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THE INFLUENCE OF ADJACENT WEED POPULATIONS ON THRIPS AND IYSV IN ONION

by

S. Andrew Swain

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Plant Science
(Weed Science)

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2019

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ABSTRACT

The Influence of Adjacent Weed Populations on Thrips and IYSV in Onion

by

Andrew Swain, Master of Science

Utah State University, 2019

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Department: Plants, Soils, and Climate

Onion thrips (*Thrips tabaci*) and Iris Yellow Spot Virus (IYSV) form a pest-diseases complex that has, in recent decades, become of global concern for *Allium* producers. Numerous weed species have been documented as host plants for both onion thrips and IYSV. A field study was conducted to explore the relationship between various weed species and thrips and IYSV incidence in associated onions.

The field studies, conducted at the USU experiment station in Kaysville, Utah, evaluated the incidence of thrips species and Iris Yellow Spot Virus in onions surrounded by several weed borders comprised of different weed species, as well as a weed-free control border. Onions were planted in 10 m² plots. Treatments were arranged in a randomized complete block design and consisted of 0.6 m borders of the following weed species surrounding each plot: common mallow, field bindweed, and prickly lettuce. Two additional treatments included borders of resident weed communities, one mowed half-way through the season. Plant samples of both

onions and weeds were taken four times throughout the season. ELISA tests were used to test plant tissues for virus presence. Counts were used to ascertain thrips adult, larvae, and egg numbers. Thrips per gram on onion dipped mid-season but then rose at end of season in 2014, and generally declined throughout the season in 2015. Among the single-species border treatments, there were no significant differences in thrips numbers on onion in either 2014 or 2015. Thrips increased markedly on onion within the mowed resident weed border compared to the unmowed resident weed border in 2014, suggesting possible thrips migration. This phenomenon was not observed in 2015. Among sampled plant species, adult onion thrips and thrips larvae densities were highest on onion, common mallow, field bindweed, and hairy nightshade in 2014, and on onion, black medic, common mallow, field bindweed, and hairy nightshade in 2015. Virus incidence, though higher in 2015 than in 2014, was relatively low in both years. IYSV presence was detected in samples of all species tested: onion, black medic, common lambsquarters, common mallow, field bindweed, hairy nightshade, prickly lettuce, and witchgrass. These results suggest thrips preferences among potential host plant species and reinforce a growing body of work showing the infection of a diverse range of host plant species by IYSV.

PUBLIC ABSTRACT

The Influence of Border Weed Species on Thrips and IYSV in Onion

S. Andrew Swain

Onion thrips (*Thrips tabaci*) and Iris Yellow Spot Virus (IYSV) constitute a pest complex of global concern for allium growers. Yield losses due to onion thrips alone can be heavy, and in tandem with IYSV, these losses can be complete.

This study was one phase of a multi-phase research project intent on exploring the potential drivers of thrips and virus infestation in onion. Preliminary observations in participating growers' fields in northern Utah pointed towards a potential link between weedy field borders and thrips/IYSV infestation in onion. Field work was carried out at the Kaysville experiment station examining the possible relationships between thrips and IYSV incidence in onion and the presence of adjacent weed populations.

This research was conducted with the intent of guiding growers' decisions regarding field border management, and to provide additional insights into onion thrips behavior. While implications for growers remain unclear, thrips preferences regarding host plant utilization were identified, as well as preliminary evidence of additional plant species capable of hosting IYSV.

ACKNOWLEDGMENTS

This research was made possible by a grant from Western SARE (Western Sustainable Agriculture Research and Education). Committee members and participating researchers included Corey Ransom, Diane Alston, Claudia Nischwitz, Daniel Drost, and Xin Dai. Student employees aided in plot maintenance and data collection. The support of my wife Jessica deserves recognition. My appreciation to all those who helped throughout the research process.

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LITERATURE REVIEW

Biology and Behavior of Onion Thrips

The onion thrips (*Thrips tabaci* Lindeman) is a pestiferous insect in the order Thysanoptera and the family Thripidae. Thrips have beak-like mouth parts used in a punch-and-suck feeding mode; *T. tabaci* uses its mouthparts primarily to extract plant cell nutrients (Childers and Achor 1995; Pourian and others 2009; Sharga 1933). Adults are 1 to 2 mm in length, elongate, and pale yellow to brown in color, with color varying according to ambient temperatures during development (Diaz-Montano and others 2011). Both pairs of wings are fringed, antennae are seven-segmented, and the pronotum (dorsal surface of the first segment behind the head) has setae (hairs) on the lower, but not upper margin. Number of antennal segments, and number and placement of pronotal and forewing setae, are important characteristics in differentiating between *T. tabaci* and other thrips found on onion (Stannard 1968).

Onion thrips are believed to have originated in the Mediterranean region. Presently, however, the species is essentially cosmopolitan (Diaz-Montano and others 2011).

Thrips tabaci is a multivoltine species, meaning that multiple life cycles are completed per year. Life cycle length is highly dependent on temperature. Jamieson et al. (2012) reported total development times ranging from 10.3 days at 30°C to 51.1 days at 12°C on onions and leeks. This study found that an accumulation of 221 degree-days above 8.1°C was required to complete the life cycle, with lower threshold temperatures of 7.3°C for pupae and 9.1°C for eggs (Jamieson and others 2012). Edelson and Magaro (1988) developed an earlier degree-day

model for onion thrips in the lab and suggested a slightly warmer lower threshold temperature of 11.5°C. Life cycle length may furthermore vary by host plant species; however, similar developmental periods of 14 to 20 days on onion and 18 to 21 days on cucumber were observed at a temperature of 25±1°C (Patel and others 2013; Pourian and others 2009). Average total life span is about a month and a half (Alston and Drost 2008; Patel and others 2013; Shaikh and others 2015). Reproduction is largely parthenogenic (asexual reproduction through unfertilized eggs), leading to almost exclusively female populations in most regions in the world (Diaz-Montano and others 2011). Females produce 30-70 eggs (Patel and others 2013; Pourian and others 2009), which are placed just under the epidermis of succulent host tissues. Eggs are elliptical, roughly 0.25 mm in length, with an average incubation period of 3 days on cucumber (Pourian and others 2009) and 4 to 5 days on onion (Patel and others 2013). Two larval instars follow egg hatch, the first lasting roughly two days, and the second approximately four days (Patel and others 2013; Pourian and others 2009). Prepupal and pupal stages are inactive, and occur on the soil surface or in protected sites on lower parts of host plants. Combined, these two stages last roughly 3 days on cucumber and 5 days on onion (Patel and others 2013; Pourian and others 2009). Thrips settling, oviposition, and subsequent viral inoculation in onion are skewed towards the basal portion of the plant (Chitturi and others 2015). Adults live two to three weeks.

Thrips tabaci, like other Thripidae, are highly polyphagous and utilize a broad range of host plants including hundreds of species in over forty plant families (Diaz-Montano and others 2011). The number of documented crop species serving as host plants includes alfalfa, asparagus, bell pepper, black pepper, cabbage, carrot, cassava, chrysanthemum, clover, corn, cotton, cucumber, garlic, leek, mandarin orange, melon, onion, persimmon, pigeonpea, potato,

pumpkin, sorghum, soybean, strawberry, sugarbeet, sunflower, tobacco, tomato, and wheat (Jones 2005; North and Shelton 1986; Raspudic and Ivezić 1998; Salas 2003). Additionally, onion thrips have been documented utilizing a wide variety of weed species, some of which are economically important in onion production, including weeds from the following families: Amaranthaceae, Apiaceae, Asteraceae, Boraginaceae, Brassicaceae, Caryophyllaceae, Chenopodiaceae, Convolvulaceae, Cyperaceae, Fabaceae, Fumariaceae, Geraniaceae, Lamiaceae, Lythraceae, Malvaceae, Myrtaceae, Rubiaceae, Scrophulariaceae, Poaceae, Polygonaceae, Portulacaceae, Ranunculaceae, Urticaceae, and Zygophyllaceae (Atakan and Uygur 2005; Morishita 2005; Sampangi and others 2007; Schellhorn and others 2010).

Thrips dispersal is characterized as either short, trivial movement from day-to-day following food, shelter, and mating signals, or as long-distance dispersal. Field studies indicate that most onion thrips movement may be classified as trivial, short-distance dispersal, but that some long-distance dispersal activity (characterized as flights at altitudes exceeding 2 m) does occur, and that this dispersal, defined as the ratio of thrips captured on above-ground sticky traps to thrips observed at ground level, seems to increase as the season progresses (Smith and others 2015). The temporal skewing of long-distance thrips dispersal activity towards late-season as opposed to early season dispersal is thought to be elicited by a number of factors including weather patterns, stages of crop maturity, harvest activity, and insecticide application regimes (Smith and others 2015).

Epidemiology of Onion Thrips

Although onion thrips constitute a serious pest in a number of crops, this review will focus primarily on *T. tabaci* in onion, its most important host species and the crop in which it is considered the primary pest species world-wide (Alston and Drost 2008; Diaz-Montano and others 2011; Jensen and others 2002). In onion, yield reduction from thrips feeding is generally due to reduced bulb size (Edelson and others 1989). This is at least partially a result of hastened plant maturity and senescence, which effectively curtails the growth period for onion (Alston and Drost 2008). Potential yield losses in onion are known to reach well over 50% due to direct feeding habit, and have been shown to reach over 70% in some untreated control plots, though most studies have found yield reduction rates to be closer to the 35% to 45% range (Diaz-Montano and others 2011; Fournier and others 1995; Haider and others 2014; Shahnawaz and Goud 2005). Thrips damage in onion varies according to a number of environmental factors including temperature (positive correlation), precipitation (negative correlation), and wind (negative correlation) (Haider and others 2014; Keshav and Veer 2013; Selvaraj and Adiroubane 2012), as well as biotic factors relating to varietal resistance in the crop. Foliar characteristics such as leaf color, epicuticular wax levels and wax crystal traits have been identified as factors relating to resistance to thrips via nonpreferential feeding activity (antixenosis), while other morphological traits such as leaf angle and neck length have also been implicated (Cramer and others 2014; Molenaar 1984; Pawar and others 1975).

Additional economic damage by onion thrips is incurred via virus transmission. *Thrips tabaci* have been shown to vector viral diseases from multiple genera including the Tospoviruses, Iris Yellow Spot Virus and Tomato Spotted Wilt Virus (TSWV is only rarely transmitted by *T. tabaci* and is suspected to only be transmitted by males), the Ilaviruses, Tobacco Streak Virus and Prunus Necrotic Ringspot Virus, the Machlovirus, Maize Chlorotic

Mottle Virus, and the Sobemovirus, Sowbane Mosaic Virus (Jones 2005). Of these diseases, Iris Yellow Spot Virus (IYSV) is the most economically important (Bulajic and others 2012).

Biology and Epidemiology of IYSV

Iris yellow spot virus (IYSV) is a member of the plant-infecting genus *Tospovirus* within the family *Bunyaviridae*. It was first observed in the early 1980's in cultivated onions in Brazil, where the disease was known colloquially among growers as "sapeco," and soon after in cultivated iris in the Netherlands (Cortes and others 1998; Gent and others 2006; Pozzer and others 1999; Pozzer and others 1994). By 1990, the virus had made its way to the US and was found in Idaho and Oregon (Hall and others 1993). It now infects US onion production from California to New York. Currently IYSV is found throughout the world with reported incidence in South America, New Zealand, Africa, Asia, the Middle East, and in Europe from Southwest Germany east to Bosnia and Herzegovina and south to Spain and Italy.

IYSV is vectored exclusively by insects in the order *Thysanoptera*. Until recently, it was believed that IYSV was vectored solely by the onion thrips (*Thrips tabaci*). It is now known, however, that at least one other species of *Thysanoptera*, *Frankliniella fusca*, can also serve as a vector (Srinivasan and others 2012).

Thrips obtain the virus through feeding on infected plant material during larval stages. Like other tospovirus-thrips relationships, IYSV is persistent and propagative within the thrips, meaning that after ingestion during the first and second larval instars, the virus is retained by the thrips for the remainder of its life. Larval acquisition of the virus is essential to adult vector

status. Upon ingestion, the virus travels through the foregut and enters the midgut, which serves as the primary site of infection. Here the virus begins to traverse a series of membranes and eventually enters the salivary gland. Once inside the salivary gland, the virus is free to travel with the saliva through a series of salivary canals, ultimately infecting subsequent plant hosts with virus-laden saliva during ensuing feedings (Whitfield and others 2005). Proportions of *T. tabaci* that ingest IYSV-infected plant material and are also transmitters (virus-laden salivary glands), has been shown to vary throughout the season (Bag and others 2014).

