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ONION THRIPS (THYSANOPTERA: THRIPIDAE) AND THEIR MANAGEMENT IN THE TREASURE VALLEY OF THE PACIFIC NORTHWEST

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ABSTRACT

Onion thrips, *Thrips tabaci* Lindeman and thrips-transmitted *Iris yellow spot virus* are the most significant pest complex affecting onion production in the Treasure Valley of eastern Oregon and southwestern Idaho. Thrips feeding damage and virus infection significantly reduce onion bulb size and economic returns for this high value crop. The high concentration of onion fields in the Treasure Valley and the long, hot, dry growing season present a number of challenges for managing onion thrips and *Iris yellow spot virus* (IYSV). Insecticides are the primary tool that growers have to manage this pest complex. With the long growing season, growers need to exercise good insecticide resistance management programs to maintain the effectiveness of currently available insecticides. To do this, growers need to rotate among available products and use as few applications as practical. A challenge for researchers is to determine not only which insecticides are effective but also to determine when during the season different products may be most effectively used. Techniques for analyzing field trial data are discussed, including comparing changes in pest populations before and after various insecticide applications are made. These comparisons can be made through the use of linear estimates and contrasts as part of analyses of variance, and they can aid in determining efficacy of different treatments by accounting for pre-application populations. These techniques will help researchers in developing sound sequence of insecticide applications for onion thrips management.

Key Words: Onion thrips, IPM, analysis of variance, linear contrasts, insecticide resistance management

RESUMEN

El trips de la cebolla *Thrips tabaci* Lindeman y el *virus de mancha amarilla de Iris* transmitido por los trips son el complejo de plagas más importantes que afectan la producción de cebolla en el Valle del Tesoro del este de Oregón y el suroeste de Idaho. El daño hecho en la cebolla por la alimentación de los trips e infección del virus pueden reducir significativamente el tamaño del bulbo y la rentabilidad económica de este cultivo de alto valor. La alta concentración de campos de cebolla en el Valle del Tesoro asi como su larga, caliente y seca temporada de crecimiento presentan una serie de desafíos para el manejo de trips de la cebolla y del *virus de mancha amarilla de Iris* (VMAI). Los insecticidas son las herramientas primarias que los productores tienen para manejar este complejo de plagas. Con la larga temporada de crecimiento, los productores necesitan ejercer buenos programas de manejo de resistencia a insecticidas para mantener la eficacia de los insecticidas actualmente disponibles. Para ello, los productores necesitan como práctica el rotar entre los productos disponibles y utilizar pocas aplicaciones. El reto para los investigadores es determinar no sólo qué insecticidas son eficaces, pero también el determinar cuando durante la temporada de cultivo los diferentes productos pueden ser utilizados con una mayor eficacia. Se discuten las técnicas para el análisis de los datos de ensayos de campo, incluyendo una examinación de la tasa de cambio en poblaciones de plagas, mediante el uso de contrastes como un parte del análisis de varianza. Estas técnicas ayudarán a los investigadores en el desarrollo de la secuencia de aplicaciones acertadas de insecticidas para el manejo de trips de la cebolla.

Palabras Clave: trips de la cebolla, el MIP, análisis de la varianza, contrastes, resistencia a los insecticidas

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The Treasure Valley of eastern Oregon and southwestern Idaho accounts for over 25% of the dry bulb onion (*Allium cepa* L.; Liliales: Liliaceae) production in the United States. Over 8,000 hectares (20,000 acres) of onions are produced annually in an intensively farmed area within a 50 km radius of Ontario, Oregon. The most significant pest problems facing onion producers in this region are onion thrips (*Thrips tabaci* Lindeman; Thysanoptera: Thripidae) and *Iris yellow spot virus*, a tospovirus that is vectored by onion thrips (Kritzman et al. 2001; Nagata et al. 1999). Onions are the most economically valuable crop for growers in the Treasure Valley, with a farm gate value of approximately $20,000 per hectare in 2012. Therefore, there is an incentive to intensively manage onion thrips and *Iris yellow spot virus* (IYSV). Onion thrips have been a longstanding pest problem in the Treasure Valley, but IYSV is a more recent problem that was first detected in seed onion fields in 1989 (Mohan et al. 1991). However, IYSV did not emerge as a significant problem in bulb onion fields until about 2000 (Mohan & Moyer 2004). The Treasure Valley was the first area where IYSV was detected in the United States, but the virus has since become an important pest in virtually all onion producing regions of the country (Gent et al. 2006).

