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Impact of Straw Mulch on Populations of Onion Thrips (Thysanoptera: Thripidae) in Onion

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ABSTRACT Development of insecticide resistance in onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), populations in onion (*Allium* spp.) fields and the incidence of the *T. tabaci* transmitted Iris yellow spot virus have stimulated interest in evaluating alternative management tactics. Effects of straw mulch applied in commercial onion fields in muck areas of western New York were assessed in 2006 and 2007 as a possible onion thrips management strategy. In trials in which no insecticides were applied for thrips control, straw mulch-treated plots supported significantly lower *T. tabaci* populations compared with control plots. In both years, the action thresholds of one or three larvae per leaf were reached in straw mulch treatments between 7 and 14 d later than in the control. Ground predatory fauna, as evaluated by pitfall trapping, was not increased by straw mulch in 2006; however, populations of the common predatory thrips *Aeolothrips fasciatus* (L.) (Thysanoptera: Aeolothripidae) were significantly lower in straw mulch plots in both years. Interference of straw mulch in the pupation and emergence of *T. tabaci* was investigated in the lab and their emergence was reduced by 54% compared with bare soil. In the field the overall yield of onions was not affected by the straw mulch treatment; however, the presence of jumbo grade onions (>77 mm) was increased in 2006, but not in 2007. These results indicate that populations of *T. tabaci* adults and larvae can be significantly reduced by the use of straw mulch without compromising overall onion yield. The use of this cultural practice in an onion integrated pest management program seems promising.

KEY WORDS *Thrips tabaci*, straw mulch, cultural management, habitat management, onions

Onion (*Allium* spp.) is a high-value crop in the United States, providing $868 million from a harvested area of 65,960 ha in 2006 (NASS 2007). Consequently, heavy reliance on chemicals for weed, disease, and insect control has resulted in onions being one of the most pesticide-intensive vegetable crops. Onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), is a major onion pest, and its control accounts for most of the insecticide use in the onion crop in New York, where onions are grown in 5,706 ha. *T. tabaci* feeding results in leaf tissue silvering, photosynthesis reduction leading to bulb size reduction and yield loss (Childers 1997). Moreover, *T. tabaci* has been identified as the main vector of an emerging disease caused by Iris yellow spot virus (family *Bunyaviridae,* genus *Tospovirus,* IYSV), which can significantly reduce bulb size (Gent et al. 2004). IYSV was first detected in commercial onion fields in New York in 2006 (Hoepting et al. 2007). Since then, surveys have found IYSV throughout the major onion producing regions in New York (B.A.N., unpublished). Effective alternative methods to control *T. tabaci* are further necessitated because resistance of onion thrips to pyrethroids and organophosphate insecticides has been recently documented in New York (Shelton et al. 2003) and Ontario, Canada (Allen et al. 2005).

Cultural practices are an important component of integrated pest management, and they have been included in pest management in several cropping systems. Common practices include the use of mulches, organic or manufactured, to control pests, conserve soil moisture, modulate soil temperature, suppress weeds, increase crop yield, and improve crop quality (Greer and Dole 2003). The positive effect of mulches against thrips has been demonstrated by the use of UV-reflective mulches; they can reduce thrips populations by disrupting their ability to recognize and land on their hosts, and their use has been shown to reduce *Frankliniella* spp. populations in tomatoes and peppers (Stavisky et al. 2002, Reitz et al. 2003). Unpublished trials in Colorado (reported by Gent et al. 2006) have indicated that wheat straw mulches in onions reduced thrips populations by up to 48%. Also, straw mulches applied to irrigation furrows increased onion yields between 64 and 74% due to decreased water runoff and increased soil moisture (Shock et al. 1999). Application of straw mulch to potato can suppress populations of the Colorado potato beetle, *Leptinotarsa*

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decemlimeata (Say) (Coleoptera: Chrysomelidae), due to physical obstruction, reduced soil temperature, and increased predation by natural enemies (Zehnder and Hough-Goldstein 1990, Brust 1994). Straw mulch has been well studied in reducing aphid infestation and virus incidence and spread in several crops (Jones 1994, Saucke and Döring 2004, Summers et al. 2004).

Such encouraging results, involving the use of straw mulch in onion, initiated a series of trials in commercial New York onion fields. The objective of this study was to compare the effect of straw mulch to bare soil on the abundance of *T. tabaci* adults and larvae and natural enemies in an onion cropping system. Furthermore, we examined the treatments for their effects on the yield and size of onions at harvest.

