Identifying Weed Species Hosts for Onion Thrips (Thrips tabaci Lindeman) and their Potential as Sources of Iris yellow spot virus (Bunyaviridae: Tospovirus) in New York Onion Fields

by Erik A Smith

IDENTIFYING WEED SPECIES HOSTS FOR ONION THRIPS (*Thrips tabaci* LINDEMAN) AND THEIR POTENTIAL AS SOURCES OF *IRIS YELLOW SPOT VIRUS* (*BUNYAVIRIDAE*: *TOSPOVIRUS*) IN NEW YORK ONION FIELDS

A Thesis

Presented to the Faculty of the Graduate School

Of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science

By

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August 2010

ABSTRACT

Onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), is a pest of onion crops and other *Allium* spp. worldwide and is the only known vector of *Iris yellow spot virus* (IYSV) (*Bunyaviridae*: *Tospovirus*), a yield-reducing pathogen infecting onion. IYSV was first detected in New York onion fields in 2006 and has since been found throughout all of the major onion producing regions in the state. Recent studies in New York have shown that IYSV can reduce bulb size, suggesting that this disease may cause serious economic losses for the onion industry.

Sources of IYSV in New York onion fields have only recently become better understood. IYSV may be annually introduced via transplanted onions imported from AZ, where the virus is established. IYSV also may be established in New York and bridge seasons through volunteer onion plants and winter-annual, biennial and perennial weeds near onion fields. However, weed species that may be important in the epidemiology of IYSV in onion fields are not known.

T. tabaci can only acquire IYSV as first instars. Therefore, a weed can only be a source for IYSV if it is also a host for immature *T. tabaci*. Because weed hosts that would support larval populations of *T. tabaci* were not known for the Great Lakes region of North America including New York, the main purpose of this research was to identify weed species that supported populations of *T. tabaci* larvae. In 2008 and 2009, common weed species and *T. tabaci* larvae were sampled from spring through early fall in the Elba Muck onion-growing region in western New York, the second largest onion growing region in the state. Ninety-eight weed species were sampled and 30 had at

least one *T. tabaci* larva. A total of 2,121 *T. tabaci* larvae were found on weeds sampled in 2008 and 2009; 17% of the weed species were members of Asteraceae and 20% were in the Brassicaceae. Most of the larvae (90%) were found on species of these two families.

Because IYSV is thought to be non-transmissible by seed, winter-annual, biennial and perennial weed species have the ability to act as overwintering reservoirs for IYSV in onion cropping systems. Thus, these types of weed species may likely be the most important sources for this virus. Of the 30 weed species hosting *T. tabaci* larvae, 25 were winter-annual, biennial and perennial weeds. Of these, only four are confirmed hosts of IYSV: common burdock, *Arctium minus*, chicory, *Cichorium intybus*, curly dock, *Rumex crispus*, and dandelion, *Taraxacum officinale*. Among these four species, plant densities and populations of *T. tabaci* larvae were highest on common burdock and dandelion, suggesting that these weed species may have the greatest potential to impact the epidemiology of IYSV in New York onion fields. Densities of *T. tabaci* larvae were estimated to be 3,536 and 3,851 larvae per hectare on common burdock in 2008 and 2009, respectively, whereas densities were estimated to be 4,720 and 24,964 larvae per hectare on dandelion in 2008 and 2009, respectively. Larvae were only observed on curly dock in 2008 (3 larvae per hectare) and on chicory in 2009 (143 larvae per hectare).

In a separate field survey in the fall of 2009, populations of *T. tabaci* larvae were highest on common burdock and dandelion plants adjacent to onion fields (0-50 m), whereas no larvae were observed on these weed species farther than 5 km from onion fields. Samples of common burdock and dandelion did not test positive for IYSV; however, the relative localization of *T.*

tabaci populations suggests that management of these weed species near onion fields in an effort to reduce the number of viruliferous *T. tabaci* that may colonize onion fields warrants further investigation.

In addition to IYSV, there are other important viruses of vegetable crops grown in muck soils. Survey results covering the presence of these weed species in the Elba Muck are presented and discussed.

BIOGRAPHICAL SKETCH

Erik Smith was born April 19, 1983 in Ithaca, New York. He was raised in nearby Interlaken and graduated from South Seneca Central School in 2001. During his undergraduate years at Oswego State University in Oswego, NY, he spent his summer vacations working as a summer assistant in Dr. Brian Nault's vegetable entomology program. In 2005, he received his B.A. in Biology from Oswego State. Prior to attending graduate school, Erik worked as a laboratory technician in Dr. Nault's lab and in Dr. Greg Loeb's grape and small fruit entomology program. In 2007, Erik began his graduate studies in the Department of Entomology under Dr. Nault. Upon completion of his Master's Degree, he will continue his studies in Dr. Nault's program in pursuit of his Ph.D.

This manuscript is dedicated to my grandparents, LeConte & Ruth Myer and William & Terry Smith

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Brian Nault for his guidance, patience, and enthusiasm during these projects. I would also like to thank my committee members, Drs. Antonio DiTommaso, Marc Fuchs, and Anthony Shelton for all of their guidance and enthusiasm. In addition, I would like to thank Mary Lou Hessney, Simon Hsu, and Derek Artz for their wise words, advice, support and assistance on behalf of my various projects. Last, I would like to thank the New York State Agricultural Experiment Station for funding my research, and the Station community for making these years truly enjoyable.

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INTRODUCTION

I. Onion, *Allium cepa* L., production in New York State

Allium is the most economically important of the twenty genera in Subfamily: Allioideae (Amaryllidaceae). Allioideae is analogous to the former family Alliaceae (Angiosperm Phylogeny Group III 2009). *Allium* crops include onion *Allium cepa* L., garlic, *A. sativum* L., shallot, *A. oschaninii* O. Fedtsch, leek, *A. ampeloprasum* L., and chive, *A. schoenoprasum* L. As of 2007 (FAO 2009), onion is the most economically important *Allium* crop worldwide and the 18th most valuable crop in the United States. Onion likely originated in central or southwestern Asia and has been cultivated for at least 5000 years (National Onion Association 2008). A storage-tolerant food source with high nutritional value, onion was prized by early Eurasian civilizations and was first brought to the Americas by Christopher Columbus. Onion is a biennial crop harvested after the first growing season when grown as a bulb crop. Onions grown for seed are allowed to fully mature through a second growing season (Voss et al. 1999).

Onion is one of New York State's most important vegetable crops, grossing between $50 million and $60 million, or roughly 5% of the state's agricultural crop market each year. New York onion crops are most often grown from seed; however, 15% of crops are grown from transplants or sets imported from other states (Nault et al. 2008b). Planting typically occurs from late March through early May. Barley, *Hordeum vulgare* L., is planted concurrently with direct seeded onions as a windbreak. Barley emerges much more quickly than onion, providing protection from soil erosion and wind

damage to onion seedlings. For a number of economical and historical reasons, onions are typically grown in the same fields year after year.

In the northern and eastern US, onion is typically grown in soils composed of highly organic humus found in drained wetlands. Soils of this nature are commonly referred to as “muck” soils. Muck soil is remarkably loose and resistant to compaction, and allows roots and tubers to grow larger and deeper than in mineral soils. Muck soils retain more moisture than mineral soils (Lyon et al. 1920); however, highly efficient drainage systems permit better drainage and a decreased incidence of rot for bulbing and tuberous vegetable crops. These characteristics make muck soil an ideal medium for growing onion. These former wetlands are located in isolated areas scattered across the landscape as a result of glacial activity. In New York, the two largest contiguous onion growing regions are in Orange County’s “Black Dirt” region and the Elba Muck region in Orleans and Genesee Counties, with smaller regions located in Oswego, Madison, Wayne, Yates, Steuben, and Livingston Counties.

New York is ranked seventh in the US in onion yield and third based on total crop value (NASS 2010). Ninety-eight percent of onions produced in New York are sold as fresh-market bulbs, while the remaining two percent represent bulbs sold for processing (Stivers 1999). In order to remain profitable year-round, it is common for New York onion growers to import large quantities of bulbs from other states or countries and then repackage the marketable bulbs under their own label for retail. Fresh-market onions are of higher value compared with crops bound for processing. This is reflected in New York State’s relatively high crop value, but this value is partially offset by high production costs. Of all crops grown in New York, onion production costs

are second only to apples (Hoffman et al. 1996) and are highest among vegetables (Stivers 1999). These high costs result from intensive chemical control of insect pests, pathogens, and weeds. All three pest groups can cause significant economic damage if not controlled (Jones 1930; Hewson 1971; Senthilnathan & Narasimhan 1992; Fournier et al. 1995; Hoffman et al. 1996; Childers 1997; Gent et al. 2004; Kumari 2008). When interactions among these pests are complimentary, effective management can be difficult, especially if these interactions are not fully understood.

II. Onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae)

A. Impact on onion

Onion thrips, *Thrips tabaci,* is a major pest of onions worldwide (Lewis 1997) and is prevalent throughout regions of onion production in New York State. *T. tabaci* cause damage to host plants by feeding on leaf tissue and by transmitting pathogens while feeding. Onion is the preferred host of *T. tabaci* (Doederlein & Sites 1993); however, *T. tabaci* exploit a wide host range (Lewis 1997). *T. tabaci* are thigmotactic, and in onion, they prefer to feed on the inner, younger leaves (Lewis 1973). As with other thysanopterans, *T. tabaci* feeds by rasping leaf tissues with the mandible and ingesting cell contents with maxillary stylets (Chisolm & Lewis 1984). As a consequence, feeding scars form on leaves that can inhibit photosynthesis and consequently reduce bulb yield by as much as 50% (Fournier et al. 1995; Childers 1997).

B. Life history

In New York, *T. tabaci* can produce as many as five generations each year, and will typically complete a life cycle in 14-30 days as temperature and

other biological and environmental factors vary (Andaloro & Shelton 1983; Fekrat et al. 2009). The life cycle of *T. tabaci* is comprised of five life stages: egg (4-10 days), larva (first instar: 1-3 days; second instar: 2-4 days), a non-feeding pre-pupa stage (1.5-2.5 days), pupa (2-4 days), and an adult stage (1-4 weeks) with a 2-5 day pre-oviposition period (Fekrat et al. 2009). *T. tabaci* have multiple reproductive modes in onion fields in New York, and the frequency of these modes vary depending on the time of year. Thelytoky is the production of females from unfertilized eggs, deuterotoky is the production of males and females by unfertilized eggs, and arrhenotoky is the production of males from unfertilized eggs and females from fertilized eggs. Populations are mainly thelytokous in June and October, but represent all three reproductive types in July, August and September (Nault et al. 2006).

