

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Alfalfa management affects infestations of *Lygus rugulipennis* (Heteroptera: Miridae) on strawberries in northwestern Italy

This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/132579> since

Published version:

DOI:10.1016/j.cropro.2008.10.006

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)



UNIVERSITÀ DEGLI STUDI DI TORINO

This Accepted Author Manuscript (AAM) is copyrighted and published by Elsevier. It is posted here by agreement between Elsevier and the University of Turin. Changes resulting from the publishing process - such as editing, corrections, structural formatting, and other quality control mechanisms - may not be reflected in this version of the text. The definitive version of the text was subsequently published in:

Crop Protection, 28 (2), 190-195, February 2009, doi: 10.1016/j.cropro.2008.10.006

You may download, copy and otherwise use the AAM for non-commercial purposes provided that your license is limited by the following restrictions:

- (1) You may use this AAM for non-commercial purposes only under the terms of the CC-BY-NC-ND license.
- (2) The integrity of the work and identification of the author, copyright owner, and publisher must be preserved in any copy.
- (3) You must attribute this AAM in the following format: Creative Commons BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/deed.en>), [<http://www.sciencedirect.com/science/article/pii/S0261219408002019>]

1 Title: Alfalfa management affects infestations of *Lygus rugulipennis* (Heteroptera: Miridae)
2 on strawberries in northwestern Italy

3

4 Marco G. Pansa, Luciana Tavella

5

6 Di.Va.P.R.A. Entomologia e Zoologia applicate all'Ambiente "Carlo Vidano", University of
7 Torino, via L. da Vinci 44, I-10095 Grugliasco (TO), Italy.

8

9 Corresponding author: Luciana Tavella.

10 Phone +39 011 6708533, fax +39 011 6708535, luciana.tavella@unito.it

11

12 Abstract (<400 words)

13 *Lygus rugulipennis* (Heteroptera: Miridae) is a highly polyphagous plant bug that causes
14 severe damage on everbearing strawberries in NW Italy. In this area strawberry fields are
15 frequently surrounded by alfalfa and other forage crops on which plant bugs usually live and
16 reproduce until mowing or harvest. A 3-year research study was conducted to test the
17 attractiveness of some herbs, including alfalfa, for ovipositing *L. rugulipennis* females, and to
18 evaluate if appropriate management of neighbouring forage crops could affect bug infestation
19 levels and damage to strawberries. In 2005, the attractiveness to ovipositing females of 4 plant
20 species (strawberry, alfalfa, red clover and chamomile), each of which is abundant in NW
21 Italy, was evaluated in laboratory trials. In 2006 and 2007, the seasonal abundance of plant
22 bugs on strawberries and alfalfa was monitored in an experimental strawberry field with a
23 strip of alfalfa along two sides. During field surveys, the influence of alfalfa management,
24 including insecticide treatments in 2007, on plant bug numbers was assessed. In the
25 laboratory, females of *L. rugulipennis* preferred, in decreasing order, chamomile, alfalfa, red

26 clover and strawberry for oviposition. However, in the field, the majority of nymphs were
27 collected on strawberries over most of the growing season, showing that *L. rugulipennis* is
28 able to reproduce and develop on this plants. During field surveys, more species of plant bugs,
29 and more individuals, were observed on alfalfa, which although attractive for mirid bugs did
30 not prevent their migration to strawberries during periods of high population density. At such
31 times, an insecticide treatment on alfalfa kept plant bug infestations on strawberries under the
32 economic threshold.

33

34 Key words (3-6): European tarnished plant bug, plant attractiveness, alfalfa, field surveys,
35 plant preference trials

36

37 **Introduction**

38 Plant bugs (Heteroptera: Miridae) include noxious pests of several crops worldwide. Severe
39 damage due to their feeding activity is reported mainly on cotton in the US (Godfrey and
40 Leigh, 1994; Greene et al., 1999; Stewart and Layton, 2000; Carrière et al., 2006), Africa
41 (Stride, 1969) and Asia (Wu et al., 2002), but also on forage (Craig, 1963; Wipfli et al.,
42 1990), vegetables (Varis, 1978; Boivin et al., 1991; Jacobson, 2002) and fruit crops (Pree,
43 1985; Michaud et al., 1989; Michaud and Stewart, 1990; Arnoldi et al., 1991; Rhains et al.,
44 2002; Hardman et al., 2004; Fleury et al., 2006). In Europe the most serious and widespread
45 plant bug is *Lygus rugulipennis* Poppius, also known as the European tarnished plant bug
46 (ETPB). This species is polyphagous, and it can live and reproduce on both herbaceous and
47 arboreous, cultivated and wild plants. More than 400 host plants have been recorded,
48 belonging to over fifty plant families, among which Brassicaceae, Asteraceae and Fabaceae
49 are the most attractive (Holopainen and Varis, 1991).

50 In Italy, *L. rugulipennis* has affected both yield and quality of kenaf (Conti and Bin, 2001),
51 lettuce (Accinelli et al., 2005), peach (Tavella et al., 1996) and strawberries (Bosio and
52 Scarpelli, 1999). Beginning in the late 1990's, high rates of catfaced or buttoned fruits have
53 been observed in strawberry fields in northwestern Italy. This is probably due to the reduction
54 in use of broad-spectrum insecticides not compatible with IPM programmes largely adopted
55 in the area (Bosio and Scarpelli, 1999). With their feeding on developing fruits, nymphs and
56 adults of plant bugs disrupt the achenes and inhibit fruit development. Misshapen fruits
57 bearing apical seediness are worthless for fresh market and often also for processing
58 (Schaefers, 1966). Such symptoms are sometimes ignored because they are confused with
59 malformation due to poor pollination or adverse weather conditions (Easterbrook, 2000).

