# AN ECONOMIC THRESHOLD FOR THRIPS IN CALIFORNIA TIMOTHY

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## ABSTRACT

Timothy is grown as a high value forage crop in California. Thrips (*Anaphothrips obscurus* Müller) have recently been implicated causing damage by increasing the quantity of brown leaves and lowering the value of this crop. Minimal studies have explored the relation of thrips levels to yield and damage in timothy and management options for this pest are extremely limited. We performed studies in 2006-2008, manipulating thrips levels with disruptive insecticides to establish a hybrid economic injury level (EIL) and provide information on the level of thrips necessary to cause economic loss. Thrips levels were documented and yield and damage was assessed. We also collected bales with varying levels of brown leaves and surveyed growers on the price that they would receive for the bales if it were first or second cutting hay. In all our manipulative experiments, there was a range of thrips levels among treatments and Tetranychid mite levels were flared with cyfluthrin in some experiments. We found no significant impact of thrips or mite levels on yield, but were able to isolate the effect of thrips alone (without mites) on damage in two experiments. The information from these two experiments was combined with the survey data to provide a measure of economic loss based on brown leaf and to establish hybrid EILs. We created EILs for first and second cutting hay prices for methidathion and cyfluthrin. EILs ranged from 19-225 accumulated thrips days/tiller. We then created economic thresholds at 75% the level of the lowest EIL calculated. Economic thresholds ranged from 2-24 thrips/tiller/week. In summary, we found that cyfluthrin can significantly flare mites and we created economic thresholds for thrips in timothy that can be used with population information at a single point in time or can be combined with population information over time.

**Key words: Economic injury level, economic threshold, thrips, mites.**

## INTRODUCTION

Timothy (*Phleum pratense* L.) is a cool-season 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 3000 ft elevation. Because it is a high-value forage, it is grown with agrichemical inputs and it must be irrigated during the dry summer in California. In 2007, California retail prices for alfalfa hay fluctuated between $160 to $225 per ton, while prices for timothy remained consistent at $300 to $350 per ton (USDA AMS 2007). This hay has stable export markets, with a high demand in Japan, and stable domestic markets, with demands in natural beef (fed only grains and grasses) and horse (race and hobby) production.

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Timothy hay is largely purchased on aesthetic 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, when compared to 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 and *Anaphothrips obscurus* Müller is the main thrips species found in California timothy (unpublished data). Other factors that may interact to cause brown leaf include mites (Tetranichidae and Eriophyidae), nutrient deficiency, especially nitrogen and potassium, seeding rates, plant senescence and disease.

The grass thrips, *Anaphothrips obscurus* Müller, was first documented in California by Bailey (1948) infesting fescue range grass. The resulting injury was referred to as "silver-top" (silvertop). In timothy, silvertop refers to damage from *A. obscusus* 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. Silvertop damage was insignificant in California, until 1999, following a mild winter. It has also been hypothesized that stress induced by thrips, such as silvertop, could interact with other factors to effect brown leaf in timothy.

Integrated pest management (IPM) was developed as an idea and goal for pest management in the early 1960's (Stern et al. 1959) and current IPM practitioners herald sustainability as its primary goal (Higley and Pedigo 1999). IPM is defined as the decision support system used to harmonize pest control tactics into a sustainable coordinated management strategy. Cost benefit analyses and the interests and impacts of management on producers, society and the environment are considered (Norris et al. 2003). With the implementation of IPM recently called into question (Barfield and Swisher 1994, Ehler 2006), scientific input in IPM is immediately needed.

The economic injury level (EIL) is defined as the pest density at which the cost of taking a pest control action equals that of the value of the crop loss. Economic thresholds (ETs) are determined at a pest density somewhere below the EIL to avoid economic damage to the crop from the pest (Stern et al. 1959). Establishment of ETs is a pivotal part of IPM and there were at least 100 ETs published for arthropod pests in 43 commodities, as of 1993 (Peterson 1996). ETs provide a standard by which economically feasible treatment decisions can be made based on scientific data.