C. Phenology

T. tabaci colonize onion fields in New York beginning in June and populations are found on the crop through August and September, when onions are harvested. At this time, adult *T. tabaci* are known to colonize and overwinter in alfalfa, *Medicago sativa* L., weedy vegetation (North & Shelton 1986; Larentzaki et al. 2007), and in the soil within and near onion fields (Larentzaki et al. 2007). During the fall in New York, Larentzaki et al. (2007) observed *T. tabaci* on common lambsquarters, *Chenopodium album* L., evening primrose, *Oenothera biennis* L., yellow nutsedge, *Cyperus esculentus* L., and smooth pigweed, *Amaranthus hybridus* L. *T. tabaci* emerge from their overwintering locations in spring and are found colonizing volunteer onions as early as March (Larentzaki et al. 2007). Volunteers are bulbs that are unintentionally left in the field at harvest. If these volunteers survive through

the winter, they will sprout in spring and will be available to onion thrips long before commercial onion crops are attractive.

III. *Iris yellow spot virus* (Family *Bunyaviridae*, Genus *Tospovirus*)

A. Virus

Bunyaviridae spp. are classified as Group V viruses, which have a single-stranded RNA genome with negative polarity. This family is comprised of six genera. Four genera are animal viruses and two, *Tospovirus* and *Tenuivirus*, are plant viruses. Genus *Tospovirus* is named for the first identified species of the taxon, *Tomato spotted wilt virus* (TSWV) (Pittman 1927). As with other members of the *Bunyaviridae,* tospoviruses have a tripartite genome comprised of small (S RNA), medium (M RNA), and large (L RNA) segments encapsulated by a 90-100 nm spherical, membrane-bound virion (Elliott 1990). The S RNA segment of IYSV is 3,105 nucleotides in length (Cortes et al. 1998), the M RNA is 4,817 nucleotides (Bag et al. 2009), and the L RNA is 8,880 nucleotides in length (Bag et al. 2010). The nucleoprotein (NP) of the S segment is used to distinguish viruliferous from non-viruliferous *T. tabaci* in laboratory assays and has an estimated molecular weight of 30 kDa (Cortes et al. 1998). The M segment codes for two proteins, NSm and Gn/Gc, with molecular weights of 34.7 and 128.84 kDa, respectively (Bag et al. 2009), and the L segment encodes for an RNA-dependent RNA polymerase estimated to be 331.17 kDa (Bag et al. 2010). The advances made in fully characterizing this virus will be valuable in formulating strategies for effective prevention through resistant cultivars or GMOs, detection methods, and potential control.

B. Vector and transmission

Thrips (Order: Thysanoptera) are the sole vectors of *Tospovirus* spp. Thrips spread tospoviruses from infected plants to susceptible plants via mucivory. *T. tabaci* is the only known vector of IYSV (Nagata et al. 1999; Kritzman et al. 2001). As with other tospoviruses, IYSV is not known to be seed-transmitted (Kritzman et al. 2001; Gent et al. 2004; Bulajić et al. 2009), nor is it easily transmitted in a mechanical manner (Bulajić et al. 2009; Marc Fuchs, personal communication). IYSV is transmitted by *T. tabaci* in a persistent, circulative, propagative manner (Whitfield et al. 2005), meaning that once a vector has acquired the virus, that individual is viruliferous for life, and the virus circulates and proliferates within the vector (Nault 1997). Vectors of tospoviruses are only known to acquire these viruses as first instars and are only known to transmit as second instars or adults (Ullman et al. 1992; Wijkamp et al. 1993; Moritz et al. 2004). Upon reaching the second instar, a viruliferous thrips can transmit the virus to any susceptible plant on which it feeds.

C. Distribution

First identified in Brazil in 1981 (de Avila et al. 1981), IYSV has since spread to regions of onion production across the globe (Gent et al. 2006). Though it was not known by its current name at the time, IYSV was first found in the US in Idaho (Hall et al. 1993). Within the past decade it has spread to major onion production regions in twelve new states and one Canadian province. IYSV has been identified in Colorado (Schwartz et al. 2002), Utah (Abad et al. 2003), New Mexico (Creamer et al. 2004), Georgia (Mullis et al. 2004), Washington (du Toit et al. 2004), Oregon (Crowe & Pappu 2005), Texas

(Miller 2006), Oregon (Gent et al. 2007), New York (Hoepting et al. 2007), Ontario, Canada (Hoepting et al. 2008), Arizona (Pappu & Matheron 2008), Nevada (Bag et al. 2009), and California (Bag et al. 2009).

IYSV was present in one of 18 fields (5.6%) sampled in Colorado in 2001 and was present in 41 of 56 fields (73.2%) in 2003 (Gent et al. 2004). In New York, IYSV was first detected in NY in 2006 (Hoepting et al. 2007). In 2007, IYSV was found in 11 of 12 fields (91.7%) in the Elba Muck region and was present in all regions of onion production in the state (Nault et al. 2008a).

D. Damage to onion

IYSV manifests itself in the form of elliptical or diamond-shaped necrotic lesions on the leaves and scape, the seed-bearing leaf of the onion. In seed crops, coalescence of these lesions can weaken the scape to the point of lodging, resulting in a total loss of seeds from the infected plant (de Avila et al. 1981). In New York, bulb crops predominate. IYSV affects bulb crops by reducing photosynthesis, resulting in a reduction of bulb size (Gent et al. 2004). Yield losses have been estimated to be as high as 100% in bulb and seed crops (Pozzer et al. 1999).

E. Movement of IYSV in host

There is still much to learn about the nature of the virus as it proliferates within its plant hosts. IYSV is systemic, but higher titers can occur in variable locations throughout the plant (Kritzman et al. 2001). A plant infected in the first year of growth will typically exhibit higher IYSV concentrations in regions of the plant where onion thrips feed, i.e. the youngest, inner-most leaves (Kritzman et al. 2001). When infected plants are allowed to mature into the

second year of the life-cycle, the virus is typically found only in the scape (Schwartz & du Toit 2006).

F. Epidemiology

Researchers have observed that IYSV incidence varies by onion cultivar and higher incidence is often observed at field edges (Gent et al. 2004; Hsu et al. 2010). Incidence of infection is inconsistent throughout infected fields and may be exacerbated by plant stress; prevailing winds or proximity to inoculum sources and alternate hosts for viruliferous *T. tabaci* may also have an effect on incidence in onion crops.

In 2007 and 2008, Hsu et al. (2010a) found that infection rates in the Elba Muck remained relatively low during onion growing seasons until August, when incidence rose above 90% in at least one field in both years of the study. Onion crops are harvested in August and September, and *T. tabaci* displaced by harvests are thought to colonize fields that have yet to be harvested. Hsu et al. (2010a) also found that *T. tabaci* population densities in August were better predictors of IYSV levels than early-season population densities. This may suggest that these migrating thrips are transmitting IYSV to fields that they colonize during this time. After all onion fields have been harvested, *T. tabaci* are known to colonize weeds and other crops (North & Shelton 1986; Larentzaki et al. 2007) where they are believed to overwinter. If these thrips are viruliferous, they could possibly transmit IYSV to any susceptible plant species upon which they feed.

G. Potential sources of IYSV in New York

IYSV may be introduced into New York's onion crops from a number of

sources. One possibility is that IYSV may be re-introduced into onion ecosystems each year. For example, most of New York's onion transplants originate in Arizona, a state where IYSV is known to occur (Pappu & Matheron 2008). Onion transplants imported to New York from the western US are commonly infested with *T. tabaci* (Schwartz et al. 2004) and transplants originating in Arizona have tested positive for IYSV (Hsu et al. 2010a). However, transplants only make up 15% of the onion crop in New York and only 0.04% of transplants tested positive for IYSV in 2007 and 2008 (Hsu et al. 2010b). This suggests that transplants may be a local source of inoculum, but may not be a major source of widespread infection.

Another possible mode of annual re-introduction could be the importation and redistribution of marketable bulbs from other states or countries where IYSV has been reported. In the process of repackaging these bulbs, any damaged or otherwise unmarketable bulbs are taken to cull piles, which are disposal sites for unmarketable bulbs. In addition to these imported bulbs, cull piles also include locally-grown bulbs. Cull piles have yielded infection rates as high as 16.7% (Hsu et al. 2010b). However, few cull piles are located near onion fields; most are scattered throughout the region and are often located miles away from the onion crop. Moreover, cull piles are not significant overwintering hosts for onion thrips (Larentzaki et al. 2007). For these reasons, this potential source appears to be a relatively minor contributor to the spread of IYSV.

As annual re-introduction through transplants and imported bulbs is unlikely to be a major factor in the epidemiology of IYSV in NY, it is more likely that IYSV persists in the growing region through the winter in volunteer onions or weeds. If these volunteers survive through the winter, they will emerge from

late March to June and are colonized by onion thrips as early as March (Larentzaki et al. 2007). At the time of *T. tabaci* emergence in spring, volunteers are likely to be more attractive hosts than seeded and perhaps transplanted onions, which are comparatively small early in the season. If volunteers are infected with IYSV, they could be a source for the commercial onion crops. However, volunteers are typically removed from the field early in the season and placed in cull piles. Volunteers have yielded infection rates of up to 20% in some fields (Hsu et al. 2010b), but as previously stated, they are quickly disposed of in cull piles along with unmarketable imported bulbs. This suggests that volunteers may also be a local source of inoculum, but as with transplants and unmarketable imported bulbs, they may not be major sources.

Unlike cull piles, weeds are largely ubiquitous in all onion growing regions. *T. tabaci* are known to overwinter on weeds bordering onion fields (Larentzaki et al. 2007) and numerous weed species are susceptible to IYSV (Gent et al. 2006).

H. Weeds as sources of *T. tabaci* and IYSV

Tospoviruses are characterized by an intimate relationship with the life history of Thysanopterans, their sole insect vectors. Because of this relationship, an understanding of the behavior and host-selection of *T. tabaci* will provide insight into the epidemiology of IYSV. The overwintering nature of IYSV is largely unknown. IYSV may overwinter in volunteer onions and in weeds bordering onion fields, or perhaps in adult *T. tabaci*. There are no data regarding IYSV overwintering in thrips; however, studies have shown that overwintering of TSWV in thrips vectors is minimal, and is not considered a primary means of TSWV overwintering (Groves et al. 2001; Gent et al. 2006).