Materials and Methods

Trials were conducted in commercial direct-seeded onion fields in muck regions of western New York during 2006 and 2007. Muck soil is rich in organic matter with high water holding capacity, and it is porous, easy to cultivate, and suitable for high-value vegetable (e.g., onions, carrots, and potatoes) production. In our trials, growers performed the standard agricultural practices, i.e., cultivating, fertilization, planting, and herbicide applications, before the application of straw mulch. In both years, when the onions had reached the second leaf stage, wheat straw mulch was shredded and spread, throughout the experimental plots, with a Berryking mechanical straw shredder and applicator (AgriMetal Inc., Quebec, Canada) at a tractor speed of 4.8 km/h with PTO speed at 1,400 rpm.

The treatments were 1) straw mulch application at a rate of 0.17 kg/m^2 (730 kg/ha) and 2) no straw mulch application (control). Treatments were arranged in a randomized complete block replicated four times. A buffer zone of 10 m separated the experimental plots. The same experimental design was followed in both years, and the experimental plots were 9.15 by 10.7 m wide and consisted of six beds, 1.15 m apart, each with four double rows 38 cm apart. No insecticide applications took place throughout the trial period in both years, and any plant diseases were controlled with fungicide treatments (Penncozeb 75 DF, Cerexagri-Nisso, King of Prussia, PA) at a rate of 0.35 kg/m^2. Uniform weed control was obtained by hand weeding.

Field Locations. In 2006, the experiment was conducted on one commercial farm in Potter, NY. Yellow-globe onion 'Millenium' seeds were planted in mid-April, and the first straw mulch application took place on 24 May. A second straw application took place by hand without shredding the straw on 19 July to compensate for some losses by strong winds. Leaf blight (*Botrytis squamosa* Walker), was controlled with fungicide treatments on 13 and 30 June.

In 2007, the experiment was conducted in four commercial farms, two in Potter (Potter 1 and Potter 2) and two in Elba (Elba 1 and Elba 2), Orleans County, NY. The yellow onion cultivars planted were 'Infinity', 'Fortress', and 'Bunker', and they were planted in early May. The straw application took place on 13 June in Elba and 14 June in Potter. Leaf blight incidence was more prevalent than in 2006 and weekly fungicide treatments were applied in all fields.

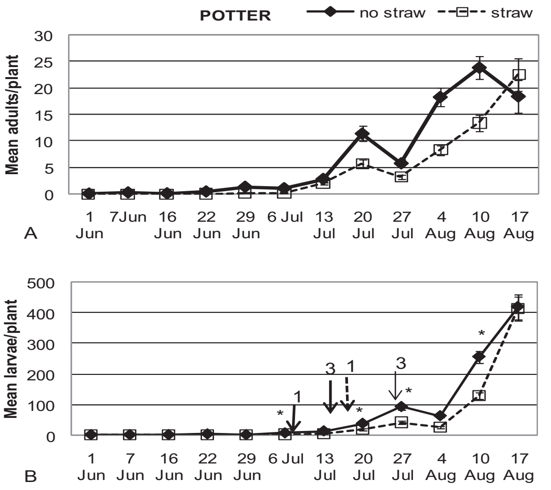

Fig. 1. Number (mean ± SEM) of *T. tabaci* adults and larvae on onion plants grown under straw and no-straw treatments in Potter, NY, during summer 2006. Asterisks indicate significant differences ($P = 0.05$). Solid and dotted line arrows indicate action thresholds (of one or three larvae per leaf) in no-straw and straw treatments respectively.

Impact of Straw Mulch on *T. tabaci* Populations. In both years, 10 onion plants were randomly collected from each plot on a weekly basis until plants started to senesce. In 2006, the sampling period was from 1 June to 17 August, whereas in 2007 it was from 20 June until 16 August. Plants were transported in plastic bags to the laboratory, where 200 ml of 65% ethyl alcohol was

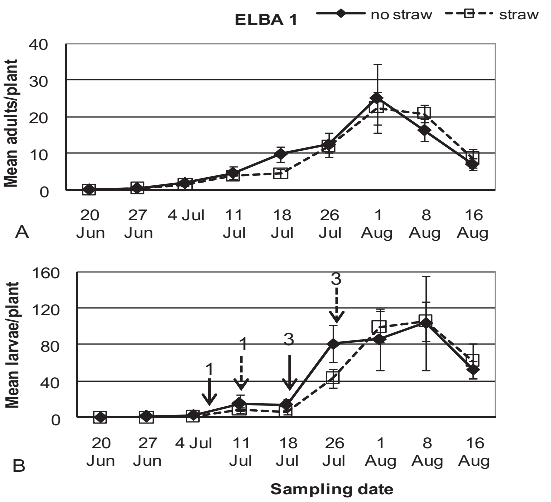

Fig. 2. Number (mean ± SEM) of *T. tabaci* adults and larvae on onion plants grown under straw and no-straw treatments in Elba 1, NY, during summer 2007. Solid and dotted line arrows indicate action thresholds (of one or three larvae per leaf) in no-straw and straw treatments respectively.