Sadof and Raupp (1996) developed a hybrid EIL for commodities that are priced based on aesthetic qualities. This hybrid EIL is appropriate for timothy, because purchases are based largely on aesthetic qualities. The hybrid EIL is defined as: *hybrid EIL* $= C/VIDK$, "where $C$ = the cost of control (e.g., \$/plant), $V$ = economic value and undamaged good (\$/plant), $I$ = proportion of injury per unit of pest density (\$lost/unit of injury/plant), and $K$ = effectiveness of control" (Sadof and Raupp 1996).

There are no ETs to indicate when thrips should be controlled. Although physical tactics such as field-burning may manage thrips (Hewitt 1914), burning may decrease plant vigor if the timothy is not dormant when burned (Wasser 1982). Hence, the only options for managing arthropod pests in California timothy are the insecticides methidathion, cyfluthrin, and 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 which 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 days (Hewitt 1914, Köppä 1970), malathion, which has a short residual period, is commonly applied 2 to 3 times more often than methidathion. This application frequency is economically and environmentally injurious and may lead to insecticide resistance.

A pyrethroid, cyfluthrin, was registered for use on grasses in California in September 2006 for armyworm control. Cyfluthrin was the preferred insecticide used by growers in 2007 and 2008 for thrips management, but 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.

## PROCEDURES

***Field and plot preparation.*** Small plots were established on 10 February and 4 July 2006, 6 April and 13 July 2007, and 10 April 2008 in an untreated timothy field in the Fall River Valley, CA, near Fall River Mills (Field 1). This field was planted in 2000 and was the variety 'Timfor'. Plots were initially established on 6 April 2007 and 10 April 2008, in a separate untreated timothy field in the Fall River Valley, CA, near Glenburn (Field 2); field age and variety were unknown. Plots were 40 x 40 ft in 2006, with 3 replicates per treatment, and 20 x 40 ft in 2007 and 2008, with 6 replicates per treatment in a randomized complete block design. Treatments consisted of a malathion (Malathion 8 Aquamul at 80 fl oz/A; Agrium, Inc.) application, a spinosad (Success at 10 fl oz/A; Dow Agrosciences) application, and a cyfluthrin (Baythroid 2 at 1.9 fl oz/A; Bayer CropScience) application in 2006. Treatments were the same in 2007, but beta-cyfluthrin (Baythroid XL at 1.9 fl oz/A; Bayer CropScience) was substituted for cyfluthrin and an organic formulation of spinosad (Entrust at 2 fl oz/A; Dow AgroSciences) was used. Furthermore, a methidathion (Supracide 2E at 64 fl oz/A; Syngenta Crop Protection, Inc.) 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) in 2007 and 2008.

Malathion was applied on 10 February 2006 and both malathion and cyfluthrin 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 approximately four-week 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. Treatments made before June in a year were applied before the first yearly cutting, while treatments made in 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 3 ft from the plot edge. In addition, tillers were not selected by sight, to avoid sample bias. All tillers were collected by carefully grasping the corm and gently pulling the tiller from the ground to avoid dislodging organisms. These tillers were stored in plastic bags and transported in a cooler to Davis, CA, where they were stored for 1-3 days in a refrigerator before processing. Tillers were washed according to the procedure described by Reisig and Godfrey (2006), but arthropods were backwashed into vials with alcohol storage and later quantification. Accumulated arthropod-days were calculated for the period after treatment (Ruppel 1983). Thrips and phytophagous mites from these experiments were not identified to species, but previous identification efforts indicate that the majority of thrips in California timothy are *A. obscurus* (unpublished data). Additionally, a sample of phytophagous mites was collected and indentified as *Oligonychus pratensis* Banks and *Tetranychus* spp. by Ronald Ochoa (personal communication) and both mites are in the Tetranychid family. Predatory thrips and mites were not present in the samples in adequate numbers for analysis. Eriophyid mites were too small to be captured in our wash method, but were not observed in the field plots.