Alternatively, weeds have shown to be important overwintering reservoirs for TSWV (Groves et al. 2001). Given the relative similarities between *Tospovirus* spp., these traits may be similar for IYSV.

At least 47 plant species in 19 families are hosts of IYSV (Table 1). At least twelve of these species are weeds that are typically found in New York onion ecosystems (EAS, personal observation), and four have tested positive for IYSV in New York (Hsu et al. 2010b). Five of these susceptible weed species are strictly summer annual species found in New York, but as previously stated, *Tospovirus* spp. are not known to be seed-transmissible. Moreover, it is unlikely that summer annuals would emerge in time to be infected with IYSV and host a generation of larvae before the initial *T. tabaci* colonization of onion crops in June. Groves et al. (2002) suggested that infected summer-annuals may act as a reservoir for TSWV in between the time of crop harvest and the emergence of winter-annual weeds; however, this study was conducted in North Carolina, and it is unclear whether such a time-gap exists in the onion cropping systems in New York. Onion crops are harvested in late summer and into autumn when many winter-annuals are likely to have germinated. Winter-annuals, biennials and perennials have the potential to be overwintering reservoirs for IYSV, unlike summer annuals. For these reasons, it is likely that weeds with these life cycles have greater potential to impact IYSV epidemiology in New York onion ecosystems.

According to Culbreath et al. (2003), in order for a plant-host to be a source of a *Tospovirus* sp.*,* the plant must support the reproduction of the insect vector for at least one generation, allow the virus to be acquired by the vector, and its life cycle must be complimentary to that of the virus and the vector. At present, there is no knowledge of a non-agricultural perennial plant

Table 1.1 Plant species reported to be hosts of IYSV.

Species	Common name	Location[1]	Reference	Habit[2]	NY[3]
Alstroemeriaceae					
Alstroemeria sp. L.	Peruvian lily	Japan	Okuda and Hanada 2001	P	
Amaranthaceae					
Amaranthus retroflexus L.	Redroot pigweed	Colorado	Gent et al. 2006	SA	x
Atriplex micrantha L.	Twoscale saltbush	Utah	Evans et al. 2009a	P	
Chenopodium album L.	Common lambsquarter	Oregon	Sampangi et al. 2007	SA	x
C. amaranticolor Coste and Reyn.	Ornamental lambsquarter	Isreal	Gera et al. 2002	SA	
C. quinoa Willd.	Quinoa	Israel	Gera et al. 1998	SA	
Gomphrena globosa L.	Globe amaranth	Israel	Mohan et al. 1991	SA	
Kochia scoparia Roth	Kochia	Oregon	Sampangi et al. 2007	SA	x
Amaryllidaceae					
Allium spp.[4] L.	Onion, garlic, leek, etc.	Brazil	de Ávila et al. 1981	B/P/C	x
Clivia miniata Regel	Kaffir-lily	Japan	Jones 2005	P	
Hippeastrum hybridum Herb.	Amaryllis	Israel	Gera et al. 1998	P/C	
Araceae					
Scindapsus sp.	Scindapsus	Iran	Ghotbi et al. 2005	P	
Asteraceae					
Arctium minus Bernh.	Common burdock	New York	Hsu et al. 2010b	B	x
Chrysanthemum sp.	Chrysanthemum	Poland	Balukiewicz & Kryczinski, 2005	P	
Cichorium intybus L.	Chicory	New York	Hsu et al. 2010b	P	x
Lactuca serriola L.	Prickly lettuce	Oregon	Sampangi et al. 2007	P	x
Sonchus asper (L.) Hill	Spiny annual sowthistle	Georgia	Nischwitz et al. 2007	WA/B/P	x
Taraxacum officinale G.H. Weber ex Wiggers	Dandelion	New York	Hsu et al. 2010b	P	x
Cycadaceae					
Cycas sp. L.	Ornamental palm	Iran	Ghotbi et al. 2005	P	
Fabaceae					
Vicia sativa L.	Common Vetch	Georgia	Mullis et al. 2004	WA/C	
Vigna unguiculata (L.) Walp.	Black-eyed pea	Iran	Ghotbi et al. 2005	C	
Gentianaceae					
Eustoma grandiflorum Salisb.	Texas bluebell	Japan	Doi et al. 2003	B/P	

Table 1.1 (Continued)

Eustoma russellianum Salisb.	lisianthus	Israel	Kritzman et al. 2000	P/C	
Geraniaceae					
Geranium carolianum L.	Carolina geranium	Georgia	Mullis et al. 2004	B	
Pelargonium x hortorum L'Hér	Common geranium	Iran	Ghotbi et al. 2005	P	
Iridaceae					
Iris holandica L.	Iris	Ned.	Cortes et al. 1998	P	
Poaceae					
Setaria viridis (L.) P. Beauv.	Green foxtail	Utah	Evans et al. 2009b	SA	x
Polygonaceae					
Rumex crispus L.	Curly dock	New York	Hsu et al. 2010b	P	x
Portulacaceae					
Portulaca oleracea L.	Common purslane	Italy	Cosmi et al. 2003	SA	x
Rosaceae					
Rosa sp. L.	Rose	Iran	Ghotbi et al. 2005	P	
Scrophulariaceae					
Linaria Canadensis (L.) Dumort.	Blue toadflax	Georgia	Mullis et al. 2004	WA/B/P	
Solanaceae					
Capsicum annuum L.	Pepper	Tunisia	Ben Moussa et al. 2005	C	
Datura stramonium L.	Jimson weed	Israel	Gera et al. 1998	SA	
Nicotiana benthamiana Domin	Ornamental tobacco	Iran	Hall et al. 1993	C	
N. rustica L.	Tobacco	Brazil	Pozzer et al. 1999	C	
Petunia x hybrid Juss.	Petunia	Iran	Ghotbi et al. 2005	P	
Solanum lycopersicum L.	Tomato	Tunisia	Ben Moussa et al. 2005	C	
S. tuberosum L.	Potato	Tunisia	Ben Moussa et al. 2005	C	x
Themidaceae					
Bessera elegans Schult. f.	Coral drops	Japan	Jones 2005	P	
Zygophyllaceae					
Tribulus terrestris L.	Puncturevine	Oregon	Sampangi et al. 2007	SA/P	

Table 1.1 (Continued)

[1]Location of first detection.
[2]Most common life history: B = biennial, P = perennial, WA = winter annual, SA = summer annual, C = crop. Combinations indicate that multiple life histories are common.
[3]Species typically found in New York's onion ecosystems.
[4]Includes seven species of *Allium*: cultivated onion, *A. cepa* (de Ávila et al. 1981; Hall et al. 1993), shallot, *A. cepa* var. *ascalonicum* (Robene-Soustrade et al. 2006), leek, *A. porrum* (Coutts et al. 2003), garlic, *A. sativum* (Robene-Soustrade et al. 2006), and wild onions, *A. altaicum, A. pskemense*, and *A. vavilovii* (Pappu et al. 2006).

outside of *Allium* that is both a host of IYSV and a reproductive host of onion thrips, and no weed species has been confirmed as an important source for IYSV (Gent et al. 2006). For these reasons, it will be important to identify the alternate hosts of onion thrips and IYSV. Identifying weed species which may serve as sources of IYSV will improve our understanding of IYSV epidemiology and may provide insight into improving management or prevention of IYSV.

IV. Research objectives

The comprehensive goal of the studies detailed in the following chapters was to identify potential weed sources of IYSV in New York. The principal objective was to identify winter annual, biennial, and perennial weed species that are both hosts of *T. tabaci* reproduction and susceptible to IYSV, and to estimate their relative importance to IYSV epidemiology. This information could aide researchers and growers in devising effective and sustainable management strategies for both onion thrips and IYSV.

The objective of research detailed in the second chapter was to identify weed species that host *T. tabaci* larvae, indicating a capability of supporting onion thrips reproduction. The relative importance of weed species to IYSV epidemiology was estimated by taking into account the abundance of hosts for both *T. tabaci* larvae and IYSV. This information can be used to identify which weed species are capable of serving as overwintering reservoirs and sources of IYSV.

The objective of research detailed in the third chapter was to estimate the most abundant weed species in the Elba Muck vegetable production region of New York. Information from this chapter can be used to estimate the

most important weed species in the epidemiology of a few important vegetable crop viruses in New York and in the Great Lakes region of North America.

The objective of research detailed in the fourth chapter was to estimate the effect of distance from onion fields on onion thrips abundance and IYSV incidence in weed-hosts. Weed species studied in this chapter were those estimated to be most important to IYSV epidemiology, common burdock and dandelion. It was hypothesized that onion thrips larval populations and IYSV incidence would decrease as distance from onion fields increased. Such information could provide insight into the importance of managing these weed species to in turn manage *T. tabaci* , IYSV, or both.

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Chapter 2

WEED HOSTS FOR ONION THRIPS (*THRIPS TABACI*) AND THEIR POTENTIAL ROLE IN THE EPIDEMIOLOGY OF *IRIS YELLOW SPOT VIRUS* IN AN ONION ECOSYSTEM

Abstract

In 2008 and 2009, weed species were surveyed from spring through early fall as possible hosts of *Thrips tabaci* Lindeman larvae in the Elba Muck vegetable production region in western New York State. Thirty weed species were identified as hosts, and 25 were winter-annual, biennial, and perennial species. Four of these 25 are confirmed hosts of IYSV, indicating that these species are potential overwintering reservoirs and sources for IYSV in New York. By estimating densities of *T. tabaci* larvae on these weeds, and estimating the abundance of these weeds in the region, common burdock, *Arctium minus* (Hill) Bernh., and dandelion, *Taraxacum officinale* G.H. Weber ex Wiggers, were estimated to be the most important weeds in the epidemiology of IYSV in this region.