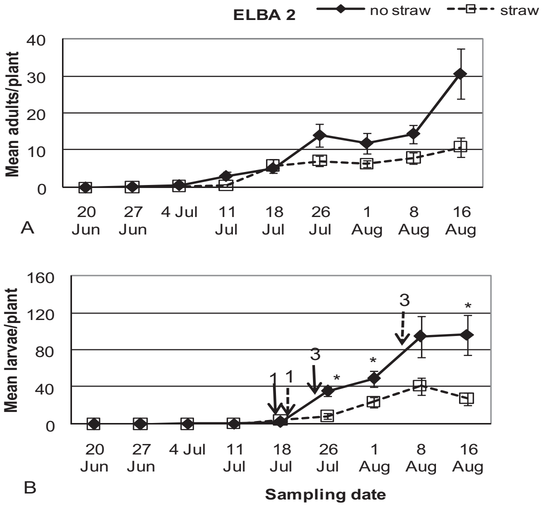

Fig. 3. Number (mean ± SEM) of *T. tabaci* adults and larvae on onion plants grown under straw and no-straw treatments in Elba 2, NY, during summer 2007. Asterisks indicate significant differences ($P = 0.05$). Solid and dotted line arrows indicate action thresholds (of one or three larvae per leaf) in no-straw and straw treatments, respectively.

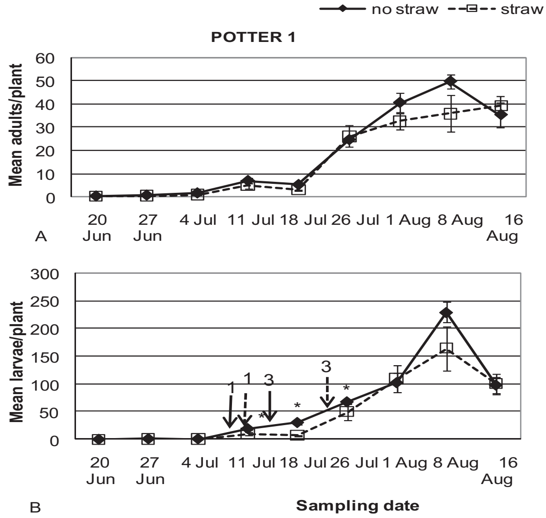

Fig. 4. Number (mean ± SEM) of *T. tabaci* adults and larvae on onion plants grown under straw and no-straw treatments in Potter 1, NY, during summer 2007. Asterisks indicate significant differences ($P = 0.05$). Solid and dotted line arrows indicate action thresholds (of one or three larvae per leaf) in no-straw and straw treatments, respectively.

added to the bag, and plants were agitated for 2 min to dislodge and kill thrips. After removing the plant parts, the solution was sieved through a fine mesh of 180 μm, and *T. tabaci* adults and larvae were counted under the microscope. *T. tabaci* is the predominant thrips species that colonizes the onion crop in western New York and typically, *T. tabaci* infestations are not evident until onion plants have between four and six leaves. In western New York, most of the direct-seeded onion crop does not reach the fourth-leaf stage until June.

In addition to comparing overall densities of *T. tabaci* through time in plots that received mulch and those that did not, we were interested in the time that populations reached an action threshold for insecticide treatment. In New York, the recommended threshold has been three thrips larvae per green leaf (Hoffmann et al. 1996), but because of poor control with many insecticides (Shelton et al. 2006, Nault and Hessney 2006) most growers now time their sprays when the number of thrips larvae is one per leaf. Both action thresholds were examined in this study.

Impact of Straw Mulch on Predator Populations. In 2006, pitfall traps were used to measure activity of ground arthropods in straw mulch and control plots. Each pitfall trap consisted of 946-ml clear plastic cup buried in the soil with the lid at surface level. Within this cup, a 473-ml plastic cup was placed and filled with ≈150 ml of 60% propylene glycol and few drops of 70% ethyl alcohol. Three traps were placed in a straight line (2 m between traps) within the fourth row of the first, fourth, and sixth bed (nine traps per plot, 27 traps per treatment). Pitfall traps were removed at weekly intervals, starting on 26 July until 16 August. On collection, the solution was strained through an acrylic sock and moved to the laboratory where arthropods were collected in 70% ethyl alcohol and identified into taxonomic groupings under the microscope.

