Suppression of Western Flower Thrips by Overhead Sprinkler Irrigation in Romaine Lettuce

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Abstract

A two year study was conducted from 2000-2002 to evaluate the use of overhead sprinkler irrigation for suppressing thrips populations in romaine lettuce. Specifically we looked at how the duration and frequency of sprinkler irrigation use reduced adult and larval populations following various irrigation applications employed specifically for thrips suppression. We also evaluated combinations of insecticide spray regimes, used in association with sprinkler irrigation runs, for suppressing thrips populations in both fall and spring seasons. The results of the study demonstrated that overhead sprinkler irrigation has the ability to suppress thrips populations in romaine lettuce. At best, we experienced about 50% population reduction using only sprinkler irrigation compared with the untreated control during these trials. Sprinkler ruins of durations of > 4 hrs and more than 4 cm of water appeared to provide the minimal necessary for suppression. Furthermore, sprinkle runs of 2 or 3 times weekly appeared to provide the most consistent suppression. In contrast, insecticide sprays consistently provided >80% suppression and provided higher yielding and better quality lettuce than sprinklers. The use of sprinkler irrigation, in addition to insecticide sprays did not significantly improve thrips suppression or yields. However, sprinkler irrigation is being used season long in some romaine fields and in organic production and should be of benefit for thrips suppression, particularly in organic systems where effective insecticide alternatives are not currently available.

Introduction

Western flower thrips, *Frankiniella occidentalis*, have rapidly become an important pest in desert head lettuce production (Kerns and Palumbo 1996). They primarily occur in large numbers on lettuce during the fall and spring and can build up to high numbers very rapidly. Under mild-winter temperatures, thrips reproduce quickly on lettuce. Adults can migrate onto lettuce crops in large numbers during the spring when weeds dry down or when crops are harvested. They are presently one of the most economically important insect pests of lettuce because of their damage potential and lack of viable management alternatives. As these small insects feed, they damage lettuce by scarring edible leaves, cause rib discoloration and contaminate marketable plant portions at harvest. Romaine, leaf lettuces and spinach are especially susceptible to thrips feeding and growers have a very low tolerance for damage and contamination (Palumbo et al. 1997). Thrips are very difficult to control because adults are quite agile and larvae inhabit plant parts that are difficult to reach with sprays, and they can rapidly develop resistance to insecticides (Lewis 1997).

Pest management programs for thrips on lettuce crops in Arizona have been developed around the availability of effective insecticides (Anonymous 1992, Kerns et al. 1995). With the exception of the recent registration of Success, thrips control has been achieved almost entirely through the use of organophosphate and carbamate insecticides. These compounds provide good control of thrips larvae on lettuce, but only marginal control against

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adults (Palumbo 1998b, Palumbo et al. 1998). Thus, growers typically tank-mix them with a pyrethroid to control both lifestages. Loss of Ops and carbamates would not only make thrips control very difficult and expensive (Anonymous 1998), but would place an enormous amount of selective pressure on Success and pyrethroids. Because of these threats, and the need for control measures for thrips in organic lettuce production, it has become clear that an effective, non-chemical control tactic for thrips management would greatly benefit the industry.

The use of overhead sprinkler irrigation has been suggested as an alternative control tactic for thrips. The action of overhead sprinklers may simulate rainfall on a crop, which is widely believed to reduce insect numbers (Kaakeh and Dutcher 1993; Gameel 1977; Davis et al.1995). Direct evidence of insect control via intermittent overhead irrigation has been shown for diamondback moths on watercress (Tabashnik and Mau 1986) and whiteflies in melons (Castle et al. 1996). More specifically, sprinkler irrigation has been reported to significantly reduce thrips populations in cotton (Leigh 1995) and onions (Hoffman et al. 1996) presumably by dislodging them from plants, as well as destroying pupae in the soil by crusting or burial. Although we are uncertain how effectively sprinkler irrigation would reduce thrips populations in leafy vegetables, anecdotal observations suggest that it may be possible. Furthermore, the use of intermittent overhead irrigation would appear to be an ideal fit for western growers. Sprinkler irrigation is commonly used in leafy vegetable production, particularly in romaine and specialty lettuces mixes where solid set sprinkler pipes remain in the field all season. Normally, these crops require about 20-40 inches of water /acre to produce a desirable crop, depending on soil types and temperatures (Kerns et al. 1999). Irrigation schedules could be modified to accommodate daily plant water needs and operated for necessary intervals to provide insect suppression. Therefore, we conducted a 2 year study to evaluate the use overhead sprinkler irrigation for suppressing thrips population in romaine lettuce. Specifically we looked at how the duration and frequency of sprinkler use affected thrips populations, and evaluated combinations of insecticide spray regimes used in association with sprinkler irrigation for suppressing thrips throughout the season.

Materials and Methods

Sprinkler Irrigation Duration Studies. Two field studies were conducted at the University of Arizona Yuma Agricultural Center in the spring 2001 to evaluate the duration of irrigation runs and volumes of water applied to romaine plants on thrips suppression. In the 1st trial (Sprinkler Duration I), romaine lettuce 'PIK 714' was direct seeded on 28 Nov into double row beds on 42 inch centers, and in the 2nd trial (Sprinkler Duration II) plots were similarly established on 8 Dec. Plots consisted of 12 beds, 60 feet long with a two bed buffer between the plots. Plots were arranged in a randomized complete block design with three replications. The sprinkler irrigation treatments are listed below:

Sprinkler Treatment	Duration (time)	Volume [a] (cm)
None	0	0
Low	2 hrs	0.2-0.4
Medium	4 hrs	0.4-0.8
High	8 hrs	1.0-1.8
Insecticide sprays	0	0

[a] see Tables 1 and 2 for average volumes applied per sprinkler run.

Solid set over head sprinkler pipe was used and fitted with Weather Tech 10-60 rainbird heads with 0.031 mc nozzles that ran at 30-35 psi. In Sprinkler Duration I, sprinkler treatments were run on 16 and 24 Feb and 14 March, 2001 and in Sprinkler Duration II, treatments were run on 14, 21, 28 and 4 and 11 Apr. Water volumes were measured by placing 4 standard rain gauges at plant level in each replicate. Three foliar insecticides sprays (Lannate at 0.8 lbs plus Warrior at 3.8 oz) were applied on the same dates in 25 GPA total volume at 40 psi in Sprinkler Duration I, and 4 sprays applied in rotation between Lannate+Warrior and Success in Sprinkler Duration II . Thrips suppression was evaluated at 1-6 days following each sprinkler run by estimating the numbers of thrips (adults and larvae) from 8 plants per replicate. Relative thrips numbers were measured by removing plants and beating them vigorously against a screened pan for a predetermined time. A 6 in. by 6 in. sticky trap was placed inside of the pan to catch the dislodged thrips. Sticky traps were then taken to the laboratory where adult and larvae were counted with the aid of a microscope. In Sprinkler Duration II, yield estimates were taken at harvest on 17 April. Five consecutive plants from two, randomly selected locations in each replicate were sampled (10 plants / replicate). Whole plant weight samples were recorded for each plant. Plants were then trimmed down to remove naturally senescent leaves and leaves containing scarring damage on leaf tissue and bronzing on midribs due to WFT feeding. Plants were then re-weighed to reflect the number of marketable plants, and the number of leaves greater than 5" in length were counted. WFT counts were transformed ($\log_{10}$ n+1) before analysis of variance to stabilize variances that were found to be heterogeneous. Untransformed means are presented in tables. Data were analyzed as a 1-way ANOVA with means compared where appropriate using a protected LSD F test $_{(p<0.05)}$.

