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Developing economic thresholds for onion thrips in Honduras

Alfredo Rueda[1], Francisco R. Badenes-Perez*, Anthony M. Shelton

Department of Entomology, Cornell University/NYSAES, Geneva, NY 144456, USA

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Abstract

Seasonal abundance and effect on onion yield reduction were studied for onion thrips, *Thrips tabaci* Lindeman, for two consecutive seasons (dry and rainy) to develop economic thresholds (ET) in Honduras. Overall, thrips populations were highest during the dry season, with average thrips per leaf per day 5.2 times higher than during the rainy season. In the two onion cultivars tested (Granex 429® and Texas Grano 438®), thrips densities were similar, but Texas Grano 438® showed 30% more yield reduction as a result of thrips damage than Granex 429®. ETs were calculated using four different methods based on the equilibrium between cost of thrips management and profits losses (based on either thrips densities or an action threshold (AT)), maximizing net profits derived from thrips management, and maximizing the rate of return of thrips management. Thrips infestations below 1.0 thrips per leaf per day did not appear to affect yield and during the rainy season thrips populations were always below this economic injury level. However, during the dry season our data indicate farmers should use an AT between 0.5 and 1.6 thrips per leaf, depending on the particular agronomic, climatic and market conditions.

Keywords: Economic threshold; Action threshold; Economic injury level; Onion thrips; *Thrips tabaci*

1. Introduction

Demand for onion, *Allium cepa* L., has been increasing in national and international markets in Honduras and other Central American countries for the last several years. Onions are planted in most subtropical areas of Honduras, particularly in the departments of Jesus de Otoro, Comayagua, Olancho, Nueva Ocotepeque and Francisco Morazan, where agronomic conditions are very favorable for onion cultivation (Sponagel et al., 1996). In Honduras, most onions are produced by small-to medium-sized landholders, usually with <3 ha of land, many of which are resource-limited.

Onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), is the major insect pest of onions in Honduras (Rueda, 2000). Onion thrips damage plants by disrupting the leaf surface and removing the contents of the mesophyll cells, thus reducing the photosynthetic ability of the plant and leading to reduced bulb size. Onion thrips can also damage onions by facilitating the entry of diseases, such as *Alternaria porri,* and by transmitting the virus that causes iris yellow spot disease, an emerging problem in some parts of the world but not yet in Central America. In Honduras, onion thrips populations are usually higher during the dry season (February–April) than during the rainy season (November–January). During the dry season, more generations of thrips occur and thrips do not suffer mortality due to being washed off the plant or drowning in pockets of water on the plant. Infestations of up to 100 or more thrips per plant have been observed in Honduras during the dry season (Sponagel et al., 1996), which happens to be the time when most onions are planted because of a better market and to avoid diseases common during the rainy season. Most studies indicate that thrips damage can significantly reduce onion yields and bulb size, in some cases by more than 55% (Kendall and Capinera, 1987; Fournier et al., 1995; Fúnez et al., 1995; Rivera, 1994; Rivera and Sponagel, 1996; Ghosheh and Al-Shannag, 2000; but see Mayer et al., 1987). Insecticides are the main

*Corresponding author. Tel.: +1 3157872352; fax: +1 3157872326.
E-mail address: frb3@cornell.edu (F.R. Badenes-Perez).
[1]Present address: Pan American School of Agriculture (Zamorano), Apartado Postal No. 93, Tegucigalpa, Honduras.

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strategy to control onion thrips and in Honduras, onion growers typically apply insecticides weekly, resulting in 9–12 insecticide applications per cropping season. Besides the economic cost and the health and environmental problems that may arise from such intensive application of insecticides, this practice is conducive to the evolution of insecticide resistance, an increasing problem with onion thrips (Rueda and Shelton, 2003; Shelton et al., 2003; MacIntyre-Allen et al., 2005).

The concept of an economic threshold (ET) to properly time insecticide applications when they are needed is a viable alternative to calendar sprays (Pedigo et al., 1986). In North America, research findings on ET for onion thrips have been variable, depending on the climate and location. Mayer et al. (1987) reported no relationship between onion thrips abundance and onion yields in Washington State. In Weslaco, TX, an ET of 1 thrips per plant increased yields and profits during the winter season (Edelson et al., 1989). An ET of 3 thrips/green leaf was suggested in studies in Michigan (Quartey, 1982) and Shelton et al. (1987) used this ET to develop a dynamic sequential sampling program procedure in New York. This procedure is the standard recommendation in New York, although caveats are made based on weather conditions and localized insecticide resistance (Reiners and Petzoldt, 2006). In Michigan, an ET of 4–10 and 10–15 onion thrips per plant is recommended for onion plant stages of 2–6 leaves and 6 leaves to maturity, respectively (Bird et al., 2004). In Canada, the recommendations are 0.9 and 2.2 thrips per leaf during wet and dry years, respectively (Fournier et al., 1995). In Central America there has not been any specific work to develop ET for onion thrips.

With the general purpose of improving onion thrips management and maximizing farmer profits, the specific objectives of this research were to investigate seasonal abundance and population trends of onion thrips; to evaluate the effects of thrips on onion yield; and to develop an ET for onion thrips under Honduran agronomic and climatic conditions.