During the experimental period, several coccinellids (Coleoptera: Coccinelidae), *Chrysoperla* species (Neuroptera: Chrysopidae), and *Aeolothrips fasciatus* (L.) (Thysanoptera: Aeolothripidae) were recovered from the collected plants; all known predators of *T.*

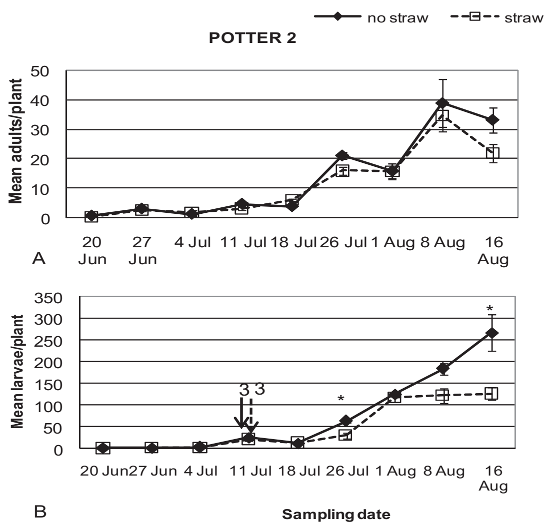

Fig. 5. Number (mean ± SEM) of *T. tabaci* adults and larvae on onion plants grown under straw and no-straw in Potter 2, NY, during summer 2007. Asterisks indicate significant differences ($P = 0.05$). Solid and dotted line arrows indicate action thresholds (of three larvae per leaf) in no-straw and straw treatments, respectively.

Table 1. Treatment, sampling date and treatment × sampling date effect on *T. tabaci* adult populations collected from onions grown under straw and no-straw in fields of New York in 2007

	Elba 1		Elba 2		Potter 1		Potter 2	
	F value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value
Treatment (df = 1, 3)	0.95	0.40	19.52	0.02	5.12	0.11	1.03	0.38
Date (df = 8, 48)	69.58	<0.001	64.11	<0.001	140.06	<0.001	133.11	<0.001
Treatment × date (df = 8, 48)	1.61	0.15	2.28	0.04	1.86	0.08	2.51	0.02

tabaci (Riudavets 1995). To record potential influence of the cultural practice on the abundance of such natural enemies, three yellow sticky traps (15.2 by 15.2 cm) were also placed in a V-shape pattern throughout the same experimental plots that pitfall trapping took place. Traps were changed weekly from 26 July until 16 August, and natural enemies were recorded.

Because numbers of ground predatory fauna were not correlated with densities of *T. tabaci* populations on onion in 2006, we focused on aerial sampling of predators using yellow sticky traps placed in the center of each plot from 13 June until 16 August 2007.

Impact of Straw Mulch on Onion Yield. For both years, onions were harvested from an undisturbed row (9.15 m) from each experimental plot on 31 August in 2006 and on 5 and 7 August 2007 from fields in Potter and Elba, respectively. Onion plants were hand topped in the field and collected. They were then allowed to dry for 3 wk and weighed and graded according to USDA standards, into jumbo (>77 mm), medium (57–77 mm), and small (<57 mm). Onions smaller than 30 mm were discarded.

Impact of Straw Mulch on *T. tabaci* Survival. To explore the physical impact of straw mulch on *T. tabaci* survival, the number of pupae surviving in soil with or without straw mulch was investigated in the laboratory. Yellow onion sets ('Stuttgart') were individually planted in 30-ml plastic cups (WinCup, Phoenix, AZ) and allowed to grow for 2.5 wk. Shredded straw was spread on top of the soil simulating the straw treatment in the field, whereas the control had no straw. Straw- and no-straw-treated plants were placed individually in a cage consisting of a clear polystyrene cylinder (30 cm in height by 10 cm in diameter) with two screened ventilation holes (5 cm in diameter). The bottom and top of the cylinder were sealed with a plastic lid. Ten late second instars of *T. tabaci,* from a colony at Cornell/NYSAES, were placed on the onion plant's leaves. After 7 d, the number of emerging adults caught on the surface of a yellow sticky trap (5 by 5 cm) placed inside the cage, was counted. Each treatment was replicated four times with each replicate consisting of five onion plants.

Data Analyses. The effects of treatment (mulch versus no mulch), sampling date and their interaction on insect count data were examined by a repeated measures analysis of variance (ANOVA) by using the PROC MIXED procedure in SAS 9.1 (SAS Institute 2006). Both treatment and sampling date were considered fixed in our models, and unstructured and first-order autoregressive covariance structures were used to model covariance between treatments and sampling dates by choosing a combination of Akaike's information criterion (AIC) and the expectation that correlations would be greater for counts taken on dates that are closer together in time. Insect count data were transformed using the $\log_{10}(x+1)$ function before analysis. Multiple pairwise comparisons with significance levels of $P = 0.05$ were used to compare treatment means on certain sampling dates. Yield data were analyzed by one-way ANOVA in 2006 and by two-way ANOVA for treatment and field in 2007 at a significance level of $P = 0.05$ (MINITAB 13.31, Minitab Inc. 2001). In the laboratory experiment, percentages of emerging adults were compared using a Student's *t*-test. Data were arcsine transformed before this analysis. All tables and figures display untransformed data and standard errors.