At the time of its discovery, the known host range for IYSV was very limited, comprising only a handful of species (Cortes and others 1998). Today, however, numerous additional species have been confirmed as hosts for the virus including redroot pigweed (*Amaranthus retroflexus*), common burdock (*Arctium minus*), twoscale saltbush (*Atriplex micrantha*), common lambsquarters (*Chenopodium album*), chicory (*Cichorium intybus*), kochia (*Kochia scoparia*), prickly lettuce (*Lactuca serriola*), curly dock (*Rumex crispus*), green foxtail (*Setaria viridis*), dandelion (*Taraxacum officinale*), and puncturevine (*Tribulus terrestris*) (Evans and others 2009a; Evans and others 2009b; Hsu and others 2011; Sampangi and others 2007). Various other species are suspected as viral hosts, including smooth brome (*Bromus inermis*), blue mustard (*Chorispora tenella*), field bindweed (*Convolvulus arvensis*), flaxweed (*Descurainia sophia*), sunflower (*Helianthus annuus*), common purslane (*Portulaca oleracea*), spiny sowthistle (*Sonchus asper*), salsify (*Tragopogon dubius*), and winter wheat (Evans and others 2009a; Hsu and others 2011; Nischwitz and others 2007; Sampangi and others 2007; Schwartz and others 2014; Szostek and Schwartz 2015). While *Allium* species, and onions particularly, represent the most important hosts for IYSV worldwide, the growing list of additional host plants is of importance because several weed species identified as being suitable hosts for onion thrips

have also been identified as alternate hosts for IYSV, indicating the need for a comprehensive management approach (Evans and others 2009a; Nischwitz and others 2007; Sampangi and others 2007). Of the weed species that have been documented as hosts for both onion thrips and IYSV, perennials and winter annuals are of particular interest due to their suspected role as overwintering sites, leading to subsequent crop infection the following year (Szostek and Schwartz 2015; Weilner and Bedlan 2013).

IYSV symptoms in onion include eye or spindle-shaped necrotic spots on leaves and scapes. Expanding lesions can coalesce, resulting in total foliar dieback (Gent and others 2006). Infection invariably leads to flower abortion (Pozzer and others 1999). Loss of photosynthetic leaf area due to lesions leads to decreased bulb size (Diaz-Montano and others 2011). Virus infection of most weed species appears to be asymptomatic (Nischwitz and others 2007).

Management of Onion Thrips and IYSV

The *T. tabaci*/IYSV pest complex constitutes a major threat to *Allium* growers worldwide. As previously stated, direct feeding damage alone by thrips can result in major crop losses. However, in conjunction with IYSV, injury incidence can reach 100% and result in total loss of seed and bulb crops (Diaz-Montano and others 2011; Pozzer and others 1999).

Control of onion thrips has been traditionally achieved by application of synthetic insecticides, and this is still considered the most important onion thrips control method, though it is frequently conceded that insecticides alone are often insufficient (Nault and others 2012). Spinosyn, tetramic acid, and avermectin insecticides have been shown to be highly effective

against onion thrips when used in conjunction with a penetrating surfactant (Nault and others 2012). Other insecticides labeled for use against onion thrips include pyrethroids, neonicotinoids, diamides, carbamates, organophosphates, and organothiophosphates (Paranjape and others 2015). Multiple applications, often as a sequenced variety of products, throughout the season are generally required for acceptable control. Unfortunately, *T. tabaci* resistance to pyrethroids, organophosphates, carbamates, avermectins, and spinosyns has been documented in populations around the world. Some research does suggest, however, that thrips demonstrating insecticide resistance may incur resulting fitness costs by way of lower fecundity (Lebedev and others 2013; Nakao and others 2014; Nault and others 2012).

Due to increasing reports of insecticide-resistant thrips populations, as well as human health and environmental concerns regarding over-application of synthetic pesticides, there exists an interest as well as a concerted effort on the part of growers and researchers to develop and employ alternative management procedures. These alternative control methods include biological as well as cultural/mechanical tactics that may be used in place of or in addition to conventional insecticides. Several microbiological control methods have shown promise. Indeed, the above-mentioned spinosyn insecticides are derived from chemical compounds produced by the bacterium *Saccharopolyspora spinosa*. Additionally, several species of entomopathogenic fungi including *Lecanicillium muscarium*, *Beauveria bassiana*, and *Metarhizium anisopliae* have been shown to be effective under field conditions (Al-Karboli and Al-Anbaki 2013; Maniania and others 2003; Shiberu and others 2013). For example, in one experiment *L. muscarium* was shown to reduce thrips densities by over 30% within a week after application, and over 70% after two weeks (Al-Karboli and Al-Anbaki 2013), and in a field trial in Kenya, *M. anisopliae* provided substantial thrips reduction while preserving populations of beneficial insects and

spiders (Maniania and others 2003). Other alternative biological control tactics include the use of botanicals. Several plant extracts including *Nicotiana spp.*, *Phytolacca dodecandra*, *Securidaca longepedunculata*, *Nicotiana tabacum*, *Chrysanthemum cinerariaefolium*, *Azadirachta indica*, and *Parthenium hysterophorous* have been shown to provide 50-70% mortality against *T. tabaci* populations in onion (Shiberu and others 2013).

While resistance to thrips does not prevent IYSV infection following transmission of the virus, it may decrease overall transmission, and thus reduce overall infection rates (Diaz-Montano and others 2012b; du Toit and Pelter 2005). Onion resistance to thrips is mediated primarily by leaf angle and spacing (closed foliage being more susceptible than open foliage) (Coudriet and others 1979; Jones and others 1934), leaf color (blue-green hues being more susceptible than yellow-green hues) (Diaz-Montano and others 2012a; Gent and others 2006), and epicuticular wax levels (non-glossy varieties being more susceptible than glossy varieties) (Molenaar 1984).

Field sanitation is an important cultural aspect of thrips and IYSV control. Epidemics have been linked to infected transplants, volunteer onion, and cull piles, which along with perennial and winter annual weeds, act as potential overwintering thrips sites. (Gent and others 2006; Horsfall 1921). Overhead irrigation practices have also been correlated with decreased IYSV damage as compared to flood or drip irrigation systems, though it is difficult to differentiate effects due to thrips mortality from effects due to onion resilience through reduced drought stress (du Toit and others 2004; Gent and others 2006). Additionally, reduced nitrogen application and certain crop rotation decisions have been shown to reduce thrips populations in onion (Buckland and others 2013).

Thrips rely heavily on visual cues to find host plants. Blue and white sticky traps have been shown to be effective in reducing thrips densities when used in conjunction with insecticides (Al-Karboli and Al-Anbaki 2013). Traps, however, are more commonly used as a monitoring tool. An additional interesting alternative management technique involves the fungicide acibenzolar-S-methyl, which has been shown to reduce thrips incidence by activating the plants' natural defense system (Mautino and others 2012).

Integrated pest management (IPM) strategies generally rely upon action thresholds to indicate when specific management efforts should be undertaken. Sampling via in situ counts or the use of sticky traps is an important component of integrated pest management of thrips and should begin early in the season when onions are in the 4 to 5 leaf stage (Alston and Drost 2008). Alston and Drost (2008) suggest an early-season threshold of 15 thrips per plant while onions are more susceptible to thrips pressure and a threshold of 30 thrips per plant by midseason. Lower early-season thresholds may also help prevent the build-up of large populations later in the season by reducing the number of eggs laid by early cohorts. Fournier (1995) conducted work indicating a threshold of 2.2 thrips per leaf (Fournier and others 1995).

Ultimately, the successful management of *T. tabaci* and IYSV relies upon the integration of multiple management decisions and tools. This becomes increasingly true in the face of ever-increasing cases of insecticide resistance. Integrated pest management strategies seek to address the challenges of pesticide resistance and environmental sustainability by combining multiple management tools to prevent economic damage while minimizing non-target effects.

Research Objectives

Traditional methods of controlling thrips (and thereby IYSV) infestations in onion rely heavily on conventional insecticides. Due to onion thrips relatively quick life-cycle as well as their parthenogenic reproductive strategies, growing resistance to a number of conventional insecticides continues to be a serious concern. Our research studied the potential effects of field border weed populations on thrips and IYSV infestation in onion. The research was conducted in the hope of implicating better field border weed management efforts as a possible cultural control method of the thrips/IYSV pest complex. Specifically, comparisons were made between densities of adult onion thrips, adult western flower thrips, thrips larvae, thrips eggs, and predatory thrips on onions surrounded by six different weed border treatments. Potential host plant preferences among the various prominent weed species were also indicated by assessing and comparing thrips densities on these species. Finally, IYSV detection on these weed species may indicate additional suitable host plant species for the virus.

MATERIALS AND METHODS

In order to evaluate the influence of adjacent weed species on thrips and Iris Yellow Spot Virus in onion, field studies were conducted in 2014 and 2015 in Kaysville Utah at the Utah Agricultural Experiment Station Kaysville Research Farm. Both years' trials were carried out in the same field on adjacent sites. The soil was classified as a Kidman sandy loam, and pipette analysis indicated a loam (50% sand, 35% silt, 15% clay). Further soil analysis revealed a pH of 7.68 and an ECe of 0.560 (John Lawley, NAPT). Environmental conditions at the trial site differed between years (Figure 1). Heat accumulation in 2014 was higher than in 2015, and cumulative precipitation, though higher through the earlier months of 2014, was ultimately lower than in 2015 following a number of large rain events in that year (Data provided by the Utah Climate Center).

Plot Establishment

'Vaquero' Spanish yellow onions (Nunhems, Parma, ID) were planted on March 18, 2014 and March 21, 2015 in two double rows per bed, with individual rows spaced 7.62 cm apart and double rows spaced 30.48 cm from center to center. Beds were made the preceding fall and spaced 91.44 cm from center to center. Plots consisted of three beds, 3.66 meters long, resulting in onion plots approximately 3.66 m long and 2.75 m wide. Because of poor stand density in 2014, onion seedlings from adjacent onion rows were transplanted into the open spaces at the three-leaf stage. Prior to onion planting, fertilizer mix (10-34-0) was applied to the

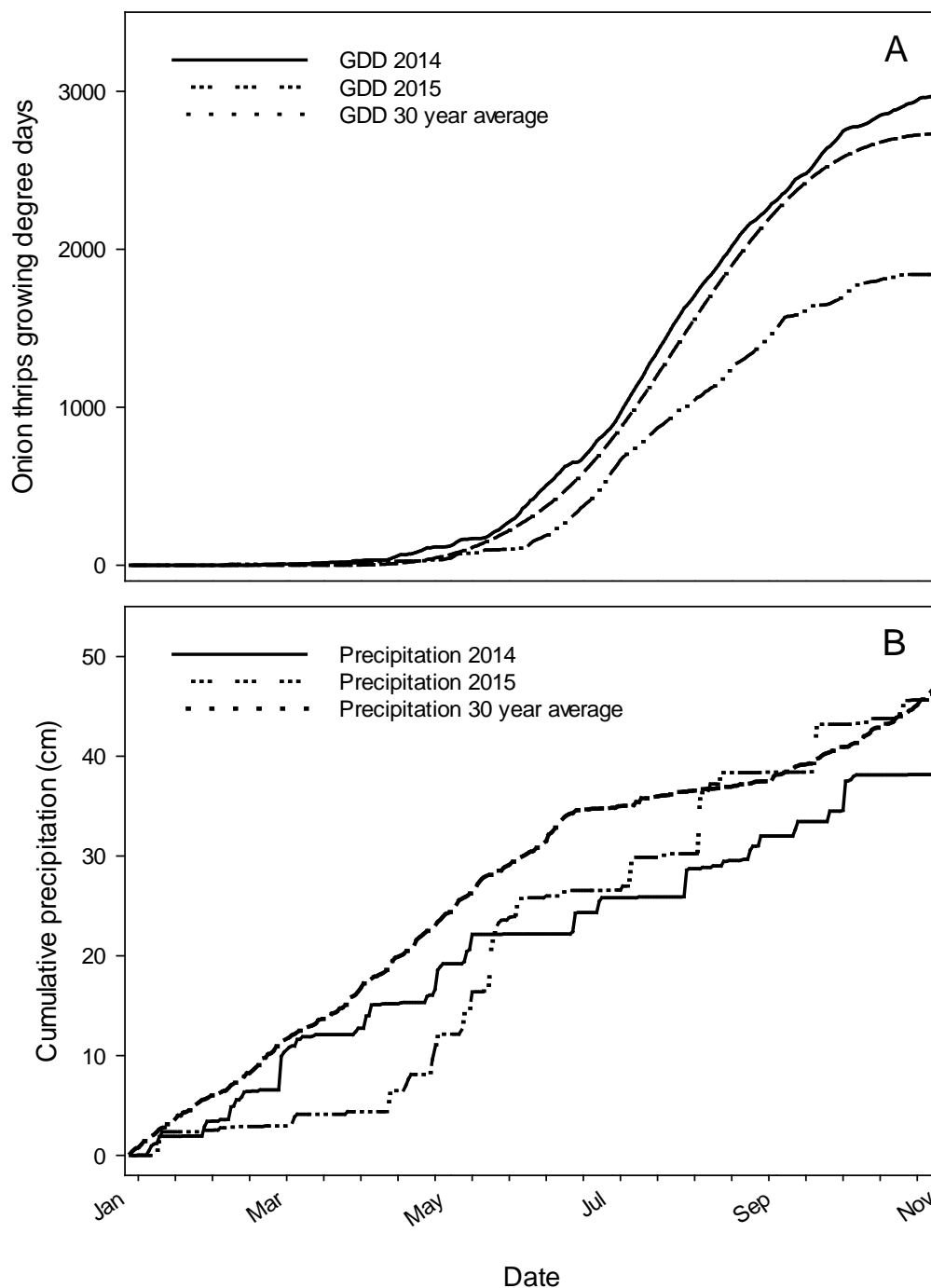


Figure 1. Environmental conditions of the trial during 2014 and 2015, including cumulative onion thrips growing degree days (base 11.5° C) (A) and precipitation (B). Environmental data for trial years was obtained from a weather station on location. Due to a limited record at the Kaysville site, 30 year average data was taken from a weather station located in Farmington, Utah, 4.2 km southeast of the research site.

site at a rate of 392 kg ha⁻¹. Irrigation was accomplished via semiweekly watering sets of two-hour duration using impact heads in 2014 and Nelson rotator heads (R2000) in 2015 on standard 5 cm aluminum pipes and 0.91 m risers. Water testing showed a pH of 7.5, with an ECe of 0.100 dS m⁻¹ (John Lawley, NAPT). During the growing season, two applications of ammonium sulfate (21-0-0) were made at a rate of 269 kg ha⁻¹. Combined nitrogen applications to the site over the course of the season totaled 151 kg ha⁻¹.