2. Materials and methods

Experiments were conducted on the research farm of the Fundación Hondureña de Investigación Agrícola (FHIA) "El Guanacaste" in Comayagua, Honduras between October 1996 and May 1997, covering two crop seasons (one rainy season and one dry season). Onions of cultivar Granex 429® (Asgrow Seed Co., West Des Moines, IA), the standard onion cultivar recommended by FHIA (Cerna et al., 1994), were used during the rainy season. During the dry season, in addition to Granex 429®, Texas Grano 438® onions (Asgrow Seed Co., West Des Moines, IA) were also used because growers believed them to be more susceptibile to thrips damage. Experiments were conducted in field plots that were 10 × 6 m and contained 6 double rows of onions with a transplant density of 200,000 plants/ha. Row beds were 1 m apart, distance between plant rows was 30 cm apart, and distance between plants within rows was 10 cm. Agronomic practices were based on local onion production recommendations (Cerna et al., 1994). For disease control, Dithane (Mancozeb, Rohm and Haas Co., Philadelphia, PA) was applied before rains, while Rovral® (Iprodione, Rhône-Poulenc Agrochemical. Co., Triangle Park, NC) and Bravo 500® (Chlorothalonil, ISK Biosciences Corporation, Mentor, OH) were applied in rotation with Dithane on a weekly basis if disease symptoms, typically *Alternaria porri*, appeared. To control *Spodoptera frugiperda*, two applications of Javelin® (*Bacillus thuringiensis* subsp. *kurstaki*, Novartis Crop Protection, Basel, Switzerland) were made.

A complete block design (Kuehl, 1994) with 4 replicates was used in the experiments conducted during the rainy season, while a split-plot design (Kuehl, 1994) with 3 replicates was used in the experiments conducted during the dry season. The split-plot design allowed comparison between cultivars, the main plot factor, for different thrips densities. Six treatments were compared: an untreated control, weekly insecticide applications (calendar), and insecticide applications at 0.5, 1, 2, 4 and 8 thrips per leaf (TL) action thresholds (AT). Any time sampling indicated that the AT of a plot was exceeded, an insecticide application was made to only that particular plot and not necessarily to the rest of the replicates under the same AT. Permethrin (Ambush 2E®, Zeneca Agrochemical. Products, Wilmington, DE) at a rate of 0.48 kg a.i./ha was the standard insecticide used to control onion thrips in the experiment. Insecticide applications were made with a motorized knapsack sprayer (Arimitzu®, Japan) delivering 500 l/ha.

Thrips adults and larvae were sampled twice a week by randomly selecting onion plants, excluding the two edge rows and one meter at the end of the rows from each plot. Routine sampling was initiated when thrips were first observed in the experimental plot and ceased when 40% of the onion leaves had fallen, i.e. foliage senescence. Thrips were counted between 7:00 and 10:00 am to avoid the hottest hours of the day, when thrips tend to shelter inside of the plant leaves and are more difficult to see. The number of plants sampled per plot for the rainy and dry season experiments were 10 and 20, respectively. Thrips per plant were counted by visually examining the whole plant, including the center leaves and the base of the plant. The average number of leaves per plant was calculated based on the number of green leaves on 20 plants in the experiment. The number of thrips per experimental plot was divided by the number of scouted plants and the average number of leaves per plant to calculate the TL, which was used as the criterion to implement the AT.

Onion yields were measured in the four central rows (40 m^2) of each plot. After pulling plants from the soil and allowing them to dry for 3–5 days, leaves and bulbs were cut, and bulbs were counted and stored in jute bags, allowing them to dry for an extra 3–5 days in the field. At the storage house, onion bulbs were weighed and classified by size and cosmetic damage. Thrips pressure on onions was expressed as the number of thrips per leaf per day (TLD) summed over the entire onion vegetative growth period, as well as for 0–30, 31–60, and 61–90 days after transplanting (DAT). The TLD for each plot was calculated using Eq. (1) below, where $[(TL_j + TL_k)/2]$ is the average number of TL from two consecutive thrips sampling dates; $(date_k - date_j)$ is the interval in days between consecutive sampling dates; and $(date_z - date_a)$ is the number of days over the entire sampling period. Date is expressed in Julian days

$$TLD = (\Sigma\{[(TL_j + TL_k)/2] \times (date_k - date_j)\})/(date_z - date_a). \quad (1)$$

Data were analyzed using analysis of variance (ANOVA) with MINITAB® Release 14 (Minitab Inc., 2003) to determine the effects of the AT on TLD, yield, insecticide applications, season, cultivar, and economic variables (control cost, gross benefit, and net benefit). When significant treatment differences were indicated by a significant F-test at $P \leqslant 0.05$, means were separated by Fisher's Protected least significant difference (Minitab Inc., 2003). Yield data were expressed as the percentage of the yield in the control plot of each block (yield at the control plot was considered 100%). The effect of TLD and AT on yield and insecticide applications was determined using linear regression analysis (Minitab Inc., 2003). Pearson correlation analysis (Minitab Inc., 2003) was used to estimate the correlation between yield and adjusted yield with TLD for the dry and rainy seasons.