Onion Thrips and *Iris Yellow Spot Virus* (IYSV)

Thrips feed by puncturing plant cells and extracting the cellular fluid (Hunter & Ullman 1989), which results in plant cell death. Because of their thigmotactic behavior and preference of thrips for inhabiting concealed spaces on plants (Lewis 1973), feeding is concentrated near the base of emerging leaves. As those leaves continue to expand and emerge, evidence of thrips feeding becomes apparent as silvered areas on the leaf surface. This feeding damage reduces the plant's photosynthetic ability (Dai et al. 2009) and ultimately reduces onion bulb size (Diaz-Montano et al. 2010; Kendall & Capinera 1987; Shock et al. 2013).

Initial symptoms of IYSV infection appear as chlorotic, elongate ringed lesions on leaves and flower scapes (Gent et al. 2006). Over time infected tissue becomes necrotic leaving straw-colored areas of dead tissue. Like direct onion thrips feeding damage, IYSV infection does not necessarily lead to plant death, except under severe pressure. Rather, infection is a plant stress that reduces photosynthetic capacity of the plant. However under severe thrips and IYSV pressure, plant death can occur and leave heavily affected fields economically unharvestable (Reitz, personal observation).

Onion Cropping System in the Treasure Valley

The cropping system in the Treasure Valley poses unique challenges for the management of onion thrips and IYSV. There is a long growing season, with onions seeded from Mar to Apr and harvested from Sep through Oct. Crops in the Treasure Valley are irrigated, with most of the water supplied through a series of gravity-fed canals. Fields are irrigated either by furrow irrigation or by subsurface drip. To accommodate the irrigation systems, fields are relatively small, with onion fields typically 10 ha or less. The high concentration of onion fields in the valley fosters movement of thrips among fields, and the concomitant spread of IYSV. Consequently, management in one field is affected by conditions in neighboring fields.

Large populations of thrips build rapidly beginning in May and persist through Jul when the weather is hot and dry. In addition to facilitating the growth of thrips populations, the hot and dry weather exacerbates the expression of thrips and IYSV injury (Lewis 1973; Shock et al. 2009). Thrips populations persist for extended periods of time before they begin to decline rapidly as plants begin to senesce about one month before harvest.

To date, growers in the Treasure Valley have relied on insecticides in to attempts to manage onion thrips and IYSV. Although some onion cultivars have greater tolerance to thrips and IYSV damage, there is no true host plant resistance to either of these pests in commercial onion cultivars (Diaz-Montano et al. 2010; Shock et al. 2008). Likewise, cultural controls, such as fertility management and crop rotation may mitigate but not completely suppress damage from onion thrips and IYSV (Buckland et al. 2013).

Through the 1990s, growers relied on synthetic pyrethroids for onion thrips management (Jensen 2001). However, the overuse of pyrethroids led to a lack of control and the need to develop new management programs (Jensen 2006). Because of how readily onion thrips populations can develop resistance to insecticides (Foster et al. 2010; Herron et al. 2008; Lebedev et al. 2012; MacIntyre Allen et al. 2005; Shelton et al. 2006), these new management programs have been based on rotations of insecticides to guard against the development of resistance.