Treatments

Treatments consisted of borders approximately 70 cm wide surrounding each onion plot. Border treatments were: Field bindweed in monoculture, common mallow in monoculture, prickly lettuce in monoculture, two resident weed community treatments, one mowed mid-season (July 28, 2014 and July 23, 2015), and a weed-free control. Common mallow and prickly lettuce borders were established by seed on March 21, 2014, and March 24, 2015 with three passes of a hand-pushed, single-row cone-seeder. Additionally, the two resident weed border treatments received a single pass with the cone-seeder, delivering a mix of both common mallow and prickly lettuce seed, in an attempt to ensure that these species were present in the resident weed community. Planted weed rows were spaced approximately 15 cm apart. Field bindweed was exceedingly prevalent on the site and, accordingly, no additional planting effort was required. All borders were maintained throughout the season via hand-weeding. Due to concerns that excessively tall weed borders may have acted as physical barriers that excluded thrips from some onion plots in 2014, border weeds were maintained at a maximum height of 50 cm throughout the 2015 season.

Sampling

To evaluate thrips numbers and virus incidence, sampling occurred four times over the course of the growing season: June 25, July 9, July 30, and August 8 in 2014 and June 25, July 13, July 27, and August 12 in 2015. Whole plant and single leaf samples were collected from onions and weeds of interest. For whole plant samples, three onions as well as three individuals from each weed species of interest in each plot were cut at ground level, placed in sealable plastic storage bags, and placed in a cooler. For larger weed species, a single mid-level lateral branch was harvested in lieu of the entire plant. A single leaf was harvested from three individuals of each species of interest in 2014, and from 10 individuals in 2015 (It was hoped that an increased sampling size in 2015 would improve virus detection rates). These samples were also bagged and placed immediately in a cooler.

Thrips Counts

Whole plant samples were washed over a 20 cm, 63-micron brass mesh sieve (Dual Manufacturing Co., Inc. Franklin Park, IL) with soapy water. Thrips were collected from the sieve and stored in a vial containing 70% ethanol until counts could be made under a microscope. Under a dissecting microscope, thrips were counted as adults, identified by species, and larvae. Adults are differentiated by prothoracic setae and by number of antennae segments. Larvae from the species present are indistinguishable from one another. After washing was complete, leaf samples were taken from each plant and stained with an acid fuchsin dye. On onions, the third youngest leaf was taken; on weeds, random, mature-sized leaves were taken, and on

smaller-leaved species (all species except prickly lettuce) three leaves rather than one were taken per plant for a total of nine leaves stained. These stained leaves were later measured and eggs counted to assess egg densities. In 2014, additional leaf samples were moistened and placed plastic bags in an incubator for one week. These samples were then washed and counted again in an attempt to estimate egg viability.

IYSV Testing

Single leaf samples were assessed for IYSV presence using an enzyme-linked immunosorbent assay (ELISA test). Approximately, 200 µg of each plant sample was macerated in general extract buffer (Agdia, Elkhart, IN). The plant extracts were stored in 1.7ml microcentrifuge tubes at -20° C until testing. To carry out the assay, a 90-well plate was pretreated with an IYSV-specific antibody the evening before the day of use. After rinsing the plate eight times with PBST (phosphate buffered saline + tween) wash buffer (Agdia, Elkhart, IN), 100 µl of each plant sample was added to individual wells. Two positive and two negative controls were also included to ensure the test was working correctly. After a two-hour incubation time, the plate was rinsed again eight times and a second antibody with an attached enzyme was added to the wells. The plates were incubated for another two hours and then rinsed for the last time. As the final step the para-Nitrophenylphosphate (PNPP) substrate (Agdia, Elkhart, IN), that is cleaved by the enzyme attached to the virus, was added and incubated in the dark for one hour. Absorbance readings at 405 nm in a Biotek ELx800 plate reader were conducted with Gen5 software. Yellow coloring of wells indicated the presence of the virus. As it is sometimes difficult to detect light yellow coloring visually, samples whose

absorbance readings were higher or equal to 2x the average of the negative controls + 3x standard deviation were also considered positive.

Leaf Area Calculation

Leaf area was calculated as the total surface area of a leaf available to an insect for oviposition. For this reason, leaf area formulae were multiplied by two in order to include both sides of the leaf. Leaf shapes were generalized and appropriate formulae applied to width and length measurements. Onions and grasses were assigned an average leaf taper length to total leaf length ratio, calculated from a random sample of 10 onion leaves, leading to the formula $A = 2[0.725(L*W)]$ (Gamiely and others 1991). Leaves from common mallow were considered to be basically circular. A length and a width measurement were taken, averaged, and divided by two in order to provide a value for the radius, and the formula $A = 2(\pi r^2)$ was applied. Leaves from common bindweed, common lambsquarters, and hairy nightshade were deemed to be essentially triangular and the formula $A = 2[(L*W)/2]$ was applied. Black medic leaves are trifoliate. Leaflets, when arranged side by side and connected at the petiole, appear triangular on the whole, and the same formula as above was applied. Prickly lettuce leaves are pinnatisect, or characterized by deep, opposite lobing. It was deemed that these leaves could be roughly described as rectangular, with approximately half of the surface area removed, and the same formula as above applied.

Biomass Sampling

A 1 m² biomass sample was collected on September 2, 2014 and August 17, 2015 from each plot border at ground level to estimate end of season weed population demographics.

Additionally, a 1 m² biomass sample was taken from the border of each resident weed mowed treatment border just before the mid-season mow took place on July 28, 2014 and July 23, 2015. This was done in an effort to identify any demographic changes occurring between mid and late season in resident weed borders. Biomass samples were sorted by species, dried, and weighed.

Estimating Thrips Population Densities Within Weed Borders

Total potential numbers of thrips residing in weed borders were estimated by multiplying the average number of adult onion thrips and thrips larvae observed on each sampled host plant species with the recorded weight of these host plant species collected in the end of season biomass sample. Estimates were then made of total numbers of thrips potentially present per meter square of weed border. Although the resident weed borders contained a more diverse community of weed species than those represented in sampling protocols, those species which were sampled represented a vast majority (>90%) of the total weed biomass present. In the case of weed species sampled in monoculture borders (prickly lettuce, common mallow, and field bindweed), thrips densities averages derived from samples of these species collected in monoculture borders were assumed to be representative of densities present on these species in monoculture as well as in polyculture. These averages were used to estimate potential thrips populations on these species within resident weed borders as well as within their respective monoculture borders.

Data Analysis

Because thrips population growth and development are determined by accumulated heat units rather than calendar days, thrips degree-days were used as an explanatory variable in

place of sample date. Temperature records were collected at an on-farm weather station and degree days were calculated using a single sine curve method and a lower temperature threshold of 11.5° C as suggested by Edelson and Magaro (Edelson and Magaro 1988). Despite this, sample dates are presented for the sake of simplicity. Data were analyzed in SAS (SAS 9.4, SAS Institute, Cary, NC 27513) using the GLIMMIX procedure. Residual panels were used to assess normality and homogeneity of variance within the data. Due to model assumption violations, all data were transformed using a log-transformation. Data presented are reverse-transformed. Significant interaction effects between sampling date and host plant species were present in all analyses dealing with thrips density on host plant species. However, in order to simplify discussion and focus on potential host plant preferences, a slice by date analysis was employed, fixing the time factor, and allowing the examination of contributions to variance by host plant species. A further slice by analysis was conducted, examining effects of sampling date on thrips density within host plant species. Letter designations presented in data reflect the slice by date analyses. Treatment means were separated using Fishers Protected LSD ($p < 0.05$ in all cases unless otherwise noted) and the Tukey-Kramer groupings.

RESULTS

Thrips Densities on Onion as Influenced by Border Treatment**Adult Onion Thrips**

In both 2014 and 2015, only date proved to be a significant main effect for adult onion thrips densities. In 2014, adult onion thrips densities on onion were highest at the first sampling date and lowest on the third sampling date (Table 1). In 2015, adult onion thrips populations generally declined across the season, except for a small spike at the July 27th sampling date (Table 2).

Table 1: Main effect of sampling date on density of various thrips species and stages, 2014.

| Thrips species and stage | Thrips density on onion | | | |
|-----------------------------|--------------------------------|---------|---------|-----------|
| | June 25 | July 09 | July 30 | August 18 |
| | -----no. g ⁻¹ ----- | | | |
| Adult onion thrips | 1.601 a | 1.171 b | 0.835 c | 1.026 bc |
| Adult western flower thrips | 0.444 a | 0.364 a | 0.368 a | 0.324 a |
| Thrips larvae | 2.886 b | 1.523 d | 2.242 c | 4.308 a |
| Thrips eggs | 0.571 a | 0.396 b | 0.397 b | 0.566 a |

Values followed by the same letter within rows are not significantly different at the p=0.05 confidence level.

Table 2: Main effect of sampling date on density of various thrips species and stages, 2015.

| Thrips species and stage | Thrips density on onion | | | |
|-----------------------------|--------------------------------|---------|---------|-----------|
| | June 25 | July 13 | July 27 | August 12 |
| | -----no. g ⁻¹ ----- | | | |
| Adult onion thrips | 1.263 a | 0.562 c | 0.739 b | 0.371 d |
| Adult western flower thrips | 0.608 a | 0.406 b | 0.370 b | 0.240 c |
| Thrips larvae | 2.922 a | 0.644 c | 0.968 b | 0.293 d |
| Thrips eggs | 0.444 a | 0.328 b | 0.454 a | 0.337 b |

Values followed by the same letter within row are not significantly different at the $p=0.05$ confidence level.

Adult Western Flower Thrips

Western flower thrips (*Frankliniella occidentalis*) is another pestiferous thrips species common in the areas surrounding the study site. Adult onion thrips and western flower thrips can be differentiated by counting antennal segments, and observing the number and placement of pronotal setae. In 2014, adult western flower thrips densities on onion were unaffected by sampling date (Table 1) or border weed treatment (data not shown). In 2015, western flower thrips densities followed densities of onion thrips with higher densities observed at the first sampling date and lowest densities observed at the final sampling date (Table 2). Weed border treatment was non-significant (data not shown).

Thrips Larvae

Since onion thrips and western flower thrips are only anatomically distinguishable in their adult stages, larval stages cannot be differentiated and were counted simply as “thrips larvae”. In 2014, larval thrips densities on onion followed the trends over time observed generally on adult stages, starting relatively high, dipping mid-season, and climbing again at end

of season (Table 1). Densities were highest at the final sampling date, second-highest at the first sampling date, and lowest at the third sampling date. Weed border treatments fell short of statistical significance as a factor at the $p=0.05$ level, but were significant at the $p=0.10$ level ($p=0.0745$) (Table 3). At this confidence level, thrips larvae densities were higher on onions surrounded by a border of common mallow than those surrounded by an unmowed resident weed border. No other treatments differed significantly. In 2015, thrips larval densities were highest at the first sampling date and generally declined as the season progressed (Table 2). Border treatment effects in this year were non-significant (data not shown).