INTRODUCTION

Onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), is a major pest of onion and other *Allium* spp. worldwide (Lewis 1997). *T. tabaci* damage onion plants by feeding on leaf tissue, often leading to significant reductions in bulb yield (Fournier et al. 1995; Childers 1997). *T. tabaci* is the only thrips species considered as a pest of dry bulb onion in New York. Populations of *T. tabaci* overwinter in crops and weedy vegetation (North &

Shelton 1986) as well as in the soil within and/or near onion fields (Larentzaki et al. 2007). Adult *T. tabaci* are observed from late March through May on volunteer onion plants (Larentzaki et al. 2007), which sprout from bulbs remaining in the field from the previous season. During this time, onion seed is planted and onion plants are transplanted. Colonization of onion crops begins in June and populations are found on the crop until harvest from late-July through September. After harvest, *T. tabaci* adults have been observed on several weed species including common lambsquarters, *Chenopodium album* L., evening primrose, *Oenothera biennis* L., yellow nutsedge, *Cyperus esculentus* L., and smooth pigweed, *Amaranthus hybridus* L. (Larentzaki et al. 2007). It was not known whether *T. tabaci* reproduce on these weeds or if they reproduce on other weeds present in this cropping system.

T. tabaci is the only reported vector of *Iris yellow spot virus* (IYSV) (*Bunyaviridae: Tospovirus*), a serious yield-reducing pathogen of onion and other *Allium* spp. worldwide (Gent et al. 2006). IYSV is transmitted by *T. tabaci* in a persistent, circulative manner (Ullman et al. 1992; Whitfield et al. 2005), and *T. tabaci* is the only naturally reported vector (Kritzman et al. 2001) although *Frankliniella fusca* has shown the ability to transmit IYSV in laboratory experiments (Srinivasan et al. 2009). Vectors are only known to acquire tospoviruses as first instars, and are only known to transmit as second instars or adults (Ullman et al. 1992; Wijkamp et al. 1993). IYSV is not known to be seed-transmitted (Gent et al. 2004), nor is it easily transmitted by mechanical means (Marc Fuchs, personal communication).

IYSV was first identified in Brazil in 1981 (de Ávila et al. 1981) and has since spread to regions of onion production across the globe (Gent et al. 2006). IYSV was first detected in New York onion fields in 2006 (Hoepting et

al. 2007) and has since been found throughout the state (Nault et al. 2008). In 2007 and 2008, surveys in New York onion fields did not detect IYSV until mid-June to mid-July and levels in these fields were very low until early to mid August; 0 to12% of samples within a field tested positive at this time (Hsu et al. 2010a). IYSV incidence levels in many onion fields increased dramatically during the second half of August with some fields experiencing infection levels greater than 90% by harvest (Hsu et al. 2010a).

In addition to onion, there are at least 46 plant species in 19 families known to host IYSV (Table 1), many of which are weed species not in the genus *Allium* (Gent et al. 2006). In 2007 and 2008 in New York, Hsu et al. (2010b) tested a number of common weed species for IYSV. Four species tested positive including common burdock, *Arctium minus* Bernh., chicory, *Cichorium intybus* L., curly dock, *Rumex crispus* L., and dandelion, *Taraxacum officinale* G.H. Weber ex Wiggers. (Table 1). The frequency of infection in each weed species was not reported. If these four species serve as sources for IYSV in the onion ecosystem, they would need to support reproduction of the vector for at least one generation, allow the virus to be acquired by the vector, their life cycles must be complimentary to that of the virus and the vector (Culbreath et al. 2003) and they would need to be relatively abundant in the landscape. Among these criteria, the most fundamental should be the ability of a weed species to support reproduction of the vector.

In addition to the aforementioned weed species, other species may be sources for IYSV in New York's onion ecosystem. However, many of the hosts for IYSV listed in Table 1 are unlikely to be significant candidates because they are summer annuals. *Tospovirus* spp. are not known to be seed-transmissible (Kritzman et al. 2001), so it is unlikely that summer annual weeds would

Table 2.1 Plant species reported to be hosts of IYSV.

Species	Common name	Location[1]	Reference	Habit[2]	NY[3]
Alstroemeriaceae					
Alstroemeria sp. L.	Peruvian lily	Japan	Okuda and Hanada 2001	P	
Amaranthaceae					
Amaranthus retroflexus L.	Redroot pigweed	Colorado	Gent et al. 2006	SA	x
Atriplex micrantha L.	Twoscale saltbush	Utah	Evans et al. 2009a	P	
Chenopodium album L.	Common lambsquarter	Oregon	Sampangi et al. 2007	SA	x
C. amaranticolor Coste and Reyn.	Ornamental lambsquarter	Isreal	Gera et al. 2002	SA	
C. quinoa Willd.	Quinoa	Israel	Gera et al. 1998	SA	
Gomphrena globosa L.	Globe amaranth	Israel	Mohan et al. 1991	SA	
Kochia scoparia Roth	Kochia	Oregon	Sampangi et al. 2007	SA	x
Amaryllidaceae					
Allium spp.[4] L.	Onion, garlic, leek, etc.	Brazil	de Ávila et al. 1981	B/P/C	x
Clivia miniata Regel	Kaffir-lily	Japan	Jones 2005	P	
Hippeastrum hybridum Herb.	Amaryllis	Israel	Gera et al. 1998	P/C	
Araceae					
Scindapsus sp.	Scindapsus	Iran	Ghotbi et al. 2005	P	
Asteraceae					
Arctium minus Bernh.	Common burdock	New York	Hsu et al. 2010b	B	x
Chrysanthemum sp.	Chrysanthemum	Poland	Balukiewicz & Kryczinski, 2005	P	
Cichorium intybus L.	Chicory	New York	Hsu et al. 2010b	P	x
Lactuca serriola L.	Prickly lettuce	Oregon	Sampangi et al. 2007	P	x
Sonchus asper (L.) Hill	Spiny annual sowthistle	Georgia	Nischwitz et al. 2007	WA/B/P	x
Taraxacum officinale G.H. Weber ex Wiggers	Dandelion	New York	Hsu et al. 2010b	P	x
Cycadaceae					
Cycas sp. L.	Ornamental palm	Iran	Ghotbi et al. 2005	P	
Fabaceae					
Vicia sativa L.	Common Vetch	Georgia	Mullis et al. 2004	WA/C	
Vigna unguiculata (L.) Walp.	Black-eyed pea	Iran	Ghotbi et al. 2005	C	
Gentianaceae					
Eustoma grandiflorum Salisb.	Texas bluebell	Japan	Doi et al. 2003	B/P	

Table 2.1 (Continued)

Eustoma russellianum Salisb.	lisianthus	Israel	Kritzman et al. 2000	P/C	
Geraniaceae					
Geranium carolianum L.	Carolina geranium	Georgia	Mullis et al. 2004	B	
Pelargonium x hortorum L'Hér	Common geranium	Iran	Ghotbi et al. 2005	P	
Iridaceae					
Iris holandica L.	Iris	Ned.	Cortes et al. 1998	P	
Poaceae					
Setaria viridis (L.) P. Beauv.	Green foxtail	Utah	Evans et al. 2009b	SA	x
Polygonaceae					
Rumex crispus L.	Curly dock	New York	Hsu et al. 2010b	P	x
Portulacaceae					
Portulaca oleracea L.	Common purslane	Italy	Cosmi et al. 2003	SA	x
Rosaceae					
Rosa sp. L.	Rose	Iran	Ghotbi et al. 2005	P	
Scrophulariaceae					
Linaria Canadensis (L.) Dumort.	Blue toadflax	Georgia	Mullis et al. 2004	WA/B/P	
Solanaceae					
Capsicum annuum L.	Pepper	Tunisia	Ben Moussa et al. 2005	C	
Datura stramonium L.	Jimson weed	Israel	Gera et al. 1998	SA	
Nicotiana benthamiana Domin	Ornamental tobacco	Iran	Hall et al. 1993	C	
N. rustica L.	Tobacco	Brazil	Pozzer et al. 1999	C	
Petunia x hybrid Juss.	Petunia	Iran	Ghotbi et al. 2005	P	
Solanum lycopersicum L.	Tomato	Tunisia	Ben Moussa et al. 2005	C	
S. tuberosum L.	Potato	Tunisia	Ben Moussa et al. 2005	C	x
Themidaceae					
Bessera elegans Schult. f.	Coral drops	Japan	Jones 2005	P	
Zygophyllaceae					
Tribulus terrestris L.	Puncturevine	Oregon	Sampangi et al. 2007	SA/P	

Table 2.1 (Continued)

[1]Location of first detection.
[2]Most common life history: B = biennial, P = perennial, WA = winter annual, SA = summer annual, C = crop. Combinations indicate that multiple life histories are common.
[3]Species typically found in New York's onion ecosystems.
[4]Includes seven species of *Allium*: cultivated onion, *A. cepa* (de Ávila et al. 1981; Hall et al. 1993), shallot, *A. cepa* var. *ascalonicum* (Robene-Soustrade et al. 2006), leek, *A. porrum* (Coutts et al. 2003), garlic, *A. sativum* (Robene-Soustrade et al. 2006), and wild onions, *A. altaicum, A. pskemense*, and *A. vavilovii* (Pappu et al. 2006).

emerge in the spring and summer infected with IYSV. Summer-annual weed species compete temporally with onion as a host for *T. tabaci* and viruliferous *T. tabaci* would need to preferentially colonize the summer annual weed species rather than the onion crop. Thus, if a summer annual weed species was an important source for IYSV, it would need to become infected in the summer, colonized by *T. tabaci* in the summer and then future generations of *T. tabaci* adults would need to disperse from it into the onion crop. Such a scenario would not occur until late in the season, perhaps when the onion crop is near harvest or already harvested.

In contrast to summer-annual species, winter-annual, biennial, and perennial weed species could be available as hosts for *T. tabaci* early in the spring and late in the fall when the onion crop is not available as a host. These weed species would have the potential to be epidemiological bridges between cropping seasons for IYSV because they survive through the winter in New York. Potential candidates include the four species identified by Hsu et al. (2010b) plus two other species: the perennial, prickly lettuce, *Lactuca serriola* L. (Sampangi and Mohan 2007), and the winter-annual, spiny sowthistle, *Sonchus asper* (L.) Hill (Nischwitz et al. 2007). Others may exist as well, but have yet to be identified.

Developing future management strategies for IYSV in onion will require knowledge about IYSV epidemiology in onion ecosystems, especially identification of non-crop hosts that may be significant sources for this virus. The objectives of this study were to: (1) identify weed species that host *T. tabaci* larvae, especially winter-annual, biennial, and perennial species; (2) determine the overall abundance and temporal patterns of *T. tabaci* densities on weed species known to be a reproductive host for *T. tabaci* and a host for

IYSV; and (3) identify weed species that may be the best candidates for impacting the epidemiology of IYSV in the onion ecosystem.

