Thresholds, Injury, and Loss Relationships for Thrips in *Phleum pratense* (Poales: Poaceae)

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**ABSTRACT**
Timothy (*Phleum pratense* L.) is an important forage crop in many Western U.S. states. Marketing of timothy hay is primarily based on esthetics, and green color is an important attribute. The objective of these studies was to determine a relationship between arthropod populations, yield, and esthetic injury in timothy. Economic injury levels (EILs) and economic thresholds were calculated based on these relationships. Thrips (Thripidae) numbers were manipulated with insecticides in small plot studies in 2006, 2007, and 2008, although tetranychid mite levels were incidentally flared by cyfluthrin in some experiments. Arthropod population densities were determined weekly, and yield and esthetic injury were measured at each harvest. Effects of arthropods on timothy were assessed using multilinear regression. Producers were also surveyed to relate economic loss from leaf color to the injury ratings for use in establishing EILs. Thrips population levels were significantly related to yield loss in only one of nine experiments. Thrips population levels were significantly related to injury once before the first annual harvest and twice before the second. Thrips were the most important pest in these experiments, and they were more often related to esthetic injury rather than yield loss. EILs and economic thresholds for thrips population levels were established using esthetic injury data. These results document the first example of a significant relationship between arthropod pest population levels and economic yield and quality losses in timothy.

**KEY WORDS**
hybrid economic injury level, economic threshold, multilinear regression, *Anaphothrips obscurus*

Timothy (*Phleum pratense* L.) is a cool-season (*C*₃) grass that is grown as a forage crop in the United States. Most timothy grass in California is grown perennially for hay production in the intermountain areas above 900-m elevation and is usually harvested (cut) twice per year. Because it is high-value forage, it is grown with agrichemical inputs and scheduled irrigations during the dry summer in California, as opposed to low-input forage crop species or rangelands. In 2007, California retail prices for alfalfa hay fluctuated between $145 to $205 per metric ton, whereas prices for timothy averaged $270 to $315 per metric ton (USDA AMS 2007). This hay has stable export markets, with a high demand in Japan for hay from the Pacific Northwest, and stable domestic markets, with demands in natural beef (fed only grains and grasses) and horse (race and hobby) production.

Currently, all timothy produced in California is sold domestically. Timothy hay is largely purchased on esthetic appearance. Visual appearance is considered the most important attribute for producers of timothy hay, followed by hay price (Curtis et al. 2007). “Brown leaf” is a condition that refers to dead leaves, usually in the lower canopy of timothy stands. These brown leaves are very obvious in a bale of hay compared with the rest of the green foliage and cause a significant loss in marketability for the producer. Thrips have recently been implicated by producers as a major factor causing brown leaf and reducing yield in timothy hay. The grass thrips, *Anaphothrips obscurus* Müller, is the main thrips species found in California timothy (unpublished data). Other factors that may interact to cause brown leaf, viz. mites (Tetranychidae and Eriophyidae), nutrient deficiencies, especially nitrogen and potassium deficiencies, seeding rates, plant senescence, and disease.

The grass thrips was first documented in California by Bailey (1948) infesting fescue range grass. The resulting injury was referred to as “silver-top” (silver-top), but no studies exist regarding the significance of this injury. In timothy, silvertop refers to injury from *A. obscurus* that occurs in the growing points of the plant, which can include dead or abnormal inflorescences and white patches on the leaves (Hinds 1900, Kamm 1971). In addition to silvertop, undesirable frass is left by the thrips on the leaves. According to Casler and Kallenbach (2007), there are no insects or diseases that are known to cause significant economic yield or injury reductions in timothy. Silvertop damage was insignificant in California, until 1999, after a mild winter. It is possible that stress induced by thrips, such as

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silvertop, could affect brown leaf in timothy alone or in combination with other factors.

Establishment of economic thresholds, based on economic injury levels (EILs) is a pivotal part of integrated pest management (IPM), and there were at least 100 economic thresholds published for arthropod pests in 43 commodities, as of 1993 (Peterson 1996). Sadof and Raupp (1996) developed a hybrid EIL for commodities that are primarily purchased on esthetic qualities. EILs have not been developed for timothy, but a hybrid EIL would be appropriate because purchases are based largely on esthetic qualities. The hybrid EIL differs from the generalized EIL in the damage (D) and value (V) parameters, founding the calculation of these terms in esthetic characteristics.