Four different methods were used to estimate the ET: determining the equilibrium point between thrips control cost and profit losses based on actual TLD, maximizing profits as a result of adequate thrips control (Ramírez and Saunders, 1999), determining the equilibrium point between thrips control cost and profit losses based on AT, and using marginal rate of return analysis (CIMMYT, 1988). To calculate the ET we used an average farm market value of US$9.00/bag of onions (22.73 kg/bag) and an insecticide application cost of US$70.00/ha based on the use of 2 l/ha of Ambush 2E® at US$60.00 and the application cost at US$10.00 (Fúnez et al., 1995). At the end of this economic analysis, a sensitivity analysis based on a fluctuating market value of onions between US$5.00 and 13.00/bag and insecticide application costs between US$40.00 and 100.00/ha was used to evaluate the proposed onion thrips ET.

3. Results and discussion

3.1. Cropping seasons

Populations of onion thrips varied dramatically between the dry and rainy season with much higher populations in the latter (Fig. 1). The range of thrips per leaf (TL) for the control treatment on a given sampling date varied from 0 to 3.2 (mean of 0.9) during the rainy season and from 1.4 to 10.7 (mean of 5.4) during the dry season. For the AT of 0.5TL, which had the most insecticide applications, the average TL ranged from 0 to 1.1 (mean of 0.9), and from 0.3 to 4.9 (mean of 1.6) for the rainy and dry seasons, respectively (Fig. 1). Thrips infestation over the entire season was represented by the formula for thrips per leaf per day (TLD) (Eq. (1)). The overall average TLD for all treatments varied by 5.2-fold between the rainy (0.6 TLD) and dry (3.1 TLD) season ($F = 65.14$; df = 1, 65; $P < 0.01$). Rainfall and temperature influenced thrips populations. When rainfall was >10 mm, thrips populations declined sharply (data not shown), while populations increased with increasing average daily maximum temperatures (°C). This reduction of thrips populations caused by rainfall has been observed in other pest thrips species (Lewis, 1973). Linear regression analysis Eq. (2) shows that for an increment of 1 °C in the daily maximum temperatures, the number of thrips in the control plots increased by 0.41 TL

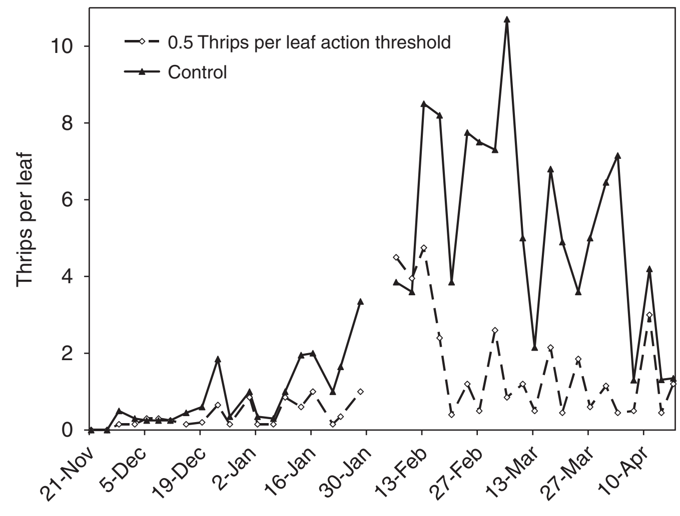

Fig. 1. Onion thrips population dynamics for the control treatment and 0.5 thrips per leaf action threshold in the rainy (November 1996–January 1997) and dry season (February–April 1997).

$$TL(\text{control plots}) = -9.28 + 0.41\,°C \quad (2)$$

$(r^2 = 0.385;\ F = 24.99;\ df = 1,40;\ P < 0.01)$.

Temperature alone however, could not adequately predict thrips population changes because of the low statistical reliability (r^2) of the model. Thus, additional factors besides temperature affect thrips populations in onion fields. Despite low thrips infestation during the rainy season, there were some significant differences in TLD for the tested AT (Fig. 2). The relationship between TLD and AT in the rainy season was explained by the linear regression equation below Eq. (3). The low TLD response and the low correlation coefficient could be due to the low thrips infestation levels detected

$$TLD\ \text{Rainy Season} = 0.45 + 0.05AT \quad (3)$$

$(r^2 = 0.53;\ F = 23.32;\ df = 1,21;\ P < 0.01)$.

Differences between AT levels were larger during the dry season than during the rainy season (Fig. 2). The relationship between TLD and AT in the dry season was explained by the linear regression equation below Eq. (4). In the dry season the thrips infestation was higher than in the rainy season, and thrips pressure over the low AT treatments resulted in higher TLD than permitted by the AT

$$\text{TLD Dry Season} = 1.46 + 0.39\text{AT} \quad (4)$$

($r^2 = 0.88$; $F = 246.45$; df $= 1, 34$; $P < 0.01$).

Considering all treatments together, onion yield was significantly different between seasons ($F = 296.95$; df = 1, 65; $P < 0.01$). The average number of bags of onions/ha was 1314 and 598 for the rainy and dry seasons, respectively. No differences were detected in the number of onion bulbs harvested in the two seasons ($F = 1.62$; df = 1, 65; $P = 0.207$), indicating that differences in onion yield were due to differences in onion size in each season (Table 1). In the rainy season larger proportions of colossal and jumbo onions (bigger size and heavier in weight) were harvested compared to the dry season when most onions were the pre-pack size (smaller).