Results

Impact of Straw Mulch on *T. tabaci* Populations. *2006.* In both treatments, populations of *T. tabaci* were low in June and early July, and they were greatest in August (Fig. 1A and B). The *T. tabaci* adult population was not affected by straw treatment ($F = 5.5$; df = 1, 3; $P = 0.10$) (Fig. 1A), but they were significantly affected by sampling date ($F = 61.1$; df = 11, 66; $P \leq 0.001$) and the interaction between sampling date and treatment ($F = 2.7$; df = 11, 66; $P < 0.01$).

The *T. tabaci* larvae population was significantly lower in straw-mulched plots ($F = 32.3$; df = 1, 3; $P < 0.05$) (Fig. 1B). This overall reduction was most evident as populations began to increase in the second half of July, for example on 27 July straw mulch de-

Table 2. Treatment, sampling date and treatment × sampling date effect on *T. tabaci* larval populations collected from onions grown under straw and no-straw in fields of New York in 2007

	Elba 1		Elba 2		Potter 1		Potter 2	
	F value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value
Treatment (df = 1, 3)	1.20	0.35	12.26	0.04	12.18	0.04	13.13	0.04
Date (df = 8, 8)	48.15	<0.001	80.34	<0.001	183.52	<0.001	206.48	<0.001
Treatment × date (df = 8, 8)	1.45	0.20	4.67	<0.001	3.78	<0.001	2.02	0.06

Table 3. Mean abundance ± SEM of predatory ground fauna recovered from pitfall traps located in straw and no-straw plots between 2 and 16 August 2006

Ground predators	Treatment	Mean no. per trap (± SEM) 2 Aug.	9 Aug.	16 Aug.
Carabidae	Straw	2.5 ± 0.4	1.1 ± 0.3	1.8 ± 0.4
	No-straw	1.6 ± 0.3	2.2 ± 0.9	3.5 ± 0.6
Staphylinidae	Straw	4.8 ± 1.3	1.5 ± 0.5	0.8 ± 0.3
	No-straw	3.8 ± 1.3	1.9 ± 0.4	1.1 ± 0.3
Araneae	Straw	1.7 ± 0.4	0.4 ± 0.1	1.8 ± 0.3
	No-straw	2.2 ± 0.4	1.1 ± 0.2	1.5 ± 0.3

Table 4. Mean abundance ± SEM of predatory insects captured on sticky traps above onion plants grown under straw and no-straw between 2 and 16 August 2006

Predator	Treatment	Mean no. per trap (± SEM) 2 Aug.	9 Aug.	16 Aug.
A. fasciatus	Straw	2.5 ± 0.5	1.4 ± 0.7	0.5 ± 0.2
	No-straw	3.8 ± 0.4	2.1 ± 0.4	1.1 ± 0.3
Coccinelidae	Straw	1.7 ± 0.8	0.7 ± 0.3	0.7 ± 0.2
	No-straw	3.7 ± 0.5	1.2 ± 0.4	0.5 ± 0.2
Chrysoperla spp.	Straw	0.9 ± 0.2	0.4 ± 0.2	0.3 ± 0.1
	No-straw	0.9 ± 0.3	0.3 ± 0.2	0.2 ± 0.2

creased the population by 63% compared with the control. Similar to adults, numbers of *T. tabaci* larvae were significantly affected by sampling date (F = 192.4; df = 9, 54; $P \leq 0.001$) and also by the interaction between sampling date and treatment (F = 2.9; df = 9, 54; $P < 0.01$). The straw mulch treatment delayed the time that larval populations would have been targeted with an insecticide application. For an action threshold of one larva per leaf, the threshold would have been reached 12 d later in the mulch treatment compared with the control, whereas a threshold of three larvae per leaf would have been met 10 d later in the mulch treatment compared with the control (Fig. 1B).

2007. Populations of *T. tabaci* increased in all fields over time, and they were highest in August (Figs. 2–5). Adult populations of *T. tabaci* were not affected by the presence of straw mulch in three of four fields (Table 1; Figs. 1A, 3A, and 4A). Adult populations were affected by sampling date in all fields, whereas the interaction of treatment and sampling date only affected two of four fields (Table 1; Figs. 2A and 4A).

T. tabaci larval densities were significantly reduced in the straw mulch treatment in three of four fields (Table 2; Figs. 3B, 4B, and 5B). Similarly, larval densities were significantly affected by sampling date in all fields and by an interaction between treatment and sampling date in two of four fields and approached significance in a third field (Table 2; Figs. 3B, 4B, and 5B).