Sprinkler Irrigation Frequency Studies. Two field studies were conducted at the University of Arizona Yuma Agricultural Center in the fall of 2001 and spring 2002 to evaluate the frequency of sprinkler irrigation runs on thrips suppression in romaine. In the 1st trial (Sprinkler Frequency I), romaine lettuce 'PIK 714' was direct seeded on 1 Oct into double row beds on 42 inch centers, and in the 2nd trial (Sprinkler Frequency II) plots were similarly established on 12 Dec. Plots consisted of 12 beds, 60 feet long with a two bed buffer between the plots. Plots were arranged in a randomized complete block design with three replications. The sprinkler irrigation treatments are listed below:

Sprinkler Frequency	**Duration (time/run)**	**Volume [a] (cm)**
Untreated	0	0
3X times weekly	3 hrs	1.5-2.0
2X weekly	4.5 hrs	1.5-2.1
1X weekly	9 hrs	1.7-2.2
Insecticide sprays	0	0

[a] see Tables 3 and 5 for average volumes applied per sprinkler run.

Solid set over head sprinkler pipe was used and fitted with Weather Tech 10-60 rainbird heads with 0.031 mc nozzles that ran at 30-35 psi. In Sprinkler Frequency I, sprinkler treatments were run on Nov 13-16, Nov 19-23, Nov 30-Dec5, and Dec 14-19, and foliar insecticide spray (Lannate+Warrior) were applied on 14, 25 Nov. and 6 Dec. In Sprinkler Frequency II, sprinkler treatments were run on Feb 4-8, Feb 13-18, Feb 25-Mar1, Mar 11-15, and Mar 25-29 and insecticide sprays applied (Lannate +Mustang) on 8, 19 Feb, and 7, 15 and 25 Mar . Water volumes were measured by placing 4 standard rain gauges at plant level in each replicate. Foliar insecticide rotation (Lannate at 0.8 lbs plus Warrior at 3.8 oz or success at 6 oz/acre) were applied on the same dates in 25 GPA total volume at 40 psi. Thrips suppression was evaluated at 1-6 days following each sprinkler run by estimating the numbers of thrips (adults and larvae) from 8 plants per replicate. Relative thrips numbers were measured by removing plants and beating them vigorously against a screened pan for a predetermined time. A 6 in. by 6 in. sticky trap was placed inside of the pan to catch the dislodged thrips. Sticky traps were then taken to the laboratory where adult and larvae were counted with the aid of a microscope. In Sprinkler Frequency II, yield estimates were taken at harvest on 4 April. Five consecutive plants from two, randomly selected locations in each replicate were sampled (10 plants / replicate). Whole plant weight samples were recorded for each plant. Plants were then trimmed down to remove naturally senescent leaves and leaves containing scarring damage on leaf tissue and bronzing on midribs due to WFT feeding. Plants were then re-weighed to reflect the number of marketable plants, and the number of leaves greater than 5" in length were counted. WFT counts were transformed ($\log_{10}$ n+1) before analysis of variance to stabilize variances that were found to be heterogeneous. Untransformed means are presented in tables. Data were analyzed as a 1-way ANOVA with means compared where appropriate using a protected LSD F test $_{(p<0.05)}$.

Sprinkler*Insecticide Interaction Studies. Two field studies were conducted at the University of Arizona Yuma Agricultural Center in the fall of 2001 and spring 2002 to evaluate the interaction of sprinkler irrigation used in combination with insecticide sprays for thrips suppression in romaine. In the 1st trial (Sprinkler*Insecticide I), romaine lettuce 'PIK 714' was direct seeded on 3 Oct into double row beds on 42 inch centers, and in the 2nd trial (Sprinkler*Insecticide II) plots were similarly established on 12 Dec. Plots consisted of 4 beds, 75 feet long with a two bed buffer between the plots. Plots were arranged in a split-plot design with three replications. Main plots consisted of sprinkler irrigated plots and non-sprinkled plots, and sub-plots consisted of the insecticide spray regimes listed below. In *Sprinkler*Insecticide I*, the following chemical regimes were applied:

1) *Conventional* (Lannate at 0.7 lbs +Mustang at 4.3 oz),
2) *Reduced-risk* (Success at 6.0 oz),
3) *Biopesticide* (AZA-Direct at 32 oz),
4) *Untreated control.*

All insecticide sprays were applied in 25 GPA total volume at 40 psi on 14, 25 Nov, and 6 Dec. All sprinkler irrigated main plot were run for 9 hours delivering an average of 1.8 cm of water on four dates: 9, 21 Nov, and 3, 10 Dec.

In *Sprinkler*Insecticide II*, the following chemical regimes were applied:

1) *Conventional* (Lannate at 0.7 lbs +Mustang at 4.3 oz applied 5 times on 8, and 19 Feb and 4, 15 and 25 Mar),
2) *Reduced-risk* (Success at 6.0 oz applied 3 times on 8, 19, Feb, and 4 Mar, and Assail at 1.7 oz applied twice on 15 and 25 Mar),
3) *Biopesticide* (AZA-Direct at 32 oz +Garlic Barrier at 10% applied twice on 8 Feb and 7 Mar, Pyganic at 32 oz +Trilogy at 2% applied twice on 19 Feb and 4 Mar, and AZA-Direct at 32 oz+Pyganic at 32 oz applied 3 times on 15, 21 and 25 Mar)
4) *Biological* (Naturalis L at 16 oz applied 7 times on 8, and 19 Feb and 4, 7 15, 21 and 25 Mar).
5) *Untreated control*