After yield results were transformed to the proportion of yield compared to the control in each block, large differences were found between the dry and rainy season. During the rainy season, no correlation was found between yield as percentage of control and observed TLD or AT (Fig. 3). During the dry season, there was a response in yield as percentage of control and observed TLD or AT (Fig. 3). In summary, there was no onion yield loss attributable to thrips damage when thrips infestations were under 1 TLD.

3.2. Differences between cultivars

During the dry season there were no differences in TLD between Granex 429® and Texas Grano 438® onions over the entire crop season ($F = 2.1$; df = 1, 2; $P = 0.285$) , with an average TLD of 3.07 for both cultivars. Yield response to thrips damage differed significantly between cultivars ($F = 82.95$; df = 1, 2; $P = 0.012$) (Fig. 4). On average, yields were 704 and 438 bags/ha for Granex 429® and Texas Grano 438®, respectively. There were no significant differences between cultivars in the number of onion bulbs harvested ($F = 9.94$; df = 1, 2; $P = 0.088$) with an average number of 142,810 bulbs/ha harvested for both cultivars. The proportion of bags/ha for all onion sizes was not different ($F = 18.0$; df = 1, 2; $P > 0.05$). For both cultivars, no colossal onion bulbs were produced and only a small fraction of the onions produced were jumbo size. Granex 429® yielded 39% of the

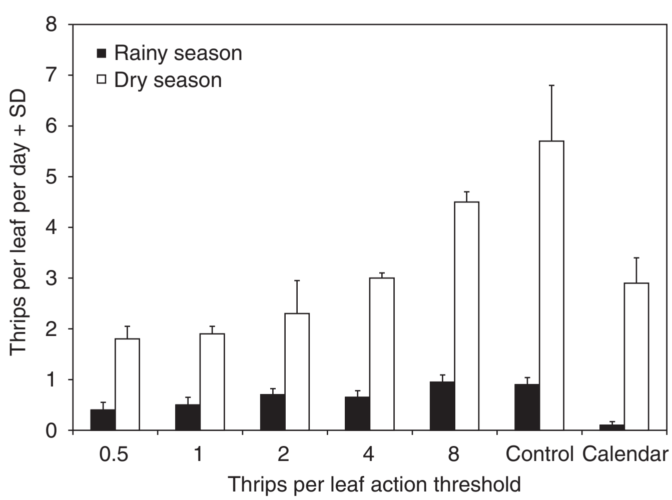

Fig. 2. Thrips per leaf per day for the different thrips per leaf action threshold treatments in the rainy and dry season (1996–1997) for onion cultivars Granex 429® (rainy season) and Granex 429® and Texas Grano 438® (dry season).

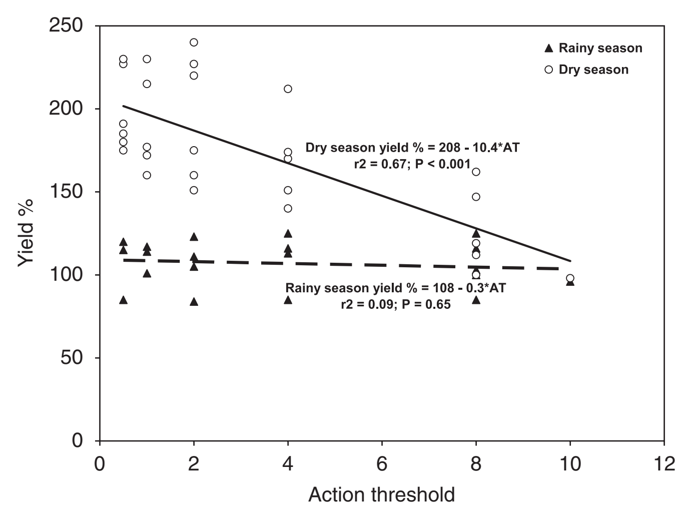

Fig. 3. Correlation between the yield percentage of the control and action thresholds for thrips management during the rainy and dry season (1996–1997) for onion cultivars Granex 429® (rainy season) and Granex 429® and Texas Grano 438® (dry season).

Table 1
Proportion of onions harvested by size in the rainy and dry season (1996–1997)

Category	Size (cm)	Dry season	Rainy season	F	$P \leqslant$
Colossal	>10	0.0±0.0	1.0±1.3	16.76	0.001
Jumbo	7.5–10	2.3±4.0	43.2±7.5	895.18	0.001
Large-medium	6.3–7.5	28.2±17.7	35.7±5.4	3.32	0.945
Pre-pack	4.3–6.3	64.8±16.9	20.1±5.7	167.90	0.001
Boiler	2.5–4.3	4.7±7.5	0.0±0.0	9.21	0.003

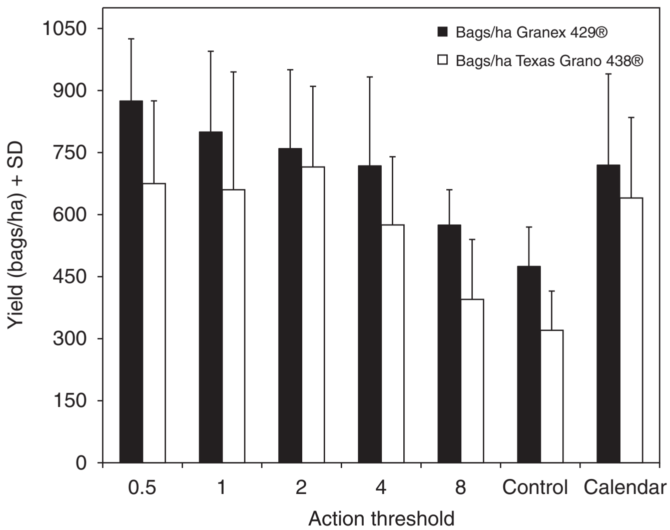

Fig. 4. Yield for Granex 429® and Texas Grano 438® by action threshold in the dry season (1997).