***Harvest.*** The timothy was harvested for yield analysis on 12 June and 7 September 2006, on 21 June and 10 September 2007 and on 13 June 2008 in Field 1; similarly, timothy was harvested on 14 June 2007 and 13 June 2008 in Field 2. A sickle bar mower was used to cut timothy in the following swath lengths: 11.68 x 2.82 ft (Field 1, 1$^{st}$ cutting, 2006), 14 x 2.82 ft (Field 1, 2$^{nd}$ cutting, 2006), and 9.74 x 2.82 ft (Field 2, 1$^{st}$ cutting, 2007). Cut hay was immediately raked onto tarps and weighed on a mechanical hanging scale tared to zero for tarp weight. A mechanical flail harvester, equipped with an electronic scale, was used to cut timothy in 3 ft wide swaths in Field 1, second cutting of 2007, and in both fields in 2008. Lengths of the swaths varied among plots and the swath length was measured after the cut was made; harvested timothy weight was recorded electronically. Lengths of the cuts ranged from approximately 26 to 38 ft. All weights were converted into yields per acre by extrapolation from the area harvested per plot. In addition, one sample was taken at random from each block immediately after harvest to determine the moisture of the hay for reference. These samples were placed in paper sacks, sealed in plastic trash bags, and weighed. The paper sack was then removed from the plastic, and placed in a forced air dryer at 120° F for 7 days. The percent moisture was determined by dividing the weight of the hay after drying by the weight of the hay directly after harvest and multiplying by 100.

For damage analysis, samples were collected from a random location within each plot on the same day that the timothy was harvested for yield analysis. We used hedge shears to cut timothy from a 1.6 ft 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 based on 5 color categories: 0-20, 21-40, 41-60, 61-80, and 81-100 % brown. We assumed that hay leaves that were 100% green were undamaged, whereas hay leaves that were 100% brown were fully damaged. Each category was placed in a paper bag and dried at 49° C for 7 days and weighed. Weights were used to calculate average damage by calculating the total proportion of hay in each damage category for each treatment replication. This was then converted into a continuous damage rating scale from 1-5. Damage category = 1 corresponded to hay that was 100% green, whereas damage 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. We surveyed six different growers and one hay buyer from 15 to 30 October, asking them to price the hay based only on the criterion of brown leaf content, ignoring other criteria affecting price. We asked them 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 damage categories based on percent brown using the same procedure as that for the plot harvest samples.

***Analysis.*** Each damage category obtained from the harvest samples was compared to the accumulated arthropod days for both thrips and phytophagous mites from their respective plot using multilinear regression. Blocks, 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. In one case, the regression was nonlinear, and a generalized linear mixed model approach was used for analysis.

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 damaged timothy. Accumulated mite days alone were only significantly correlated with damage ratings on one occasion and we did not consider this one significant regression to have sufficient predictive power to provide a robust hybrid EIL. Finally, there were two regressions where accumulated thrips days alone were significantly correlated with damage ratings (Field 2, first cutting, 2007-2008). We chose to use these two regressions for our hybrid EIL.

Prices from the seven different survey participants in the bale ratings were averaged into price for first cutting hay and price for second cutting hay. These average prices were then regressed against the damage ratings obtained from the sample taken from the bale. This gave us a measure of how the price of the hay responded to our damage ratings for first cutting hay and second cutting hay prices.

***Hybrid EIL coefficients.*** Costs of control (*C*) were estimated based on the current (summer 2008) prices for chemicals (Supracide at $70/gal and Baythroid XL at $379/gal) and air application ($10/A). At these rates, including the cost of aerial application, growers are spending $45/A for a methidathion treatment and $15.63/A for cyfluthrin treatment (Daniel Marcum, personal communication).