60 In NW Italy *L. rugulipennis* usually migrates to strawberry fields late in the growing season,
61 often as a consequence of cultural practices in the adjacent crops, such as mowing fodder or
62 harvesting winter cereals. The removal, or the reduction, of herbaceous host plants in the
63 agro-ecosystem induces the movement of ETPB adults to strawberry plants (Bosio and
64 Scarpelli, 1999). Therefore, damage is more severe on everbearing varieties, which in NW
65 Italy flower and fruit from June to October, as also observed in the UK (Easterbrook, 1996).

66 In strawberry fields, the control of plant bugs is generally achieved by applying insecticides
67 (Cross and Easterbrook, 1998), according to damage thresholds developed in various
68 countries (Schaefers, 1980; Jay et al., 2004). However, chemical control is difficult to apply
69 successfully in northwestern Italy because, following the recent EEC regulations, very few
70 selective and non-persistent products are now authorized on strawberries.

71 Alternative control measures have been investigated, mainly in North America and the UK, to
72 reduce the incidence of plant bugs on strawberries, i.e. reflective mulch between rows
73 (Rhains et al., 2001), vacuum devices to remove insects (Vincent and Chagnon, 2000;
74 Rancourt et al., 2003; Swezey et al., 2007), and augmentation of the egg parasitoid *Anaphes*

75 *iola* Girault (Hymenoptera: Mymaridae) (Norton and Welter, 1996; Udayagiri and Welter,
76 2000). However, these measures have often provided less effective control levels than with
77 conventional insecticides. Also the use of “trap crops”, i.e. plants more attractive and suitable
78 for the target pest than crop plants (Hokkanen, 1991), has been tested to avoid the migration
79 of plant bugs to strawberries in UK with conflicting results (Easterbrook and Tooley, 1999).
80 In NW Italy, strawberries are usually grown in agricultural areas where livestock and cereal
81 farming are widespread, often representing the main farm activities. Therefore, everbearing
82 strawberry fields are frequently surrounded by alfalfa and other forage crops on which plant
83 bugs live and reproduce until harvest. In recent years mirid damage to strawberries has been
84 increasing but at the same time the market requires more organic or integrated production.
85 This research was aimed at: i) testing the attractiveness for ovipositing females of selected
86 herbs, including alfalfa; ii) evaluating if appropriate management of the neighbouring forage
87 crops could affect plant bug infestation levels and, as a consequence, damage to strawberries.

88 **Materials and methods**

89 Collection and mass rearing of *L. rugulipennis*

90 During spring and summer, 2005, *L. rugulipennis* adults were collected monthly using a
91 sweep net in 3 sites: Moretta, Boves and Lagnasco (province of Cuneo, Piedmont, NW Italy),
92 and transferred to our laboratories (Di.Va.P.R.A., University of Torino). Here, they were first
93 identified using the key of Wagner and Weber (1964); then they were reared on French bean
94 pods (*Phaseolus vulgaris* L., Fabaceae) and sprouted potatoes (*Solanum tuberosum* L.,
95 Solanaceae) inside 3L plastic boxes. The lid of these boxes (265mm×175mm) was cut in the
96 middle and closed with net. Mass rearing was conducted in climatic chambers maintained at
97 25±1°C, 70±5% RH and a 16L:8D photoperiod.

98 Evaluation of plant attractiveness in the laboratory

99 In 2005, laboratory trials were carried out to evaluate the attractiveness to ovipositing females
100 of 3 plant species [alfalfa, *Medicago sativa* L. (Fabaceae), var. Europa (10%) and Elena
101 (90%) (Bottos Sementi, Italy); red clover, *Trifolium pratense* L. (Fabaceae), var. Viola
102 (Bottos Sementi, Italy); chamomile, *Matricaria chamomilla* L. (Asteraceae) (Semeurop,
103 Italy)] versus strawberry [*Fragaria x ananassa* Duchesne cv Diamante (Rosaceae)]. Alfalfa,
104 red clover and chamomile were chosen because they are common in northwestern Italy and
105 are well-known host plants of *L. rugulipennis* (Holopainen and Varis, 1991) and, more
106 generally, of the genus *Lygus* (Esquivel and Mowery, 2007).

107 The trials were conducted using Plexiglass and net cages (300×300×300mm) placed in
108 climatic chambers under the same conditions as the mass rearing. Inside each cage, 4
109 similarly-sized potted plants (1 strawberry, 1 alfalfa, 1 clover, 1 chamomile) were carefully
110 arranged so that one plant was never in contact with another. Ten-day-old mass reared *L.*
111 *rugulipennis* adults (12 females, 8 males) were introduced to the middle-bottom of each cage.
112 Adults were kept for 7 days [i.e. embryonic development time assessed in previous
113 experiments (unpublished data)], after which they were removed and counted. Plants were
114 also removed from the cages, carefully surveyed and singly isolated in a Plexiglass cylinder
115 (height 200mm, Ø 120mm) placed on each pot. Each plant was then kept in climatic
116 chambers under the conditions described above, and checked daily to assess the presence of
117 newly hatched nymphs. To facilitate the inspection, a white paper disk (Ø 120mm) was
118 placed at the base of the plant. The plants were checked until no nymphs were seen for 4 days.
119 Overall, 12 replications of the experiment were made.

120 Evaluation of the impact of alfalfa on bug infestation on strawberries in the field

121 In 2006 and 2007, field trials were carried out in Boves, Piedmont, NW Italy (44°20'N
122 7°32'E, 580m a.s.l.) to survey the seasonal abundance of plant bugs on strawberries and on
123 alfalfa, and to evaluate the influence of management of alfalfa on the bug infestation on

124 strawberries. For the trials, a strawberry field of 432m² (80×5.4m), consisting of 5 rows of an
125 everbearing variety (cv Albion), was planted in early April 2006. Throughout the growing
126 season, from late May to September in both years, the field was covered with a black shading
127 net, as usually performed on strawberries in this area. Along the two major sides, 2 strips of
128 alfalfa (80×4m) were sown in late April 2006; in both years the alfalfa was irrigated monthly
129 during spring and late summer, and weekly in July and August, and mowed at the beginning
130 of flowering, namely 3 times in 2006 (4 July, 20 July, and 20 August) and 5 times in 2007 (25
131 May, 21 June, 8 July, 30 August, and 17 September). During mowing, alfalfa was cut
132 alternately only on half of each strip, i.e. half near the strawberry field on one side and half far
133 from the strawberry field on the other side (Fig. 1). This practice was to ensure that alfalfa
134 was available to the plant bugs throughout the experiment.