MATERIALS AND METHODS

A. Sampling Location and Period

Thrips were collected and weeds sampled from five sites located in the Elba muck region of western New York (43.1N, 78.1W), the second largest onion producing region in the state, in 2008 and 2009. Sites were separated from each other by a distance of at least 1.5 km. Data collection sites were selected for their proximity to onion fields and were located in areas of fallow land 10m to 50m parallel and adjacent to onion fields. Each site was sampled in both years of this study through the duration of the onion growing season, starting before onions were colonized by thrips and ending after onions were harvested. In addition to sampling thrips on weeds, 15 onion plants in the field nearest to the weed sample site were visually inspected for onion thrips larvae and the number per plant was recorded. In 2008, data were collected every two weeks from 9 May to 30 August and again on 26 September (10 sampling dates). In 2009, data were collected every two weeks from 18 May through 5 October (11 sampling dates). This schedule was chosen to ensure that data were collected before, during and after the onion growing season.

B. Sampling Weeds and *T. tabaci*

At each of the five collection sites in both years of this study, entire plants or leaf subsamples were collected and the numbers of *T. tabaci* adults and larvae were recorded. No more than five plants per weed species were collected per collection site. Plants were combined to produce one composite

weed species-sample per site per sampling date; however, data were represented as the number of thrips per plant per site per sampling date. Not all weed species were present at each site and not all species were collected on each sample date. The composite samples were placed in a 5.68 L polypropylene container (Sterilite Corporation, Townsend, MA) and maintained in an environmental chamber at 29°C, 78% RH, and 16:8 L:D until analysis. Lids of containers were fitted with thrips-proof screen for ventilation (150µ x 150µ). Entire plants were collected when possible, but larger plants required the collection of a representative sub-sample of leaves. In such cases, leaf numbers were recorded for each sampled plant so thrips populations could be extrapolated to a per-plant basis for further comparisons.

C. Identifying *T. tabaci* from Weeds

If *T. tabaci* larvae were collected from a weed species, the weed was considered as a reproductive host. Because identification keys do not exist for *T. tabaci* larvae, thrips larvae were removed from plant samples and reared to the adult stage. Using a fine paintbrush, up to 30 larvae per composite weed sample were transferred to ventilated petri dishes containing leaf disks of cabbage, *Brassica oleracea* L. (Capitata group), and reared to adulthood following the procedure described in Nault et al. (2006). Based on experience rearing *T. tabaci* larvae, those larvae that were clearly not *T. tabaci* were not collected. Adult thrips were identified and counted according to species (Moritz et al. 2001). The percentage of thrips larvae determined to be *T. tabaci* was multiplied by the total number of larvae in the petri dish to estimate the number of *T. tabaci* larvae per plant. Voucher specimens are maintained at the NYSAES in Geneva, NY.

D. Weed Population Density Estimates

Each sample date, weed densities at each of the five sites were estimated by recording the number of individuals of each weed species in 0.5m by 0.5m quadrats placed every 10m along a 90m linear transect parallel to the respective onion fields[1]. Numbers of plants per species in all 10 quadrats were totalled at each site and then across all sites on each sampling date. These totals were divided by the total area sampled per date (12.5 m^2) to estimate the number of plants per m^2. Weed densities are presented on a plants per hectare basis by extrapolating the mean number of plants per species on each sampling date. Values for all sampling dates were averaged to obtain an estimated mean number of plants per hectare for each weed species.

E. Identifying weed species that may be important in IYSV epidemiology

A weed species that may be an important epidemiological source for IYSV must be a reproductive host for *T. tabaci*, but also may need to be relatively abundant in the landscape. The potential importance of a weed species being a source of IYSV was estimated by calculating numbers of *T. tabaci* larvae per hectare for each weed species. *T. tabaci* larval populations (larvae per plant per sampling date) on IYSV-susceptible winter-annual, biennial and perennial weed species were multiplied by each species' respective population density (plants per hectare) to determine the number of larvae per hectare per sampling date.

[1] Transects at each of the five collection sites occurred in the same locations through the duration of this study and were adjacent to areas where weeds were collected for thrips population surveys.

RESULTS

A. Larval *T. tabaci* population survey on weeds

Sixty-nine winter-annual, biennial, and perennial weed species and four crop species were sampled over two years. Twenty-five weed species and three crop species were identified as hosts for *T. tabaci* larvae (Table 2). No *T. tabaci* larvae were observed on 44 weed species and one crop species (Table 3). Of the 25 weed species that were hosts for *T. tabaci* larvae, only common burdock, chicory, curly dock, and dandelion are known hosts for IYSV (Hsu et al. 2010b). *T. tabaci* larvae were identified on common burdock and dandelion in both 2008 and 2009, but were found on curly dock only in 2008 and on chicory only in 2009 (Figure 1). Mean densities of *T. tabaci* larvae were highest on common burdock in 2008 and highest on both common burdock and dandelion in 2009.

Though they are not likely to be important epidemiological sources for IYSV, *T. tabaci* larvae were identified on the following summer annual weeds: redroot pigweed, *Amaranthus retroflexus* (Amaranthaceae), common lambsquarters (Amaranthaceae), lady's-thumb, *Persicaria maculosa* (Polygonaceae), wild buckwheat, *Polygonum convolvulus* (Polygonaceae), and green smartweed, *P. scabrum* (Polygonaceae).

B. Seasonal dynamics of *T. tabaci* on weeds and onions

In 2008 and 2009, populations of *T. tabaci* were much greater on onion plants than on weeds. Peaks in adult *T. tabaci* populations on weeds were recorded on common burdock, chicory, curly dock, and dandelion early in the season, and again late in the season when onions were harvested (Figures 2A and 2B). On chicory, adults were only observed on 9 June and 26 September,

Table 2.2 Winter annual, biennial, and perennial weed species found to be reproductive hosts of *T. tabaci* in the Elba Muck onion growing region near Elba, New York.

Family / Species[1]	Common name	Habit[2]	Period[3]	*T. tabaci* larvae per plant[4] 2008	$SE_{\bar{x}}$[5]	2009	$SE_{\bar{x}}$[5]
Weed species							
Apiaceae							
Conium maculatum L.	Poison hemlock	B	A	0.54	0.36	0.52	0.23
Asclepiaceae							
Asclepias syriaca L.	Common milkweed	P	A	0.36	0.24	0	0
Asteraceae							
Arctium minus Bernh.*	Common burdock	B	A	0.36	0.22	0.46	0.25
Cichorium intybus L.*	Chicory	P	A	0	0	0.02	0.02
Cirsium arvense (L.) Scop.	Canada thistle	P	A	0	0	0.05	0.05
Solidago Canadensis L.	Goldenrod	P	A	0.06	0.03	0.09	0.09
Taraxacum officinale G.H. Weber ex Wiggers*	Dandelion	P	A	0.08	0.05	0.44	0.44
Brassicaceae							
Barbarea vulgaris Ait. f.	Yellow rocket	WA/B/P	A	0.23	0.14	2.45	1.64
Capsella bursa-pastoris (L.) Medik.	Shepherd's purse	WA	Sp	0.39	0.34	0	0
Lepidium virginicum L.	Virginia pepperweed	WA	Sp, F	0.51	0.33	0.34	0.34
Raphanus raphanistrum L.	Wild radish	WA	Sp	1.80	N/A	N/A	N/A
Sinapis arvensis L.	Wild mustard	WA/B/P	A	1.07	0.52	3.42	1.73
Thlaspi arvense L.	Field pennycress	WA	Sp	0.09	0.09	2.27	2.27
Convolvulaceae							
Calystegia sepium (L.) R. Br.	Hedge bindweed	P	Sp, Su	0.04	0.04	0	0
Fabaceae							
Medicago lupulina L.	Black medic	P	A	0	0	0.13	0.12
Lamiaceae							
Lamium purpureum L.	Purple deadnettle	WA	Sp	0.04	0.04	0	0
Nepeta cataria L.	Catnip	P	A	0	0	1.14	0.64
Malvaceae							
Malva neglecta Wallr.	Common mallow	WA/B/P	A	0.54	0.50	0	0
Onagraceae							
Oenothera biennis L.	Evening primrose	B	A	0.03	0.03	0.24	0.24

Table 2.2 (Continued)

Oxalidaceae							
Oxalis stricta L.	Yellow woodsorrel	P	Su, F	0.27	0.18	N/A	N/A
Plantaginaceae							
Plantago lanceolata L.	Buckhorn plaintain	P	A	0	0	0.04	0.04
Poaceae							
Lolium sp.	Ryegrass	WA/B/P	Su	N/A	N/A	0.60	N/A
Polygonaceae							
Rumex crispus L.*	Curly dock	P	A	0.02	0.02	0	0
Scrophulariaceae							
Verbascum Thapsus L.	Common mullein	B	A	0.04	0.04	0	0
Urticaceae							
Urtica dioica L.	Stinging nettle	P	A	0.01	0.01	0	0
Crop species							
Amaryllidaceae							
Allium cepa L.*	Onion	B	A	27.74	18.29	14.56	4.64
Fabaceae							
Medicago sativa L.	Alfalfa	P	Sp, Su	0.10	0.10	0	0
Poaceae							
Secale sp., *Avena* sp., or *Hordeum* sp.	Rye, Oat, or Barley winter cover crop	WA	F	N/A	N/A	1.40	N/A

[1]Species denoted with an asterisk (*) are confirmed hosts of IYSV (Hsu et al. 2010b).
[2]Most common life history: SA = summer-annual, WA = winter annual, B = biennial, P = perennial, WA/B/P indicates that all three life-history variations are possible and are known to occur.
[3]Period when plants were sampled, indicating prevalence in the sampling location. Sp = spring sampling (May, June), Su = summer sampling (July, August), F = autumn sampling (September, October), A = sampling through the duration of the onion growing season (May through September and October).
[4]Populations were estimated to number of larvae per plant per sampling date except on hedge bindweed, black medic, purple deadnettle, ryegrass, common mallow, yellow woodsorrel, alfalfa, and the winter cover crop, where populations were estimated to number of larvae per $0.0125m^2$ per sampling date. N/A = no plants were sampled.
[5]Standard error of larvae per plant per sampling date or larvae per $0.0125m^2$ per sampling date. N/A = insufficient number of samples were collected for calculation (0 or 1).