Value of the timothy (*V*) was estimated based on the values from the two damage regressions obtained from the hay bale survey for first cutting and second cutting hay prices. To obtain hybrid EILs based on different yields, the values from the regression obtained for first cutting hay were then multiplied by typical yields for first cutting timothy (5, 6 and 7 tons/A) and the values for second cutting hay were then multiplied by significant yields for second cutting timothy (2, 3 and 4 tons/A).

Damage ratings from the two significant regressions (Field 2, first cutting, 2007-2008) were converted to percent brown leaf for each plot ((Damage rating-1)*100/4). We used these values in a regression with accumulated thrips days per tiller and the slope was used to represent the amount of discoloration caused by an individual arthropod pest (*I*).

To estimate the proportion of consumers perceiving damage per unit of pest injury (*D*), we chose to estimate "*D*" 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 due to brown leaf. We estimated of percent loss due to brown leaf and regressed it against the percent brown leaf for each hay bale. The slopes obtained from these two regressions were used to calculate the "*D*" coefficient for the hybrid EIL equation.

Finally, we assumed that the effectiveness of control (*K*) was 100%, so that *K* = 1.0.

## RESULTS

Percent moistures of the harvested timothy ranged from ~60-70%. Although there was a range of thrips levels among treatments before every cutting and some instances where there was a range of mite levels (Figures 1-3), there were no instances in which accumulated thrips and/or mite days were significantly correlated with yield. However, accumulated mite days alone were significantly positively correlated with damage (percent brown leaf) before the second cutting 2006. Similarly, accumulated thrips days alone were significantly positively correlated with damage before the first cutting 2007-2008 in Field 2. Finally, both accumulated thrips and mite days were significantly positively correlated with damage before the first cutting in Field 1 in 2007 and 2008. In contrast, both accumulated thrips and mite days were significantly negatively correlated with damage before the first cutting in Field 1 in 2008. Accumulated thrips and mite days for significant regressions are presented (Figures 1-3).