Results in 2007 were similar to those in 2006 in that straw mulch delayed the time that larval populations reached action thresholds. In Elba 1, larval densities reached a threshold of one and three thrips per leaf 7 to 10 d later, respectively, in straw mulch treatments compared with control plots (Fig. 2B). In both Elba 2 and Potter 1, larval densities reached these thresholds in mulch treatments seven to 14 d later than control plots (Figs. 3B and 4B). In Potter 2, both thresholds were met at the same time in mulch and control plots (Fig. 5B).

Impact of Straw Mulch on Predator Populations, Ground Samples. In total, 4,498 arthropods were collected from pitfall traps in 2006. Collembola was the most abundant insect order (81.5 and 78% in the straw mulch and control treatments, respectively). From the 2,449 specimens collected from the straw treatment, 4.7% were Carabidae, 11.1% Staphylinidae, and 6.5% Araneae. From the 2,049 specimens collected from the control, 6.5% were Carabidae, 8.1% were Staphylinidae, and 6.4% were Araneae. Carabids were significantly reduced in the straw treatment (F = 35.86; df = 1, 2; P = 0.03) (Table 3). Neither staphylinids (F = 0.63; df = 1, 2; P = 0.50) nor Araneae (F = 2.00; df = 1, 2; P = 0.06) were affected by straw treatment (Table 3).

Aerial Samples. In 2006, densities of *A. fasciatus* adults captured on sticky cards in the straw mulch treatment did not differ from those captured in control plots ($P > 0.05$) (Table 4). In 2007, mean numbers of *A. fasciatus* adults captured on sticky cards in control plots were greater than those captured in the mulch treatments (Fig. 6). In two of four fields, significantly more *A. fasciatus* adults were captured on sticky cards in the control than in mulch treatments, whereas no difference existed among means in the other two fields (Table 5). Numbers of *A. fasciatus* adults increased in all fields as the season progressed (i.e., significant sampling date) and numbers were influenced by a significant treatment × date interaction in the two Elba fields, but not in the two Potter fields (Table 5).

Among the coccinellids captured, the most predominant species were *Coleomegilla maculata* (DeGeer) (66.9%) and *Harmonia axyridis* Pallas (33.1%). The mean number of coccinellid predators captured on sticky traps in the straw mulch treatment did not differ from those in the control ($P > 0.05$) in 2006 (Table 4) or in 2007 (Table 6; Fig. 7). Numbers of coccinellids captured on sticky cards significantly varied through time, and they were affected by a treatment × date

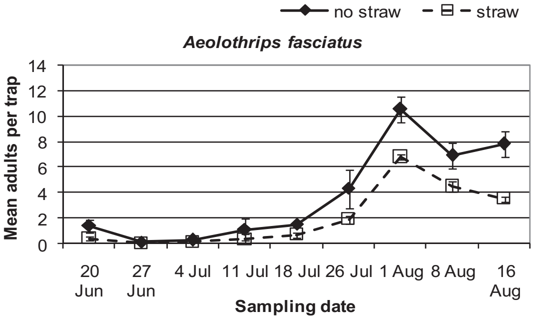

Fig. 6. Number (mean ± SEM) of *A. fasciatus* adults captured on sticky traps above onion plants grown under straw and no-straw treatments during summer 2007. Data presented are averages for the four fields.

Table 5. Treatment, sampling date and treatment × sampling date effect on *A. fasciatus* adult populations collected on sticky traps above onions grown under straw and no-straw in fields of New York in 2007

	Elba 1		Elba 2		Potter 1		Potter 2	
	F value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value
Treatment (df = 1, 3)	9.04	0.06	18.37	0.02	2.46	0.21	38.49	0.008
Date (df = 8, 48)	17.45	<0.001	6.83	<0.001	26.71	<0.001	37.17	<0.001
Treatment × date (df = 8, 48)	2.61	0.02	3.83	<0.001	0.36	0.93	1.76	0.11

interaction on some sampling dates, but no patterns were obvious (Table 6; Fig. 7).

Numbers of *Chysoperla* spp. caught on sticky cards in straw mulch plots did not differ from those in control plots in 2006 ($P > 0.05$) (Table 4). In 2007, captures of *Chrysoperla* spp. were minimal (only nine individuals captured during entire sampling period).

Impact of Straw Mulch on Onion Yield. Total onion yield weight was not affected by straw mulch in 2006 or in 2007 ($P > 0.05$) (Table 7). Although different onion cultivars were planted in the selected onion fields in 2007, straw treatments did not affect any yields. In contrast, production of jumbo grade onions was significantly increased in the straw mulch treatment in 2006 ($F = 6.44$; df = 1, 2; $P = 0.04$), but not in 2007 (Table 7). Perhaps, the dry conditions in 2007 were responsible for the lack of jumbo-sized onions. The mean number and weight of the other onion grades were not significantly affected by treatment in either year ($P > 0.05$) (Table 7).