California timothy producers use various tactics against thrips, although economic injury attributable to thrips has never been scientifically documented. Physical tactics such as field-burning may manage thrips (Hewitt 1914), but burning may decrease plant vigor if the timothy is not dormant when burned (Wasser 1982). Hence, most California timothy producers manage arthropods with methidathion, cyfluthrin, and/or malathion. Long-term availability of methidathion is uncertain because it is registered under a special local needs label; moreover, both methidathion and malathion are organophosphate materials that are under regulatory scrutiny. Furthermore, in California, timothy treated with methidathion may only serve as horse feed. Because this thrips is multivoltine, with a short developmental time of 12–30 d (Hewitt 1914, Köppä 1970), malathion, which has a short residual period, is commonly applied two to three times more often than methidathion. This application frequency is economically and environmentally injurious and may lead to insecticide resistance.

Finally, a pyrethroid, cyfluthrin, was registered for use on grasses in California in September 2006. This insecticide was labeled for management of armymworm (Noctuidae) species. Armymworm species inhabiting timothy in California are not known, nor are armymworms a major pest. Cyfluthrin was the preferred insecticide used by growers in 2007 and 2008 for thrips management, and it is restricted to one application per year. Unfortunately, pyrethroid insecticides can flare Tetranychid mite populations in other crops such as cotton (Reisig and Godfrey 2006), but without sustainable control options, producers are forced to accept these unwanted consequences.

These studies were designed to first test the hypothesis that potential pest–arthropod species present in California timothy are related to decreased yield. Second, these studies tested the hypothesis that potential pest–arthropod species present in California timothy are related to injury (brown leaf) in timothy. Phytophagous mites and thrips were the pest species of focus in these studies. If relationships could be documented between pests and timothy yield or between pests and injury to timothy, data would be gathered and analyzed to create EILs and economic thresholds. The ultimate goal was to provide growers with a preliminary form of IPM using economic thresholds as a justification for treatment of pests.

Materials and Methods

Field and Plot Preparation. Six separate small plot experiments were established on 10 February (field 1) and 4 July 2006 (field 1), 6 April (field 1) and 13 July 2007 (field 1), and 10 April (field 1) and 24 July 2008 (field 1). Plots were located in an insecticide-free timothy field in the Fall River Valley, CA, near Fall River Mills (Field 1). This field was planted in 2000 with the variety ‘Timfor’. Field 1 received grower inputs of 52 kg N/ha (46-0-0 urea) in mid-March, before the first cutting, and 52 kg N/ha in early July, after the first cutting in 2006 and 2007. Furthermore, the grower applied 45 kg N, 34 kg K, 34 kg P, and 5 kg Zn per ha in mid-March 2007 to field 1. Finally, a dicamba + 2,4-dichlorophenoxyacetic acid (Banvel + 2,4-D at 2.242 g [AI] dicamba/ha and 6,434 g [AI] 2,4-D/ha; BASF, Florham Park, NJ) was made by the grower in March of 2006 and 2007. Nutrient and herbicide data were unavailable for 2008. However, management of this field was representative of most timothy fields in the Fall River Valley, except no insecticides were applied.

Three additional small plot experiments were established on 6 April 2007 (field 2) and on 10 April (field 2) and 10 July 2008 (field 2) in a separate insecticide-free timothy field in the Fall River Valley, CA, near Glenburn (field 2); field age and variety were unknown. Field 2, in contrast to field 1, was atypical because it had never received nutrient or pesticide input. Nitrogen, 140 kg N/ha (46-0-0 urea) was applied to all plots on 26 April 2007 in field 2 and on 11 May 2007 in field 1 using a hand spreader (Scotts Handy Green II Hand-Held Spreader; The Scotts Miracle-Gro Company, Maysville, OH) to enhance timothy growth. Finally, the grower applied 52 kg N/ha (46-0-0 urea) in mid-March, before the 2008 first cutting, but did not apply any nutrients before the 2008 second cutting in field 2. Timothy was irrigated as needed throughout the spring and summer in both fields.