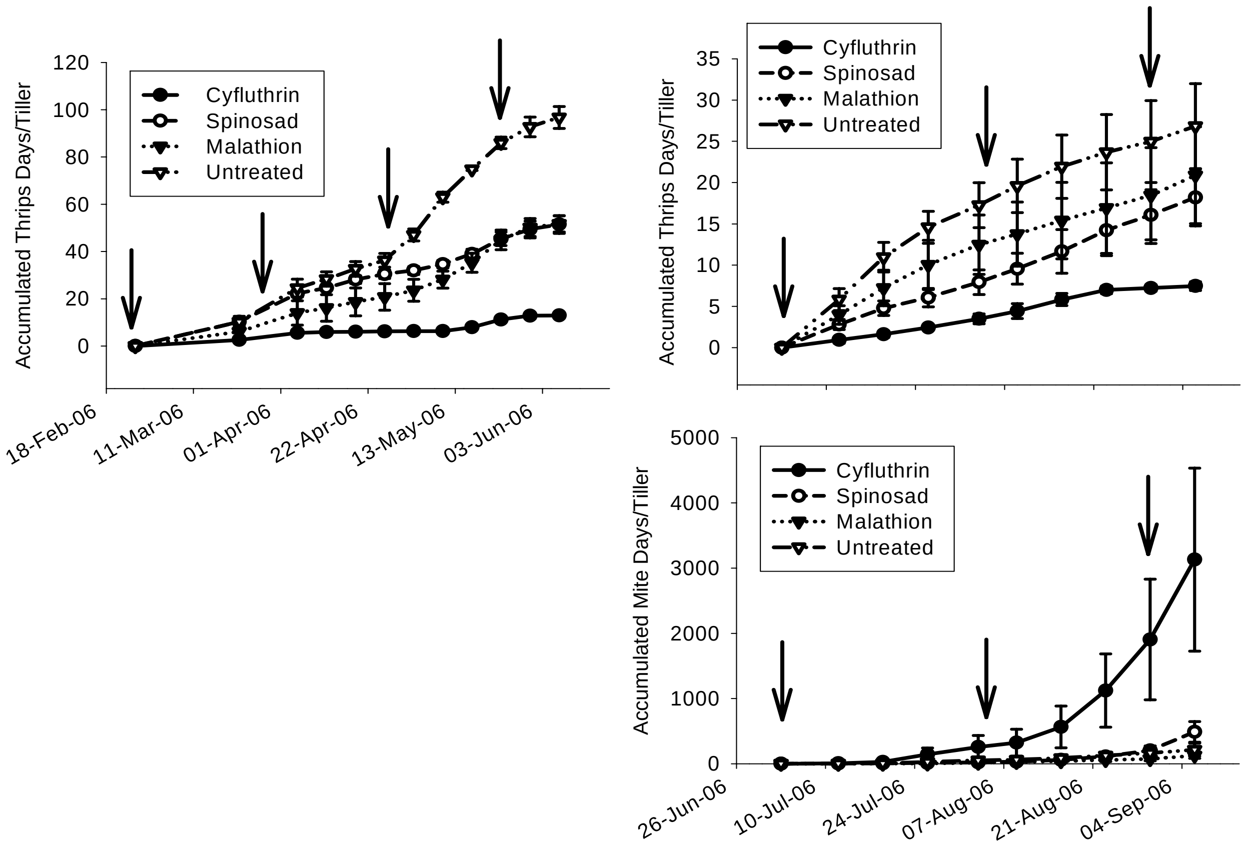


Figure 1. Accumulated arthropod days/tiller ± SE 2006, Field 1. Arrows represent insecticide application. Arthropod results presented for significant MLR regression terms only.