Impact of Straw Mulch on *T. tabaci* Survival. In the laboratory, straw mulch covered soil reduced survival of *T. tabaci* to adulthood. Significantly fewer adults were captured on sticky cards in cages containing potted onion plants with straw covering the soil than in control ($t = -5.95$, df = 4, $P = 0.004$). Only 39% of *T. tabaci* larvae completed pupation and emerged as adults from potted onion plants treated with straw mulch, whereas 83.5% of the initial larval population emerged successfully from the control.

Discussion

Our results demonstrate that straw mulch may have a significant role in integrated pest management for *T. tabaci* in onion. A straw mulch treatment decreased the numbers of *T. tabaci* larvae throughout the sampling period in most fields sampled. Because thrips locate suitable host plants through visual cues in the UV spectrum (Terry 1997), such materials that reflect UV radiation have been shown to have a repellent effect on polyphagous and anthophilous thrips by obscuring their host location cues. UV reflective plastic mulches on onion crops in New Zealand reduced early season abundance of onion thrips populations, but their efficacy decreased over time (vanToor et al. 2004). Populations of *Frankliniella occidentalis* (Pergande) and *Frankliniella tritici* (Fitch) on tomato flowers have been significantly reduced by the use of UV-reflective mulches (Stavisky et al. 2002). UV-reflective mulch significantly reduced early season abundance of adult *Frankliniella* species in field-grown peppers (Reitz et al. 2003). UV reflectance has been suggested as the mode of action of wheat straw mulches in cropping systems when alate aphid landings were fewer on straw-mulched than nontreated cotton (Liewehr and Cranshaw 1991) and when the greenbug, *Schizaphis graminum* (Rondani), populations were significantly reduced on wheat straw plots (Burton and Krenzer 1985).

The mechanisms by which straw mulches reduce pest populations are not well defined. Differences in light reflectance between nontreated and straw-mulched onions have been reported previously (Gent et al. 2006). Still, the high-density commercial plantings of onions would limit the reflective area of straw mulches, minimizing their effect as season progressed. Nevertheless, during both years studied, there was a consistent decrease of *T. tabaci* larvae in straw mulch plots, and it was mostly evident when populations peaked. Although adult numbers were lower in straw-treated plots, no significant differences were evident with no-straw treatments, probably underrating the importance of the light reflectance of straw on *T. tabaci* adults. As populations increased over time, the treatment effect was more evident, indicating that straw mulch probably had a greater impact on reducing the within-field development of the thrips population than on reducing the colonization of the field by *T. tabaci.* Perhaps, a denser straw mulch layer would contribute to a more evident light reflectance effect and delayed colonization of adult thrips, but this remains to be tested.

Conservation of ground predators, and resulting pest suppression, have been commonly reported with

Table 6. Treatment, sampling date and treatment × sampling date effect on coccinelids collected on sticky traps above onions grown under straw and no-straw in fields of NY in 2007

	Elba 1		Elba 2		Potter 1		Potter 2	
	F value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value
Treatment (df = 1, 3)	0.01	0.91	2.23	0.23	5.02	0.11	4.46	0.12
Date (df = 8, 48)	1.03	0.42	5.46	<0.001	3.59	0.002	6.70	<0.001
Treatment × date (df = 8, 48)	0.62	0.76	0.74	0.66	2.21	0.04	0.80	0.61

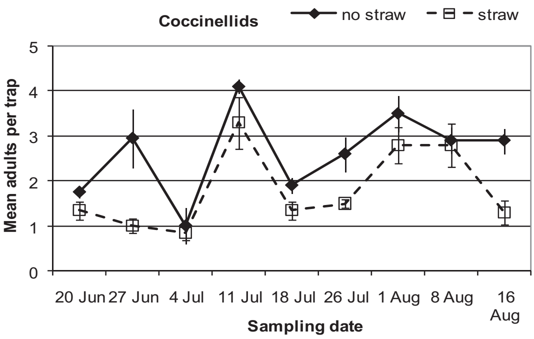

Fig. 7. Number (mean ± SEM) of coccinellid predators captured on sticky traps above onion plants grown under straw and no-straw treatments during summer 2007. Data presented are averages for the four fields.

the use of straw mulches (Halaj et al. 2000; Johnson et al. 2004). The potential or increased abundance of natural enemies was examined in both years but we found no evidence that straw mulch affected the ground predatory fauna in 2006. However, the most commonly observed predatory thrips was negatively affected by the presence of straw mulch in 2007, suggesting that light reflectance could obscure their prey finding cues in a similar way to the herbivorous *T. tabaci.* Similar negative effects of UV-reflective mulches have been reported for the predatory *Orius insidiosus* (Say) (Heteropetra: Anthocoridae) disrupting the natural control against thrips in peppers (Reitz et al. 2003).