135 In 2006, plant bugs were sampled every two weeks on strawberries and neighbouring alfalfa
136 from 8 June to 11 October. On strawberries, sampling was carried out on 6 groups of 10
137 plants: the foliage of each plant was first visually inspected and then beaten on a white dish
138 (Ø 330mm). On alfalfa, plant bugs were sampled using a sweep net, 3 series of 10 sweeps per
139 each side. All nymphs and adults collected on strawberries and alfalfa were counted, and
140 identified following Wagner and Weber (1964) and Rinne (1989).

141 In 2007, to evaluate if chemical treatments on alfalfa could prevent bug migration to
142 strawberries, the field was divided into 2 plots (A_{str} and B_{str}), as well as the neighbouring
143 alfalfa strips (A_{alf} and B_{alf}) (Fig. 1). On strawberries the same horticultural practices were
144 adopted in the 2 plots; on alfalfa, in one plot per strip (A_{alf}, control) no treatments were
145 applied, whereas in the other plot (B_{alf}) chemicals were used when plant bug populations
146 increased and exceeded on average 2 individuals per sweep. Two treatments were made, one
147 with λ-cyhalothrin (Karate xpress®, Syngenta Crop Protection, Switzerland) on 10 July, and
148 one with etofenprox (Trebon star®, Sipcam, Italy) on 17 September. In 2007 plant bugs were

149 sampled every two weeks from 16 May to 3 October. Sampling was carried out with the same
150 methods adopted in 2006, on 3 groups of 10 plants per plot on strawberries, and with 4 series
151 of 10 sweeps per each plot on neighbouring alfalfa.

152 Statistical analysis

153 In the laboratory trials, the numbers of nymphs detected on each plant species were compared
154 using a non-parametric analysis (Kruskal-Wallis); values were separated by Mann-Whitney's
155 test ($p < 0.05$) when the Kruskal-Wallis analysis was significant (SPSS[®] 12.0 version). To
156 compare plant bug populations in the plots (A_{str} and B_{str} ; A_{alf} and B_{alf}) during field trials in
157 2007, sampling data on each date were firstly tested for homogeneity of variance (Levene
158 test) and normality (Shapiro-Wilk test) (SPSS[®] 12.0 version). On strawberries, numbers of
159 bugs collected on the 30 plants per plot were analyzed by a non-parametric analysis (Kruskal-
160 Wallis) because variance homogeneity test and normality test failed. On alfalfa, numbers of
161 bugs collected in 4 series of 10 sweeps per plot were compared with a one-way analysis of
162 variance (ANOVA), with a 5% significance threshold (SPSS[®] 12.0 version).

163 **Results**

164 Evaluation of plant attractiveness in the laboratory

165 In the laboratory, for oviposition *L. rugulipennis* females preferred, in decreasing order:
166 chamomile, alfalfa, red clover and strawberry (Fig. 2). During the trials, adult mortality
167 ranged between 0-22%, and was on average slightly higher in males than in females (14%
168 males and 9% females). Newly hatched nymphs were observed between the 6th and the 16th
169 day after the isolation of single plants inside Plexiglass cylinders, with maximum densities
170 between the 7th and the 11th day. Moreover, nymphs were not found on strawberries in 4 out
171 of 12 replications, whereas they were always observed, although in different amounts, on the
172 other plant species in all replications.

173 Evaluation of the impact of alfalfa on bug infestation on strawberries in the field

174 The total numbers of plant bugs collected on strawberries and alfalfa in 2006 and 2007 are
175 reported in Tables 1 and 2, respectively. In both crops and years *L. rugulipennis* was the
176 predominant plant bug species. Other plant bugs sampled only occasionally on strawberries
177 but more frequently on alfalfa were *Lygus pratensis* L., and *Adelphocoris lineolatus* (Goeze).
178 The latter species was rare on strawberries but very abundant on alfalfa especially in 2007.
179 Another plant bug species, *Polymerus vulneratus* (Panzer), was common on alfalfa but never
180 collected on strawberries. Generally, the majority of the field-collected plant bugs were
181 nymphs. For example, in 2006, nymphs comprised 89% and 77% of the total plant bugs
182 collected on strawberries and on alfalfa, respectively (Table 1). In 2007, nymphs were always
183 more abundant than adults, even if with lower percentages, 77% and 59% of collected insects
184 were nymphs on strawberries and alfalfa, respectively (Table 2). Within the genus *Lygus*,
185 nymphs were not identified to the species level, but on the basis of adult collection they were
186 considered to belong mostly to *L. rugulipennis* (Tables 1 and 2).

187 In 2006, plant bugs were first detected on alfalfa and on strawberries in early and late June,
188 respectively (Fig. 3). On these sampling dates, only adults were collected, whereas in the
189 following dates nymphs were collected in greater numbers as well on both alfalfa and
190 strawberries. Plant bug populations showed similar trends on both crops with two peaks. The
191 first peak occurred on alfalfa (52.7 individuals per 10 sweeps) on 13 July and later on
192 strawberries (0.6 individuals per plant) on 26 July. The second peak occurred on both alfalfa
193 (51.5 individuals per 10 sweeps) and strawberries (1.4 individuals per plant) on 5 September.
194 Although alfalfa was cut only on half of each strip, population increase was observed on
195 strawberries after mowing alfalfa on 4 July, 20 July, and 20 August.