Plots were 12.2 by 12.2 m in 2006, with three replicates per treatment, and 6.1 by 12.2 m in 2007 and 2008, with six replicates per treatment in a randomized complete block design. Treatments consisted of a malathion (Malathion 8 Aquamul at 5,604 g [AI]/ha; Agrium, Calgary, Alberta, Canada) application, a spinosad (Success at 175 g [AI]/ha; Dow Agrosciences, Indianapolis, IN) application, and a cyfluthrin (Baythroid 2 at 33.3 g [AI]/ha; Bayer CropScience, Research Triangle Park, NC) application in 2006. Treatments were the same in 2007, but β-cyfluthrin (Baythroid XL at 16.6 g [AI]/ha; Bayer CropScience) was substituted for cyfluthrin and an organic formulation of spinosad (Entrust at 112 g [AI]/ha; Dow AgroSciences) was used. Furthermore, a methidathion (Supracide 2E at 1,121 g [AI]/ha; Syngenta Crop Protection, Basel, Switzerland) treatment was added. Treatments were the same in 2007, as in 2008, but the formulation and rate of spinosad that were used in 2006 was substituted for the formulation used in 2007.
All chemicals were combined with a silicone surfactant (Sylgard 309 at 0.25% total spray volume; Wilbur-Ellis Company, Fresno, CA) in 2007 and 2008.

Malathion was applied on 10 February 2006, and both malathion and cythrin were applied on 24 February 2006 to their respective treatment plots. After these initial applications, all pesticides were applied to their respective treatment plots in ~4-wk intervals. Treatments were made on 28 March, 26 April, and 24 May 2006; 4 July, 3 August, and 30 August 2006; 6 April, 10 May, and 7 June 2007; 13 July, 10 August, and 6 September 2007; and 10 April, 6 May, and 4 June 2006. In summer 2008, treatments were applied to field 1 on 24 July and 21 August, whereas treatments were applied on 10 July, 7 August, and 4 September to field 2. Only two treatments were made to field 1 in summer 2008 because the field was harvested late in June, and the timothy had not recovered as early as field 2. Treatments made before July in a year were applied before the first yearly cutting, whereas treatments made during or after July were applied after the first cutting and before the second yearly cutting.

Sampling. Arthropods were sampled weekly by collecting 10 tillers per plot. Tillers were collected at approximately equal distances from one another within the plots, but at least 1 m from the plot edge. To avoid sample bias, tillers were not selected by sight. Tillers were collected by carefully grasping the haleocorn and gently pulling the tiller from the ground to avoid dislodging organisms on them. These tillers were stored in plastic bags and transported in a cooler to Davis, CA, where they were stored for 1–3 d at 4°C before processing. Tillers were washed according to the procedure described by Reisig and Godfrey (2006), but arthropods were backwashed into vials with alcohol storage for later quantification. Accumulated arthropod-days were calculated for the period after treatment (Ruppel 1983). Additionally, a sample of phytophagous mites was collected and identified as Oligonychus pratensis Banks and Tetramychus spp. by Ronald Ochoa (personal communication). Predatory thrips and mites were not present in the samples in adequate numbers for analysis.

Harvest. Timothy was harvested for yield analysis on 12 June and 7 September 2006, on 21 June and 10 September 2007, and on 13 June and 8 September 2008 in field 1. Timothy was harvested on 14 June 2007 and on 13 June and 8 September 2008 in field 2. A sickle bar mower (Troy–Bilt Sickle Bar Mower Quantum Power 4HP; MTD Products, Cleveland, OH) was used to cut timothy from each plot in the following swath lengths: 3.56 × 0.86 m (field 1, first cutting 2006), 4.27 × 0.86 m (field 1, second cutting 2006), and 2.97 × 0.86 m (field 2, first cutting 2007). Cut hay was immediately raked onto tarps and weighed on a mechanical hanging scale (Chatillon 60 × 1/10 lb. Milk Scale; AMETEK, Paoli, PA) tared to zero for tarp weight. Cut hay was immediately raked onto tarps and weighed on a mechanical hanging scale (Chatillon 60 × 1/10 lb. Milk Scale; AMETEK, Paoli, PA) tared to zero for tarp weight. A mechanical flail harvester (Carter Forage Harvester; Carter Manufacturing, Brookston, IN), equipped with an electronic scale (Weigh-tronix scale model 615; Avery Weigh-Tronix, Fairmont, MN), was used to cut timothy from each plot in 0.91-m-wide swaths in field 1, second cutting 2007, and in all 2008 experiments. Swath lengths varied among plots and were measured after the cut was made; harvested timothy weight was recorded electronically. Lengths of the cuts ranged from ~8 to 11.6 m. One swath was cut per plot in 2006 and 2007 and before the first cutting in 2008. Three cuts per plot were harvested in both fields before the second cutting in 2008 to increase the power of detecting a yield difference among treatments. All weights were converted into yields per unit area by extrapolation from the area harvested per plot. In addition, one sample was taken at random from each block immediately after harvest to determine moisture. These samples were placed in paper sacks, weighed, and sealed in plastic trash bags. The paper sack was removed from the plastic and placed in a forced air dryer at 49°C for 7 d. Dry matter percentage was determined by dividing the weight of the hay after drying by the fresh weight of the hay directly after harvest and multiplying by 100.