Table 3: Main effect of border treatments on larvae and total thrips density on onion in 2014 and 2015.

| Border treatment | Thrips density on onion | | | |
|---------------------|--------------------------------|---------|----------|---------|
| | Larvae | | Total | |
| | 2014 | 2015 | 2014 | 2015 |
| | -----no. g ⁻¹ ----- | | | |
| Prickly lettuce | 2.743 ab | 1.059 a | 3.029 ab | 1.930 a |
| Common mallow | 3.056 a | 1.250 a | 3.339 a | 2.094 a |
| Field bindweed | 2.686 ab | 1.164 a | 2.946 ab | 2.020 a |
| Resident weed | 2.059 b | 1.142 a | 2.333 b | 1.946 a |
| Resident weed mowed | 3.120 ab | 1.312 a | 3.500 ab | 2.192 a |
| Handweeded | 2.775 ab | 1.313 a | 3.168 ab | 2.291 a |

Values followed by the same letter within columns are not significantly different at the $p=0.1$ confidence level.

Total Onion Thrips

Because thrips populations consist of both adults and larvae, there is interest in quantifying the combined number of individuals across these developmental stages. For this

purpose, data for adult onion thrips were combined with data for thrips larvae. The resulting data were titled “total onion thrips” and represent an over-estimation of the number of total hatched onion thrips, as some of the thrips larvae included in the data were undoubtedly western flower thrips larvae. Nonetheless, these numbers may still prove useful in some applications. In 2014, total onion thrips were highest at the first and last sampling dates, and lowest at the middle two sampling dates (Table 1). Treatment was not a significant factor at the $p=0.05$ level, but was significant at the $p=0.10$ level ($p=0.0658$) (Table 3). At this confidence level, total thrips levels were higher on onions surrounded by a border of common mallow than on those surrounded by an unmowed resident weed border. No other treatments appeared to differ significantly. In 2015, sampling date was the only significant factor (Table 2). Densities were highest at the first sampling date, declined steeply by the second sampling date, rose slightly on the third sampling date, and were lowest at the final sampling date.

Thrips Eggs

Thrips egg densities, measured as the number of eggs per cm^2 , started high in 2014, dipped mid-season, and then rose again by the final sampling date (Table 1). Densities at the first and last sample dates did not differ significantly from one another, and were significantly higher than densities at the two middle sample dates. In 2015, densities were highest at the first and third sampling dates, and lowest at the second and fourth sampling dates (Table 2). Weed border treatment effects were non-significant in both seasons (data not shown).

Thrips Densities on Host Plant Species

Because the study also sought to address possible host preference by thrips amongst the host plant species present, weed species within border treatments were also sampled for thrips, and thrips densities compared to those observed on onion. This was a comparison of host plant species rather than an analysis of weed border effects. Dominant host plant species in 2014 included onion, common lambsquarters, common mallow, field bindweed, hairy nightshade, and prickly lettuce. In 2015, black medic and witchgrass were sampled in addition to those species sampled in 2014. Adult onion thrips and western flower thrips, larval thrips, and thrips eggs were recorded on each weed species and compared to thrips presence on onion. In each case, thrips densities were significantly affected by host plant species, sampling date, and the interaction between these two factors. However, in order to simplify discussion and focus on potential preferences among sampled host plant species, data were analyzed within each date. Data were then analyzed to assess effects of sampling date on each species separately.

Adult Onion Thrips

At the first and second sampling dates, adult onion thrips densities were higher on onion than on any other host plant species (Table 4). Densities did not differ between other host plant species at these sampling dates. At the third sampling date, adult onion thrips densities were numerically highest on onion, but did not differ significantly from densities on hairy nightshade. Densities among weedy host plant species did not differ significantly. At the final sample date, onion once again hosted the highest densities of adult onion thrips, but did not differ significantly from field bindweed or hairy nightshade. Densities on field bindweed were

significantly higher than on all other weedy host plant species except hairy nightshade. Densities on hairy nightshade did not differ from densities on field bindweed, common mallow, or prickly lettuce, but were higher than those on common lambsquarters, which held the lowest densities of adult onion thrips at that date.

Table 4. Adult onion thrips density on a number of host plant species, 2014.

| Host plant species | Adult onion thrips density | | | | | | | |
|----------------------|--------------------------------|-----------------|---------|----------------|---------|------------------|-----------|-----------------|
| | June 25 | | July 09 | | July 30 | | August 18 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 1.576 | A _a | 1.171 | A _b | 0.832 | A _c | 0.987 | A _{bc} |
| Common lambsquarters | 0.304 | B _a | 0.240 | B _a | 0.255 | B _a | 0.314 | C _a |
| Common mallow | 0.442 | B _a | 0.236 | B _a | 0.318 | B _a | 0.500 | BC _a |
| Field bindweed | 0.263 | B _b | 0.238 | B _b | 0.422 | B _b | 0.927 | A _a |
| Hairy nightshade | 0.511 | B _{ab} | 0.240 | B _b | 0.500 | AB _{ab} | 0.751 | AB _a |
| Prickly lettuce | 0.240 | B _b | 0.240 | B _b | 0.278 | B _b | 0.435 | BC _a |

Values followed by the same capitalized letter within columns are not significantly different at the p=0.05 confidence level. Values followed by the same lowercase letter within rows are not significantly different at the p=0.05 confidence level.

Effects of sampling date on adult onion thrips densities varied by species in 2014 (Table 4). On onion, densities were highest at the first sampling date, and declined steadily and significantly across the next two dates. Densities at the final sampling date appeared to rise slightly from those observed at the third date, but did not differ significantly from those observed at the second or third dates. On common lambsquarters and common mallow, thrips densities appeared to remain constant across all four sampling dates. On field bindweed and

prickly lettuce, densities seemed to remain constant across the first three sampling dates, before rising at the final date. On hairy nightshade, densities observed at the second sampling date were significantly lower than those observed at the final date. No other dates differed significantly.

In 2015, high densities of adult onion thrips were found on onion at the first three sampling dates (Table 5). However, in each case, these densities did not differ significantly from those observed on black medic, common mallow, or hairy nightshade. With the exception of the first sampling date, they did not differ from densities on field bindweed either. During these three earlier sampling dates, densities were generally lower on common lambsquarters, prickly lettuce, and witchgrass. At the fourth sampling date densities on onion dropped relative to densities on other host species. Hairy nightshade held the highest densities at the final sampling date, though these did not differ significantly from densities observed on field bindweed, common mallow, or common lambsquarters. Densities on common lambsquarters rose somewhat relative to densities on other host species at this sampling date. Thrips densities on onion, black medic, prickly lettuce, and witchgrass were significantly lower than those observed on hairy nightshade. No other significant differences were observed at the final sampling date.

Adult onion thrips densities were not affected by sampling date uniformly on host plant species (Table 5). On onion, densities were highest at the first sampling date, declined at the second date, rose slightly but significantly at the third date, and fell to the lowest observed densities at the final sampling date. On black medic, densities at the first and third sampling dates were higher than those at the last, but not significantly higher than those at the second date. On common lambsquarters, densities were highest at the final sampling date, but were only significantly higher than those observed on the second date. On common mallow, densities

Table 5. Adult onion thrips density on a number of host plant species, 2015.

| Host plant species | Adult onion thrips density | | | | | | | |
|----------------------|--------------------------------|----------|---------|----------|---------|----------|-----------|----------|
| | June 25 | | July 13 | | July 27 | | August 12 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 1.259 | A a | 0.561 | A c | 0.733 | A b | 0.369 | BC d |
| Black medic | 0.894 | AB a | 0.548 | AB ab | 0.790 | A a | 0.240 | C b |
| Common lambsquarters | 0.415 | C ab | 0.313 | B b | 0.385 | BC ab | 0.527 | AB a |
| Common mallow | 1.236 | A a | 0.423 | AB b | 0.662 | AB b | 0.442 | ABC b |
| Field bindweed | 0.717 | BC ab | 0.517 | AB ab | 0.752 | A a | 0.514 | AB b |
| Hairy nightshade | 1.274 | A a | 0.824 | A a | 0.711 | AB a | 0.765 | A a |
| Prickly lettuce | 0.390 | C A | 0.290 | B ab | 0.365 | BC ab | 0.258 | C b |
| Witchgrass | 0.547 | BC a | 0.294 | B b | 0.263 | C b | 0.331 | BC b |

Values followed by the same capitalized letter within columns are not significantly different at the $p=0.05$ confidence level. Values followed by the same lowercase letter within rows are not significantly different at the $p=0.05$ confidence level.

were highest at the first sampling date and did not differ significantly between the last three dates. On field bindweed, densities were highest at the third sampling date, but only differed significantly from those observed at the final date. Sampling date appeared to have no significant effect on thrips densities on hairy nightshade. Densities on prickly lettuce were highest at the first sampling date, but only differed significantly from those observed at the final sampling date. Similar to trends observed on common mallow, densities on witchgrass were also highest on the first sampling date, while those on the other three dates did not differ significantly between the other three dates.

Adult Western Flower Thrips

At the first and second sampling dates of 2014, western flower thrips densities were significantly higher on common mallow and hairy nightshade than on any other host species (Table 6). No other observations differed significantly at these dates. At the third sampling date, western flower thrips densities on hairy nightshade were significantly higher than those on prickly lettuce. No other species differed significantly at this sampling date. At the final sampling date, densities on hairy nightshade were significantly higher than those on prickly lettuce, common mallow, and onion. No other observations differed significantly.

Table 6. Adult western flower thrips density on a number of host plant species, 2014.

| Host plant species | Western flower thrips density | | | | | | | |
|----------------------|--------------------------------|--------|---------|--------|---------|----------|-----------|---------|
| | June 25 | | July 09 | | July 30 | | August 18 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 0.435 | B a | 0.363 | B a | 0.366 | AB a | 0.317 | B a |
| Common lambsquarters | 0.470 | B a | 0.422 | B a | 0.467 | AB a | 0.524 | AB a |
| Common mallow | 0.840 | A a | 1.171 | A a | 0.627 | AB ab | 0.409 | B b |
| Field bindweed | 0.418 | B a | 0.491 | B a | 0.417 | AB a | 0.571 | AB a |
| Hairy nightshade | 1.170 | A a | 1.105 | A a | 0.819 | A a | 0.948 | A a |
| Prickly lettuce | 0.641 | B a | 0.311 | B b | 0.323 | B b | 0.317 | B b |

Values followed by the same capitalized letter within columns are not significantly different at the p=0.05 confidence level. Values followed by the same lowercase letter within rows are not significantly different at the p=0.05 confidence level.

In 2014, sampling date did not significantly affect western flower thrips densities on onion, common lambsquarters, field bindweed, or hairy nightshade (Table 6). Densities on common mallow began relatively high, were constant over the first two sampling dates, and then declined until the final sampling date. Densities on prickly lettuce were highest at the first sampling date and were lower for the last three dates.

In 2015, hairy nightshade and common mallow held high densities of western flower thrips at the first sampling date, consistent with observations made in 2014 (Table 7). Black medic, though not a species sampled in 2014, also held very high densities of western flower thrips at this date. Relatively low densities were observed on onion, common lambsquarters, prickly lettuce, and witchgrass. Densities on field bindweed did not differ significantly from those of any other species apart from common mallow. These observations, with the addition of witchgrass, are also largely consistent with observations made in 2014. At the second sampling date, black medic, common mallow, and hairy nightshade had higher Western flower thrips densities than those found on onion, common lambsquarters, and prickly lettuce. Densities on field bindweed and witchgrass did not differ from those found on any of the other host species. At the third sampling date, densities on common mallow were significantly higher than those on onion, prickly lettuce and witchgrass. Densities on common lambsquarters, field bindweed, and hairy nightshade were also significantly higher than those on onion and prickly lettuce. No other differences were determined to be statistically significant at that sampling date. At the fourth sampling date, no western flower thrips were observed.

Densities on black medic, common mallow, field bindweed, prickly lettuce, and witchgrass did not change significantly over the first three sampling dates (Table 7). Densities on

Table 7. Adult western flower thrips density on a number of host plant species, 2015.

| Host plant species | Adult onion thrips density | | | | | | | |
|----------------------|--------------------------------|---------|---------|---------|---------|----------|-----------|--------|
| | June 25 | | July 13 | | July 27 | | August 12 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 0.606 | B a | 0.406 | B b | 0.367 | B b | 0 | A c |
| Black medic | 1.598 | A a | 1.288 | A a | 1.122 | AB ab | 0 | A b |
| Common lambsquarters | 0.575 | B b | 0.437 | B b | 0.872 | B a | 0 | A c |
| Common mallow | 1.658 | A a | 1.133 | A a | 1.695 | A a | 0 | A b |
| Field bindweed | 0.792 | AB a | 0.758 | AB a | 1.055 | AB a | 0 | A b |
| Hairy nightshade | 1.211 | A a | 1.184 | A a | 0.846 | B b | 0 | A c |
| Prickly lettuce | 0.383 | B a | 0.319 | B ab | 0.440 | B a | 0 | A b |
| Witchgrass | 0.784 | B a | 0.757 | AB a | 0.682 | B a | 0 | A b |

Values followed by the same capitalized letter within columns are not significantly different at the $p=0.05$ confidence level. Values followed by the same lowercase letter within rows are not significantly different at the $p=0.05$ confidence level.

onion and hairy nightshade were higher at the first sampling date than at the second and third, though in the case of hairy nightshade, the difference in densities between the first and second dates was non-significant. Densities on common lambsquarters appeared to be constant across the first two sampling dates, then rose at the third date. No western flower thrips were observed on any host plant species at the final sampling date.