All insecticide sprays were applied in 25 GPA total volume at 40 psi and all sprinkler irrigated main plot were run for 9 hours delivering an average of 1.7 cm of water on 6 dates : 5, 15, 22 Feb and 8, 14, and 26 Mar. Thrips suppression was evaluated at 1-6 days following each sprinkler run by estimating the numbers of thrips (adults and larvae) from 5 plants per replicate. Relative thrips numbers were measured by removing plants and beating them vigorously against a screened pan for a predetermined time. A 6 in. by 6 in. sticky trap was placed inside of the pan to catch the dislodged thrips. Sticky traps were then taken to the laboratory where adult and larvae were counted with the aid of a microscope. Yield estimates were taken at harvest on 20 December in Sprinkler*Insecticide I, and on 5 April in Sprinkler Frequency II. Ten plants were randomly selected in each replicate and whole plant weight samples were recorded for each plant. Plants were then trimmed down to remove naturally senescent leaves and leaves containing scarring damage on leaf tissue and bronzing on midribs due to WFT feeding. Plants were then re-weighed to reflect the number of marketable plants (hearts), and the number of leaves greater than 5" in length were counted. WFT counts were transformed ($\log_{10}$ n+1) before analysis of variance to stabilize variances that were found to be heterogeneous. Untransformed means are presented in tables. Data were analyzed as a 1-way ANOVA with means compared where appropriate using a protected LSD *F* test $_{(p<0.05)}$.

Results and Discussion

Sprinkler Irrigation Duration Studies. *Sprinkler Duration I.* This preliminary study was designed to evaluate how different irrigation durations and volumes suppressed thrips in romaine. Adult and larval thrips populations were low at the beginning of the first irrigation run, and increased to moderate levels at the end of the study. There were no significant effects among the sprinkler irrigation treatments following the 1st run with the exception of the 8 hr sprinkler run which resulted in fewer adults compared to the control at 3 DAT. Thrips numbers were significantly lower in the insecticide sprayed treatment. We were not able to achieve the desired volumes for each treatment during the 1st run due to low water pressure (10-15 psi) and windy conditions (> 15 mph). Following the 2nd and 3rd sprinkler runs, we were able to achieve adequate water volumes for each sprinkler duration and did not experience windy conditions. Consequently treatment effects were observed in both irrigation runs. Following the 2nd run, we observed significant treatment effects on both adults and larvae, where populations were significantly suppressed similar to the insecticide spray treatment. Similarly following the 3rd run, all treatments appeared to provide good knockdown suppression compared with check, but not as effective as the insecticide spray. At 6 DAT, the longer duration and greater volume appeared to more effective on larvae. Overall, the results from this preliminary trial at low-moderate thrips numbers suggested that sprinklers irrigation could provide short term suppression (50%) when volume exceeded 0.4 cm for more than 2 hrs duration.

Sprinkler Duration II. This trial was conducted later in the spring under heavier thrips pressure, and sprinkler duration/volume treatments were run throughout the season. Seasonal suppression of thrips populations following sprinkler irrigation runs of various time intervals is shown in Fig 1. Adult suppression varied within the season. Following the initial run, none of the sprinkler treatment provided significant suppression. However, all treatments suppressed thrips populations similar to the insecticide sprays following the final three irrigation runs. At harvest the 2 and 8 hr durations had significantly fewer adults than the sprayed plants. The 8 hr duration appeared to be more effective on thrips larvae, particularly following the first 2 irrigation runs. However, thereafter all sprinkler treatments provided similar levels of suppression larvae and larval numbers were significantly lower than in the untreated control. In general, insecticide sprays consistently suppressed thrips larvae at significantly lower levels.

These population trends are clearly summarized in Table 2. Seasonal average numbers of adults did not differ among the sprinkler treatments and the insecticide spray treatments. All sprinkler treatments contained significantly fewer larvae and total thrips numbers than the untreated control, but did not suppress populations as well as the insecticide sprays. Overall, the sprinkler treatments provided about 40% suppression of thrips, regardless of duration or volume, when averaged across the season. Yield differences among treatments were closely related to the level of thrips suppression that the treatments provided. Measurements of trimmed weights and marketable leaves per heart reflect the resulting romaine product following the discard of thrips damaged foliage. Consequently yields were greatest in the insecticide spray treatment. There were no differences in yield among the three sprinkler treatments, but all were significantly greater than the check. Difference in whole plant wts among treatments may express the feeding effects of thrips on plant growth throughout the study, particularly given the high thrips numbers. However, it is important to note that the incidence of downy mildew was significantly greater in the sprinkler irrigation plots run for 4 and 8 hrs, than any other treatments. Mildew was very low in the check and sprayed treatments and just beginning to infect plants in the 2 hr treatment.

Sprinkler Irrigation Frequency Studies. *Sprinkler Frequency I.* These studies were designed to measure the effects of sprinkler irrigation frequency (number of times run per week) on thrips suppression. This preliminary study was designed specifically to measure residual effects of the same volume of irrigation applied for a 9 hr period at various intervals during the week (either once for 9 hrs, twice for 4.5 hrs or three times at 3 hrs; Table 3). The study was conducted during fall and thrips numbers were relatively low. After 4 consecutive sprinkler runs, the 3 sprinkler treatments provided similar suppression of thrips adults and larvae (Table 3). In each case, thrips numbers in the sprinkler treatments were significantly lower than the untreated check. In contrast, the insecticide spray treatment provided significantly greater control of thrips than the sprinkler treatments. Overall, under low thrips pressure, sprinkler runs of once or twice per week appeared to provide consistent suppression of thrips. However, insecticide sprays maintained thrips populations at negligible levels.

Sprinkler Frequency II. This trial was conducted in the spring under heavier thrips pressure. Figure 2 shows the seasonal suppression of thrips adults and larvae following sprinkler irrigation runs of various frequencies per week. The results in this study varied from our fall study in that a single sprinkler irrigation run per week did not differ from the untreated check throughout the season, and particularly as thrips densities increased near harvest. In contrast, sprinkler that ran 2 or 3 X times per week provided significantly better suppression of thrips adults and larvae than either the untreated check or 1X sprinkler treatment. This was particularly evident near harvest (Mar 22) where the 3X sprinkler treatment had significantly lower thrips numbers than all other treatments with the exception of the insecticide spray treatment. Lannate and Warrior sprays applied at the same intervals as the sprinklers maintained thrips numbers at very low levels throughout the season.

When averaged across the entire season, sprinkler irrigation applied twice (2X) a week provided the most significant thrips control (>50%) among the sprinkler treatments. Again, the weekly sprinkler run (1X) did not differ from the untreated check despite the fact that the same amount of water was applied to the all the sprinkler treatments. Insecticide sprays provided the best control (>80%) among all treatments. Consistent with thrips populations, yields were significantly greater in the sprayed treatment than any other treatment. Only the 2X sprinkler treatment was consistently different from the untreated check. These results are somewhat contrary to our finding in the previous Sprinkler Duration studies where 8 hr sprinkler durations provided in most cases 3-6 suppression of thrips. However these frequency studies may suggest that when sprinklers are used season long, more frequent runs at shorter durations (3-5 hrs) may be adequate to provide comparable or better suppression of thrips than long durations sprinkler runs.