For quality analysis, samples were collected from a random location within each plot on the same day that the timothy was harvested for yield analysis. Hedge shears were used to cut timothy from a 0.5-m quadrat to the same height as the sickle bar mower and mechanical harvester. These samples were transported to Davis, CA, where a subsample of the hay leaves was separated from the stems based on five color categories: 0–20, 21–40, 41–60, 61–80, and 81–100% brown. Hay leaves that were 100% green were categorized as uninjured, whereas hay leaves that were 100% brown were categorized as fully injured. Each category was placed in a paper bag and dried at 49°C for 7 d and weighed. Weights were used to calculate average injury by calculating the total proportion of hay in each injury category for each treatment replication. This was converted into a continuous injury rating scale from 1 to 5. Injury category = 1 corresponded to hay that was 100% green, whereas injury category = 5 corresponded to hay that was 100% brown.

Hay Bale Survey. Fourteen hay bales were selected from seven different growers in the Fall River Valley, each contributing one to three bales. These bales were chosen on the basis of brown leaf content and represented a range of hay from almost no brown leaf to extremely high brown leaf content. Six different growers and one hay buyer were surveyed from 15 to 30 October 2008, asking them to price the hay based only on the criterion of brown leaf content, ignoring other criteria affecting price. They were asked to assume the hay would be sold on that day and asked them to record the price that they would receive if it were first cutting hay and the price that they would receive if it were second cutting hay. A sample was taken from each bale and leaves were separated and quantified into five injury categories based on percent brown using the same procedure as that for the plot harvest samples.

Statistical Analysis. Average injury categories for each treatment were compared with the accumulated arthropod-days for both thrips and phytophagous mites from their respective plot using multilinear regression ($P < 0.05$; PROC REG; SAS Institute, Cary, NC). Accumulated thrips-days and accumulated mite-days were selected for inclusion or exclusion by Mallow’s Cp criterion (Mallows 1966) and the lowest variance inflation factor (Mallows 1966) and the lowest variance inflation factor.
factor. The same procedure was used to analyze all nine experiments using injury, as well as yield data.

Significant regressions between accumulated thrips and/or mite-days were assessed for use in a hybrid EIL. Regressions that included significance for both thrips and mites were not considered for use, because the presence of one arthropod confounded the impact of the other on injured timothy. There was one regression where accumulated thrips-days were significantly related to injury ratings before the first cutting (field 2, 2008) and two regressions where accumulated thrips-days were significantly related to injury ratings before the second cutting (field 1 and field 2, 2008). The single significant regression from the spring data were used for the first cutting hay hybrid EIL, and the two significant regressions from the summer data were used for the second cutting hay hybrid EIL.

Three separate analyses of variances [analysis of variance (ANOVA); P < 0.05; PROC MIXED; SAS) were performed to assess the range of hay bales selected for the survey, as well as to test the robustness of the survey data for inclusion in the EIL. The seven survey participants were included as a categorical variable, which was assigned as a random factor. Fixed factors included hay bale and percent brown leaf for the first ANOVA, hay bale and average price for first cutting hay for the second ANOVA, and hay bale and average price for second cutting hay for the third ANOVA.

Hybrid EIL Coefficients. Costs of control (C) were estimated based on summer 2008 prices for chemicals (Supracide at $18.50 per liter and Baythroid XL at $100.12 per liter) and air application ($4.05 per hectare). At these rates, including the cost of aerial application for second cutting hay, growers paid $18.21/ha for a methidathion treatment (Supracide at $18.50 per liter and Baythroid XL at $100.12 per liter) and air application ($4.05 per hectare). These values were used in a regression with accumulated thrips-days per tiller (PROC REG; SAS), and the slope was used to represent the amount of discoloration caused by an individual thrips (I).