Current recommendations include not making more than 2 applications of a particular insecticide per season (Rinehold et al. 2014). With onion thrips occurring at economically damaging levels for 8-12 weeks during a typical growing season, growers may need to make 6-8 insecticide applications. Therefore, growers would need a minimum of 3-4 different chemistries to use over the course of a season for a successful resistance management program.

Insecticide Sequences for Management of Onion Thrips

At present, the most commonly used insecticides for onion thrips management in the Treasure Valley are spirotetramat (Movento™, Bayer CropScience, Research Triangle Park, North Carolina), abamectin (Agri-Mek®, Syngenta, Greensboro, North Carolina), spinetoram (Radiant®, Dow Agrosciences, Indianapolis, Indiana) and methomyl (Lannate®, DuPont, Wilmington, Delaware). The use of these 4 chemicals offers certain advantages for managing onion thrips in the Treasure Valley. They belong to different Insecticide Resistance Action Committee (IRAC) mode of action groups, [spirotetramat is in Group 23 (acetyl CoA carboxylase inhibitor);

abamectin is in Group 6 (chloride channel activator); spinetoram is in Group 5 (nicotinic acetylcholine receptor allosteric activator), and methomyl is in Group 1A (acetylcholine esterase inhibitors-carbamates); http://www.irac-online.org/eClassification/#]. Rotating among these products reduces the likelihood that resistance to any one of the chemistries will develop (Gao et al. 2012). In addition, each of these products has translaminar and/or systemic activity so that they are able to penetrate into areas of the plant where thrips are located. These, of course, are not the only insecticides that growers use, and there are new products that continue to be registered. In deciding upon insecticide use programs, growers need to select products and patterns of use that will best assure a satisfactory return on their investment.

Therefore, from a research perspective, it is important to determine not just which insecticides are effective, but when and in what sequence during the season that they would best be used. One approach to meet these goals that has been used in research in the Treasure Valley is to compare programs of different products when applied sequentially over the course of the season. The effectiveness of various season-long programs can be compared by evaluating their respective yields and economic returns (Reitz et al. 1999). An objective of the following presentation is to demonstrate how additional comparisons can be made to evaluate the effectiveness of specific insecticide treatments that are components of season-long programs.

Materials and Methods

As an example of evaluating season-long treatment programs and their components, results from a small plot field trial with different sequences of the 4 most commonly used insecticides can be compared (Table 1). The trial presented as an example was conducted at the Malheur Experiment Station in Ontario, Oregon, and the results discussed below include data for 5 insecticide sequence programs and an untreated control.

Onion seed (Vaquero; Nunhems, Parma) was planted on March 15 in double rows, spaced 7.6 cm apart at 29.5 seeds per meter of each single row, giving 370,000 seeds per ha. Each double row was planted on beds spaced 56 cm apart. For this trial, insecticides were applied weekly for 8 weeks, with each product being applied twice in consecutive weeks and then rotating to the next product in a sequence. Insecticides were applied with a CO_2-powered backpack sprayer fitted with a 4 nozzle boom and 11004 nozzles, and operating at 207 kPa and delivering 337 L per ha. There were 4 replications of each insecticide sequence treatment with the experiment arranged as a randomized complete block. Each experimental plot consisted of 4 double rows of onions (2.2 m wide) and measured 8.2 m long. There was a 1.2 m buffer between plots.

TABLE 1. INSECTICIDE APPLICATION SEQUENCES USED FOR ONION THRIPS AND *IRIS YELLOW SPOT VIRUS* MANAGEMENT AND ONION YIELDS FOR THOSE SEQUENCES. INSECTICIDES WERE APPLIED ON THE DATES LISTED IN THE TABLE WITH A CO_2 POWERED BACKPACK SPRAYER OPERATING AT 207 KPA AND 327 LITERS PER HECTARE.