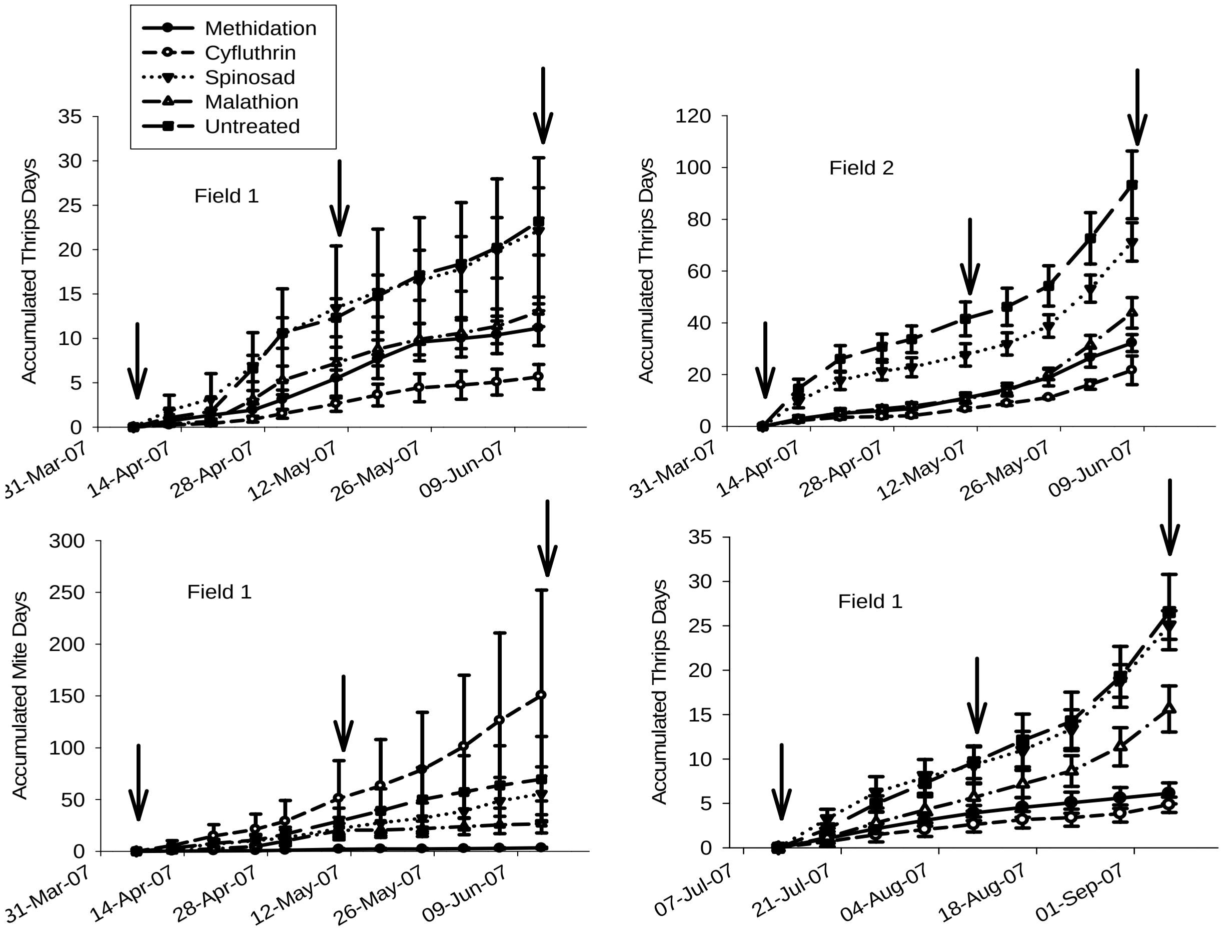


Figure 2. Accumulated arthropod days/tiller ± SE 2007, Fields 1 and 2. Arrows represent insecticide application. Arthropod results presented for significant MLR regression terms only.