Table 2.3 Winter-annual, biennial, and perennial weed species sampled from the Elba Muck onion growing region near Elba, NY in 2008 and 2009 that were not found to be hosts of *T. tabaci* larvae.

Family Species	Common name	Habit[1]
Apiaceae		
Daucus carota L.	Wild Carrot	B
Pastinaca sativa L.	Wild Parsnip	B
Apocynaceae		
Apocynum cannabinum L.	Hemp Dogbane	P
Asteraceae		
Achillea millefolium L.	Common Yarrow	P
Centaurea stoebe L. ssp. *micranthos* (Gugler) Hayek	Spotted Knapweed	P
Cirsium vulgare (Savi) Ten.	Bull Thistle	B
Conyza canadensis (L.) Cronq.	Horseweed	P
Erigeron philadelphicus L.	Philadelphia Fleabane	B/P
Hieracium canadense Michx	Canadian Hawkweed	P
Hieracium caespitosum Dumort	Yellow Hawkweed	P
Hypochaeris radicata L.	Catsear	P
Lactuca serriola L.	Prickly Lettuce	SA/WA/P
Senecio vulgaris L.	Common Groundsel	SA/WA
Sonchus arvensis L.	Perennial Sowthistle	P
Symphyotrichum novae-angliae (L.) G.L. Nesom	New England Aster	P
Brassicaceae		
Alliaria petiolata (M. Bieb.) Cavara & Grande	Garlic Mustard	B
Descurainia sophia (L.) Webb ex Prantl	Flixweed	WA/SA
Hesperis matronalis L.	Dame's Rocket	B/P
Rorippa palustris fernaldiana (Butters & Abbe) Jonsell	Marsh Yellow Cress	SA/WA/P
Caryophyllaceae		
Cerastium fontanum Baumg.	Mouse Ear Chickweed	P
Saponaria officinalis L.	Bouncing Bet	P
Silene latifolia alba (Mill.) Greuter & Burdet	White Campion	P
Dipsacaceae		
Dipsacus fullonum L.	Common teasel	B
Fabaceae		
Lotus corniculatus L.	Bridsfoot Trefoil	P
Trifolium pratense L.	Red Clover	P
Trifolium repens L.	White Clover	P
Lamiaceae		
Lamium amplexicaule L.	Henbit	WA
Oxalidaceae		
Oxalis stricta L.	Woodsorrel	P
Phytolaccaceae		
Phytolacca americana L.	Am. Pokeweed	P
Plantaginaceae		
Plantago major L.	Broadleaf Plantain	P

Table 2.3 (Continued)

Poaceae		
Bromus inermis Leyss.	Smooth Brome	P
Bromus secalinus L.	Rye Brome (cheat)	WA
Bromus tectorum L.	Downy Brome	SA/WA
Dactylis glomerata L.	Orchardgrass	P
Elytrigia repens (L.) Gould	Quackgrass	P
Holcus lanatus L.	Common Velvetgrass	P
Lolium multiflorum Lam.	Italian Ryegrass	WA/B/P
Phleum pratense L.	Timothy	P
Phragmites australis (Cav.) Trin. Ex Steud.	Phragmites	P
Poa annua L.	Annual Bluegrass	WA
Poa compressa L.	Canada Bluegrass	P
Ranunculaceae		
Ranunculus bulbosus L.	Bulbous Buttercup	P
Rosaceae		
Potentilla norvegica L.	Rough Cinquefoil	SA/WA/B/P
Potentilla recta L.	Sulphur Cinquefoil	P
Rubus spp. (R. occidentalis, etc.) L.	Wild Raspberry	B/P
Vitaceae		
Parthenocissus quinquefolia (L.) Planch.	Virginia Creeper	P
Vitis labrusca L.	Fox Grape	P

[1]SA = summer-annual, WA = winter-annual, B = biennial, P = perennial, and combinations indicate that multiple life histories are known to occur.

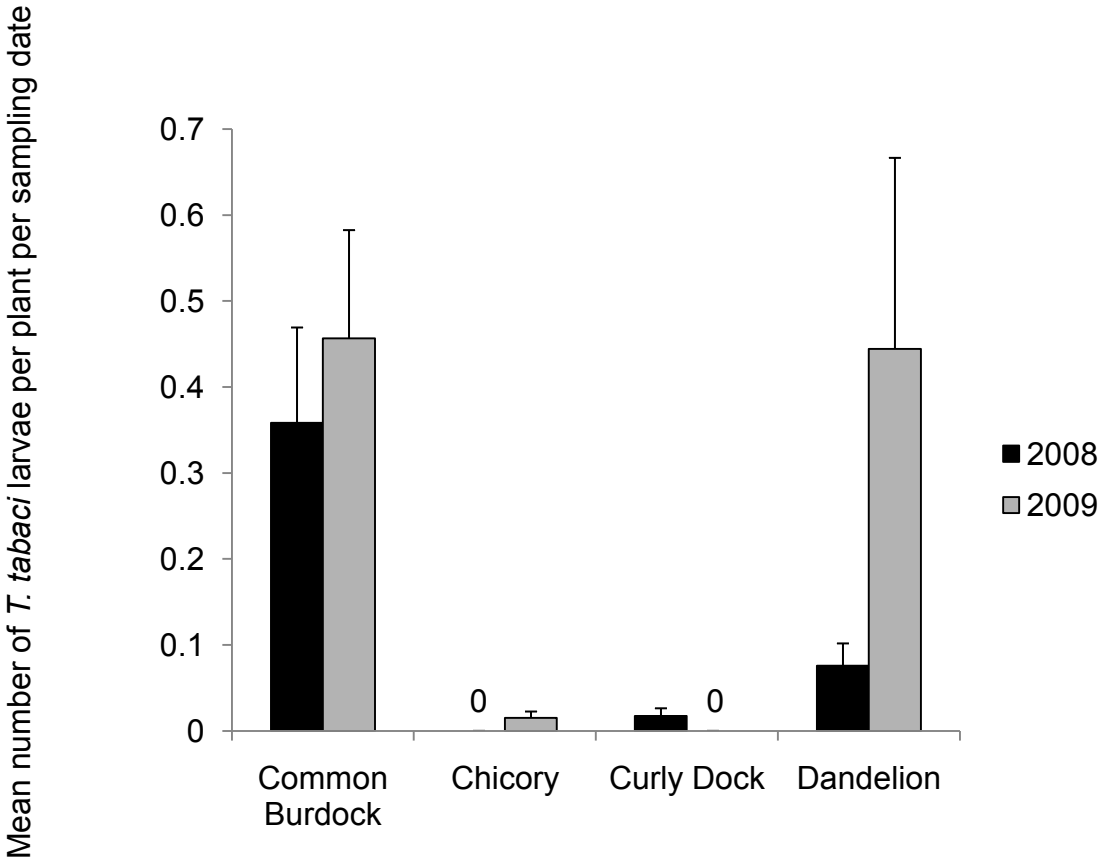

Figure 2.1 Mean populations of *T. tabaci* larvae ± (SE) on weed species known as hosts for IYSV in the Elba Muck onion growing region near Elba, New York, USA in 2008 and 2009.

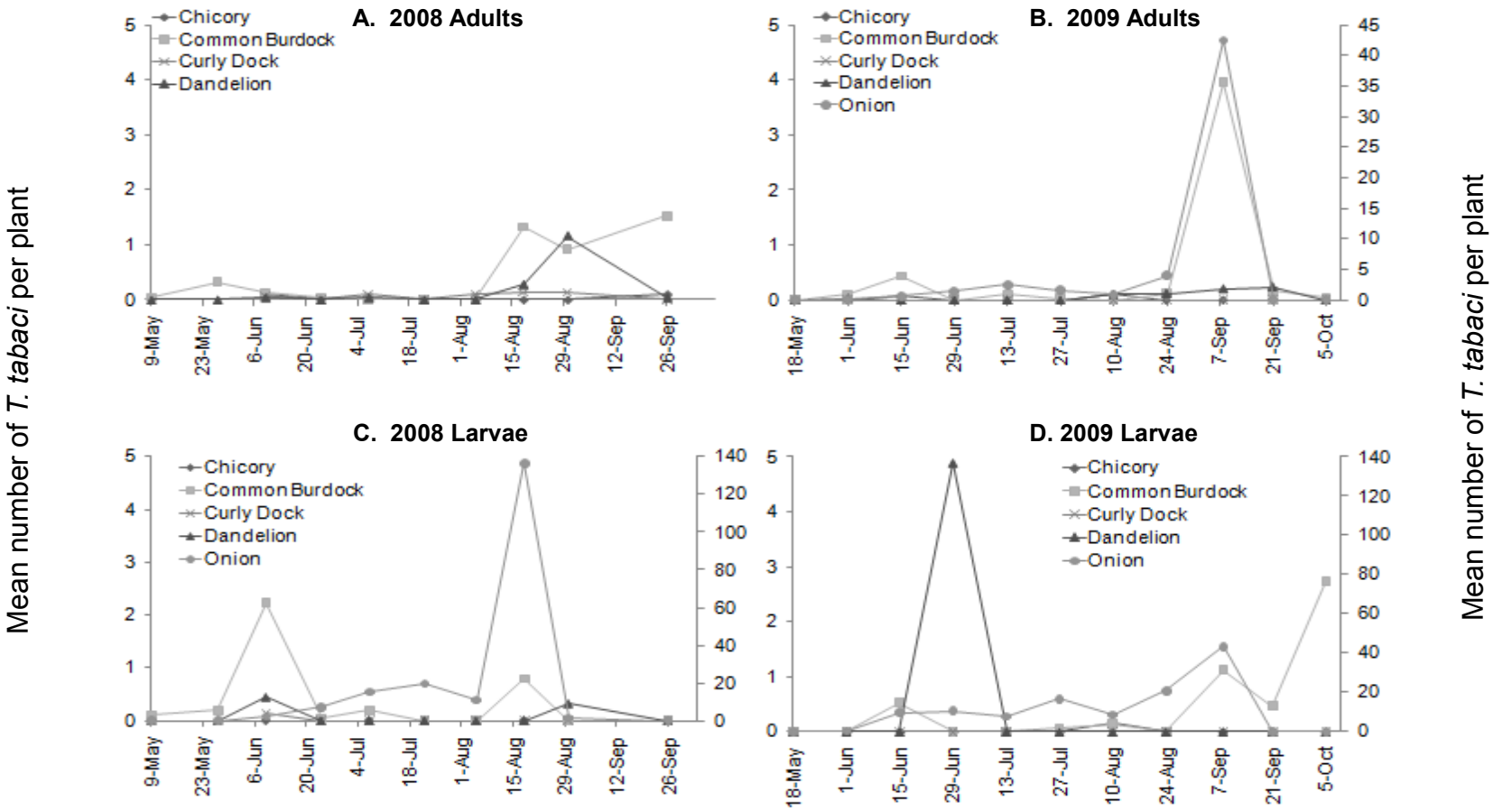

Figure 2.2 Temporal population densities of *T. tabaci* adults and larvae on onion and on four weed species known to be hosts for IYSV in 2008 and 20009 in the Elba Muck onion growing region near Elba, New York, USA[1].