Thrips Larvae

At each sampling date in 2014 densities of thrips larvae were very high on onion, though they did not differ significantly from those observed on common mallow or hairy nightshade at

the second sampling date (Table 8). Densities among weedy species only differed significantly from one another at the first two sampling dates. At the first sampling date, densities on hairy nightshade were significantly higher than those on common lambsquarters, field bindweed, and prickly lettuce. Densities on common mallow were also significantly higher than those observed on common lambsquarters. At the second sampling date, densities on common lambsquarters, field bindweed, and prickly lettuce were again significantly lower than those found on the other sampled host species. Overall, onion held significantly higher densities of thrips larvae compared to sampled weed species, and among weed species, prickly lettuce and common lambsquarters held relatively low larvae densities.

Table 8. Thrips larvae density on a number of host plant species, 2014.

| Host plant species | Western flower thrips density | | | | | | | |
|----------------------|--------------------------------|----------|---------|---------|---------|---------|-----------|--------|
| | June 25 | | July 09 | | July 30 | | August 18 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 2.865 | A b | 1.498 | A c | 2.228 | A b | 4.169 | A a |
| Common lambsquarters | 0.478 | D b | 0.394 | B b | 0.635 | B b | 1.734 | B a |
| Common mallow | 1.293 | BC ab | 1.423 | A ab | 0.852 | B b | 2.002 | B a |
| Field bindweed | 0.657 | CD c | 0.620 | B c | 1.048 | B b | 2.015 | B a |
| Hairy nightshade | 1.690 | B ab | 1.374 | A ab | 0.950 | B b | 2.148 | B a |
| Prickly lettuce | 0.573 | CD ab | 0.366 | B b | 0.489 | B ab | 1.087 | B a |

Values followed by the same capitalized letter within columns are not significantly different at the $p=0.05$ confidence level. Values followed by the same lowercase letter within rows are not significantly different at the $p=0.05$ confidence level.

During the 2014 season, thrips larvae densities on onion fell from the first sampling date to the second, then rose again at the third date to levels similar to those observed at the first date, and rose again at the final sampling date to season high levels (Table 8). On common lambsquarters, larval densities appeared constant over the first three sampling dates, before rising at the end of the season. On common mallow and hairy nightshade, larval densities were highest at the final sampling date but only differed significantly from densities observed at the third sampling date. On field bindweed, densities started relatively low and held constant over the first two sampling dates; densities then rose steadily and significantly over the last two dates. On prickly lettuce, larval densities were significantly lower at the second sample date than at the final date. No other dates differed significantly.

In contrast to results observed in 2014, thrips larvae densities on onion were not distinctly higher than those found on all other sampled host species in 2015 (Table 9). At the first sampling date, higher densities of thrips larvae were observed on black medic than were observed on any other species except for common mallow. Densities on onion were similar to those observed on common mallow, field bindweed, and hairy nightshade. Common lambsquarters, prickly lettuce, and witchgrass all held relatively low densities of larvae. This general grouping pattern was observed again at the second sampling date. By the third sampling date, larval densities on onion did not differ significantly from those on black medic, common lambsquarters, common mallow, field bindweed, or hairy nightshade. The highest average larval densities were again observed on black medic, though of the species just listed, only densities on hairy nightshade were significantly lower. Relatively low densities were observed on common lambsquarters, prickly lettuce, and witchgrass. At the final sampling date, densities on

prickly lettuce were significantly lower than those observed on onion, black medic, common mallow, field bindweed, and hairy nightshade. No other observations differed significantly.

Table 9. Thrips larvae density on a number of host plant species, 2015.

| Host plant species | Adult onion thrips density | | | | | | | |
|----------------------|--------------------------------|---------|---------|-----------|---------|---------|-----------|---------|
| | June 25 | | July 13 | | July 27 | | August 12 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 2.964 | B a | 1.505 | B c | 2.204 | AB b | 0.999 | A d |
| Black medic | 4.541 | A a | 2.999 | A b | 3.621 | A ab | 1.288 | A c |
| Common lambsquarters | 0.985 | D a | 0.846 | CDE ab | 0.907 | C ab | 0.530 | AB b |
| Common mallow | 3.827 | AB a | 1.432 | BC c | 2.319 | AB b | 0.968 | A c |
| Field bindweed | 2.500 | BC a | 1.390 | BCD ab | 2.541 | AB a | 0.897 | A b |
| Hairy nightshade | 2.689 | B a | 1.936 | B b | 1.725 | B b | 1.160 | A c |
| Prickly lettuce | 1.339 | CD a | 0.481 | E b | 0.613 | C b | 0.328 | B b |
| Witchgrass | 1.508 | CD a | 0.778 | DE b | 0.556 | C b | 0.578 | AB b |

Values followed by the same capitalized letter within columns are not significantly different at the $p=0.05$ confidence level. Values followed by the same lowercase letter within rows are not significantly different at the $p=0.05$ confidence level.

During the 2015 season, thrips larvae densities were consistently high at the first sampling date relative to other dates (Table 9). Thrips larvae densities on onion were highest at the first sampling date, fell at the second date, rose slightly but significantly at the third date, and fell to season low levels at the last date. On black medic, densities were also highest at the first sampling date and fell at the second; larval densities at the third date did not differ from

either those observed at the first or the second date, and densities observed at the last date were the lowest for the season on this species. On common lambsquarters, thrips larvae densities were highest at the first date and seemed to decline to season low levels at the final sampling date; however, only the densities observed at the first and last sampling dates differed significantly. Densities on common mallow followed similar trends to those observed on onion, although densities on the second and fourth sampling dates in this case did not differ significantly. On field bindweed, larval densities appeared to hold relatively constant across the first three sampling dates before falling at the final sampling date; densities observed at the second and fourth sampling dates did not differ significantly however. On hairy nightshade, larval densities were highest at the first sampling date, fell at the second, and held constant until falling again at the final date. On prickly lettuce and witchgrass, larval densities were highest at the first sampling date and then fell and appeared to remain constant for the last three dates.

Total Onion Thrips

In 2014, combined data for adult onion thrips and thrips larvae, titled “total onion thrips” followed similar trends as those observed for larvae data alone in the same year (Table 10). This was largely attributable to the significant contribution to this measurement by thrips larvae. At the first sampling date, onion held higher total onion thrips densities than any other host plant species. Common mallow and hairy nightshade held the highest densities among weedy host plant species at this sampling date, and no significant differences were observed between common lambsquarters, field bindweed, and prickly lettuce. At the second sampling date, onion again held relatively high thrips densities, though not significantly different from

those observed on common mallow or hairy nightshade. Densities on the remaining host species did not differ significantly. At the third sampling date onion again held higher thrips densities than any other host plant species. Among weedy host plant species, field bindweed held significantly higher densities than observed on prickly lettuce. No other significant differences were observed between host plant species at the third sampling date. At the final sampling date onion again held significantly higher densities than any of the weedy host plant species. No significant differences were observed among densities on weedy host plant species at the final sampling date.

Table 10. Total onion thrips density on a number of host plant species, 2014.

| Host plant species | Total onion thrips density | | | | | | | |
|----------------------|--------------------------------|-----------------|---------|-----------------|---------|-----------------|-----------|----------------|
| | June 25 | | July 09 | | July 30 | | August 18 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 3.336 | A _a | 1.969 | A _B | 2.420 | A _b | 4.295 | A _a |
| Common lambsquarters | 0.526 | C _b | 0.394 | B _b | 0.660 | BC _b | 1.764 | B _a |
| Common mallow | 1.362 | B _{ab} | 1.421 | A _{ab} | 0.881 | BC _b | 1.569 | B _a |
| Field bindweed | 0.671 | C _c | 0.621 | B _c | 1.154 | B _b | 2.272 | B _a |
| Hairy nightshade | 1.803 | B _{ab} | 1.374 | A _{ab} | 1.068 | BC _b | 2.275 | B _a |
| Prickly lettuce | 0.573 | C _b | 0.366 | B _b | 0.533 | C _b | 1.251 | B _a |

Values followed by the same capitalized letter within columns are not significantly different at the p=0.05 confidence level. Values followed by the same lowercase letter within rows are not significantly different at the p=0.05 confidence level.

During the 2014 season, total onion thrips densities on onion were highest at the first sampling date, fell at the second, and remained constant at the third date before rising at the fourth sampling date to levels similar to those observed at the first of the season (Table 10). On weed species, total thrips density trends over time mirrored larval trends closely.

At the first sampling date of 2015, highest total onion thrips densities were observed on black medic, though these were not statistically different from common mallow (Table 11). Densities on onion were similar to those on common mallow, field bindweed, and hairy nightshade. Lowest densities at this date were found on common lambsquarters, prickly lettuce, and witchgrass, though the latter two did not differ significantly from densities on field bindweed. At the second sampling date, highest thrips densities were found on black medic. Hairy nightshade and onion and held the second highest densities, though these did not differ from common mallow or field bindweed, Densities on common lambsquarters, though some of the lowest, were not significantly lower than those on common mallow or field bindweed. Prickly lettuce and witchgrass held very low densities at this sampling date, though not significantly lower than common lambsquarters. At the third sampling date, total onion thrips densities were highest on onion, black medic, common mallow, field bindweed, and hairy nightshade, and lowest on common lambsquarters, prickly lettuce, and witchgrass. At the final sampling date, total onion thrips densities were higher on hairy nightshade than on common lambsquarters, and witchgrass, as well as those on prickly lettuce, which were significantly lower than densities on all other tested host plant species other than common lambsquarters and witchgrass. No other significant differences were observed between densities on the remaining host plant species.

Table 11. Total onion thrips density on a number of host plant species, 2015.

| Host plant species | Adult onion thrips density | | | | | | | |
|----------------------|--------------------------------|----------|---------|----------|---------|---------|-----------|---------|
| | June 25 | | July 13 | | July 27 | | August 12 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 3.248 | B a | 1.626 | B c | 2.349 | A b | 1.051 | AB d |
| Black medic | 4.650 | A a | 3.061 | A b | 3.684 | A ab | 1.294 | AB c |
| Common lambsquarters | 1.068 | D a | 0.878 | CD a | 0.994 | B a | 0.768 | BC a |
| Common mallow | 4.020 | AB a | 1.496 | BC c | 2.420 | A b | 1.105 | AB c |
| Field bindweed | 2.607 | BC ab | 1.483 | BC bc | 2.668 | A a | 1.045 | AB c |
| Hairy nightshade | 2.996 | B a | 2.120 | B b | 1.920 | A b | 1.440 | A c |
| Prickly lettuce | 1.403 | CD a | 0.521 | D b | 0.681 | B b | 0.344 | C b |
| Witchgrass | 1.624 | CD a | 0.812 | D b | 0.565 | B b | 0.649 | BC b |

Values followed by the same capitalized letter within columns are not significantly different at the $p=0.05$ confidence level. Values followed by the same lowercase letter within rows are not significantly different at the $p=0.05$ confidence level.

As was the case in 2014, total onion thrips densities in 2015 followed temporal patterns similar to those observed in thrips larvae densities within the same year (Table 11). However, slightly different patterns were observed on two species. On common lambsquarters, total onion thrips densities appeared to remain constant across all four sampling dates in 2015. On field bindweed, thrips densities were moderately high at the first sampling date, declined numerically but not significantly at the second date, rose significantly at the third date, and fell at the final date to levels numerically but not significantly lower than those observed on the second sampling date.

As was the case in 2014, total onion thrips densities in 2015 followed temporal patterns similar to those observed in thrips larvae densities within the same year (Table 11). However, slightly different patterns were observed on two species. On common lambsquarters, total onion thrips densities appeared to remain constant across all four sampling dates in 2015. On field bindweed, thrips densities were moderately high at the first sampling date, declined numerically but not significantly at the second date, rose significantly at the third date, and fell at the final date to levels numerically but not significantly lower than those observed on the second sampling date.