The perceived damage per unit of pest injury (D) was estimated as damage resultant from each unit of injury based on survey results (Sadof and Raupp 1996, Klingeman et al. 2001). This component was estimated from the hay bale survey pertaining to dollars lost because of brown leaf. Damage ratings from the hay bale survey were converted into percent brown leaf for each hay bale, and the average prices from the grower survey were converted into a measure of percent loss. This was accomplished by calculating the price for completely undamaged hay using the values from the two damage regressions from the hay bale survey for first cutting and second cutting hay prices. These estimations were used to calculate the percent loss caused by brown leaf. Finally, this measure of percent loss caused by brown leaf was regressed against the percent brown leaf for each hay bale (PROC REG; SAS). The slopes obtained from these two regressions were used to calculate the coefficient for the hybrid EIL equation. The effectiveness of control (K) was assumed to be 100%.

Economic thresholds were determined by averaging the EILs obtained from each experiment at each chemical and proposed yield combination and multiplying by 0.75. Economic thresholds were established for both first and second cutting hay.

Results

Arthropod Effects on Yield and Injury. Percent moisture values of the harvested timothy ranged from 60 to 70% among the nine experiments. Thrips levels were manipulated by the treatments in all experiments (Fig. 1), and phytophagous mite densities were different among treatments in four experiments (Fig. 2). Figures with accumulated arthropod-days are only presented for terms selected for inclusion in the multilinear regressions (Tables 1 and 2). First cutting dry matter yields in plots ranged 4–6 (field 1, 2006), 10–18 (field 1, 2007) 7–13 (field 2, 2007), 5–11 (field 1, 2008), and 3–12 t/ha (field 2, 2008). Second cutting dry matter yields in plots ranged 2–6 kg/ha (field 1, 2006), 4–10 kg/ha (field 1, 2007), 1–3 t/ha (field 1, 2008), and 2–4 t/ha (field 2, 2008). Yield was significantly negatively related to accumulated thrips-days in field 2 before the first 2008 cutting (Table 1).

Injury (brown leaf) was significantly positively related to accumulated mite-days in field 1 before the second cutting in 2006 and before the first cutting in 2007 (Table 2; Fig. 2). Injury values obtained from the plots ranged from 2.3 to 4.2, with a median of 3. Many of the plants did not regrow in 2007 (field 1) but were killed by the mites in the plot with the highest mite levels. As a result, the 2007 experimental plots were moved from this area within the field. Mite populations in these experiments were significantly flared by the use of cyfluthrin; accumulated mite-days per tiller ranged widely in the second cutting field 1, 2006 cyfluthrin-treated plots (5,980, 3,039, 57) and the first cut-
ting field 1, 2007 cyfluthrin-treated plots (655, 92, 78, 45, 24, 8). Moreover, accumulated mite-days were below 526 in all other treatment plots in the 2006 experiment and below 116 in the 2007 experiment. As a result, the slope of the regression was significantly influenced by the presence of two cyfluthrin-treated plots with the highest mite levels in the 2006 experiment and the single cyfluthrin-treated with high mite levels in the 2007 experiment. Because there were not enough plots with a range of mite population levels, a single significant regression from the period before the first and second cutting was not considered to have sufficient predictive power to provide a robust hybrid EIL.

Injury was also significantly positively related to accumulated thrips-days before the first cutting in field 2, 2008, and before the second cutting in fields 1 and 2, 2008 (Table 2). Injury values ranged from 2.5 to 3.7 in field 2 before the first 2008 cutting, with a median value of 3. Second cutting in 2008 injury ratings ranged from 1.6 to 3.8 in field 1 and 1.6 to 3.6 in field 2, with respective median values of 2.3 and 2.9. There were no cases where injury was related to both accumulated thrips and mite-days. Although there was only a single significant regression where thrips were related to injury before the first cutting, when blocks were included as a covariate in the model, injury was also related to accumulated thrips-days before the first cutting in field 2 before the first 2007 cutting ($F = 8.25; df = 29; P = 0.0016$).

**EILs and Thresholds.** Survey participants identified a significant range of brown leaf among the 14 bales ($F = 31.88; df = 13,62; P = 0.0001$). There was also a significant range of prices among the bales, as as-
accumulated thrips-days, respectively, for cyfluthrin. For an expected second cutting hay, ranging from 18 to 171 and 7 to 60 accumulated thrips-days for EILs were lower for second cutting hay, ranging from 82 accumulated thrips-days for methidathion and cyfluthrin, respectively. The EILs for first cutting hay ranged from 59 to 180 and 7 to 60 accumulated thrips-days for cyfluthrin. The EILs were lower for second cutting hay, ranging from 18 to 171 and 7 to 60 accumulated thrips-days for methidathion and cyfluthrin, respectively.