196 In 2007, plant bugs were present in both plots on strawberries and alfalfa already during the
197 first field survey in mid-May, before strawberry flowering (Fig. 4). From this date until mid-
198 July the population trend on strawberries was similar in both plots A_{str} and B_{str} (near untreated

199 and treated alfalfa, respectively), reaching infestation levels of 0.4 individuals per plant on 11
200 July, immediately after the treatment with λ -cyhalothrin on alfalfa in the plot B_{alf} on 10 July.
201 Afterwards bug populations decreased on strawberries in both plots. However, higher
202 population levels were observed in the plot A_{str} (near untreated alfalfa), where the population
203 reached a second peak of 0.4 individuals per plant on 22 August, and thereafter declined
204 gradually until the last sampling on 3 October. In the plot B_{str} (near treated alfalfa), the bug
205 population was low until 22 August; then it increased until 3 October, reaching the highest
206 density of 0.5 individuals per plant in the growing season.

207 The Kruskal-Wallis analysis highlighted significant differences between mirid densities in the
208 two strawberry plots (Fig. 4a). On sampling dates following λ -cyhalothrin application in plot
209 B_{alf} (treated) (25 July and 8 August), mirid densities were significantly lower in plot B_{str} (near
210 treated alfalfa), when compared with plot A_{str} (near untreated alfalfa). However, after the
211 etofenprox application to plot B_{alf} (treated), mirid densities were significantly greater in plot
212 B_{str} (near treated alfalfa) (19 September and 3 October) (Fig. 4a).

213 On alfalfa, plant bugs reached an initial peak of 26.8 and 28.5 individuals per 10 sweeps in
214 the plots A_{alf} (untreated) and B_{alf} (treated), respectively, on 27 June (Fig. 4b). Afterwards in
215 the plot A_{alf} (untreated) the mirid population continued increasing until early September (48.5
216 individuals per 10 sweeps on 5 September), then it decreased dramatically until early October.
217 By contrast, in the plot B_{alf} (treated) the bug population dropped following the treatment with
218 λ -cyhalothrin and started rising gradually in August, reaching the maximum of the growing
219 season of 76.3 individuals per 10 sweeps on 5 September. Then it decreased dramatically in
220 both plots A_{alf} (untreated) e B_{alf} (treated), without being seemingly influenced by the
221 treatment with etofenprox on 17 September. Significant differences between mirid densities in
222 the two alfalfa plots were observed on 11 and 25 July, and 9 August, i.e. in the sampling dates

223 following the treatment with λ -cyhalothrin on alfalfa in the plot B_{alf}. On these dates, mirid
224 densities were significantly higher in the plot A_{alf} (untreated) (Fig. 4b).

225 **Discussion**

226 In laboratory trials, the most attractive plant species for *L. rugulipennis* oviposition was
227 chamomile, belonging to the family Asteraceae, on which the highest numbers of nymphs
228 were always found. Of the tested plants, strawberry was the least attractive plant species.
229 However, in our region chamomile is an invasive weed, usually growing in wastelands and
230 flowering throughout the summer, and hard to manage and control. It is not advisable to use
231 this plant as a trap crop, although it resulted very attractive in the laboratory trials. Moreover,
232 in previous field trials conducted in the UK, chamomile was not always able to prevent the
233 migration of *L. rugulipennis* to strawberries (Easterbrook and Tooley 1999).

234 In the laboratory, alfalfa and red clover were very attractive to ovipositing females of *L.*
235 *rugulipennis*. Since alfalfa is a common forage crop in the surveyed area, in the field trials
236 this plant species was chosen and grown around the strawberry plots to assess its role in
237 influencing bug infestations on strawberries. In field trials in Sweden red clover was used
238 successfully to control an infestation of *L. rugulipennis* on lettuce [*Lactuca sativa* L.
239 (Asteraceae)] (Rämert et al., 2001).

240 During the 2-year field surveys, the majority of plant bugs were collected from alfalfa in both
241 total numbers of individuals and total numbers of species; in fact, *A. lineolatus* and *P.*
242 *vulneratus* were captured almost exclusively on alfalfa. By contrast, *L. rugulipennis* was
243 found both on alfalfa and strawberries; actually, on the latter crop it can be considered one of
244 the most noxious pests, as observed also in other European countries (Easterbrook, 1996;
245 Cross and Easterbrook, 1998). Except at the beginning and end of each growing season, most
246 of the plant bugs captured on both alfalfa and strawberries were nymphs. *L. rugulipennis*
247 overwinters as adults (males and females), and accomplishes 3-4 generations a year in

248 northwestern Italy (Rancati et al., 1996). Inter-crop movement is effected by adults in the
249 search of suitable host plants; so adults prevailed early and late in the season, in conjunction
250 with the initial colonization of the crop and before the final migration towards overwintering
251 refuges, respectively. The presence of large numbers of nymphs on strawberries indicates that
252 *L. rugulipennis* can reproduce and develop on this plant despite it being the least attractive
253 species for oviposition in our laboratory tests.

254 In 2006, alfalfa proved to be attractive to mirids, but was unable to prevent their migration to
255 strawberries when populations reached high levels, as observed by Easterbrook and Tooley
256 (1999) in strawberries and Accinelli et al. (2005) in lettuce. Starting from mid-July, plant bug
257 density on strawberries was always higher than the economic threshold proposed by Jay et al.
258 (2004) of 1 *L. rugulipennis* individual per 40 plants. In 2007, bug populations on strawberries
259 generally exceeded this threshold during the growing season, even one day after the first
260 chemical treatment on alfalfa. However, the obvious population increase on strawberries on
261 11 July could be due to a temporary movement from alfalfa to neighbouring crops of plant
262 bugs disturbed by the insecticide intervention. Afterwards, plant bugs returned to alfalfa, and
263 in the plot treated by the pesticide they were controlled. In the following dates in the plot near
264 alfalfa treated with λ -cyhalothrin mirid populations declined next to the economic threshold
265 (1.33 individuals of *L. rugulipennis* per 40 plants on 25 July and 9 August), whereas in the
266 plot near untreated alfalfa the population level remained higher than the economic threshold
267 (8 individuals of *L. rugulipennis* per 40 plants). On these two dates populations were
268 significantly different in the two plots near treated and untreated alfalfa.