Thrips Eggs

At the first sampling date of 2014, onion and hairy nightshade held higher thrips egg densities than field bindweed, common lambsquarters, prickly lettuce, and common mallow (Table 12). No other significant differences were observed. At the second sampling date, onion and hairy nightshade had higher densities than field bindweed and prickly lettuce. At the third sampling date, densities on onion did not differ significantly from those observed on any weedy host plant species. Among weedy host plants sampled, densities on hairy nightshade and common lambsquarters were significantly higher than those observed on common mallow. At the final sampling date, densities on onion and common lambsquarters were significantly higher than those observed on bindweed, but no other differences were observed.

Oviposition trends across time were not uniform across all species in 2014 (Table 12). On onion, egg densities were highest at the first and last sampling dates, and lower at the middle two dates. On common lambsquarters, densities began relatively low and appeared to rise as the season progressed until the final sampling date; densities on common lambsquarters

Table 12. Thrips egg density on a number of host plant species, 2014.

| Host plant species | Western flower thrips density | | | | | | | |
|----------------------|--------------------------------|--------|---------|----------|---------|---------|-----------|---------|
| | June 25 | | July 09 | | July 30 | | August 18 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 0.566 | A a | 0.396 | A b | 0.397 | AB b | 0.562 | A a |
| Common lambsquarters | 0.347 | B b | 0.370 | AB ab | 0.568 | A a | 0.689 | A a |
| Common mallow | 0.293 | B a | 0.361 | AB a | 0.294 | B a | 0.407 | AB a |
| Field bindweed | 0.366 | B a | 0.296 | B a | 0.354 | AB a | 0.317 | B a |
| Hairy nightshade | 0.910 | A a | 0.493 | A ab | 0.627 | A ab | 0.388 | AB b |
| Prickly lettuce | 0.295 | B a | 0.286 | B a | 0.341 | AB a | 0.351 | AB a |

Values followed by the same capitalized letter within columns are not significantly different at the $p=0.05$ confidence level. Values followed by the same lowercase letter within rows are not significantly different at the $p=0.05$ confidence level.

did not differ significantly among chronologically contiguous sampling dates. Egg densities on common mallow, field bindweed, and prickly lettuce remained constant across all four sampling dates. On hairy nightshade, egg densities began the season high and declined as the season progressed, with densities on the first and last sampling dates differing significantly.

At each of the four sample dates in 2015, average egg densities on onion were among the highest of any of the species sampled (Table 13). In cases where average densities on other species were slightly higher than those on onion, these differences were insignificant. At the first sample date, highest egg densities were observed on hairy nightshade, though these did not differ significantly from those observed on onion or black medic. Densities on onion were significantly higher than those observed on field bindweed, common lambsquarters, prickly

lettuce, and witchgrass, but did not differ significantly from those observed on hairy nightshade, black medic, or common mallow. Densities on black medic were only significantly higher than those observed on prickly lettuce and witchgrass. Witchgrass hosted the lowest egg densities of all sampled host plant species. At the second sampling date egg densities observed among the sampled host plant species did not differ significantly. At the third sampling date, average egg densities were numerically highest on hairy nightshade, but these did not differ significantly from those observed on onion, black medic, or common lambsquarters, which only differed significantly from densities observed on prickly lettuce. Prickly lettuce held the lowest observed average egg density, but this was only significantly lower than those found on hairy nightshade, onion, black medic, and lambsquarters. At the final sample date, densities on onion were significantly higher than those observed on witchgrass, prickly lettuce, common mallow, and black medic.

As in 2014, oviposition trends across time were not uniform across all species in 2015 (Table 13). On onion, hairy nightshade, and witchgrass, thrips densities were relatively high at the first sampling date, dropped at the second, rose again at the third to similar levels as those observed at the initial date, and then dropped again at the final sampling date to levels similar to those observed at the second. On black medic, common lambsquarters, and field bindweed, egg densities remained constant across the season. On common mallow and prickly lettuce, egg densities were highest at the first sampling date and then held constant over the last three dates.

Table 13. Thrips egg density on a number of host plant species, 2015.

| Host plant species | Adult onion thrips density | | | | | | | |
|----------------------|--------------------------------|----------|---------|---------|---------|---------|-----------|---------|
| | June 25 | | July 13 | | July 27 | | August 12 | |
| | -----no. g ⁻¹ ----- | | | | | | | |
| Onion | 0.444 | AB a | 0.328 | A b | 0.454 | A a | 0.337 | A b |
| Black medic | 0.418 | ABC a | 0.366 | A a | 0.357 | A a | 0.239 | B a |
| Common lambsquarters | 0.329 | CD a | 0.288 | A a | 0.345 | AB a | 0.276 | AB a |
| Common mallow | 0.365 | BCD a | 0.250 | A b | 0.286 | BC b | 0.245 | B b |
| Field bindweed | 0.336 | CD a | 0.295 | A a | 0.279 | BC a | 0.294 | AB a |
| Hairy nightshade | 0.580 | A a | 0.384 | A ab | 0.603 | A a | 0.302 | AB b |
| Prickly lettuce | 0.312 | D a | 0.251 | A b | 0.257 | C b | 0.245 | B b |
| Witchgrass | 0.267 | E a | 0.243 | A b | 0.275 | BC a | 0.247 | B b |

Values followed by the same capitalized letter within columns are not significantly different at the $p=0.05$ confidence level. Values followed by the same lowercase letter within rows are not significantly different at the $p=0.05$ confidence level.

Degree Day Calculations

Because population trends differed dramatically between 2014 and 2015, i.e. date effects were not constant across years, an effort was made to reconcile these differences using degree day modeling. In 2014, thrips populations generally fell from the first sampling date to the second, rose slightly at the third sampling date, and rose again at the final sampling date (Figure 2). In 2015, thrips populations generally declined across the season. In 2014 the first sampling date occurred at 760 degree days, the second at 1107, the third at 1664, and the final sampling date at 2,090 accumulated degree days. In 2015, far fewer degree days accumulated throughout the season. The first sampling date in 2015 occurred at 456 degree days, the second

at 791, the third at 996, and the final sampling date at 1,188 accumulated degree days. When population trends are described on a degree day basis, it can be said that in both years, thrips populations began relatively high and then declined throughout the first 1,100 or 1,200 accumulated degree days. Following the initial decline in 2014, thrips populations rose through subsequent degree day accumulation. In 2015, however, no additional sampling occurred beyond this point of degree day accumulation. Perhaps higher degree-day accumulation in 2014 allowed thrips populations to climb again following the mid-season dip, while lower degree-day accumulation in 2015 did not allow for this late-season population rebound. It would appear that using a degree day model in place of calendar days resolves the apparent dissimilarities of sample timing effect between the two seasons.

Plant Species Composition within Weed Borders

In 2014, mid-season sampling in borders of resident weed communities revealed that weed species included in thrips sampling protocols made up over 90% of total present weed biomass in these borders. Common lambsquarters was the primary component in these resident weed communities. In the four plots sampled, common lambsquarters comprised 72% on average of total present biomass. Field bindweed was also a significant component making up 13% on average of total biomass. Other present species contributed on average 5% or less of the total present biomass.

At the end of the season in 2014, resident weed communities in the mowed and unmowed borders were still dominated by common lambsquarters (Figure 3). In unmowed borders, lambsquarters comprised 89% on average, and 66% on average in mowed borders. Field bindweed also remained the second-largest component of resident weed communities,

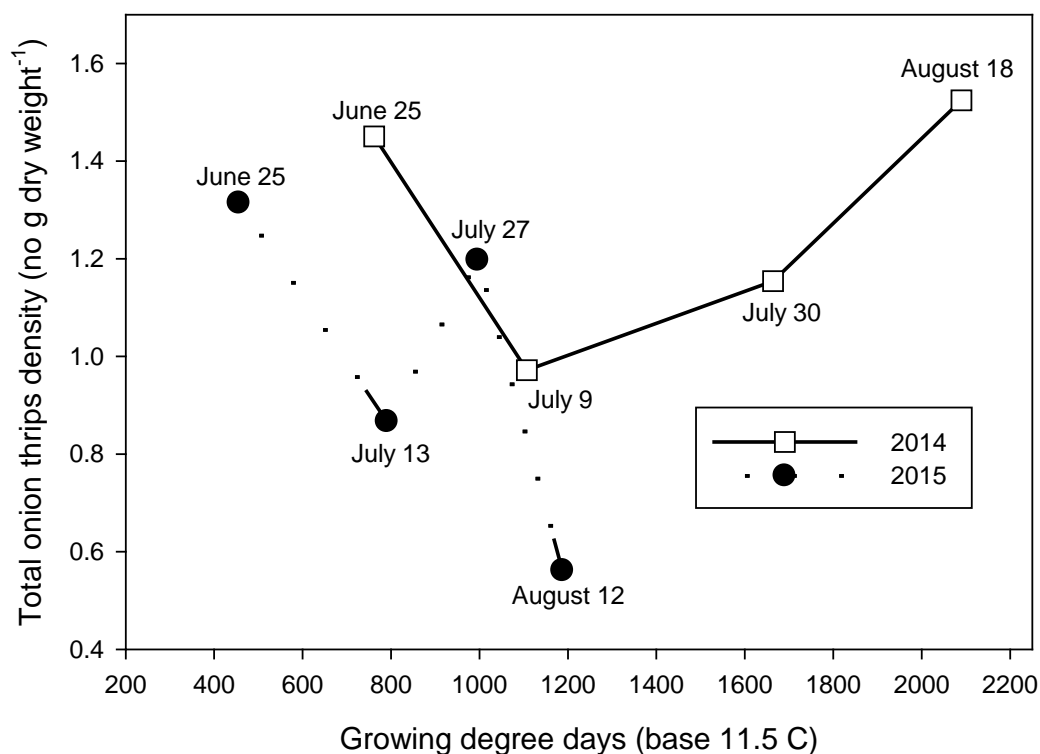


Figure 2. Thrips density on onion averaged over all border treatments as influenced by degree day accumulation in 2014 and 2015.

comprising 6% on average of total present biomass in unmowed borders, and 18% on average in mowed borders. Other weed species accounted for less than 5% each of total biomass, with the exception of hairy nightshade, which comprised 6% on average of total biomass in mowed borders. In weed borders comprised of a single monoculture species, the assigned monoculture species represented more than 90% of all present biomass, with the exception of one common mallow border in which field bindweed had encroached heavily. Field bindweed was present to some degree in all plot borders.

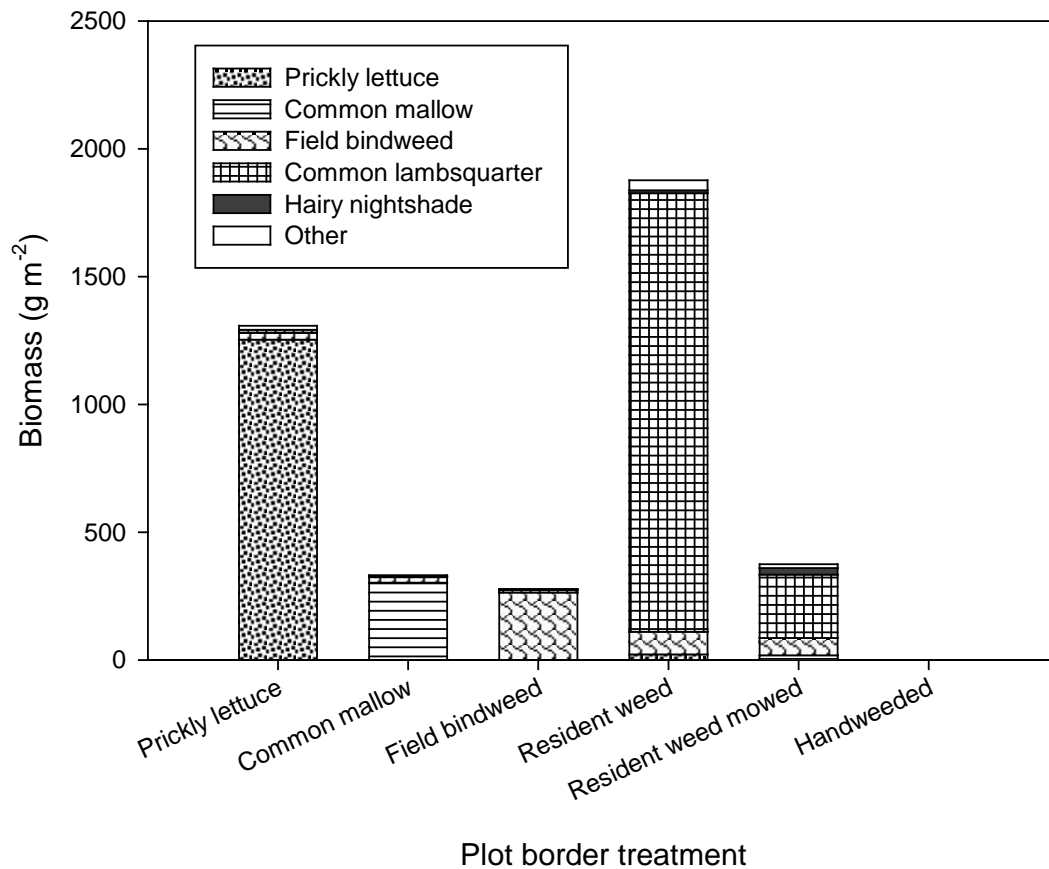


Figure 3. Weed biomass present in weed border treatments at end of season, 2014.