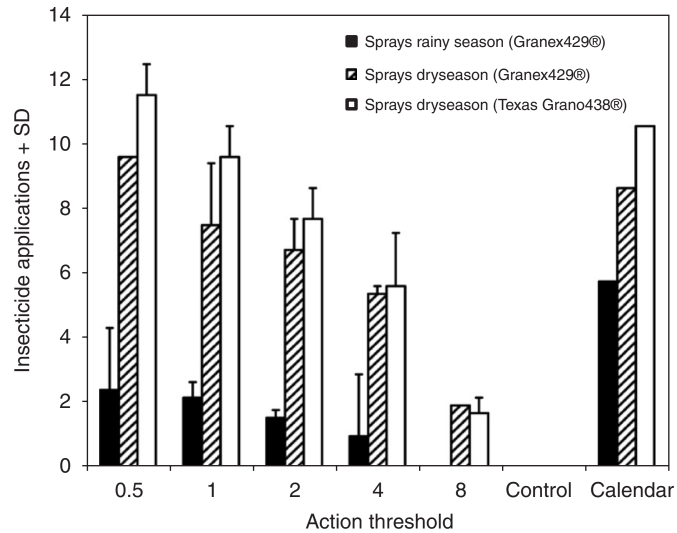

Fig. 5. Number of insecticide applications per action threshold in the rainy and dry season for Granex 429® and Texas Grano 438® (1996–1997).

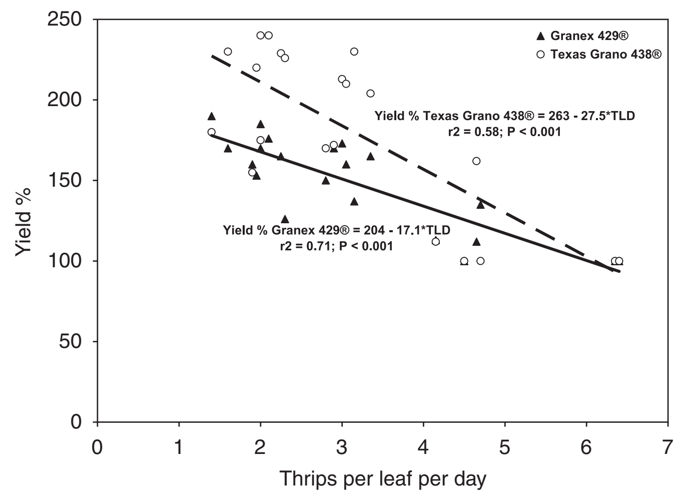

Fig. 6. Correlation between thrips per leaf per day and percentage of yield from the control for Granex 429® and Texas Grano 438® during the dry season trial (1997).

bulbs as jumbo and large-medium compared to 24.5% with Texas Grano 438®. Most onions harvested for both cultivars were in the pre-pack size (58% and 78% for Granex 429® and Texas Grano 438®, respectively).

Harvest data for the dry season trial were standardized to the percentage of its own control group yield in each cultivar and block to evaluate cultivar yield response to onion thrips infestation. Under similar thrips infestation, the average yield response to thrips infestation for both cultivars was 150% and 181% of the control yield for Granex 429® and Texas Grano 438®, respectively ($F = 340$; $\mathrm{df} = 1, 2$; $P = 0.003$), indicating that Texas Grano 438® was more susceptible to thrips damage than Granex 429®.

3.3. Differences between AT

To develop an economic injury level (EIL), first it is necessary to know the relationship between insect pest densities and plant yield reduction, which was investigated by testing different ATs. In the rainy season, when thrips populations were lowest, there was no onion yield response to the tested ATs, as TLD values in the experiment fell below all predetermined AT levels. The maximum average number of insecticide applications required to maintain the predetermined AT was 2.5 for the 0.5TL AT and 6 for the calendar application treatment (Figs. 5 and 6). The lack of thrips pressure in the rainy season resulted in low correlation coefficient (0.13) between yield and TLD levels, which was not statistically significant (Table 2). Therefore, we conclude that in the rainy season, with thrips infestations <1 TLD, there were no detectable yield losses.

Thrips populations were similar for both cultivars in the dry season experiment ($F = 2.1$; $\mathrm{df} = 1, 2$; $P = 0.285$). In the dry season (hotter and drier climatic conditions than in the rainy season), all predetermined AT levels exceeded their threshold at least twice in the season and it was difficult to maintain thrips populations under the predetermined AT. Values of TLD for the 0.5, 1 and 2 TL AT exceeded their predetermined value by 230%, 113%, and 10%, respectively (Fig. 2).