269 The application of λ -cyhalothrin was able to reduce pest density in alfalfa and, as a
270 consequence, prevent their movement into strawberries for approximately one month. Only in
271 late August, bug populations did return to damaging levels, thereby requiring another
272 insecticide intervention. But the treatment with etofenprox in mid-September did not seem to

273 positively influence the infestation level on strawberries since significantly higher numbers of
274 plant bugs were sampled in the plot near treated alfalfa in the two dates following the
275 intervention. The efficacy of etofenprox against *L. rugulipennis* was already assessed in both
276 laboratory and semi-field trials in peach orchards of NW Italy (Pansa et al., 2008). Therefore,
277 this treatment in mid-September could have advanced the natural dispersal towards
278 overwintering refuges occurring at the end of the season, and attested by the decline until
279 disappearance of bug populations on alfalfa in both plots. In particular, after the treatment
280 with etofenprox, plant bugs moved from the treated alfalfa to the strawberries near treated
281 alfalfa and caused high infestation levels before migrating to winter refuges.

282 In conclusion, forage crops, such as alfalfa, can act as either a sink or a source of plant bugs.
283 The appropriate management of fields adjacent to strawberries is crucial to prevent the
284 insect's inter-crop movement in fragmented landscapes. Time and methods of alfalfa mowing
285 should be investigated in relation to life cycle and dispersal ability of plant bugs; in particular,
286 the dispersal ability of nymphs should be studied, which so far remains unknown. During this
287 research project, greater numbers of plant bugs, mainly nymphs, were collected on
288 strawberries after mowing even if alfalfa was cut alternately (only half of each strip at a time).
289 Therefore, when bug populations increased on alfalfa, a localized insecticide application can
290 be useful to reduce their migration to strawberries. However, further investigations, being to
291 be carried out on a larger scale including more replications, should be focused to assess the
292 minimum surface to be treated to protect yield quality and safeguard environmental health.

293 **Aknowledgements**

294 We thank M. Baudino and R. Giordano of CRESO of Boves (province of Cuneo, Italy) for
295 technical assistance in the field trials. Research was supported by a grant from Regione
296 Piemonte.

297 **References**

298 Accinelli, G., Lanzoni, A., Ramilli, F., Dradi, D., Burgio, G., 2005. Trap crop: an
299 agroecological approach to the management of *Lygus rugulipennis* on lettuce. Bull.
300 Insectology 58, 9-14.

301 Arnoldi, D., Stewart, R.K., Boivin, G., 1991. Field survey and laboratory evaluation of the
302 predator complex of *Lygus lineolaris* and *Lygocoris communis* (Hemiptera: Miridae) in
303 apple orchards. J. Econ. Entomol. 84, 830-836.

304 Boivin, G., Le Blanc, J.P.R., Adams, J.A., 1991. Spatial dispersion and sequential sampling
305 plan for the tarnished plant bug (Hemiptera: Miridae) on celery. J. Econ. Entomol. 84,
306 158-164.

307 Bosio, G., Scarpelli, F., 1999. Aumentano su fragola i danni da *Lygus rugulipennis*. Infotore
308 Agr. 55 (25), 70-73.

309 Carrière, Y., Ellsworth, P.C., Dutilleul, P., Ellers-Kirk, C., Barkley, V., Antilla, L., 2006. A
310 GIS-based approach for areawide pest management: the scales of *Lygus hesperus*
311 movements to cotton from alfalfa, weeds, and cotton. Entomol. Exp. Appl. 118, 203-
312 210.

313 Conti, E., Bin, F., 2001. Native *Lygus* spp. (Heteroptera: Miridae) damaging introduced
314 *Hibiscus cannabinus* in Italy. J. Econ. Entomol. 94, 648-657.

315 Craig, C. H., 1963. The alfalfa plant bug, *Adelphocoris lineolatus* (Goeze) in northern
316 Saskatchewan. Can. Entomol. 95, 6-13.

317 Cross, J. V., Easterbrook, M. A., 1998. Integrated management of flower pests of strawberry.
318 IOBC/WPRS Bull. 21 (10), 81-87.

319 Easterbrook, M.A., 1996. Damage to strawberry fruits by the European tarnished plant bug,
320 *Lygus rugulipennis*. Proceedings of the Brighton Crop Protection Conference, Pests and
321 Diseases 1996, pp. 867-872.

- 322 Easterbrook, M.A., 2000. Relationships between the occurrence of misshapen fruit on late-
323 season strawberry in the United Kingdom and infestation by insects, particularly the
324 European tarnished plant bug, *Lygus rugulipennis*. Entomol. Exp. Appl. 96, 59-67.
- 325 Easterbrook, M.A., Tooley, J.A., 1999. Assessment of trap plants to regulate numbers of the
326 European tarnished plant bug, *Lygus rugulipennis*, on late-season strawberries.
327 Entomol. Exp. Appl. 92, 119-125.
- 328 Esquivel, J.F., Mowery, S.V., 2007. Host plants of the tarnished plant bug (Heteroptera:
329 Miridae) in central Texas. Environ. Entomol. 36, 725-730.
- 330 Fleury, D., Paré, J., Vincent, C., Mauffette, Y., 2006. Feeding impact of *Lygus lineolaris*
331 (Heteroptera: Miridae) on *Vitis vinifera*: a behavioural and histological study. Can. J.
332 Bot. 84, 493-500.
- 333 Godfrey, L.D., Leigh, T. F., 1994. Alfalfa harvest strategy effect on *Lygus* bug (Hemiptera:
334 Miridae) and insect predator population density: implications for use as trap crop in
335 cotton. Environ. Entomol. 23, 1106-1118.
- 336 Greene, J.K., Turnipseed, S.G., Sullivan, M.J., Herzog, G.A., 1999. Boll damage by southern
337 green stink bug (Hemiptera: Pentatomidae) and tarnished plant bug (Hemiptera:
338 Miridae) caged on transgenic *Bacillus thuringiensis* cotton. J. Econ. Entomol. 92, 941-
339 944.
- 340 Hardman, J.M., Jensen, K.I.N., Moreau, D.L., Franklin, J.L., Bent, E.D., 2004. Effect of
341 ground cover treatments and insecticide use on population density and damage caused
342 by *Lygus lineolaris* (Heteroptera: Miridae) in apple orchards. J. Econ. Entomol. 97, 993-
343 1002.
- 344 Hokkanen, H.M.T., 1991. Trap cropping in pest management. A. Rev. Ent. 36, 119-139.
- 345 Holopainen, J.K., Varis, A.L., 1991. Host plants of the European tarnished plant bug *Lygus*
346 *rugulipennis* Poppius (Het., Miridae). J. Appl. Entomol. 111, 484-498.