Sequence ID	Treatment Sequences and Application Dates				Total Marketable Yield (kg/ha)	Colossal & Super Colossal Yield (kg/ha)[1]
	Application 1 & 2	Application 3 & 4	Application 5 & 6	Application 7 & 8		
	May 23, 30	June 6, 12	June 20, 27	July 3, 11	x ± SE	x ± SE
A	Untreated	Untreated	Untreated	Untreated	125,369 ± 3,530 a[2]	37,069 ± 5,401 a[2]
B	Movento (0.37 L/ha)	Agri-Mek (0.26 L/ha)	Radiant (0.58 L/ha)	Lannate (3.51 L/ha)	141,109 ± 2,541 bc	65,468 ± 4,979 b
C	Movento (0.37 L/ha) + Requiem (2.34 L/ha)	Agri-Mek (0.26 L/ha) + Requiem (2.34 L/ha)	Radiant (0.58 L/ha) + Requiem (2.34 L/ha)	Lannate (3.51 L/ha) + Requiem (2.34 L/ha)	132,007 ± 4,034 ab	65,358 ± 4,395 b
D	Radiant (0.58 L/ha)	Movento (0.37 L/ha)	Lannate (3.51 L/ha)	Agri-Mek (0.26 L/ha)	148,451 ± 5,553 c	83,119 ± 7,451 c
E	Movento (0.37 L/ha)	Radiant (0.58 L/ha)	Lannate (3.51 L/ha)	Agri-Mek (0.26 L/ha)	143,765 ± 3,624 cd	68,228 ± 4,080 b
F	Lannate (3.51 L/ha)	Movento (0.37 L/ha	Agri-Mek (0.26 L/ha)	Radiant (0.58 L/ha)	155,571 ± 7,544 d	85,323 ± 6,883 c

[1]Super colossal onions are those greater than 10.8 cm in diameter. Colossal onions are those 10.2 – 10.8 cm in diameter. These size classes are typically more valuable than smaller size classes.
[2]Means within a column marked by the same letter are not significantly different (Least Squares Means, P > 0.05).
Note: The common names of these insecticides are as follows: Movento™ (spirotetramat), Agri-Mek® (abamectin), Radiant® (spinetoram) and Lannate® (methomyl).

Thrips were counted approximately weekly, on 15 plants per plot, beginning before insecticide applications started and continuing for 2 weeks after applications ended. Yield was determined based on the weight, size and quality of onions from the middle two double rows in each plot. The onions were lifted on 13 Sep to field cure. Then onions were topped by hand and bagged on September 24 and graded on 1 Oct. During grading, bulbs were separated according to quality: bulbs without blemishes (No. 1s), split bulbs (No. 2s), neck rot (bulbs infected with the fungus *Botrytis allii* in the neck or side), plate rot (bulbs infected with the fungus *Fusarium oxysporum*), and black mold (bulbs infected with the fungus *Aspergillus niger*). The No. 1 bulbs were graded according to diameter: small (< 5.7 cm), medium (5.7–7.6 cm), jumbo (7.6–10.2 cm), colossal (10.2–10.8 cm), and supercolossal (> 10.8 cm).

Data were analyzed with generalized linear mixed model techniques. Analyses were performed with the Statistical Analysis System, using the Glimmix procedure (SAS Institute 2010). ESTIMATE and CONTRAST statements in Proc Glimmix were used to construct linear estimates of differences and contrasts among treatments within sample days, and changes in the difference in thrips numbers between particular treatment programs over consecutive sample dates. Linear estimates provide an estimate of the magnitude of the difference in two means. Contrasts allow tests of the same hypotheses as estimates to be made, but contrasts also allow more flexible hypothesis tests among multiple groups to be made (Sokal & Rohlf 1995). Estimate, and corresponding contrast, statements were designed according to methods described in (Kiernan et al. 2011; SAS Institute 2005). The comparisons among treatments within each sample day establish if there are differences among thrips populations following an insecticide application. However, these types of comparisons do not take into account initial differences in thrips abundance among treatment programs before a particular insecticide application is made. Evaluating changes in thrips populations before and after insecticide applications allow the effectiveness of a particular insecticide application in comparison with another insecticide.