Economic thresholds were based on 75% of the average EIL for each chemical and cutting combination. For an expected first cutting yield of 16, 13, or 11 t/ha, economic thresholds were calculated at 45, 51, and 62 accumulated thrips-days, respectively, for methidathion and 15, 18, and 22 accumulated thrips-days, respectively, for cyfluthrin. For an expected second cutting yield of 9, 7, or 5 t/ha, economic thresholds were calculated at 39, 52, and 78 accumulated thrips-days, respectively, for methidathion and 14, 18, and 27 accumulated thrips-days, respectively, for cyfluthrin.

Discussion

Yield. Thrips had a limited effect on timothy yield and, although mite population densities were incidentally increased by the use of cyfluthrin, relationships were not documented between mite population levels and timothy yield. Accumulated thrips-days were significantly positively related to yield loss and an increase in injury only in field 2 in the first 2008 cutting. Interestingly, accumulated thrips-days were not significantly related to yield in this same field before the 2008 second cutting. This second cutting experiment had the highest thrips levels and an even larger amount of hay subsampled from each plot for yield analysis. In this experiment, thrips levels were significantly positively related to injury, but there was no relationship between accumulated thrips-days and yield. Moreover, accumulated thrips-days in field 2 before the first 2007 cutting were similar to those in field 2 in the first 2008 cutting, although there was no significant relation between arthropod levels and injury or yield in this experiment. The overall lack of relation among yield, mites, and thrips may be a result of other unmeasured factors, such as nutrient availability, weather, or other pests.

Table 1. Multilinear regression equations for dry matter yield (kg/ha) and arthropod presence over time as measured by accumulated thrips- and mite-days

<table>
<thead>
<tr>
<th>Field</th>
<th>Cut</th>
<th>Year</th>
<th>Multilinear regression models</th>
<th>F</th>
<th>df</th>
<th>R²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>First</td>
<td>2006</td>
<td>Yield = -20.3(AccM⁴) + 473.4</td>
<td>1.11</td>
<td>11</td>
<td>0.10</td>
<td>0.3168</td>
</tr>
<tr>
<td>1</td>
<td>Second</td>
<td>2006</td>
<td>Yield = -0.03(AccM) + 3356</td>
<td>4.32</td>
<td>11</td>
<td>0.30</td>
<td>0.0644</td>
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<tr>
<td>1</td>
<td>First</td>
<td>2007</td>
<td>Yield = -0.34(AccM) + 14562</td>
<td>0.00</td>
<td>29</td>
<td>0.00</td>
<td>0.9582</td>
</tr>
<tr>
<td>2</td>
<td>First</td>
<td>2007</td>
<td>Yield = 1.1(AccT) + 8962.8</td>
<td>2.46</td>
<td>29</td>
<td>0.08</td>
<td>0.1279</td>
</tr>
<tr>
<td>1</td>
<td>Second</td>
<td>2007</td>
<td>√(Yield) = 0.05(AccM) + 78.7</td>
<td>0.20</td>
<td>29</td>
<td>0.01</td>
<td>0.6581</td>
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<tr>
<td>1</td>
<td>First</td>
<td>2008</td>
<td>Yield = 528.8(AccM) + 7219.8</td>
<td>1.83</td>
<td>29</td>
<td>0.06</td>
<td>0.1666</td>
</tr>
<tr>
<td>2</td>
<td>First</td>
<td>2008</td>
<td>Yield = -24.2(AccT) + 8710.5</td>
<td>6.15</td>
<td>29</td>
<td>0.18</td>
<td>0.0194</td>
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<tr>
<td>1</td>
<td>Second</td>
<td>2008</td>
<td>(Yield)⁻¹ = 0.000000175(AccT) + 0.0000549</td>
<td>2.64</td>
<td>29</td>
<td>0.09</td>
<td>0.1153</td>
</tr>
<tr>
<td>2</td>
<td>Second</td>
<td>2008</td>
<td>Yield = 115(AccM) + 2738.3</td>
<td>1.68</td>
<td>29</td>
<td>0.06</td>
<td>0.2051</td>
</tr>
</tbody>
</table>

Table 2. Multilinear regression equations for injured timothy and arthropod presence over time as measured by accumulated thrips- and mite-days