In 2015, mid-season biomass sampling illustrated that common lambsquarters played a much more modest role in overall biomass contribution than in 2014. While still the primary component, common lambsquarters comprised only 36% on average of total present biomass. Additionally, field bindweed and hairy nightshade were major components, averaging 27% each of total present biomass. Witchgrass represented a relatively small percentage of overall biomass, 6% on average. Other species represented less than 5% each of total present biomass.

At the end of the season in 2015, common lambsquarters was no longer the largest component in resident weed mowed borders, and only a marginally larger component than field bindweed in unmowed resident weed borders (Figure 4). Field bindweed represented 29% on average of total present biomass in unmowed plot borders, and 39% on average in mowed borders, while common lambsquarters represented 35% on average in unmowed resident weed borders and 28% on average in mowed resident weed borders. Hairy nightshade continued to comprise a major portion of present weed biomass, and accounted for 21% on average in unmowed plots, and 26% on average in mowed plots. Witchgrass remained a moderate component, contributing 12% on average in unmowed plots, and 5% on average in mowed plots. All other weed species present in resident weed borders represented only minor components (1% or less of total present biomass). Similar to the 2014 season, single-species weed borders were overwhelmingly populated with the assigned weed species, which represented more than 90% of total weed biomass in every case.

Estimated Thrips Populations within Weed Borders

In 2014, estimates of total onion thrips populations varied among weed borders (Figure 5). Estimated total onion thrips numbers were highest in resident weed borders and were estimated to hold almost twice as many thrips as prickly lettuce borders. Prickly lettuce borders in turn were estimated to hold more than twice as many thrips as common mallow, field bindweed, and resident weed mowed borders. Although not shown in figures, adult onion thrips numbers at end of season were estimated to be highest in resident weed borders, followed closely by prickly lettuce borders. Field bindweed borders were estimated to support an intermediate number of adult onion thrips, followed finally by common mallow and resident

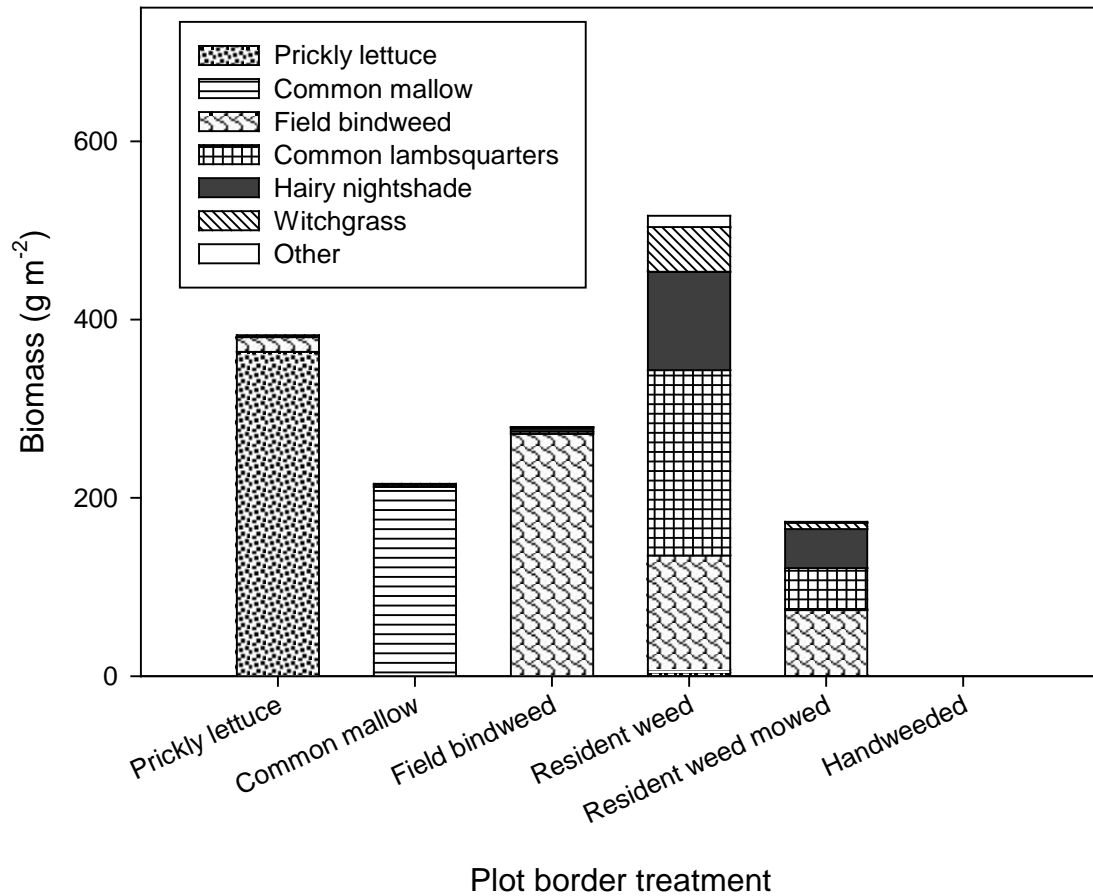


Figure 4. Weed biomass present in weed border treatments at end of season, 2015.

weed mowed borders. Thrips larvae numbers were also estimated to be highest in resident weed borders. Although larvae numbers were estimated to be next highest in prickly lettuce borders in agreement with adult onion thrips estimates, larvae numbers in resident weed borders were estimated to be more than twice as high as those in prickly lettuce borders, rather than only modestly higher, as in the case of adult numbers. Larvae numbers in common mallow,

field bindweed, and resident weed mowed borders were estimated to be similar to one another, and less than half the estimated larvae numbers in prickly lettuce borders.

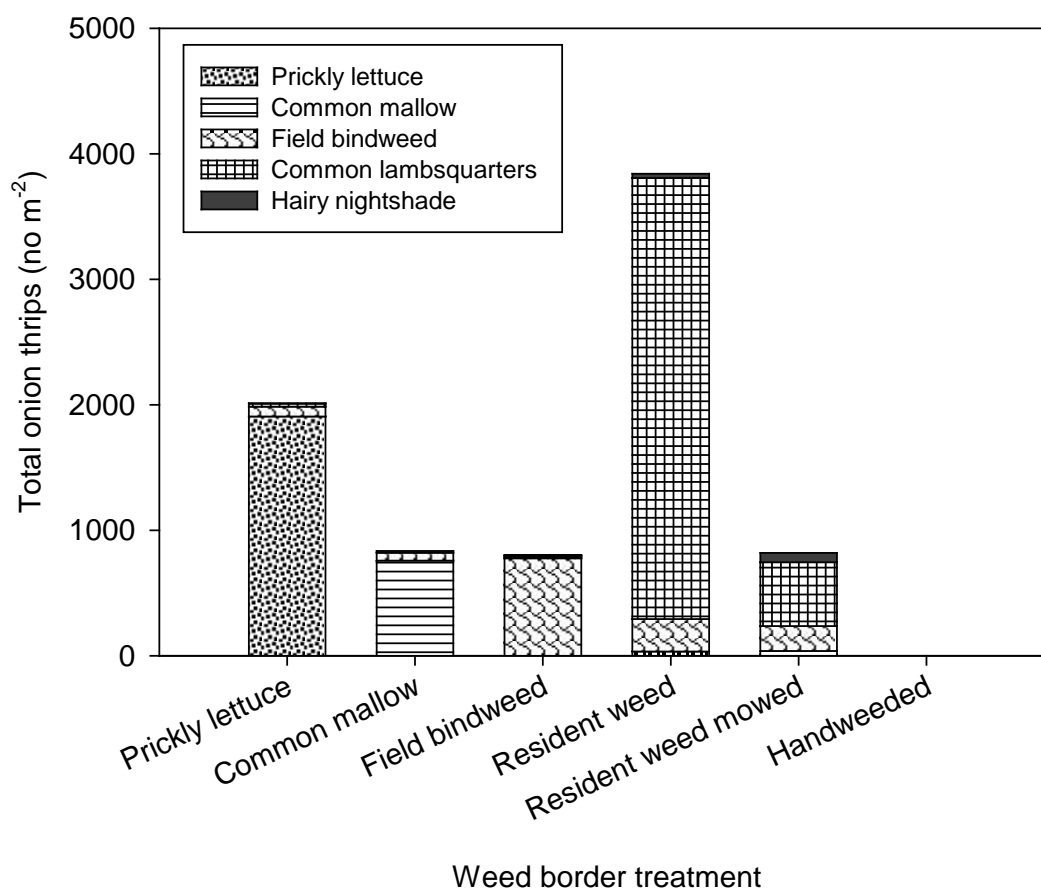


Figure 5. Number of total onion thrips estimated to be present in weed border treatments on various weed species at end of season, 2014.

In 2015 at end of season, total onion thrips numbers in resident weed borders were estimated to support nearly twice as many thrips as field bindweed borders, which in turn held roughly 30% more thrips than common mallow borders, while prickly lettuce and resident weed mowed borders were estimated to hold the lowest number of total thrips (Figure 6). While not

shown in figures, resident weed borders were estimated to hold roughly twice as many adult onion thrips as field bindweed borders, which in turn held roughly 50% more adult onion thrips than prickly lettuce, common mallow, and resident weed mowed borders. Similar to estimates of adult onion thrips numbers, resident weed borders were estimated to also hold the highest numbers of thrips larvae, followed first by field bindweed borders, then by common mallow borders, and finally by prickly lettuce and resident weed mowed borders.

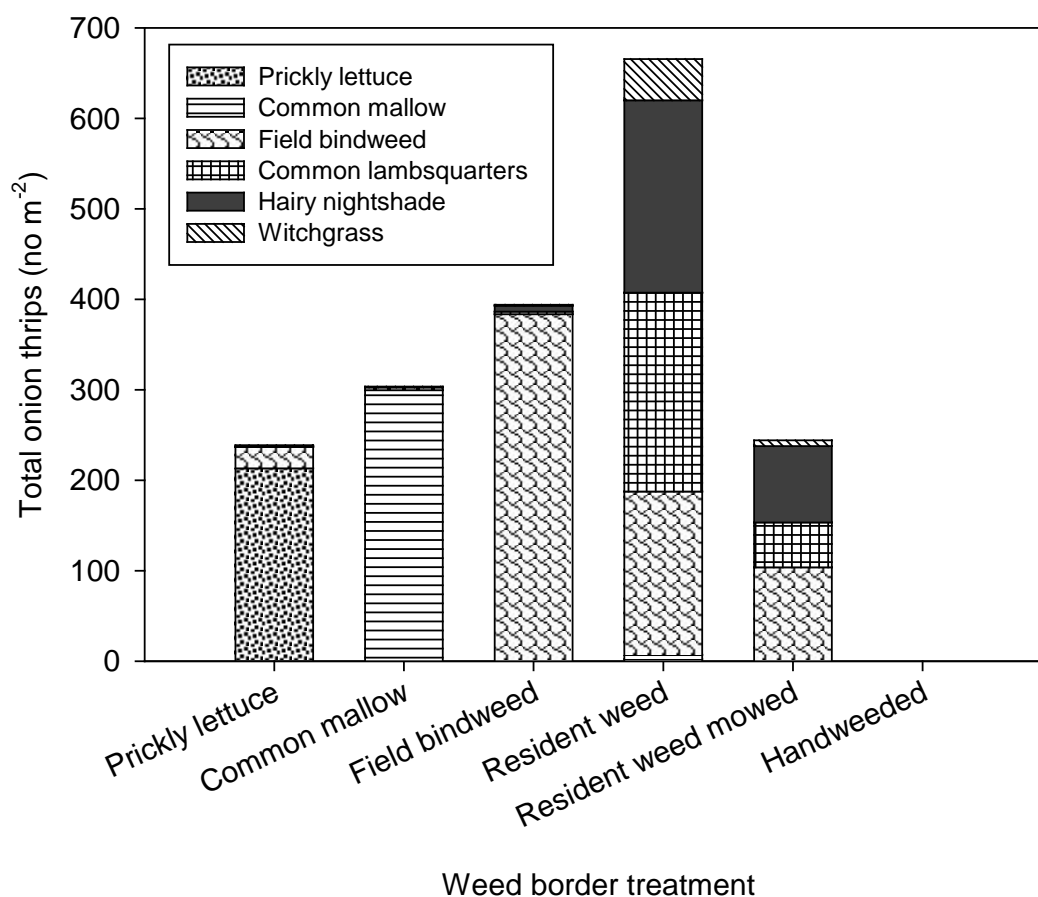


Figure 6. Number of total onion thrips estimated to be present in weed border treatments on various weed species at end of season, 2015.