Results and Discussion

As seen in Table 1, the insecticide programs led to significantly greater yields when compared with the untreated control ($F_{5, 15} = 9.73$, $P = 0.0003$). This was especially evident in terms of the largest and most valuable size classes of onions where the insecticide programs had 76 – 130% greater yields than the untreated control ($F_{5, 15} = 29.97$, $P < 0.0001$). There were also significant differences among the 5 insecticide sequence programs, indicating that it is not just the particular insecticides that are applied but their timing during the season that affects yield. For example, insecticide sequences D and F had higher yields of the 2 largest size classes than did the other sequences (Table 1).

The effectiveness of individual product treatments used within a program can be assessed by comparing numbers of a target pest following each application. In the example of this field trial with onion thrips, there were significant differences among the treatments in the samples collected after each insecticide application ($P < 0.001$; Table 2; Fig. 1). These analyses suggest that Lannate was most effective when applied early in the season (e.g., Sequence F), but Lannate was not as effective at the very end of a treatment program (e.g., Sequences B and C). Radiant was most effective from the 3rd through the 8th application times, suggesting that it could be used effectively throughout most of the season. The results also indicate that combining Requiem® (Bayer CropScience) with the other insecticides provided the best overall onion thrips management (Table 2, Fig. 1). Requiem is a composition of synthesized terpenes based on extracts of the plant *Dysphania (=Chenopodium) ambrosioides* (L.) (Caryophyllales: Amaranthaceae). Interestingly, the combination of Requiem with the other 4 insecticides did not appear to improve yields (Table 1).

These evaluations of insecticides on a sample day basis can provide valuable information for growers, but they provide little information on the

TABLE 2. MEAN NUMBERS OF ONION THRIPS IN DIFFERENT INSECTICIDE TREATMENT SEQUENCES ON EACH SAMPLE DATE FOLLOWING INSECTICIDE APPLICATIONS. DATA WERE ANALYZED BY ANALYSIS OF VARIANCE, WITH MEANS COMPARED BY THE LEAST SQUARES MEANS PROCEDURE (PROC GLIMMIX, SAS INSTITUTE, 2010). THERE WERE SIGNIFICANT DIFFERENCES AMONG THE SIX TREATMENT SEQUENCES ON EACH OF THE LISTED SAMPLE DATES.

Sequence ID	June 3	June 10	June 17	June 26	July 1	July 8	July 15
A	33.08 a[1]	45.22 a	51.29 a	47.20 a	54.98 a	32.35 a	53.17 a
B	28.37 a	12.62 b	26.60 bc	8.43 bc	10.20 bc	11.05 b	44.43 ab
C	20.60 a	6.62 c	14.55 c	5.75 c	6.30 c	17.52 b	34.03 ab
D	20.59 a	61.79 a	31.87 ab	10.55 b	8.30 bc	14.28 b	32.85 b
E	29.65 a	6.72 c	15.15 c	7.67 c	13.57 b	14.17 b	36.20 ab
F	7.74 b	56.54 a	19.97 bc	13.13 b	10.27 b	7.47 c	16.02 c

[1]Means within a column marked with the same lower case letter are not significantly different (P > 0.05).

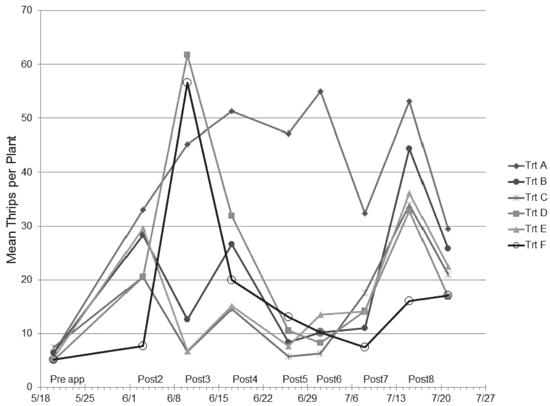

Fig. 1. Mean numbers of onion thrips in onions over time for 6 different insecticide treatment sequences. The different insecticides used in the treatment sequences (A-F) are given in Table 1. For clarity, when samples were collected in reference to insecticide application numbers are noted along the x axis. Samples were collected before insecticide treatments began, then 4-6 days after each application with a final sample taken 10 days following the last (8th) insecticide application.