<table>
<thead>
<tr>
<th>Field</th>
<th>Cut</th>
<th>Year</th>
<th>Multilinear regression models</th>
<th>F</th>
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<th>R²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>First</td>
<td>2006</td>
<td>Injury = 0.000607(AccM⁴) + 1.62</td>
<td>3.71</td>
<td>11</td>
<td>0.27</td>
<td>0.8028</td>
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<tr>
<td>1</td>
<td>Second</td>
<td>2006</td>
<td>Injury = 0.00002564(AccM⁴) + 2.53</td>
<td>12.44</td>
<td>11</td>
<td>0.55</td>
<td>0.0055</td>
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<tr>
<td>1</td>
<td>First</td>
<td>2007</td>
<td>√(Injury) = 0.0008919(AccM) + 1.32</td>
<td>19.24</td>
<td>26</td>
<td>0.43</td>
<td>0.0002</td>
</tr>
<tr>
<td>2</td>
<td>First</td>
<td>2007</td>
<td>Injury = 0.000224(AccT) + 2.36</td>
<td>1.44</td>
<td>29</td>
<td>0.05</td>
<td>0.2308</td>
</tr>
<tr>
<td>1</td>
<td>Second</td>
<td>2007</td>
<td>Injury = -0.00027(AccT) + 1.88</td>
<td>0.63</td>
<td>27</td>
<td>0.02</td>
<td>0.4335</td>
</tr>
<tr>
<td>1</td>
<td>First</td>
<td>2008</td>
<td>(Injury)⁻¹ = -0.00313(AccM) + 0.49</td>
<td>3.42</td>
<td>29</td>
<td>0.11</td>
<td>0.0750</td>
</tr>
<tr>
<td>2</td>
<td>First</td>
<td>2008</td>
<td>Injury = 0.00031(AccT) + 2.89</td>
<td>5.17</td>
<td>29</td>
<td>0.16</td>
<td>0.0308</td>
</tr>
<tr>
<td>1</td>
<td>Second</td>
<td>2008</td>
<td>Injury = 0.01327(AccT) + 2.89</td>
<td>23.15</td>
<td>29</td>
<td>0.45</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>2</td>
<td>Second</td>
<td>2008</td>
<td>Injury = 0.00288(AccT) + 2.27</td>
<td>58.54</td>
<td>29</td>
<td>0.68</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Notes:

- a Accumulated thrips-days.
- b Accumulated mite-days.
- c α < 0.05.
- d α < 0.01.
- e α < 0.001.
- √, square root transformation.
I. Injury. Thrips populations were significantly related to injured timothy on three occasions, one of which was during the period before the first annual harvest and two of which were during the period before the second annual harvest. Accumulated thrips-days were related to injured timothy in field 2 on two occasions but were only related on one occasion in field 1. Additionally, thrips population levels were significantly related to injured timothy on all occasions in field 2 when blocks were included in the model as a covariate. Omitting the results from field 1 in 2006, accumulated thrips-days were significantly related to injured timothy when accumulated thrips-days were above 35 in at least one treatment.

Phytophagous mite population levels were significantly related to injured timothy in one first cutting and one second cutting experiment. Tetanychid mites are often found in spatially disparate patches (Hanna et al. 1996, Reisig and Godfrey 2006), and this phenomenon was observed in these experiments. Two plots of 30 with relatively high mite densities influenced the significant first cutting regression and 1 plot of 30 with relatively high mite densities influenced the significant second cutting regression. An EIL was not calculated for phytophagous mites from this data, because it would be more robust with multiple experiments documenting a significant between injury and mite population levels and a wide range of population levels. Because insecticides were used to manipulate arthropod levels, they are a confounding factor in these experiments. Studies have shown a negative impact of pesticides on plant physiology on plants such as lettuce (Toscano et al. 1982, Johnson et al. 1983, Haile et al. 2000), cotton (Youngman et al. 1990), strawberries (LaPre et al. 1982), and oranges (Jones et al. 1983). This impact was measured as a decrease in gas exchange or photosynthesis. However, because the insecticide-treated plots in these studies generally had less-injured timothy than untreated plots, the possible negative effect of the insecticide on the physiology of the plant was most likely negligible to the injury resulting from thrips feeding.

II. EILs and Thresholds. Hay bales selected with the survey had enough significant differences among brown leaf content to obtain a range of values for first and second cutting hay based on the brown leaf criterion. The EILs were based on a single significant regression for first cutting hay and two significant regressions for second cutting hay. Furthermore, when block was included as a covariate, accumulated thrips-days were positively related to injured hay before the first cutting in field 2, 2007. Additional EILs were calculated using the regression slope parameter from this experiment. Recalculation of the economic threshold for first cutting hay with inclusion of these EILs and the EILs from field 2 before the first 2008 cutting only resulted in a change of =2 accumulated thrips-days. As a result, the economic thresholds calculated for first cutting hay were robust whether 1 or 2 yr of experimental data were included. Economic thresholds for second cutting hay were based on two experiments in different fields.