- 347 Jacobson, R.J., 2002. *Lygus rugulipennis* (Het. Miridae): Options for integrated control in
348 glasshouse-grown cucumbers. OILB/SROP Bull. 25 (1), 111-114.
- 349 Jay, C.N., Cross, J.V., Burgess, C., 2004. The relationship between populations of European
350 tarnished plant bug (*Lygus rugulipennis*) and crop losses due to fruit malformation in
351 everbearer strawberries. Crop Prot. 23, 825-834.
- 352 Michaud, O.D., Stewart, R.K., 1990. Susceptibility of apples to damage by *Lygocoris*
353 *communis* and *Lygus lineolaris* (Hemiptera: Miridae). Phytoprotection 71, 25-30.
- 354 Michaud, O.D., Boivin, G., Stewart, R.K., 1989. Economic threshold for tarnished plant bug
355 (Hemiptera: Miridae) in apple orchards. J. Econ. Entomol. 82, 1722-1728.
- 356 Norton, A.P., Welter, S.C., 1996. Augmentation of the egg parasitoid *Anaphes iole*
357 (Hymenoptera: Mymaridae) for *Lygus hesperus* (Heteroptera: Miridae) management in
358 strawberries. Environ. Entomol. 25, 1406-1414.
- 359 Pansa, M.G., Demaria, D., Vittone, G., Tavella, L., 2008. Le sostanze attive più efficaci
360 contro i miridi su pesco. Infotore Agr. 64 (16), 58-60.
- 361 Pree, D.J., 1985. Control of tarnished plant bug *Lygus lineolaris* Palisot de Beauvois on
362 peaches. Can. Entomol. 117, 327-331.
- 363 Rämert, B., Hellqvist, S., Ekbohm, B., Banks, J.E., 2001. Assessment of trap crops for *Lygus*
364 spp. in lettuce. Int. J. Pest Mgmt 47 (4), 273-276.
- 365 Rancati, M., Tavella, L., Arzone, A., 1996. Biologia di *Lygus rugulipennis* Poppius
366 (Rhynchota Miridae). Redia 79 (2): 143-151.
- 367 Rancourt, B., Vincent, C., De Oliveira, D., 2003. Field evaluation of efficacy and persistence
368 of an insect vacuum device against the tarnished plant bug (Hemiptera: Miridae) in a
369 day-neutral strawberry field. J. Econ. Entomol. 96, 401-406.

370 Rhainds, M., Kovach, J., Dosa, E.L., English-Loeb G., 2001. Impact of reflective mulch on
371 yield of strawberry plants and incidence of damage by tarnished plant bug (Heteroptera:
372 Miridae). J. Econ. Entomol. 94, 1477-1484.

373 Rhainds, M., Taft, T., English-Loeb, G., Dunst, R., Weigle, T., 2002. Ecology and economic
374 impact of two plant bugs (Hemiptera: Miridae) in commercial vineyards. J. Econ.
375 Entomol. 95, 354-359.

376 Rinne, V., 1989. Review of the European *Polymerus* subgenus *Poeciloscytus* (Heteroptera,
377 Miridae), with two new species and special reference to the Finnish fauna. Annales
378 Entomologici Fennici 55, 89-101.

379 Schaefers, G.A., 1966. The reduction of insect-caused apical seediness in strawberries. J.
380 Econ. Entomol. 59, 698-706.

381 Schaefers, G.A., 1980. Yield effects of tarnished plant bug feeding on June-bearing strawberry
382 varieties in New York state. J. Econ. Entomol. 73, 721-725.

383 Stewart, A.C., Layton, M.B., 2000. Cultural controls for the management of *Lygus*
384 populations in cotton. Southwest. Entomol. 23, 83-95.

385 Stride, G.O., 1969. Investigations into the use of a trap crop to protect cotton from attack by
386 *Lygus vosseleri* (Heteroptera: Miridae). J. Ent. Soc. Sth. Afr. 32 (2), 469-477.

387 Swezey, S.L., Nieto, D.J., Bryer, J.A., 2007. Control of western tarnished plant bug *Lygus*
388 *hesperus* Knight (Hemiptera: Miridae) in California organic strawberries using alfalfa
389 trap crops and tractor-mounted vacuums. Environ. Entomol. 36, 1457-1465.

390 Tavella, L., Arzone, A., Alma, A., Galliano, A., 1996. IPM application in peach orchards
391 against *Lygus rugulipennis* Poppius. IOBC/WPRS Bull. 19 (4), 160-164.

392 Udayagiri, S., Welter, S.C., 2000. Escape of *Lygus hesperus* (Heteroptera: Miridae) eggs from
393 parasitism by *Anaphes iole* (Hymenoptera: Mymaridae) in strawberries: plant structure
394 effects. Biol. Control 17, 234-242.