Sprinkler*Insecticide Interaction Studies. *Sprinkler*Insecticide I.* Thrips abundance was moderate at the beginning of the season, and declined to relatively lower levels at harvest during December. In general, main plot effects (Sprinkler irrigation and none) were only significant on a few occasions in the Reduced-risk, Biopesticide and Untreated control treatments (Table 5). When differences were significant, thrips numbers were always lower in the sprinkler plots. Sprinkler irrigation did not significantly improve thrips control in the conventional treatments on any sample dates. Sub-plot effects (insecticide regime) were significant on most sample dates for both thrips adults and larvae. The conventional and Reduced-risk regimes provided the most significant suppression, whereas the Biopesticide regime was inconsistent at best and did not differ from the untreated check on many sample dates.

Seasonal average numbers of adults were lowest in the Conventional and Reduced-risk treatments, irrespective of the use of sprinkler irrigation (Table 6). The Biopesticide regime did not differ from the untreated when sprinkler irrigation was applied, however, in the absence of the sprinklers, the Biopesticide treatments has significantly fewer adults than the untreated check. Treatment effects were similar for larvae and total thrips numbers. Both the conventional and Reduced-risk treatments provided the greatest suppression, but were unaffected by sprinklers. In contrast, the number of larvae and total thrips did not differ between the Biopesticide regime and untreated check. However, biopesticide efficacy of larvae was significantly better when used in association with sprinkler irrigation

(Table 6). Romaine yields differed significantly among the insecticide treatments, but did not differ between sprinkler treatments (Table 7). The Conventional and Reduced-risk spray regimes provided the most consistent yields. Biopesticide yields in most cases were significantly better than the untreated control.

*Sprinkler*Insecticide II.* The spring trial had considerable higher thrips numbers than the fall study. Main plot sprinkler effects were only significant on 2 sample dates and only the Reduced-risk and Biological spray regimes were affected (Table 8). Subplot insecticide regime effects were significant on every sample date. In general, results of this study were comparable to the fall study where the Conventional and Reduced-risk spray treatments provided the most consistent suppression of thrips larvae and adults following the spray and sprinkler regimes (Table 8). These effects were consistent when thrips numbers were averaged across the season (Table 9). Conventional and Reduced risk insecticide regimes provided the most significant suppression of thrips and were not significantly affected by the use of sprinkler. Overall, the use of sprinkler had no significant affect on thrips numbers in the effective insecticide treatments. The Biopesticide regime appeared to be more consistent in suppressing thrips larvae than did the Biological regime which consisted of an entonophagus fungi, *Beauvari bassiana.* We speculated that the use of sprinkler might allow the *B. bassiana* to be a viable control agent because it requires moisture and humidity to sporulate. Although it provided significantly better control of thrips larvae than the untreated check, damage caused by thrips resulted in low yields (Table 10). The Conventional regime provided the most significant yields among all treatments irregardless of sprinklers. The Reduced-risk regime yielded higher than either the Biopesticide or Biological regimes, with the exception of marketable leaves under sprinkler conditions.

The results of this study demonstrated that overhead sprinkler irrigation has the ability to suppress thrips populations in romaine lettuce. However, used exclusively, we do not consider them an effective alternative to insecticides for thrips control. At best, we experienced about 50% population reduction using only sprinkler irrigation compared with the untreated control during these trials. The suppression we observed with sprinkler irrigation was predominantly against larval populations, and adult suppression was sporadic. This is consistent with the observations of Leigh (1995) and Hoffman (1997) who suggested sprinkler could be used to dislodge immature thrips from plants, and bury or suffocate then in the soil where they pupate. This hypothesis would explain to some extent why more frequent sprinkler runs (2X or 3X / week) provided better suppression when overlapping generations occur in the spring.

In contrast, insecticide sprays consistently provided >80% suppression of both adults and larvae, and provided higher yielding and better quality lettuce when employed throughout the season. The use of sprinkler irrigation and insecticide sprays together did not improve suppression or yields. This is not surprising considering the excellent activity of Lannate, pyrethroids and Success when used properly. Thus we could not recommend the use of sprinklers exclusively for thrips management in conventional lettuce production. However, sprinkler irrigation is being used season long in some romaine fields and in organic production and should be of benefit for thrips suppression, particularly in organic systems where effective insecticide alternatives are not currently available. Furthermore, based on our results, it may be possible to reduce the number of sprays normally needed to prevent thrips contaminant and yield reductions in conventional production when sprinkler irrigation is used in association with during the season. Unfortunately, the present study was not designed to determine this, but suggests the need for further research.

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Table 1. Mean adult and larval thrips numbers following various durations of sprinkler irrigation in romaine lettuce, Sprinkler Duration I, YAC, Spring 2001.

		Avg. Thrips/ Plant						
		1st Sprinkler Run (3 DAT)				2nd Sprinkler Run (2 DAT)		
Sprinkler Treatment	Avg. Irrig. (cm)	Adults	Larvae	Total	Avg. Irrig. (cm)	Adults	Larvae	Total
0 hrs	0	4.7 a	17.5 a	22.2 a	0	5.7 a	24.2 a	29.9 a
2 hrs	0.2	3.6 ab	18.0 a	21.6 a	0.3	1.7 b	9.1 b	10.8 b
4 hrs	0.4	3.9 a	20.3 a	24.1 a	0.7	4.4 a	11.8 b	16.3 b
8 hrs	0.7	2.5 b	14.8 a	17.3 a	1.1	2.6 b	11.4 b	14.0 b
Sprayed	--	0.3 c	7.6 b	7.9 b	--	1.1 b	8.9 b	10.0 b

		3rd Sprinkler Run (1 DAT)				3rd Sprinkler Run (6 DAT)		
Sprinkler duration	Avg. Irrig. (cm)	Adults	Larvae	Total	Avg. Irrig. (cm)	Adults	Larvae	Total
0 hrs	0	10.9 a	30.9 a	41.8 a	0	22.8 a	16.9 a	39.7 a
2 hrs	0.4	8.1 ab	13.9 b	22.0 b	0.4	6.5 b	17.5 a	24.0 b
4 hrs	0.9	6.1 bc	14.5 b	20.6 b	0.9	7.2 b	18.4 a	25.5 b
8 hrs	1.8	7.3 b	15.9 b	23.2 b	1.8	6.4 b	12.0 b	18.3 b
Sprayed	--	3.1 c	4.3 c	7.3 c	--	9.6 b	10.4 b	20.0 b

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$

Table 2. Seasonal mean adult and larval thrips numbers following various durations of sprinkler irrigation in romaine lettuce, Sprinkler Duration II, YAC, Spring 2001.