[1]Adult *T. tabaci* were not counted on onion in 2008. The left Y axis corresponds to populations on chicory, common burdock, curly dock, and dandelion; In B, C, and D, the right Y axis corresponds to populations on onion.

2008, and on 15 June and 10 August, 2009. On common burdock, peaks in adult populations occurred on 27 May, 18 August and 26 September, 2008, and on 15 June and 8 September, 2009. On curly dock, minor peaks were observed on 9 June, 7 July, and on 18 August and 30 August, 2008. Adult *T. tabaci* were not observed on curly dock in 2009. On dandelion, minor peaks occurred on 9 June and 7 July, and one major peak occurred on 30 August, 2008. Similar observations were made on dandelion in 2009, where one minor peak occurred on 1 June, and populations increased from 10 August to a relatively major peak on 21 September. Adult onion thrips were present but not recorded on onion crops in 2008; however, adults were recorded on onion in 2009 as the value of comparing populations in weeds and onions became apparent. Adult populations on onion experienced an early-season peak of 2.5 thrips per plant on 13 July, 2009, declined in numbers over the next month, but began to rise again during August to a final peak of 42.47 thrips per plant on 8 September.

Peaks in larval populations on these weed species followed peaks in adult populations both early in the growing season (June) and during onion harvest (late August through September in 2008 and 2009, and into October in 2009) (Figures 2C and 2D). On chicory, larvae were not observed in 2008, and were observed only on 10 August, 2009. On common burdock, peaks in larval populations occurred on 9 June and 18 August, 2008, and on 15 June and on 8 September and 5 October, 2009. On dandelion, peaks in larval populations occurred on 9 June and 30 August, 2008, and on only 29 June, 2009. On curly dock, *T. tabaci* larvae were only observed on 9 June, 2008, and were not observed in 2009. Larval *T. tabaci* populations were first recorded on onion crops in early June of both years of this study. Populations

peaked on 22 July, and again on 18 August, 2008, and on 27 July, and 8 September, 2009.

C. Estimated weed population densities of potential IYSV sources

Dandelion averaged 21 and 44 times more abundant than common burdock, 6 and 8 times more abundant than chicory in 2008 and 2009, respectively (Fig. 3). Dandelion averaged to be 341 times more abundant than curly dock in 2008, and curly dock was not observed in survey transects in 2009. Curly dock was quite rare in survey transects in 2008, and thus it is not particularly surprising that it was absent in 2009 despite an observed presence in the region.

D. Estimated population densities of *T. tabaci* larvae on IYSV-positive weed hosts on a per area basis

In 2008 and 2009, the estimated populations of *T. tabaci* larvae per hectare per sampling date on common burdock and dandelion were considerably higher than those on chicory and curly dock (Figure 4).

DISCUSSION

T. tabaci utilized 25 weed species representing 14 families as reproductive hosts. These results indicate that despite a preference for onion (Doederlein & Sites 1993), *T. tabaci* larvae can exploit a wide variety of taxonomically diverse hosts. Still, 40% of the reproductive hosts (11 of 25 species) were members of Asteraceae (5 species) and Brassicaceae (6 species), and 84% of *T. tabaci* larvae observed on weeds during this study were observed on members of these two taxa.

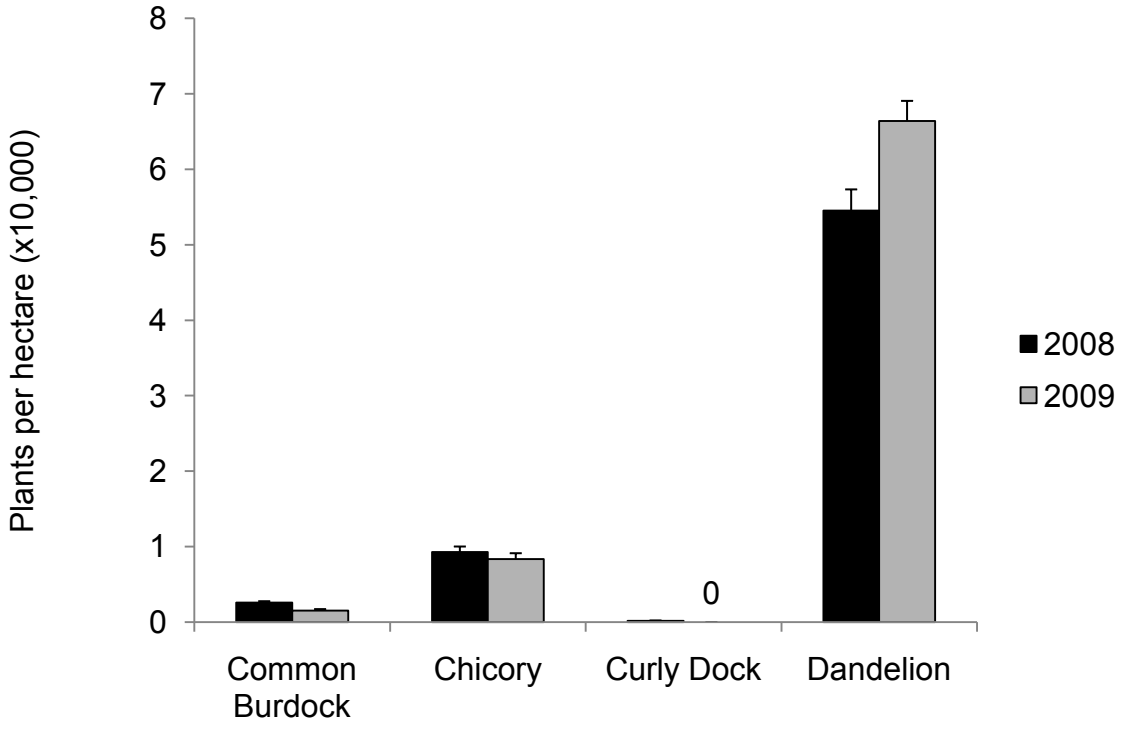

Figure 2.3 Estimated population densities ± (SE) of IYSV-positive weed species in 2008 and 2009 in the Elba Muck onion growing region near Elba, New York, USA.

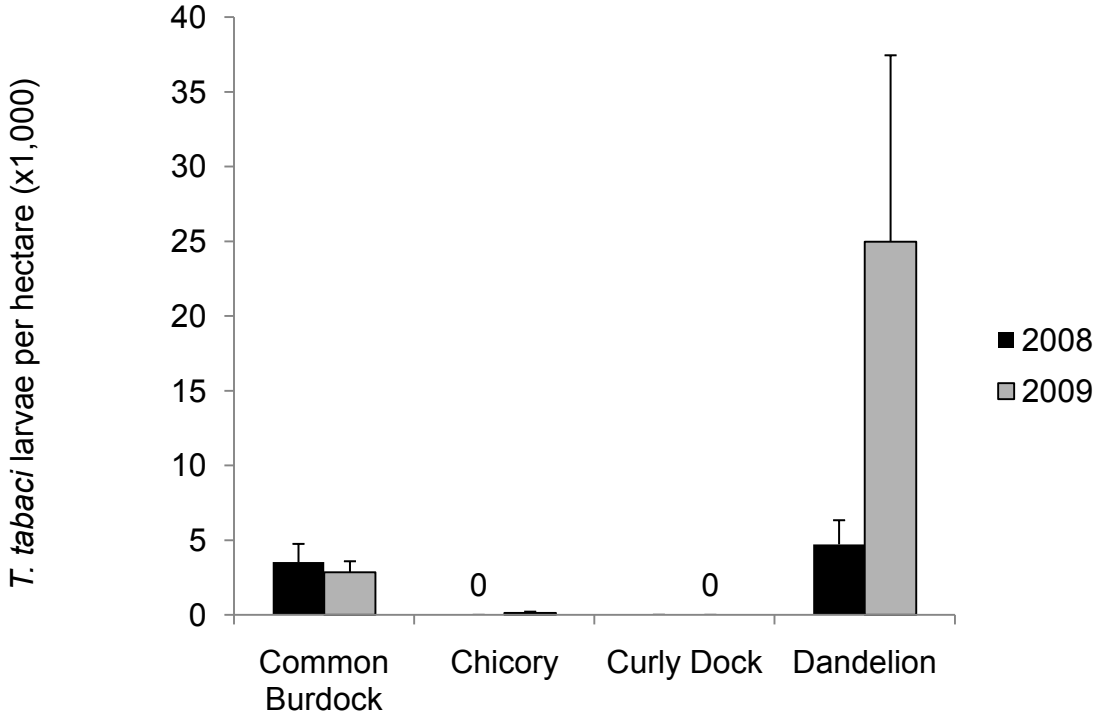

Figure 2.4 Estimated abundance ± (SE) of *T. tabaci* larvae per hectare on IYSV-positive weed species in the Elba Muck onion growing region near Elba, New York, USA.

A number of factors are likely responsible for *T. tabaci* to utilize a weed species as a host. Some of these factors include attraction to plant volatiles, nutrition, a relative absence of predators, or plant architecture that is favorable to thrips' cryptophilic and thigmotropic behavior (Lewis 1973). One of the more likely causes may be the abundance of Asteraceae and Brassicaceae species in the Elba Muck region. Asteraceae and Brassicaceae account for 22% and 9% of species in this region, respectively, and populations of their respective species are among the highest in the region (see Chapter 3). The highest larval densities were observed on four cruciferous species, yellow rocket, *Barbarea vulgaris* Ait. f., wild radish, *Raphanus raphanistrum* L., wild mustard *Sinapis arvensis* L., and field pennycress, *Thlaspi arvense* L. Populations of *T. tabaci* larvae were greater than 1 larva per plant per sampling date on all four of these species, and populations on wild mustard were greater than 2 larvae per plant per sampling date during this study. In addition to onion, *T. tabaci* is also a major pest of cabbage crops worldwide (North & Shelton 1986; Shelton et al. 1998; Zezlina & Blazic 2003). This suggests that there may be a characteristic of cruciferous plants that is conducive to supporting high populations of *T. tabaci*. The habit and architecture of cabbage and other cruciferous crops provide favorable habitats for *T. tabaci* as thigmophilic animals; however, this is not true for weedy crucifers. This suggests that the relative preference for Brassicaceae spp. over other surveyed weed species may have less to do with physical characteristics than other factors such as attraction to plant volatiles, nutritional value, or a lack of predators. As onion is the overall preferred host, however, no wild *Allium* spp. were observed in this study.