In the absence of evidence of an increase in natural enemy abundance, physical or chemical properties of straw mulch could contribute to a decrease in *T. tabaci* populations. Our laboratory studies indicated that pupation and/or emergence of *T. tabaci* was hampered in onions grown in straw mulch and, although implications of straw mulch on *T. tabaci* emergence are not well understood, they could explain differences in thrips populations in the field by creating an unfavorable microenvironment for completion of pupation and successful emergence. Such effect would be important in *T. tabaci* management by reducing the adult emergence and population increase in the onion field. For example, coarse composted mulch beneath avocado trees reduced peak emergence of adult *Scirtothrips perseae* (Nakahara) (Thysanoptera: Thripidae), and it was suggested that this may be due to antagonistic microanthropods, release of secondary plant compounds, or increase of entomopathogens or nematodes (Hoddle et al. 2002).

Although differences in *T. tabaci* larval populations in treatments with and without mulch were evident in both years of the study, they were not accompanied by any increase in bulb size and yield in the straw-mulched treatments. The increased number of jumbo onions observed in 2006 was not repeated in 2007. The agronomic benefits of straw mulches on onions include decreased water runoff and increased lateral movement of soil moisture in mulched plots when straw mulch is applied to irrigation furrows (Shock et al. 1999) and increased soil water potential (Diaz-Perez et al. 2004). Perhaps the high water retention ability of muck soils diminishes the benefits of increased water retention capacity by the straw mulch. Nevertheless, increases in yield have been reported in the production of jumbo and colossal (>10 cm) onions under straw mulch treatments in Oregon (Shock et al. 1999), whereas medium-sized onion production (which is the main New York marketable yield) was not affected.

Insecticides were not applied during this study to demonstrate the effects of straw mulch on regulation of *T. tabaci* populations. The amount of straw required for mulch in a commercial onion field would cost approximately \$166.7/ha (excluding transportation and application costs). Both conventional and organic farmers should consider the use of straw mulch for *T. tabaci.* The action threshold for timing insecticide sprays to control *T. tabaci* was reached later in the straw mulch treatments, indicating that onion growers could delay the initiation of insecticide applications and/or increase the gap between consecutive insecticide sprays. Also, the mechanical harvesting process followed by the growers at the end of our experiments in both years was not impeded by the presence of straw mulch in the onion fields, which is encouraging for the implementation of such cultural method in the onion cropping system.

Regardless of the mode of action of straw mulch, its use suppresses *T. tabaci* larval populations in onions and with the concerns of environmental contamination by pesticide applications, insecticide resistance to commonly used chemicals and the incidence of IYSV

Table 7. Yield of different onion sizes produced in one double row of onions (9.15 m long) (mean ± SEM) grown under different cultural practices during summers 2006 and 2007

	Treatment	Total yield (kg)	Mean wt (kg) ± SE (no. ± SE)		
			Jumbo	Medium	Small
2006	Straw	19.4 ± 3.6a	3.8 ± 0.9a (13.2 ± 3.1)	14.6 ± 3.2a (85.5 ± 18.4)	1.0 ± 0.1a (13.5 ± 1.5)
	No straw	15.9 ± 2.5a	1.1 ± 0.4b (4.5 ± 1.5)	13.2 ± 2.8a (92.5 ± 14.1)	1.6 ± 1.8a (22.0 ± 13.4)
		$F_{1,6} = 0.6, P = 0.5$	$F_{1,6} = 6.0, P = 0.05$	$F_{1,6} = 0.1, P = 0.8$	$F_{1,6} = 0.1, P = 0.8$
2007	Straw	17.4 ± 1.6a	1.5 ± 0.8a (6.0 ± 2.3)	11.7 ± 3.0a (88.7 ± 18.5)	4.2 ± 1.3a (74.6 ± 23.0)
	No straw	16.2 ± 1.8a	0.5 ± 0.2a (1.5 ± 0.8)	10.5 ± 1.5a (86.5 ± 1.0)	5.2 ± 0.6a (69.7 ± 11.8)
		$F_{1,6} = 0.3, P = 0.6$	$F_{1,6} = 1.3, P = 0.3$	$F_{1,6} = 1.0, P = 0.3$	$F_{1,6} = 0.2, P = 0.7$

Results shown are for one field in 2006 and the average of four fields in 2007.

in New York onion fields, straw mulches may play an important role on *T. tabaci* management.

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