		Seasonal Avg. Thrips/ Plant			Yield / Plant		
Sprinkler duration	Avg. Irrig. (cm)	Adults	Larvae	Total	Whole plant wt (g)	Trimmed wt (g)	Marketable Leaves/heart
0 hrs	0	30.1 a	92.8 a	122.9 a	588.1 bc	187.3 c	10.1 c
2 hrs	0.3	17.5 b	56.9 b	74.4 b	619.6 b	236.4 b	12.1 b
4 hrs	0.7	20.0 b	57.2 b	77.2 b	542.8 c	212.2 b	12.1 b
8 hrs	1.4	20.6 b	48.5 b	69.1 b	589.6 bc	231.1 b	12.7 b
Sprayed	--	14.3 b	20.4 c	34.7 c	764.8 a	376.1 a	17.2 a

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$

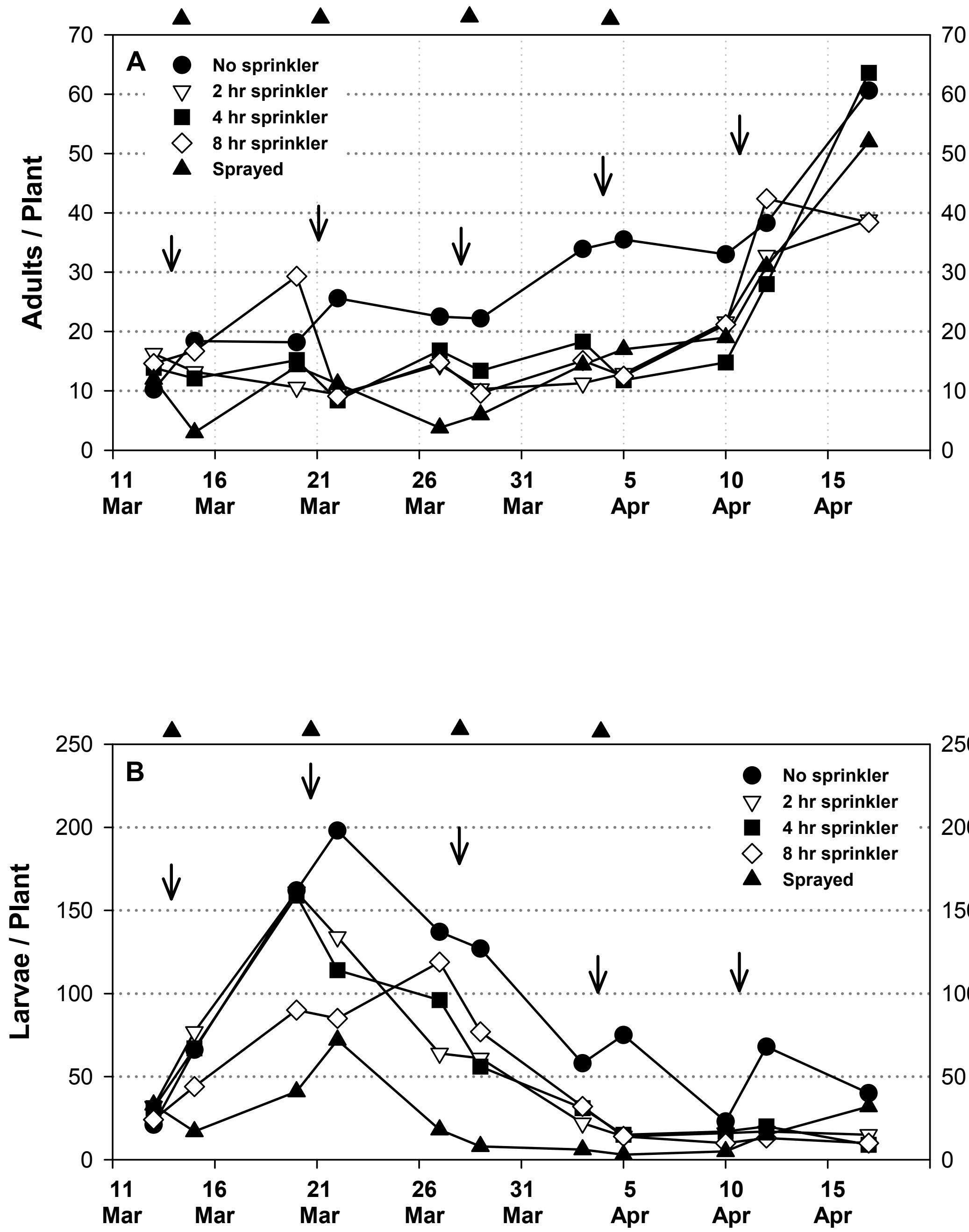

Figure 1. *Sprinkler Duration II.* Seasonal suppression of thrips adults (A) and larvae (B) following sprinkler irrigation runs of various intervals. Arrows indicate when sprinklers were in use. Pyramids on top of chart indicate when foliar insecticide spray was applied.

Table 3. Mean adult and larval thrips numbers following various frequencies of sprinkler irrigation in romaine lettuce, Sprinkler Frequency I, YAC, Fall 2001.

		Avg. Thrips/ Plant						
		1st Sprinkler Run (3 DAT)				**2nd Sprinkler Run (3 DAT)**		
Sprinkler frequency	Avg. Irrig. (cm)	Adults	Larvae	Total	Avg. Irrig. (cm)	Adults	Larvae	Total
Untreated	0	7.6 a	21.1 a	28.7 a	0	6.1 a	12.4 a	18.5 a
3X weekly	1.5 a	3.0 b	12.4 b	15.4 b	1.8 a	2.1 b	6.0 b	8.1 b
2X weekly	1.5 a	3.0 b	15.1 b	18.1 b	2.1 a	1.7 bc	4.8 b	6.5 b
1X weekly	1.7 a	3.2 b	15.4 ab	18.6 b	2.2 a	2.1 b	5.0 b	7.1 b
Sprayed	--	0.6 c	3.4 c	4.1 c	--	0.6 c	2.2 c	2.8 c

		2nd Sprinkler Run (6 DAT)				**3rd Sprinkler Run (3 DAT)**		
Sprinkler frequency	Avg. Irrig. (cm)	Adults	Larvae	Total	Avg. Irrig. (cm)	Adults	Larvae	Total
Untreated	0	6.1 a	15.2 a	21.3 a	0	6.9 a	24.5 a	31.4 a
3X weekly	1.8 a	2.6 b	8.8 b	11.4 b	1.8 a	1.8 bc	6.1 b	7.9 b
2X weekly	2.1 a	3.0 b	5.6 c	8.6 b	1.8 a	3.0 b	7.6 b	10.5 b
1X weekly	2.2 a	2.6 b	8.5 b	11.1 b	2.0 a	3.3 b	7.7 b	11.0 b
Sprayed	--	0.5 c	2.2 d	2.7 c	--	0.7 c	1.2 c	1.9 c