Predictably, in both 2014 and in 2015, larvae numbers were considerably higher than adult thrips numbers. Furthermore, end of season thrips numbers in 2015 were consistently lower than in 2014.

IYSV Infection Rates

IYSV incidence in both 2014 and 2015 was too low to allow for statistical comparisons to be made. Over the course of the 2014 season, no onions from plots surrounded by prickly lettuce or resident weed borders tested positive for IYSV presence (Table 14). Furthermore, no positive test results were obtained on prickly lettuce in that year and although it is estimated that a relatively high number of thrips were present in prickly lettuce borders, low thrips densities were generally observed on this species (Table 15). Thrips densities on onions surrounded by resident weed mowed borders were relatively low in 2014, as were estimated end of season thrips populations. Conversely however, onions surrounded by common mallow borders tested positive at a numerically higher rate than those surrounded by any other borders with the exception of field bindweed. Despite the fact that relatively high densities of thrips were observed on common mallow in 2014, low biomass production by this species resulted in low estimates of actual thrips numbers present in these borders. Furthermore, no common mallow samples tested positive for IYSV in this year.

In 2015, onions surrounded by field bindweed tested positive for IYSV at a numerically lower rate than those surrounded by other weed border treatments (Table 14). However, field bindweed itself tested positive at a numerically higher rate than other species with the exception of black medic and witchgrass (Table 15). Additionally, field bindweed did not support especially low thrips densities, and overall thrips numbers were estimated to be relatively high

Table 14. Iris Yellow Spot Virus incidence in onion surrounded by different weed border treatments.

| Border Treatment | Positive IYSV Tests | |
|---------------------|---------------------|------|
| | 2014 | 2015 |
| | ----- % ----- | |
| Prickly Lettuce | 0.00 | 4.38 |
| Common Mallow | 8.33 | 5.00 |
| Field Bindweed | 8.33 | 1.25 |
| Resident Weed | 0.00 | 4.38 |
| Resident Weed Mowed | 6.25 | 5.00 |
| Handweeded | 4.17 | 4.38 |

Table 15. Iris Yellow Spot Virus incidence on different plant species.

| Host Plant Species | Positive IYSV Tests | |
|----------------------|---------------------|-------|
| | 2014 | 2015 |
| | ----- % ----- | |
| Onion | 4.51 | 4.07 |
| Black Medic | -- | 6.25 |
| Common Lambsquarters | 6.25 | 5.00 |
| Common Mallow | 0.00 | 1.88 |
| Field Bindweed | 4.17 | 5.63 |
| Hairy Nightshade | 8.33 | 3.75 |
| Prickly Lettuce | 0.00 | 4.38 |
| Witchgrass | 6.25 | 11.88 |

in that year compared to other borders. Witchgrass tested positive at a numerically higher rate than other tested host species in 2015, and nearly twice as high as the 2014 rates.

Despite the low overall IYSV infection rates and the lack of clarity concerning any potential relationship between IYSV in onions and factors such as thrips populations in weed

borders or IYSV infection rates in surrounding weed species, it is interesting to note that over the course of both seasons, one or more positive test results were acquired on all sampled species (Tables 14 and 15).

DISCUSSION

In agreement with previous work conducted by Goncalves and Sousa e Silva (2003) indicating that thrips densities on onion were similar whether the onion was planted in monoculture or intercropped with different border plant species, on the whole, border weed treatments in this study did not seem to significantly impact thrips densities in onion. Nevertheless, in 2014 some statistical differences were observed at the $p=0.1$ confidence level. In this case, densities of thrips larvae and combined thrips larvae and adult onion thrips (total onion thrips) were shown to be higher on onions surrounded by a common mallow weed border than on those surrounded by a resident weed border. Follow up work conducted by Goncalves (2005) dealing with thrips population dynamics in relation to border plants showed an increase in bulb size in onion bordering weeds as opposed to those bordering fodder radish and buckwheat. This could indicate that in select incidences, border species may in fact play some role in thrips incidence and subsequent crop yield.

Interestingly, raw data in 2014 pointed to a strong response to mid-season mowing treatments, with thrips densities climbing dramatically at the final sampling date in onions surrounded by the resident weed mowed borders. At the final sampling date, nearly twice as many thrips per gram of dry host plant material were observed on onions surrounded by mowed weeds than on those surrounded by any other weed border treatment (data not shown). This initially seemed to indicate thrips migration onto onions following the removal of weed biomass that had perhaps acted as either additional habitat for large numbers of thrips, or as a physical barrier preventing thrips from infesting surrounded onions during the earlier portion of the season. However, while this response was clearly observed in three of four

replications, it was completely absent in the fourth. Although numeric averages exhibited the strong response in spite of one low data point and analysis of the raw data seemed to confirm the statistical significance of this observation, enough variation was introduced that a geographic mean of the log-transformed data failed to show any significant response to this treatment. Furthermore, 2015 results failed to demonstrate any significant effect following mid-season mowing. It may be possible that the failure to demonstrate any strong response to mowing in 2015 was a result of season-long efforts to maintain border weed heights at or below 50 cm. These actions, accomplished with hedge trimmers in resident weed, resident weed mowed, and, to a somewhat lesser extent, prickly lettuce borders, likely reduced thrips populations in these borders via habitat removal and regular disturbance. If this is indeed the case, a single data point in 2014 and a change in plot management methods in 2015 may have covered up a very real migratory response in thrips to mid-season weed management efforts. Indeed, weed management strategies such as burning of weedy field borders have been suggested as a thrips suppression tactic for many years (Chittenden 1919). The timing of such efforts may be critical to suppress thrips populations without driving extant populations onto adjacent crops. It is apparent that this question warrants further study.

Although weed border effects on thrips densities in onion were generally weak and at best ambiguous in one case, data for thrips densities on weed species did reveal likely host plant preferences. Not surprisingly, densities of adult onion thrips, thrips larvae, and thrips eggs were quite high on onion. Using these measurements, no other host plant species supported significantly higher thrips densities than onion in 2014. Only black medic supported higher densities of thrips larvae and total onion thrips (not adult onion thrips or eggs) in 2015. In general, thrips densities under all categories were relatively low on common lambsquarters,

prickly lettuce, and witchgrass, indicating that these species are likely poor hosts. Conversely, species such as black medic, hairy nightshade, field bindweed and common mallow showed reasonably high densities of thrips under all metrics applied. Hairy nightshade proved particularly reliable in hosting high thrips densities, including egg densities. These results generally confirm reports demonstrating the ability of onion thrips to effectively utilize a range of host plant species (Atakan and Uygur 2005; Diaz-Montano and others 2011; Morishita 2005; Sampangi and others 2007; Schellhorn and others 2010).

Nitrogen levels within host plant material likely played an important role in observed host plant preferences. Previous work conducted by Buckland et al. (2013) and Malik et al. (2009) shows that onion thrips densities in onion increase with higher rates of nitrogen fertilizer. Black medic, a legume, consistently hosted relatively high thrips densities. It is possible that the nitrogen-fixing properties of this species played an important role in observed thrips preferences towards it. Furthermore, fertilizer applications were made uniformly across the research area, meaning that weed borders were fertilized along with onion plots. Differential nitrogen uptake within extant weed species may have also played some role in observed thrips preferences.

Thrips density data used to assess host plant preferences in thrips is influenced by the relative growth rates of the various species included for comparison. This fact represents an important limitation when making conclusions regarding thrips preferences vis-à-vis host plant species. Species with high rates of growth, for example, may hold diminishing thrips densities as the season progresses if biomass production outstrips thrips population growth. Because host plant biomass samples were not taken regularly throughout the season, this study is unable to

directly address this particular limitation. However, previous work detailing growth habits of some of the host plants represented in this study can be used to make inferences in regards to some of these relationships. For example, separate studies investigating growth rates of onion and common lambsquarters at various temperatures show that, under all temperature regimes tested, biomass accumulation is already radically higher in common lambsquarters by 11 weeks. Within this time frame, onion dry weights under all temperatures studied remained well below five grams dry weight per plant (Butt 1968). In contrast, optimal temperature regimes in common lambsquarters resulted in dry weights well over 11 grams per plant, and firmly above onion weights under all temperatures tested. To provide an even more striking example, another weed tested, redroot pigweed, accumulated nearly 50 grams of biomass per plant within these same 11 weeks (Chu and others 1978). These studies support field observations made during this study—specifically that some weed species, including common lambsquarters, grew at much higher rates than others (such as onion) and that this phenomenon was observable beginning quite early in the season and became even more pronounced as the season progressed.

It was anticipated that combining thrips host plant preference information with weed biomass data may offer useful insights into onion thrips infestation patterns by identifying weedy areas neighboring onion plantings wherein large numbers of onion thrips may reside, and correlating this information to infestation rates in onion. As mentioned above, some 2014 results regarding mid-season mowing of just such a weedy area seemed to result in increased thrips infestation of adjacent onions. However, when data for end of season thrips population estimates in weedy borders were compared with thrips densities on onions within these borders, correlations were generally quite weak and trended negative (data not shown). These

results were surprising considering that preliminary work conducted by Dr. Diane Alston at Utah State University suggested that thrips infestation of commercial onion fields increases in severity with proximity to unmanaged field borders. In this study, rather than lead to increased thrips infestation in onion, undisturbed weed borders may have acted more as a catch crop, if an effect was observed at all.

Weed characteristics likely play an important role in determining thrips infestation outcomes. For example, it is appropriate to consider the comparative importance of thrips density on a particular weed to the amount of biomass rendered by that weed. This study would seem to indicate that disparate weed biomass levels present in weed borders contributed more heavily to overall thrips numbers than observed differences in thrips densities on the various weed species.

Weed life cycles are likely also important factors influencing thrips population outcomes from year to year. Summer annual weeds may have a reduced capacity, when compared to winter annual and perennial weeds, for temporal expansion of thrips habitat availability into late fall after harvests have occurred and early spring before onion emergence. Furthermore, summer annuals are ultimately unable to facilitate thrips population carryover, or “green-bridging” between years. These phenomena are known to occur with varying levels of attainment in a number of weedy host plant species (Atakan and Uygur 2005; Carrizo 2001; Cho and others 1995; Horsfall 1921).

Physical and temporal scales likely play a significant role in thrips infestation patterns as influenced by the presence of weedy host plant species. The small physical scale of this trial relative to scales typical in commercial operations represents a key weakness of this study.

Thrips movement between plots, though impossible to measure, potentially occurred to a greater extent than would occur between large commercial fields. The possible movement of thrips between plots may have served to dampen observed plot border effects through inter-plot contamination. Rather than examine the effect of weed presence on thrips across multiple seasons and planting rotations, this study demonstrates the influence from a single season's exposure to weed presence. This limitation represents another meaningful weakness as effects within season may differ from effects across seasons. For example, early and late season habitat availability likely enables thrips populations to complete additional life cycles each year, contributing to increased thrips populations throughout the growing season. Unfortunately, this study was largely unable to capture this phenomenon as weed borders were established concurrently with onion plantings and were eliminated at the end of each season. Additionally, while this study indicates that weed presence leading to increased populations of thrips within a given locale does not necessarily contribute to increased infestation rates on onion within a given season, it is possible that thrips populations may be harbored for numerous years in persistently weedy field borders, serving as inoculation sources for sensitive crops in ensuing seasons. Unfortunately, this study was unable to assess year-to-year effects such as those described above because the trial was removed and re-set between seasons.

Finally, growing conditions affecting weed productivity and longevity are likely important factors in thrips infestation and migration patterns. In our trial, weeds were irrigated throughout the season and were well fertilized. In other settings, weeds growing on field borders may not receive either fertilizer or water, and may mature and die much earlier than those in our trial.

Insect movement, including migration and dispersal, is a common phenomenon among insect pests (Stinner and others 1983). Migratory movements have generally been attributed to the development of unfavorable conditions in the insects' environment. The seasonal migrations of the beet leaf hopper represent a particularly poignant example of pest migration from one host plant to another. In this case, large populations of beet leaf hopper migrate each year from uncultivated ranges, where they are found on host plants including species of saltbush and filaree, to invade the sugar beet cultivations of the Sacramento and San Joaquin Valleys of California, as well as other locals in the western United States. Though the cause of leafhopper migration is not fully understood, the annual dry-down of uncultivated host plants in mid to late spring has long been suggested as the primary driver (DeLong 1971; Severin 1933; Soto and Gilbertson 2003). This example is striking because it represents another case in which disturbance of uncultivated range plants drives a virus-laden insect pest into cultivated crop areas.

While this and other work seem to indicate that close proximity to other plant species alone does not seem to increase thrips infestation rates in onion, further work is needed to establish what effect, if any, weed management efforts may have on thrips migration and subsequent infestation in onion and other susceptible crops.

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