The profit margin decreased between the first and second cuttings because there are lower expected yields and a lower selling price for second cutting hay. However, the EILs based on expected yield were sometimes lower in the second cutting than the first. Moreover, there was a wider range of EIL values among expected second cutting yields compared with expected first cutting yields. One reason for this difference can be explained by examining the slopes for the accumulated thrips-days per tiller parameter. This was obtained from the regressions between injured hay and accumulated thrips-days per tiller before the second (field 1, 2008, =0.003 and field 2, 2008, =0.01) and first cutting (field 2, 2008, =0.0003). Based on these slopes, thrips injured timothy over three times as fast in field 2 before the second cutting than in field 1. Additionally, thrips numbers were greater in field 2 than field 1 before the second 2008 cutting. Treatments with the lowest and highest average accumulated thrips-days per tiller ranged from 7 to 59 in field 1 and from 41 to 384 in field 2. As a result, the 2008 second cutting regression slopes may differ because thrips numbers were so different. However, field and nutrient differences, as well other unmeasured plant or environmental characteristics, may also be responsible for this difference.

In addition to differences among slopes, the differences in the range of observed hay quality had an effect on the EILs. Based on parameters from the hay bale survey regressions, undamaged first cutting hay should have been worth $310.86/t and undamaged second cutting hay should have been worth $282.13/t. Growers typically gross a lower profit for second cutting than first cutting hay, as a result of many less desirable aesthetic characteristics usually present in second cutting hay, including higher brown leaf content. Results presented in this study are based entirely on percent brown leaf. The plot with the lowest injury in the experiment 2008 before the first cutting in field 2 had an injury rating of 2.5, which was =0.06% more injured than the plot with the lowest injury in the other two second cutting experiments used for the EILs. Based on the regression models obtained from the hay bale survey, the price for the top quality hay from this experiment was $224.13/t. Prices for the other two experiments were $275.08 (field 1, second cutting 2008), and $273.00 (field 2, second cutting 2008). The V parameter used in the EILs was based on the price

### Table 3. Hybrid EILs for methidathion (M) and cyfluthrin (C), with prices for first and second cutting hay expressed in accumulated thrips-days per tiller

<table>
<thead>
<tr>
<th>Field</th>
<th>Year</th>
<th>Cut</th>
<th>Chemical</th>
<th>Hybrid EIL (expected DM yield; t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2008</td>
<td>1</td>
<td>M</td>
<td>59  68  82</td>
</tr>
<tr>
<td>1</td>
<td>2008</td>
<td>2</td>
<td>M</td>
<td>18  25  37</td>
</tr>
<tr>
<td>2</td>
<td>2008</td>
<td>2</td>
<td>M</td>
<td>24  30</td>
</tr>
<tr>
<td>1</td>
<td>2008</td>
<td>1</td>
<td>C</td>
<td>20  24  29</td>
</tr>
<tr>
<td>1</td>
<td>2008</td>
<td>2</td>
<td>C</td>
<td>24  27  37</td>
</tr>
<tr>
<td>2</td>
<td>2008</td>
<td>2</td>
<td>C</td>
<td>30  40  60</td>
</tr>
</tbody>
</table>

Values are accumulated thrips-days per tiller. Expected dry matter (DM) yield is based on the typical range for first and second cutting hay in the Fall River Valley, CA.
for the best quality hay obtained from these experiments. Hence, the EILs for second cutting hay were based on experiments with hay that was less injured and more valuable even though growers typically gross lower profits for second cutting hay.

These studies document a single instance where thrips populations were related to yield reduction and multiple instances where thrips populations were related to injury of timothy. These results are significant because this is the first time that EILs and economic thresholds have been documented for thrips in timothy. Sampling techniques for thrips in this crop have been evaluated (Reisig 2009) and can be incorporated with these thresholds to provide growers with a preliminary IPM management tool. Timothy growers should use caution when applying cyfluthrin for thrips management, because it can flare tetranychid mite populations in the spring or summer. Future studies could strengthen the EIL for first cutting hay by investigating the relationship between thrips population levels and timothy injury across various grower fields and conditions. Furthermore, the focus of these thresholds on thrips and mites should be extended across pest classes and finally the entire agroecosystem.

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