		3nd Sprinkler Run (6 DAT)				**4th Sprinkler Run (6 DAT)**		
Sprinkler Frequency	Avg. Irrig. (cm)	Adults	Larvae	Total	Avg. Irrig. (cm)	Adults	Larvae	Total
Untreated	0	4.9 a	12.8 a	17.7 a	0	4.4 a	13.6 a	18.0 a
3X weekly	1.8 a	2.5 b	9.6 a	12.1 b	2.0 a	3.1 b	9.6 b	12.8 b
2X weekly	1.8 a	2.6 b	4.6 b	7.2 c	1.9 a	3.8 ab	5.8 c	9.6 bc
1X weekly	2.0 a	2.2 b	4.9 b	7.1 c	2.1 a	2.9 b	4.4 c	7.3 c
Sprayed	--	0.5 c	1.3 c	1.8 d	--	0.3 c	0.9 c	1.2 d

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$

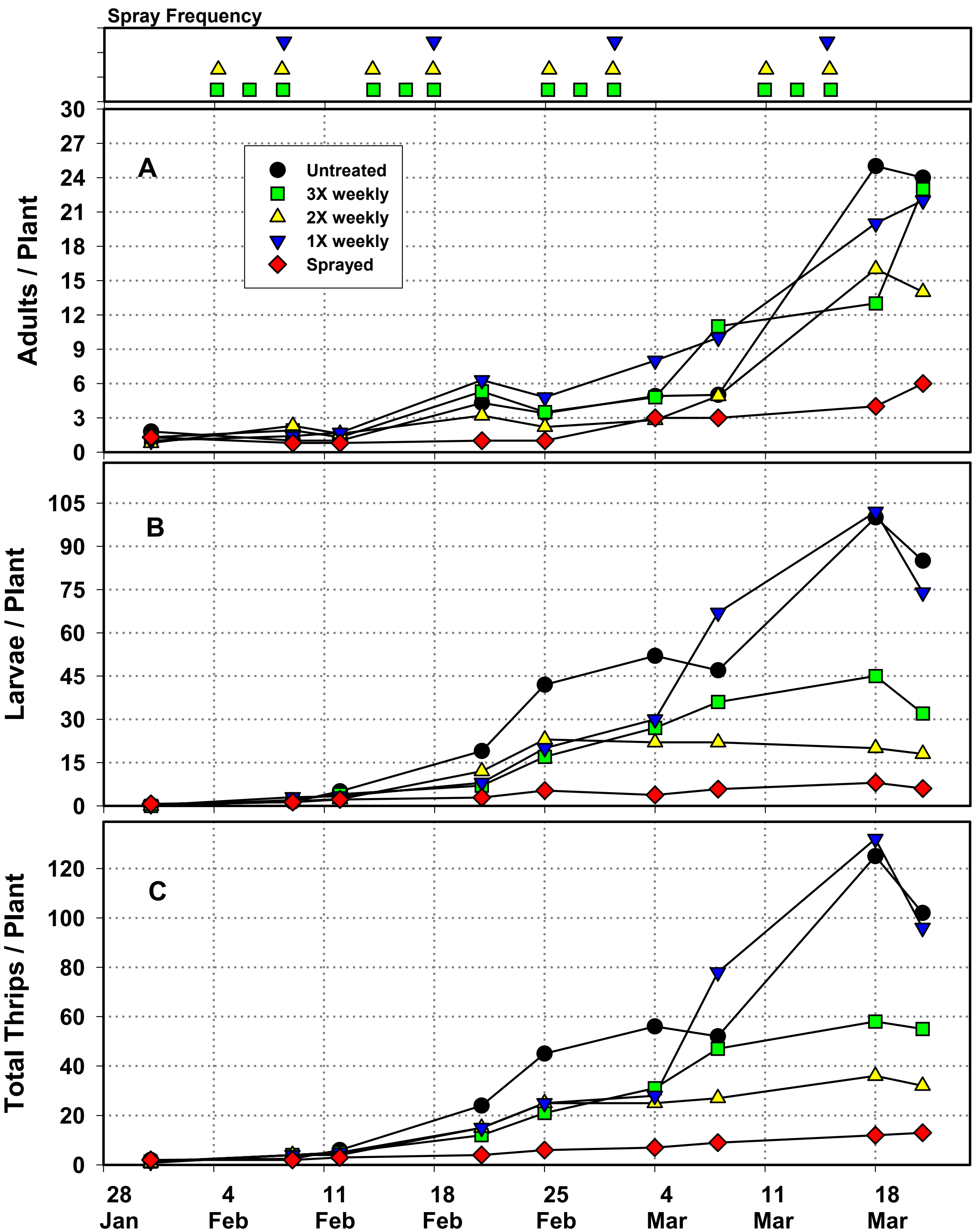

Figure 2. Sprinkler Frequency II. Seasonal suppression of thrips adults (A), larvae (B), and tital thrips (C) following sprinkler irrigation runs of various frequencies per week. Symbols indicate when sprinklers were in use, YAC, Spring 2002.

Table 4. Seasonal mean adult and larval thrips numbers following sprinkler irrigation runs of various frequencies per week in romaine lettuce, Sprinkler Frequency II, YAC, Spring 2002.

		Seasonal Avg. Thrips / Plant			Yield / Plant		
Sprinkler Treatment	Avg Irrig. (cm)	Adults	Larvae	Total	Whole plant wt (g)	Trimmed wt (g)	Marketable Leaves/heart
Untreated	0	7.5 b	41.1 a	48.6 a	41.1 c	10.8 c	15.5 c
3X weekly	1.7 a	7.7 b	20.0 b	27.7 b	45.9 b	11.7 bc	17.2 b
2X weekly	1.8 a	5.7 c	14.3 b	19.9 c	45.9 b	13.3 b	17.8 b
1X weekly	2.0 a	9.0 a	36.6 a	45.6 a	39.1 c	10.1 c	15.2 c
Sprayed	--	2.5 d	4.74 c	7.2 d	48.7 a	16.5 a	20.6 a

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$

Table 5 . Mean adult and larval thrips numbers in romaine lettuce grown under treatment combinations of sprinkler irrigation and insecticide regimes , Sprinkler Frequency I, YAC, Fall 2001.