To maintain the TL for each treatment, insecticide applications were used each time a plot exceeded its predetermined level (Fig. 5). The number of sprays on each AT for both cultivars can be explained with the linear regression Eq. (5) below, indicating that to reduce 1 TLD over the entire dry season would require 2.4 insecticide applications

$$\text{No. of Insecticide Applications} = 13.79 - 2.42\text{TLD} \quad (5)$$

($r^2 = 0.737$; $F = 75.4$; $\mathrm{df} = 1, 41$; $P < 0.01$; $n = 42$).

Table 2
Pearson correlation coefficients between thrips per leaf per day (TLD) and onion yield (bags/ha) and percentage of yield loss for the rainy and dry season (1996–1997), by periods of days during the growing season

Period (days)	Dry season Granex 429®		Dry season Texas Grano 429®		Rainy season Granex 429®	
	Bags/ha	Yield%	Bags/ha	Yield%	Bags/ha	Yield%
All	−0.597	−0.841	−0.503	−0.767	−0.126	−0.233
P	0.004	<0.001	0.020	<0.001	0.523	0.232
0–30	−0.378	−0.512	0.157	−0.196	0.104	−0.178
P	0.091	0.018	0.497	0.395	0.598	0.364
31–60	−0.492	−0.803	−0.568	−0.730	0.275	−0.138
P	0.023	<0.001	0.007	<0.001	0.157	0.485
61–90	−0.667	−0.820	−0.719	−0.860	−0.288	−0.211
P	0.001	<0.001	<0.001	<0.001	0.137	0.280

To find the best yield predictor, Pearson correlations were calculated for each experiment (Table 2). Onion yields and TLD were better correlated when considering the entire crop season and the last 61 to 90 DAT than the 0 to 30 and 31 to 60 DAT periods. Better correlations were also found when yield was represented as a percentage of the control rather than the actual yield. Other polynomial regression models tested did not fit as well statistically as the linear models.

The correlations between percentage of yield response and TLD for the entire season are represented by the following linear regression equations:

$$\%\text{Yield from control for dry season with Granex 429}^{®} = 204 - 17.10\text{TLD} \quad (6)$$

($r^2 = 0.71;\ F = 46.09;\ \text{df} = 1, 19;\ P < 0.01;\ n = 21$).

$$\%\text{Yield from control for dry season with Texas Grano 438}^{®} = 263 - 27.50\text{TLD} \quad (7)$$

($r^2 = 0.58;\ F = 27.19;\ \text{df} = 1, 19;\ P < 0.01;\ n = 21$).

The slopes of Eqs. (6) and (7) indicate the cultivar's susceptibility to onion thrips damage. These equations indicate that for each TLD, onion yield was reduced by 17.1% and 27.5% for Granex 429® and Texas Grano 438® onions, respectively. Under the same thrips pressure, Texas Grano 438® experienced 10.4% more yield loss than Granex 429®.

The actual yields that these figures represent can be obtained by re-converting the percentage figures to actual yield with the average control yield as 100%. For Granex 429® and Texas Grano 438®, the average control treatment yields were 466 and 313 bags/ha, respectively. Replacing the percentage of yield Eqs. (6) and (7) with actual onion yield (bags/ha), the new equations are:

$$\text{Granex 429}^{®}: \text{No. Bags/ha} = 950.60 - 79.69\text{TLD}, \quad (8)$$

$$\text{Texas Grano 438}^{®}: \text{No. Bags/ha} = 823.20 - 86.08\text{TLD}. \quad (9)$$

3.4. Economic threshold (ET)

3.4.1. TLD equilibrium point

The AT can be used as a reference point to time control measures. A method to obtain the AT is to use the economic injury level (EIL), defined as the population density where control cost equals the damage caused by a particular pest in monetary terms (Pedigo et al., 1986). To develop a formula for this definition we need the onion yield response to thrips populations Eq. (8) and the number of insecticide applications needed to control a given population of thrips Eq. (5). Eqs. (5) and (8) require transformation into monetary terms to have them in the same units. Starting with Eq. (8), for Granex 429® during the dry season, making these changes, the yield equation Eq. (10) is now the gross benefit equation ($GB)

$$\$GB = \$P(950.60 - 79.69\text{TLD}), \quad (10)$$

where $P is the unit yield price. Eq. (10) needs to be transformed from a yield reduction equation to represent monetary yield losses ($L). The transformation can be done by inverting the $GB equation slope and replacing the maximum yield constant by 0

$$\$L = \$P79.69\text{TLD}. \quad (11)$$

As for the transformation of Eq. (5) into monetary units, the new equation will be the control cost ($CC), and the price for a single insecticide application would be $A

$$\$CC = \$A(13.79 - 2.42\text{TLD}). \quad (12)$$

Using our definition for ET, the representative equation is

$$\text{ET} = \text{TLD (when } L = \text{CC)}. \quad (13)$$

The ET can be found at the interception point of the regression lines given by Eqs. (11) and (12), where the loss of revenue caused by a particular thrips density equals the thrips control cost at that density. The resulting mathematical equation is

$$\text{ET in TLD units} = 13.79/[(79.69\$P/\$A) + 2.42]. \quad (14)$$

Resolving Eq. (14) with $P = $9.00 and $A = $70.00

$$\text{ET} = 1.09\text{TLD}.$$

This 1.09TLD ET means that the thrips population in the dry season should be maintained below 1.09TLD, which would require 11.2 insecticide applications according to Eq. (5). This low ET value of 1.09TLD is an indication of the large effect that onion thrips can have on onion yields. However, because of our methodological procedures, 1.09TLD ET cannot be recommended because it falls outside of the prediction limit boundaries of the range given by the two regression Eqs. (5) and (6) used to generate the ET formula Eq. (14). If we transform this 1.09TLD ET value to the experimentally tested AT using a regression line that correlates observed TLD to experimental AT Eq. (15)

$$\mathrm{AT} = -3.42 + 2.48\mathrm{TLD} \tag{15}$$

($r^2 = 0.86$, $F = 174.53$; df $= 1, 28$; $P<0.01$, $n = 30$).