- 395 Varis, A.L., 1978. *Lygus rugulipennis* (Heteroptera, Miridae) damaging greenhouse
396 cucumbers. *Annales Entomologici Fennici*, 44 (2), 72.
- 397 Vincent, C., Chagnon, R., 2000. Vacuuming tarnished plant bug on strawberry: a bench study
398 of operational parameters versus insect behavior. *Entomol. Exp. Appl.* 97, 347-354.
- 399 Wagner, E., Weber, H.H., 1964. Faune de France, Hétéroptères Miridae. Fédération Française
400 des Sociétés de Sciences Naturelles, Paris, 67, pp. 591.
- 401 Wipfli, M.S., Wendberg, J.L., Hogg D.B., 1990. Cultural and chemical control strategies for
402 three plant bug (Heteroptera: Miridae) pests of birdsfoot trefoil in Northern Wisconsin.
403 *J. Econ. Entomol.* 83, 2086-2091.
- 404 Wu, K., Li, W., Feng, H., Guo, Y., 2002. Seasonal abundance of the mirids, *Lygus lucorum*
405 and *Adelphocoris* spp. (Hemiptera: Miridae) on Bt cotton in northern China. *Crop Prot.*
406 21 (10), 997-1002.

407 **Figure captions**

408

409 Figure 1 – Experimental strawberry field, with 2 strips of alfalfa along the sides, surveyed in
410 2006-2007.

411

412 Figure 2 – Attractiveness for *Lygus rugulipennis* ovipositing females, expressed as mean
413 number of nymphs emerged on alfalfa, chamomile, red clover, and strawberry in laboratory
414 trials. Values followed by different letters are significantly different (test Mann-Whitney,
415 $p < 0.05$).

416

417 Figure 3 – Mean numbers (\pm SE) of plant bugs per plant on strawberries (a) and of plant bugs
418 per 10 sweeps on alfalfa (b) in 2006.

419

420 Figure 4 – a. Mean numbers (\pm SE) of plant bugs per plant sampled in the 2 plots A_{str} and B_{str}
421 of strawberries in 2007. In the dates with * values are significantly different between plots
422 (Kruskal-Wallis analysis, $p < 0.05$). b. Mean numbers (\pm SE) of plant bugs per 10 sweeps in
423 the 2 plots A_{alf} (untreated) and B_{alf} (treated) of alfalfa in 2007. The arrows indicate the
424 insecticide treatments in the plot B_{alf}. In the dates with * values are significantly different
425 between plots (ANOVA, $p < 0.05$).

426

427 **Table 1** – Total numbers of plant bugs collected on strawberries and alfalfa during field

428 surveys carried out every two weeks from 8 June to 11 October 2006.

Plant bugs	strawberry	alfalfa
<i>Lygus rugulipennis</i> , adults	20	164
<i>Lygus pratensis</i> , adults	1	6
<i>Lygus</i> spp., nymphs	202	798
<i>Adelphocoris lineolatus</i> , adults	5	131
<i>Adelphocoris lineolatus</i> , nymphs	16	104
<i>Polymerus vulneratus</i> , adults	0	64
<i>Polymerus vulneratus</i> , nymphs	0	300
total bugs	244	1567

429

430 **Table 2** – Total numbers of plant bugs collected on strawberries and alfalfa during field
 431 surveys carried out every two weeks from 16 May to 3 October 2007.

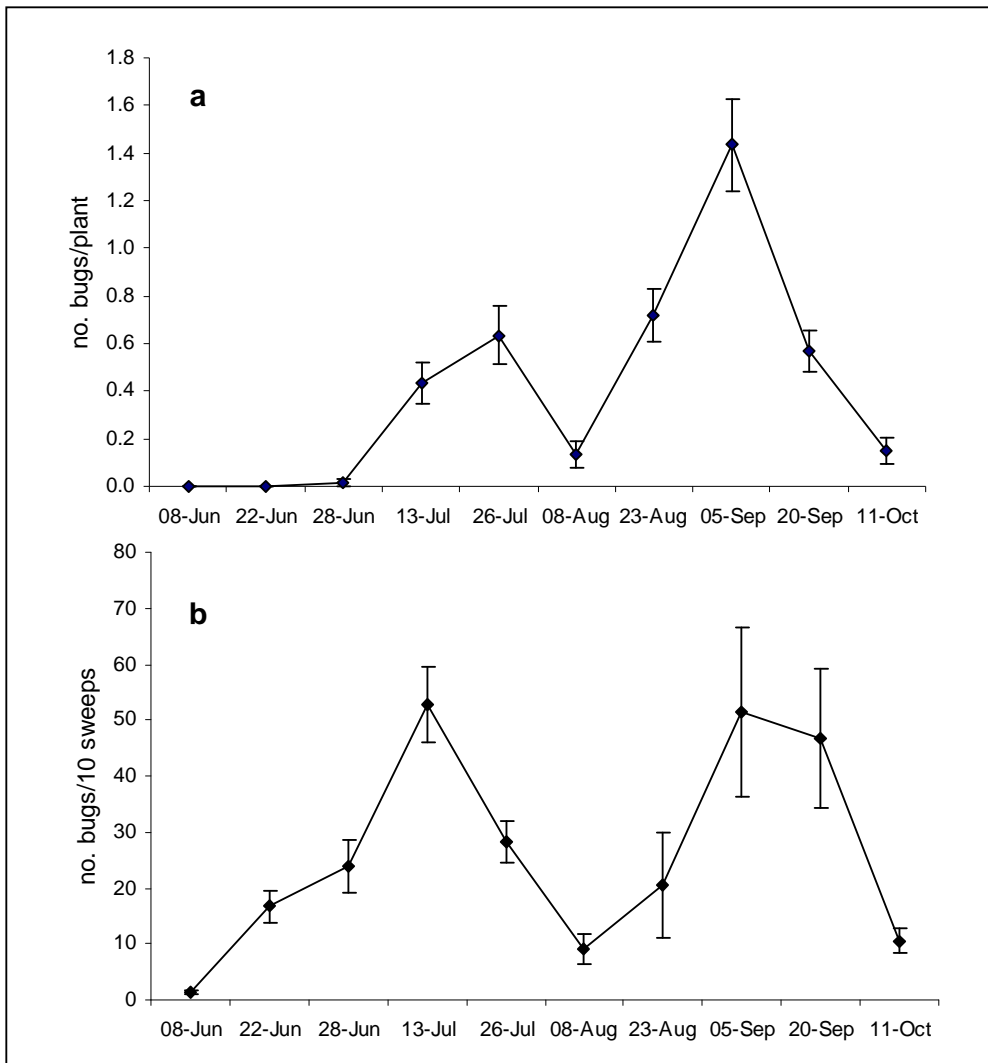
Plant bugs	strawberry near		alfalfa	
	treated alfalfa	control alfalfa	treated plot	control plot
<i>Lygus rugulipennis</i> , adults	10	10	114	179
<i>Lygus pratensis</i> , adults	0	0	3	4
<i>Lygus</i> spp., nymphs	34	33	267	349
<i>Adelphocoris lineolatus</i> , adults	0	2	141	214
<i>Adelphocoris lineolatus</i> , nymphs	4	6	98	181
<i>Polymerus vulneratus</i> , adults	0	0	40	44
<i>Polymerus vulneratus</i> , nymphs	0	0	91	84
total bugs	48	51	754	1055