	Avg. No.Thrips / Plant								
	Adults			Larvae			Total thrips		
Spray Treatment	Sprinkler	None	*P>t*	Sprinkler	None	*P>t*	Sprinkler	None	*P>t*
16-Nov									
Conventional	0.1 b	0.7 b	ns	3.5 b	6.6 a	ns	3.7 b	7.3 a	ns
Reduced-risk	1.7 a	1.2 b	ns	15.5 a	34.6 a	ns	17.1 ab	35.9 a	ns
Biopesticide	1.9 a	5.5 a	ns	11.9 ab	31.8 a	*	13.9 ab	37.3 a	*
Untreated	1.7 a	4.7 a	*	8.7 ab	26.1 a	*	10.4 b	30.9 a	*
20-Nov									
Conventional	0.5 c	0.6 b	ns	3.4 b	8.1 b	ns	3.9 b	8.7 c	ns
Reduced-risk	0.8 bc	1.5 b	ns	7.4 ab	10.7 b	ns	8.2 ab	12.2 bc	ns
Biopesticide	1.9 ab	4.7 a	*	12.3 a	28.5 ab	ns	14.2 a	33.2 ab	ns
Untreated	2.7 a	7.1 a	*	10.7 ab	32.5 a	ns	13.5 a	39.7 a	ns
26-Nov									
Conventional	0.5 a	0.7 b	ns	1.1 b	2.1 b	ns	1.6 b	2.8 b	ns
Reduced-risk	0.7 a	1.3 ab	ns	1.0 b	1.7 b	ns	1.7 b	3.1 b	ns
Biopesticide	1.1 a	1.9 ab	ns	7.9 a	11.2 b	ns	9.0a	13.1 a	ns
Untreated	1.1 a	3.3 a	ns	3.5 ab	16.8 a	ns	4.6 ab	20.1 a	ns
29-Nov									
Conventional	0.4 a	0.9 c	ns	0.9 b	2.5 b	ns	1.3 b	3.4 b	ns
Reduced-risk	0.9 a	1.1 c	ns	2.4 b	4.8 b	ns	3.3 b	5.9 b	ns
Biopesticide	1.3 a	2.7 b	ns	6.2 a	26.6 a	ns	7.5 a	29.3 a	ns
Untreated	1.9 a	5.4 a	*	6.5 a	22.9 a	ns	8.4 a	28.3 a	ns
3-Dec									
Conventional	0.1 b	0.5 c	ns	0.3 a	1.7 b	ns	0.4 a	2.2 b	ns
Reduced-risk	0.5 b	1.5 c	*	0.3 a	3.2 b	*	0.7 a	4.7 b	*
Biopesticide	1.1 ab	3.5 b	ns	2.1 a	14.7 a	ns	3.2 a	18.2 a	ns
Untreated	1.8 a	5.5 a	ns	4.1 a	16.7 a	ns	5.9 a	22.2 a	ns
5-Dec									
Conventional	0.4 b	0.4 c	ns	0.9 b	2.1 c	ns	1.3 c	2.5 c	ns
Reduced-risk	0.5 b	1.5 c	ns	1.3 b	2.2 c	ns	1.7 bc	3.7 c	ns
Biopesticide	1.2 ab	4.1 b	ns	4.3 a	12.8 b	ns	5.5 ab	16.9 b	ns
Untreated	2.3 a	6.0 a	*	5.8 a	20.5 a	*	8.1 a	26.5 a	*
10-Dec									
Conventional	0.3 b	0.4 c	ns	0.7 c	0.9 c	ns	1.0 c	1.3 c	ns
Reduced-risk	0.8 ab	1.2 bc	ns	2.1 bc	2.1 c	ns	2.9 bc	3.3 c	ns
Biopesticide	0.9 ab	2.6 b	ns	3.1 b	7.6 b	ns	4.1 b	10.2 b	ns
Untreated	1.5 a	4.9 a	ns	6.5 a	14.4 a	ns	8.0 a	19.3 a	ns
14-Dec									
Conventional	0.4 c	0.5 b	ns	0.3 b	2.1 c	ns	0.7 b	2.7 c	ns
Reduced-risk	1.3 bc	1.4 b	ns	1.1 ab	1.8 c	ns	2.4 b	3.2 c	ns
Biopesticide	1.8 b	4.8 a	ns	3.4 ab	7.0 b	*	5.2 ab	11.8 b	*
Untreated	3.3 a	5.8 a	*	7.8 a	14.2 a	ns	11.1 a	20.0 a	ns
17-Dec									
Conventional	0.3 b	0.1 c	ns	0.1c	0.9 b	ns	0.4 c	1.0 c	ns
Reduced-risk	0.6 b	0.7 bc	ns	2.2 bc	1.9 b	ns	2.8 bc	2.7 bc	ns
Biopesticide	1.8 a	2.3 b	ns	3.4 ab	5.3 b	*	5.2 ab	7.7 b	*
Untreated	2.8 a	4.5 a	*	5.0 a	12.9 a	*	7.8 a	17.3 a	*

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$

Table 6.

	Seasonal Avg. No.Thrips / Plant								
	Adults			Larvae			Total thrips		
Spray Treatment	Sprinkler	None	*P>t*	Sprinkler	Furrow	*P>t*	Sprinkler	Furrow	*P>t*
Conventional	0.3 c	0.5 c	ns	1.3 c	3.1 b	ns	1.6 c	3.5 b	ns
Reduced-risk	0.8 c	1.3 c	ns	3.7 b	7.0 b	ns	4.5 b	8.3 b	ns
Biopesticide	1.4 b	3.6 b	ns	6.0 a	16.2 a	*	7.5 a	19.7 a	*
Untreated	2.1 b	5.2 a	*	6.5 a	19.7 a	ns	8.6 a	24.9 a	ns

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$

Table 7.

	Yields (mean /plant)								
	Whole plant wt (g)			Trimmed plant wt (g)			Marketable leaves		
Spray Treatment	Sprinkler	None	*P>t*	Sprinkler	None	*P>t*	Sprinkler	None	*P>t*
Conventional	923.4 a	814.8 a	ns	766.7 a	669.8 a	ns	31.0 a	29.5 a	ns
Reduced-risk	869.3 a	912.0 a	ns	681.2 a	695.4 a	ns	28.5 b	28.3 a	ns
Biopesticide	786.6 ab	857.9 a	ns	376.4 b	396.2 b	ns	19.3 c	19.7 b	ns
Untreated	726.7 b	755.3 a	ns	290.7 b	267.9 c	ns	16.2 d	15.2 c	ns

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$

Table 8. Mean adult and larval thrips numbers in romaine lettuce grown under treatment combinations of sprinkler irrigation and insecticide regimes , Sprinkler Frequency II, YAC, Spring 2002.