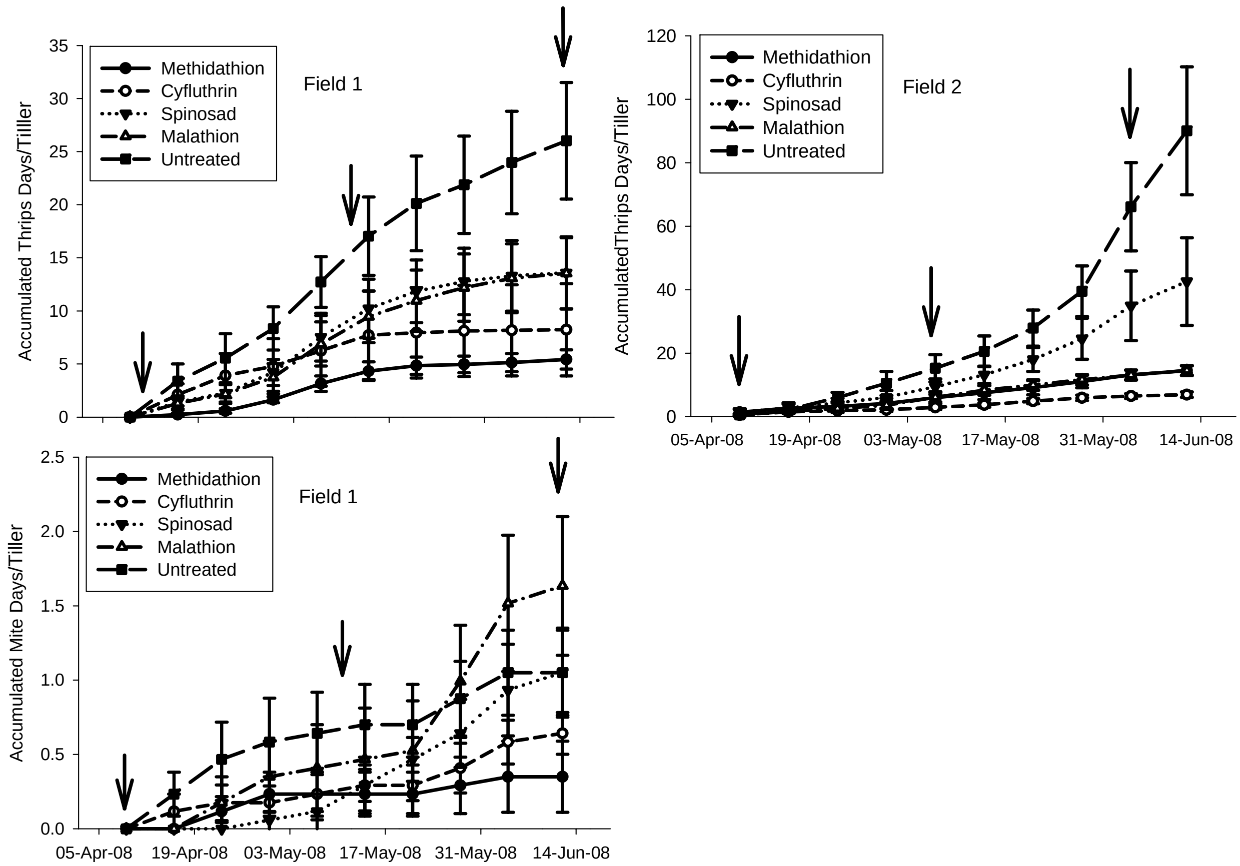


Figure 3. Accumulated arthropod days/tiller ± SE 2008, Fields 1 and 2. Arrows represent insecticide application. Arthropod results presented for significant MLR regression terms only.

***Hybrid EIL.*** From the two regressions significant for accumulated thrips days alone versus damage, we were able to calculate a hybrid EIL that varied with yield (Table 1). The EIL from Field 2 in 2007 ranged from 55-76 accumulated thrips days for methidathion and 19-27 accumulated thrips days for cyfluthrin for first cutting hay prices. The EIL for Field 2 in 2007 was higher for second cutting hay prices, ranging from 102-203 and 35-71 accumulated thrips days for methidathion and cyfluthrin, respectively. EILs were similar for Field 2 in 2008 (Table 3), and accumulated aphid days were similar among treatments compared to the previous year (Figures 2 & 3). In 2008, for first cutting prices, the EIL ranged from 58-82 for methidathion and 20-29 for cyfluthrin. The EIL for second cutting prices ranged from 113-225 for methidathion and 39-78 for cyfluthrin.

| Year | Cut | Chemical | hybrid EIL | | | | | | ET | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Yield (tons/A) | | | | | | | | | | | |
| | | | 7 | 6 | 5 | 4 | 3 | 2 | 7 | 6 | 5 | 4 | 3 | 2 |
| 2007 | 1 | M | 55 | 64 | 76 | | | | 6 | 7 | 8 | | | |
| 2007 | 2 | M | | | | 102 | 136 | 203 | | | | 11 | 15 | 22 |
| 2008 | 1 | M | 58 | 68 | 82 | | | | 6 | 7 | 9 | | | |
| 2008 | 2 | M | | | | 113 | 150 | 225 | | | | 12 | 16 | 24 |
| 2007 | 1 | C | 19 | 22 | 27 | | | | 2 | 2 | 3 | | | |
| 2007 | 2 | C | | | | 35 | 47 | 71 | | | | 4 | 5 | 8 |
| 2008 | 1 | C | 20 | 24 | 29 | | | | 2 | 3 | 3 | | | |
| 2008 | 2 | C | | | | 39 | 52 | 78 | | | | 4 | 6 | 8 |

Table 1. 2007 and 2008 hybrid economic injury levels (EILs) and economic threshold (ET) levels for methidathion and cyfluthrin with prices for first and second cutting hay. Yield amount choices represent typical results for first and second cutting hay. EILs expressed in accumulated thrips days/tiller, ETs expressed in terms of thrips/tiller/week. M= methidathion; C= cyfluthrin.

We wanted to set ETs at 75% the EIL. In addition, we wanted to express the ET in terms of thrips/week/tiller, rather than accumulated thrips days/tiller. As a result, we divided the EIL number by 7 for each respective year, multiplied it by 0.75, and rounded to the nearest integer to obtain the ETs (Table 1).