432



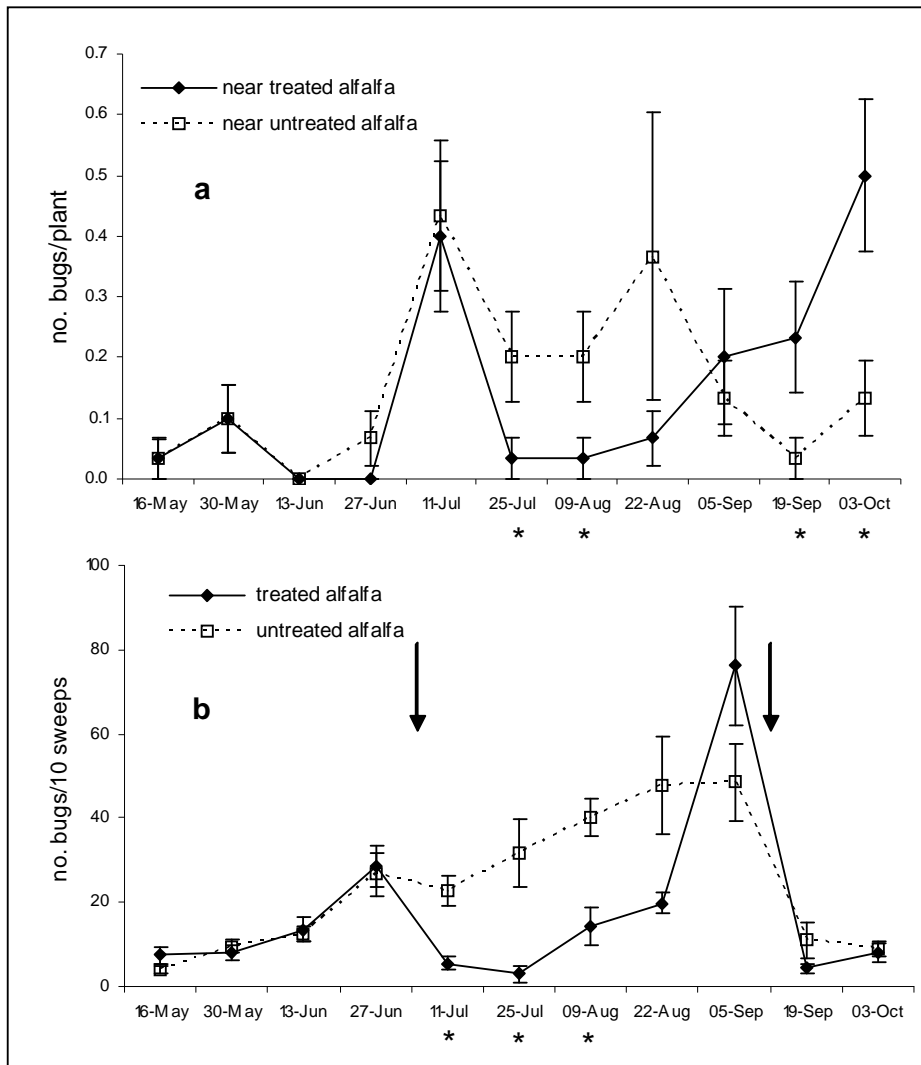
437

438 Figure 2 – Attractiveness for *Lygus rugulipennis* ovipositing females, expressed as mean
439 number of nymphs emerged on alfalfa, chamomile, red clover, and strawberry in laboratory
440 trials. Values followed by different letters are significantly different (test Mann-Whitney,
441 $p < 0.05$).



443

444 Figure 3 – Mean numbers (\pm SE) of plant bugs per plant on strawberry (a) and of plant bugs
 445 per 10 sweeps on alfalfa (b) in 2006.



447

448 Figure 4 – a. Mean numbers (\pm SE) of plant bugs per plant sampled in the 2 plots A_{str} and B_{str}
 449 of strawberry in 2007. In the dates with * values are significantly different between plots
 450 (Kruskal-Wallis analysis, $p < 0.05$). b. Mean numbers (\pm SE) of plant bugs per 10 sweeps in
 451 the 2 plots A_{alf} (untreated) and B_{alf} (treated) of alfalfa in 2007. The arrows indicate the
 452 insecticide treatments in the plot B_{alf} . In the dates with * values are significantly different
 453 between plots (ANOVA, $p < 0.05$).

454

455