	Avg. No.Thrips / Plant								
	Adults			Larvae			Total thrips		
Spray Treatment	Sprinkler	None	*P>t*	Sprinkler	None	*P>t*	Sprinkler	Furrow	*P>t*
12-Feb									
Conventional	0.8 b	1.8 a	*ns*	3.3 a	2.1 b	*ns*	4.1 a	3.9 b	*ns*
Reduced-risk	1.2 b	1.1 a	*ns*	4.5 a	2.2 b	*ns*	5.7 a	3.3 b	*ns*
Biopesticide	2.2 ab	1.3 a	*ns*	1.8 a	8.1 a	*ns*	4.0 a	9.4 a	*ns*
Biological	2.9 a	1.7 a	*ns*	2.0 a	5.3 ab	*ns*	4.9 a	6.9 ab	*ns*
Untreated	2.8 a	1.3 a	*ns*	3.8 a	3.5 ab	*ns*	6.6 a	4.8 ab	*ns*
18-Feb									
Conventional	1.3 b	1.1 a	*ns*	4.9 a	3.0 b	*ns*	6.2 bc	4.1 b	*ns*
Reduced-risk	1.1 b	1.4 a	*ns*	4.1 a	7.1 b	*ns*	5.2 c	8.6 b	*ns*
Biopesticide	3.4 a	3.3 a	*ns*	9.9 a	18.7 a	*ns*	13.3 ab	22.0 a	*ns*
Biological	2.9 a	2.4 a	*ns*	11.7 a	6.0 b	*ns*	14.6 a	8.4 b	*ns*
Untreated	2.7 a	2.5 a	*ns*	6.3 a	6.8 b	*ns*	9.0 abc	9.3 b	*ns*
25-Feb									
Conventional	1.2 b	1.3 c	*ns*	2.8 b	5.4 b	*ns*	4.0 c	6.7 b	*ns*
Reduced-risk	1.0 b	2.3 bc	*	3.8 b	5.6 b	*ns*	4.8 c	7.9 b	*ns*
Biopesticide	2.0 ab	4.3 ab	*ns*	8.1 ab	18.8 a	*ns*	10.1 bc	23.0 a	*ns*
Biological	4.2 a	5.4 a	*ns*	10.2 a	11.3 ab	*ns*	14.3 ab	16.8 ab	*ns*
Untreated	3.7 a	5.5 a	*ns*	12.8 a	19.3 a	*ns*	16.5 a	24.8 a	*ns*
7-Mar									
Conventional	1.7 d	3.2 b	*ns*	5.2 c	6.2 b	*ns*	6.9 c	9.4 b	*ns*
Reduced-risk	3.2 cd	2.4 b	*ns*	7.9 c	7.0 b	*ns*	11.1 c	9.4 b	*ns*
Biopesticide	7.3 ab	6.6 ab	*ns*	35.4 ab	40.3 a	*ns*	42.8 ab	46.9 a	*ns*
Biological	6.0 bc	11.1 a	*ns*	28.0 b	25.9 ab	*ns*	34.0 b	37.0 ab	*ns*
Untreated	9.8 a	11.8 a	*ns*	51.0 a	55.0 a	*ns*	60.8 a	66.8 a	*ns*
18-Mar									
Conventional	3.2 c	3.0 d	*ns*	6.8 b	8.9 b	*ns*	10.0 b	11.9 c	*ns*
Reduced-risk	5.4 bc	11.1 c	*	4.9 b	17.8 b	*	10.3 b	28.9 bc	*
Biopesticide	10.8 ab	11.3 bc	*ns*	23.0 a	38.2 ab	*ns*	33.8 a	49.6 ab	*ns*
Biological	13.8 a	16.6 a	*	37.4 a	53.9 a	*ns*	51.2 a	70.4 a	*ns*
Untreated	11.8 a	14.9 ab	*ns*	30.6 a	68.2 a	*ns*	42.3 a	83.1 a	*ns*
29-Mar									
Conventional	10.5 b	13.6 b	*ns*	23.3 c	26.5 d	*ns*	33.9 c	40.2 d	*ns*
Reduced-risk	24.0 a	36.1 a	*ns*	31.5 bc	26.7 cd	*ns*	55.5 bc	82.8 cd	*ns*
Biopesticide	27.9 a	36.0 a	*ns*	62.1 b	83.1 bc	*ns*	90.0 b	119.1 bc	*ns*
Biological	22.7 a	28.4 a	*ns*	117.0 a	125.4 b	*ns*	139.7 a	153.8 b	*ns*
Untreated	26.7 a	38.0 a	*ns*	144.1 a	198.6 a	*ns*	170.8 a	236.6 a	*ns*

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$

Table 9.

	Seasonal Avg. No.Thrips / Plant								
	Adults			Larvae			Total thrips		
Spray Treatment	Sprinkler	None	*P>t*	Sprinkler	None	*P>t*	Sprinkler	None	*P>t*
Conventional	3.1 c	4.0 b	*ns*	7.7 d	8.7 c	*ns*	10.8 d	12.7 c	*ns*
Reduced-risk	6.0 b	9.0 a	*ns*	9.4 d	14.4 c	*ns*	15.4 d	23.5 c	*ns*
Biopesticide	8.9 a	10.5 a	*ns*	23.4 c	34.6 b	*ns*	32.3 c	44.9 b	*ns*
Biological	8.7 a	10.9 a	*ns*	34.4 b	37.9 b	*ns*	43.1 b	48.9 b	*ns*
Untreated	9.6 a	12.3 a	*ns*	41.4 a	58.5 a	*ns*	51.0 a	70.9 a	*ns*

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$

Table 10.

	Yields (mean /plant)								
	Whole plant wt (g)			Trimmed plant wt (g)			Marketable leaves		
Spray Treatment	Sprinkler	None	*P>t*	Sprinkler	None	*P>t*	Sprinkler	None	*P>t*
Conventional	1318.8 a	1338.4 a	*ns*	467.4 a	458.9 a	*ns*	21.2 a	21.6 a	*ns*
Reduced-risk	1276.8 ab	1307.4 ab	*ns*	384.7 b	404.7 b	*ns*	18.4 b	19.3 b	*
Biopesticide	1173.2 bc	1209.6 abc	*ns*	327.8 c	333.5 c	*ns*	17.4 bc	17.1 c	*ns*
Biological	1128.4 c	1190.0 bc	*ns*	287.9 c	305.0 c	*ns*	16.5 cd	16.1 d	*ns*
Untreated	1159.2 c	1156.4 c	*ns*	299.3 c	290.7 c	*ns*	15.8 d	16.0 d	*ns*

Means followed by the same letter are not significantly different, ANOVA; LSD $_{(p<0.05)}$