With the 1.09TLD, the resulting AT obtained through Eq. (15) is a negative number (−0.72), which implies that we should spray insecticides any time a thrips is present in the onion field. Our threshold will not be valid because we did not test such treatment, but we can conclude that onion thrips are economically important during the dry season in Honduras because 1TLD results in 17.1% yield reduction from Eq. (6).

3.4.2. Maximizing the profits of control practices

Another method to estimate economic thresholds is based on maximizing the net profits derived from pest control practices (Ramírez and Saunders, 1999). This method is based on the relationship between pest control costs and revenue from onion yields. To use this method, we estimated cost of thrips control and yield revenue using linear regression from the actual AT tested on the experiments. Thrips numbers found through scouting were only used to determine when each plot needed to be sprayed after populations exceeded the predetermined AT. The control cost and yield revenue equations for Granex 429® in the dry season were

$$\mathrm{Yield\,(bags/ha)} = 855.98 - 36.85\mathrm{AT} \tag{16}$$

($r^2 = 0.85$; $F = 97.37$; df $= 1, 16$; $P<0.001$, $n = 18$),

$$\text{No. of applications} = 9.31 - 0.937\mathrm{AT} \tag{17}$$

($r^2 = 0.915$; $F = 182.90$; $df = 1, 16$; $P<0.001$; $n = 18$).

After transforming both regression lines into monetary terms, \$GB and \$CC in Eqs. (10) and (12) can be calculated as

$$\$\mathrm{GB} = \$P(855.99 - 36.85\mathrm{AT}), \tag{18}$$

$$\$\mathrm{CC} = \$A(9.31 - 0.94\mathrm{AT}). \tag{19}$$

Net benefits (\$NB) of pest control practices can be calculated by subtracting \$CC from \$GB

$$\$\mathrm{NB(AT)} = \$\mathrm{GB} - \$\mathrm{CC}, \tag{20}$$

$$\$\mathrm{NB(AT)} = \$P(855.99 - 36.85\mathrm{AT}) - \$A(9.31 - 0.94\mathrm{AT}). \tag{21}$$

The mathematical solution for this set of equations determines that the maximum net benefit for thrips control in our experiment is an AT of 0 TL. This is because both equations for \$GB and \$CC are linear and have the same direction of slope. This analysis confirms the important effect of thrips in onion yield reduction and suggests that farmers should spray insecticides any time that a single thrips is present. However, we cannot recommend to farmers a 0TL threshold because we did not test that AT in our experiment. Based on the method of maximizing profits of control practices, we can tentatively recommend a threshold of 0.5TL, the lower AT that we tested.

3.4.3. AT at equilibrium point

Another alternative to estimate an adequate threshold is to find the equilibrium point between thrips control and yield losses. This method uses the same approach as the economic threshold method based on the TLD equilibrium point, but is based on the actual AT tested. Thrips numbers found through scouting are only used to determine the time each plot needs to be sprayed. During the dry season, from Eqs. (18) and (19), after inverting the slope of gross benefits to yield loss, we have that

$$\mathrm{AT} = \mathrm{TL}(\$L = \$\mathrm{CC}). \tag{22}$$

To find our AT the mathematical equation is

$$\text{AT in TL units} = 9.31/\{[(36.85\$P)/\$A] + 0.94\}\mathrm{TL}. \tag{23}$$

Resolving Eq. (10) with $\$P = \$9.00$ and $\$A = \$70.00$

$$\mathrm{AT} = 1.64\mathrm{TL}.$$

This AT indicates that farmers should spray for thrips each time that the population reaches 1.64TL, which would result in 7.8 insecticide applications compared to the 10 applications used on the basis of a weekly calendar.

Because the AT changes depending on the onion price and the cost of the insecticide application, a sensitivity analysis was performed. Using Eq. (23), we tested onion prices of \$5.00, 9.00 and 10.00/bag and insecticide application cost of \$40.00, 70.00 and 100.00/application. The sensitivity analysis (Table 3) indicates that with the same application cost (\$70.00) and onion prices changing from \$5.00 to \$13.00 a bag, the AT will move from 2.61 to 1.20TL AT. Caution must be used with this methodology, because it estimates the equilibrium between control costs

Table 3
Sensitivity analysis for the action threshold equilibrium point for onions in the dry season (1997) for several onion bag prices and insecticide application costs

Cost of insecticide application (US\$)	Onion bag price (US\$)		
	5.00	9.00	13.00
40.00	1.68	1.01	0.72
70.00	2.61	1.64	1.20
100.00	3.35	2.19	1.63

and profits losses when in practice, most farmers think in terms of maximizing overall profits.