performance of different individual components of the programs and whether all components of a program may be useful. This is especially true in the case of pests like onion thrips, which reproduce in a target crop (i.e., onions) and where both immature and adult stages cause significant damage to the crop. In these situations the numbers of a pest can be affected by the effectiveness of a previous treatment application. For example, if large numbers of individuals survive a particular insecticide application, those large populations may bias the interpretation of a subsequent insecticide treatment, especially when that treatment is compared with another where the beginning baseline population was low.

The use of linear estimates and contrasts to assess the changes from one sample time to the next sample time for various treatment programs is a complementary approach to analyzing these types of data that helps to account for population levels at the sample point before a treatment is made (Sokal & Rohlf 1995). For example, there was no significant difference between Sequence B and Sequence F on the 17 Jun sample date (Table 2). This date corresponds to the sample taken after the second Agri-Mek application in Sequence B and the second Movento application in Sequence F. However, examination of the slopes from the 10 Jun to the 17 Jun sample (Fig. 1) shows that onion thrips populations actually increased (positive slope) from 10 Jun to 17 Jun in Sequence B. In contrast, onion thrips populations decreased in Sequence F from 10 Jun to 17 Jun (negative slope). The linear estimate comparing these 2 slopes shows that they are significantly different (P = 0.0003). The difference in the slopes suggest that at this time point in the growing season, Movento was more effective in reducing onion thrips abundance than Agri-Mek even though there was no significant difference in the means on the 17 Jun sample date.

As another example, there was a significant difference between the control (Sequence A) and Sequence D on 15 Jul, the sample date after the 8th insecticide application. However, a comparison of the slopes from the 8 Jul to the 15 Jul samples for these sequences show there was no significant difference. This result indicates that the increases in onion thrips populations were similar (Fig. 1). Although Agri-Mek appeared to be effective at other points in the season, the last application of Agri-Mek in Sequence D may not have provided a substantial benefit to justify making that application.

Conclusions

Onion thrips and thrips-transmitted IYSV are serious problems for onion producers in the Treasure Valley of Oregon and Idaho. Damage accumulates over the course of the season, but early and mid-season control (at the time of bulb initiation in late Jun–early Jul) appear to be the most critical times for thrips damage to occur. Effective management of onion thrips at these times would enable larger bulbs to be produced.

Field trials to assess different season-long insecticide programs are useful to evaluate programs and encourage growers to use insecticide resistance management programs. Analysis of the effectiveness of these programs can be complex, but it is possible to employ complementary analyses to draw conclusions about the effectiveness of different pest management programs. As shown in the examples above, linear estimates and contrasts can be constructed to examine differences between insecticide treatments over specific time intervals. The examples provided above are intended to be illustrative; it is best to use preplanned comparisons when employing contrasts (Sokal & Rohlf 1995), and trials should be replicated over time before attempting to draw definitive conclusions. Linear estimates can be used to determine assess whether changes from one sample point to the next are significantly greater than 0, indicating that populations are increasing or significantly less than 0, indicating that populations are decreasing. Furthermore, they can be used to estimate the magnitude of differences over time between two groups by estimating the differences in the two slopes. Linear contrasts can be used to test similar hypotheses or to make other hypothesis tests that the researcher may be interested in addressing. These types of analyses are useful in determining whether particular insecticide applications are beneficial in suppressing a target pest. Understanding the performance of insecticides will aid in improving the timing of applications and the management of onion thrips and IYSV, as well as other pests (Nault & Shelton 2010).

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