvae were lower in the strip-harvested alfalfa than in a contiguous area of the same crop in which conventional harvesting was used. According to Hossain *et al*. (2000a, 2000b, 2001, 2002) natural enemies exploit unharvested strips as refuges and the within-field community of natural enemies enhanced by strip-harvesting contributes towards pest management.

In another point of view, we increased vegetation diversity in alfalfa field by leaving unharvested strips therein, thereby conserving natural enemies. Summers (1976) noted that more stable environment created within the alfalfa ecosystem by the uncut hay reduced emigration of many natural enemy species at harvest. According to Andow (1991), diversity in agroecosystems may favour reduced pest pressure and enhanced activity of natural enemies.

According to Flint & van den Bosch (1981), it is particularly important, however, to proceed with caution when diversifying a managed ecosystem. The introduction of a new plant species may also provide alternate hosts for serious pests, especially plant pathogens. On some sampling dates during this study, we observed that alfalfa common leaf spot disease (*Pseudopeziza medicaginis* (Lib.) Sacc.) in unharvested strips within strip-harvested field was greater than in conventionally-harvested field. However, more studies are needed to determine the effect of this disease on alfalfa quality and yield reduction in strip-harvested field.

In this study we collected and identified a nearly vast range of alfalfa aphid natural enemies which are most important for control of aphids and specially to conserve aphid natural enemies by various forms of conservation biological methods such as habitat

management (Landis & Wratten, 2000), modification of harvesting patterns (Stern *et al*. 1964) which discussed above, vegetational diversity (Kogan *et al*., 1998), etc.

Acknowledgement

We would like to thank the following specialists for identifying the specimens: Mr Mehrparvar; Mr Bagheri; Mr Minaei; Dr Saboori; Dr Tomanovic, Belgrad, Yugoslavia; Dr Gaimari, California, USA; Dr Oswald, Texas, USA; Dr Moullet, France; and Dr Linnavuori Saukkokuja, Finland.

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Received: 19 August 2008
Accepted: 29 December 2009