## DISCUSSION

Phytophagous mites alone were only significantly correlated with damaged timothy before the second cutting in 2006. Mites were significantly flared by the use of cyfluthrin; however, because Tetranychid mites are often found in spatially disparate patches (Hanna et al. 1996, Reisig and Godfrey 2006) accumulated mite days per tiller ranged widely in the cyfluthrin-treated plots (5980, 3039, 57), but were all below 526 in the other treatments in this experiment. As a result, the slope of the regression was significantly leveraged by the presence of two cyfluthrin-treated plots with the highest mite levels. Both thrips and mite levels together were significantly associated with damage in two other experiments. As a result, we could not successfully isolate mite damage from thrips damage. Tetranychid mites appeared to lead to brown leaf in timothy and yield was visibly reduced in these plots, although the results were not significant.

Interestingly, on one occasion both the presence of both thrips and mites was strongly negatively correlated with damage.  Even though mite levels were extremely low compared to other years in this field, the presence of mites in some treatments may have offset the damage caused by the absence of thrips, and vice versa.  Another explanation may be that the numbers of thrips and mites were low enough to stimulate compensatory regrowth, even though the thrips numbers were comparable to some of the other experiments.  The phenomenon is common in grass, but is dependent on many factors, with nitrogen status in the plant being one of the most important factors (Ferraro and Osterheld 2002).  Because we did not measure nitrogen levels, but only assessed the impact of thrips and mites on the timothy, we were not able to explain why this was the single negative correlation of arthropod levels with damage.

Accumulated thrips days alone were never correlated with damaged timothy in Field 1 because the presence of phytophagous mites often confounded the results.  However, before the first cutting 2006, mites were not selected for inclusion in the multilinear regression and had little effect on timothy damage.  Accumulated thrips days were correlated with damaged timothy, but not significantly.  This was probably because we lower power of detection in 2006, compared with 2007 and 2008 when the number of replications were doubled.  Omitting these results from Field 1 in 2006, accumulated thrips days alone were significantly correlated with damaged timothy when accumulated thrips days were above ~35 in at least one treatment.

We selected hay bales for our survey with 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.  From this data, we obtained hybrid EILs that were similar between 2007 and 2008.  The EIL range based on expected yield was higher in the second cutting than the third, due to the decreasing profit margin with lower yields and the nature of the hybrid EIL equation.

Both the ETs that we calculated, as well as the EILs are useful.  Our economic thresholds ranged from 2-24 thrips/tiller/week depending on expected yield and the proposed chemical for management.  If populations of the ET are reached, growers should manage thrips.  However, damage can also accumulate over time, with lower populations of thrips damaging timothy over time periods longer than a week.  For example, the experiments in Field 2 in 2007 and 2008 took place over 62 and 64 days.  Assuming we were going to manage thrips in the first cutting with cyfluthrin, we would achieve economic damage at around 25 accumulated thrips days/tiller.  Populations were slower to build early in 2008 than in 2007, but built more quickly closer to the harvest than in 2007 in untreated plots.  As a result, we recommend that growers treat for thrips at these economic threshold levels, but that they track thrips population levels over time.  Taking a conservative approach and selecting the lowest ET, we recommend the following:

| Cut | Chemical | ET (thrips/tiller/week) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Yield (tons/A) | | | | | |
| | | 7 | 6 | 5 | 4 | 3 | 2 |
| 1 | Methidathion | 6 | 7 | 8 | | | |
| 2 | Methidathion | | | | 11 | 15 | 22 |
| 1 | Cyfluthrin | 2 | 2 | 3 | | | |
| 2 | Cyfluthrin | | | | 4 | 5 | 8 |

These economic thresholds were created using accumulated thrips days, which were a measure of thrips population pressure over time. Thrips populations do not build evenly and, although these ETs are represented in terms of thrips/tiller/week, any practitioner can easily convert their thrips numbers obtained by sampling into a measure of pressure by multiplying the number of thrips/tiller/week found in a certain field by the number of weeks that sampling was done in the field.

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