3.4.4. Marginal rate of return

The marginal analysis proposed by CIMMYT (1988) is based on the investment return of pest control. Using this method, the costs and net benefits of thrips control were calculated for each treatment. The marginal rate of return (MRR) was calculated as the proportion of the increment in net benefits divided by the increment in control costs between two adjacent treatments. Treatments with lower net benefit than the next one were discarded and the MRR was calculated for the next treatment. Using this analysis (Tables 4 and 5), results indicate that the AT of 1.6TL is

Table 4
Marginal rate of return (MRR) analysis for the development of thrips per leaf action threshold (AT) for onions in the dry season (1997)

AT	Bags/ha	Gross income ($)	No. of sprays	Control cost ($)	Net income ($)	MRR[a]
Control	466 d	4194	0	0	4194	[b]
8	589 c	5308	2	140	5169	6.96
4	719 b	6479	5.3	371	6109	4.07
2	757 b	6821	7	490	6331	1.87
1	789 ab	7102	7.7	539	6563	4.73
0.5	873 ab	7861	10	700	7161	3.71
Calendar	717 b	6458	9	630	5829	Discarded[c]

Means in a column with a letter in common are not significantly different ($P>0.05$, Fisher's protected LSD).
[a]Calculated as net benefits increment divided by control costs increment between adjacent treatments.
[b]Not calculable given that the control is the first treatment considered.
[c]Calendar treatment was discarded because this treatment generated less benefit and resulted in higher costs than some of the AT tested.

Table 5
Equations and parameters used to study thrips populations and determine economic and action thresholds for thrips management in the rainy (November 1996–January 1997) and dry season (February–April 1997). Abbreviations used in the formulas: thrips per leaf (TL), daily maximum temperature in °C, thrips per leaf per day (TLD), action threshold (AT), monetary yield losses ($L), unit yield market price ($P), net benefit ($NB), gross benefit ($GB), thrips control cost ($CC), price of a single insecticide application ($A), economic threshold (ET)

Parameter to be determined	Equation used and/or obtained in this study
Trips abundante	TL (control plots)[a] = −9.28 + 0.41 °C
	TLD Rainy Season[b] = 0.45 + 0.05AT
	TLD Dry Season[c] = 1.46 + 0.39AT
No. of insecticide applications	No. of insecticide applications[c] = 13.79–2.42TLD[a]
	No. of insecticide applications[d] = 9.31–0.94AT
Trips effect on onion yields	% Yield from control for dry season[b] = 204.00–17.10TLD
	% Yield from control for dry season[e] = 263.00–27.50TLD
	No. of Bags/ha[c] = 950.60–79.69TLD
	No. of Bags/ha[d] = 823.20–86.08TLD
	No. of Bags/ha[d] = 855.98–36.85AT
	$L[d] = $*P*79.69TLD
Benefit from onion yields	$GB[d] = $*P*(950.60–79.69TLD)
	$GB[d] = $*P*(855.98–36.85AT)
	$NB (AT) = $GB—$CC
	$NB[d](AT) = $*P*(855.98–36.85AT)—$*A*(9.31–0.94AT)
Cost of insecticide application	$CC[d] = $*A*(13.79–2.42TLD)
	$CC[d] = $*A*(9.31–0.94AT)
Economic thresholds	ET = TLD (when $*L* = $CC)
	ET in TLD units[d] = 13.79/{[(79.69$*P*)/$*A*] + 2.42}
	ET = 1.09TLD with $*P* = $9.00 and $*A* = $70.00
Action thresholds	AT[d] = −3.42 + 2.48TLD
	AT = TL(when $*L* = $CC)
	AT in TL units[d] = 9.31/{[(36.85$*P*)/$*A*] + 0.937}
	AT = 1.64TL with $*P* = $9.00 and $*A* = $70.00

[a]With Granex 429® and Texas Grano 438® during dry and rainy season combined.
[b]With Granex 429®.
[c]With Granex 429® and Texas Grano 438® during dry season.
[d]With Granex 429® and during the dry season.
[e]With Texas Grano 438® and during the dry season.

also a viable alternative to the calendar insecticide applications. The MRR for calendar sprays was discarded because this treatment generated less benefit and resulted in higher costs than some of the AT tested.

4. Conclusion

This research shows that the use of an AT as a decision tool for timing insecticide applications in Honduras is better than the most common current practice of calendar applications. For onions grown under favorable climatic conditions, thrips infestations under 1 TLD do not affect yield in Honduras. Climatic conditions appeared to be responsible for the difference in AT recommendations between rainy and dry seasons. The earlier farmers can plant in the (dry) season, the fewer problems they will have with onion thrips. Based on our results for onions produced in the dry season, the estimated AT lies between between 0.5 and 1.6TL. We cannot recommend a fixed AT because our analysis indicated that with the 1.6TL AT farmers will recover their investment in control cost; however, with the 0.5TL AT, farmers will maximize their investment in thrips control. The best AT estimate would depend on the particular conditions of the farmer context (i.e., market prospects and climatic conditions). For example, if farmers need to plant later in the (dry) season, they will find that it is almost impossible to keep onion fields clean of thrips. In those cases, it would be better to work with an AT of 0.5–1.6 or even higher because thrips population will be high even with calendar applications.

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