In both years of this study, populations of *T. tabaci* larvae peaked on

weeds in early to mid-June. As onions are seeded and transplanted in April and May, they are too small to be colonized in May and early June (EAS, personal observation). Although data were not collected in March or April in either year of this study, Larentzaki et al. (2007) found *T. tabaci* on volunteer onions as early as March. This indicates that *T. tabaci* are active well before colonizing onion crops (Fig. 2). During July and early August, densities of *T. tabaci* larvae decreased in weeds, but increased in onion crops. Late in the onion growing seasons of both years, larval densities experienced a second major peak in August and September, and into October in 2009. Larentzaki et al. (2007) observed adult *T. tabaci* on weeds as late as November. Onion crops are harvested from July through September, and *T. tabaci* adults originating in onion may migrate from these fields into nearby weeds to feed and reproduce.

Weeds are largely ubiquitous in all onion growing regions. *T. tabaci* adults have been found on weeds bordering onion fields (Larentzaki et al. 2007), and at least 47 plant species in 19 families are hosts of IYSV (Table 1). Eleven of these species are non-*Allium* weed species typically found in New York onion ecosystems (EAS, personal observation), and four have tested positive for IYSV in New York (Hsu et al. 2010b). Five of these 11 susceptible weed species are strictly summer annual species in New York, but as previously stated, *Tospovirus* spp. are not known to be seed-transmissible. Moreover, it is unlikely that summer annuals contribute significantly to the epidemiology of IYSV based on the reasons mentioned in the Introduction.

Winter-annuals, biennials and perennials have the potential to be overwintering reservoirs for IYSV, unlike summer annuals. Groves et al. (2002) suggested that infected summer-annuals may act as a reservoir for

TSWV in-between crop harvest and emergence of winter-annual weeds; however, this study was conducted in North Carolina, and it is unclear whether such a gap exists in the onion ecosystems in New York as onion crops are harvested in late-summer and into autumn when many winter-annuals have already germinated. Furthermore, infected biennial and perennial species are present throughout the year and could also bridge this gap, if it exists in New York. For these reasons, it is likely that winter-annual, biennial and perennial weeds have greater potential than summer-annuals as significant epidemiological sources of IYSV in New York onion ecosystems.

Of all weed species sampled in this study, common burdock, chicory, curly dock and dandelion were the only four species to (1) be identified as hosts of IYSV, (2), have winter-annual, biennial, or perennial life histories, and (3), host *T. tabaci* larvae. Considering these three criteria (Culbreath et al. 2003), four weed species have the capability to allow IYSV to persist in onion ecosystems in New York between growing seasons and to be sources of inoculum in spring if IYSV successfully overwinters and *T. tabaci* utilize them as reproductive hosts.

In both years of this study, common burdock and dandelion were observed as supporting the most *T. tabaci* larvae compared with chicory and curly dock. Prickly lettuce, *Lactuca serriola*, is a known host of IYSV (Sampangi et al. 2007) and *T. tabaci* larvae (Chatzivassiliou et al. 2007) and is a perennial weed known to inhabit agro-ecosystems in New York. However, of the 73 prickly lettuce plants sampled in this study, none were observed to be hosts of *T. tabaci* larvae.

Population density is likely to be an important factor in estimating the relative importance of a given weed species as a source of IYSV. As

important will be rates of acquisition and transmission of IYSV by *T. tabaci* among the most populous weed species. While transmission efficiencies are unknown in weed species associated with *T. tabaci* and IYSV, Okazaki et al. (2009) evaluated acquisition and transmission rates of TSWV by *Frankliniella occidentalis* (Thysanoptera: Thripidae) in sticky chickweed, *Cerastium glomeratum* Thuill., black nightshade, *Solanum nigrum* L., common chickweed, *Stellaria media* (L.) Vill., and *Galinsoga quadriradiata* Cav. TSWV acquisition rates by *F. occidentalis* for each species was 85.4%, 73.6%, 72.6%, and 35.6%, respectively, and transmission rates were 76.4%, 60.9%, 61.3%, and 29.9%, respectively. Their results indicate that weed species vary in their abilities as sources of TSWV. As IYSV and TSWV are closely related, this degree of variability in acquisition and transmission may be likely for *T. tabaci* and weed hosts of IYSV. Analogous studies involving *T. tabaci* transmission efficiencies of IYSV from weeds to onions and from onions to weeds will be important steps in identifying the most important weed sources of IYSV in the onion ecosystem.

Populations of *T. tabaci* larvae per hectare on common burdock and dandelion were estimated to be greater than on chicory and curly dock. These observations suggest that the potential impacts of chicory and curly dock on IYSV epidemiology in New York may be relatively inconsequential when compared with the likely impacts of common burdock and dandelion. Common burdock has been observed with high populations of *T. tabaci* larvae, but its relative infrequency in the landscape suggests that its impact on the spread of IYSV may be more localized than that of dandelion.

Common burdock's biennial life habit may also affect its relative impact on IYSV persistence. TSWV has known to persist in perennial plants for

multiple years (Groves et al. 2002). While such studies have not been conducted with regard to IYSV, this may mean that IYSV has the ability to persist in dandelion plants for multiple seasons. Conversely, common burdock lives through only one winter before the plant's life cycle is complete, and an infected burdock plant is likely to be a source for only one onion growing season. This may be especially important for IYSV persistence following cool, wet growing seasons as thrips populations are known to be negatively impacted by such conditions (Liu 2004). In addition to these reasons, the compact rosette growth habit of dandelion plants offer *T. tabaci* a suitable habitat. For these reasons, dandelion may have the greatest impact on IYSV epidemiology among the candidate weed species that are likely sources for IYSV.

Upon further research, we will be able to more accurately estimate the relative importance of weed species to the epidemiology of this virus. This research should include investigation of the dispersal capabilities of *T. tabaci* and the effect of distance of weeds to onion crops on *T. tabaci* populations and IYSV incidence. Overwintering capabilities of IYSV in specific weeds as well as acquisition and transmission efficiencies must also be investigated. These findings will provide us with valuable information needed to formulate strategies for effective IYSV management in the future.

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Chapter 3

ABUNDANCE OF POTENTIAL WEED HOSTS FOR MAJOR VIRUSES OF MUCK VEGETABLE CROPS IN WESTERN NEW YORK STATE

Abstract

In 2008 and 2009, ninety-eight weed species were recorded in a season-long survey in the Elba Muck vegetable production region in western New York State. Forty-nine of the species were members of three plant families: Asteraceae, Brassicaceae, and Poaceae. At least seventeen of the weed species are confirmed hosts of *Iris yellow spot virus* (IYSV) (*Bunyaviridae: Tospovirus*), *Potato leafroll virus* (PLRV) (*Luteoviridae*: *Polerovirus*), and *Potato virus Y* (PVY) (*Potyviridae*: *Potyvirus*). These pathogens are most deleterious to onion and potato crops. Weed hosts of IYSV, PLRV and PVY are among the most abundant in the region, and as such, effective weed control strategies should comprise a key role in the management of these highly damaging plant viruses.

INTRODUCTION

Muck soil is a highly organic soil type that is remarkably loose and resistant to compaction and allows roots and tubers to grow larger and deeper than in mineral soils. Muck soils retain more moisture than mineral soils (Lyon et al. 1920); however, highly efficient drainage systems permit better drainage and a decreased incidence of root-rot for bulbing and tuberous vegetable crops. These characteristics make muck soil an ideal medium for growing onion, *Allium cepa* L., and potato, *Solanum tuberosum* L.

Onion is one of New York State's most valuable crops, typically grossing $50 to 60 million annually (NASS 2010). Potato is also a major crop in NY, typically valued at $55 to 85 million (NASS-NY 2009). While nearly all onion crops are grown in muck soil in NY, a relatively small portion of potato crops are grown in muck in NY; however, muck acreage devoted to potato is highest in the Elba Muck vegetable production region of western New York (43.1N, 78.1W) (NASS-NY 2008). The Elba Muck region is an area of approximately 2,500 contiguous hectares of muck soils and is almost entirely devoted to vegetable crops, two of the most valuable crops being onion and potato.

Several weed species have been documented as hosts of deleterious viruses infecting onion and potato (Gent et al. 2006; Johnson 2008). *Iris yellow spot virus* (IYSV) (*Bunyaviridae*: *Tospovirus*) is a yield-reducing pathogen of onion and other *Allium* crops (Gent et al. 2004). IYSV is found in areas of onion production worldwide (Gent et al. 2006), and at least 46 plant species have tested positive for IYSV, many of which are weeds (see Chapter 2). In NY, redroot pigweed, *Amaranthus retroflexus* L., common burdock, *Arctium minus* Bernh., common lambsquarters, *Chenopodium album* L., chicory, *Cichorium intybus* L., curly dock, *Rumex crispus* L., and dandelion, *Taraxacum officinale* G. H. Weber ex Wiggers, were identified as weed hosts of IYSV as well as its vector, onion thrips, *Thrips tabaci* Lindeman (see chapter 2). There may be additional weed species that are hosts for IYSV, but have yet to be identified.

Potato leafroll virus (PLRV) (*Luteoviridae*: *Polerovirus*) and *Potato virus Y* (PVY) (*Potyviridae*: *Potyvirus*) are the two most important viruses infecting potato crops (Hooker 1981; Singh et al. 2008). There are also common weed

species known as hosts for both PLRV and PVY such as shepherd's purse, *Capsella bursa-pastoris* (L.) Medik. (Ellis 1992; Kazinczi et al. 2004) and lamsquarters (Kazinczi et al. 2004). Redroot pigweed is a host for PLRV (Natti et al. 1953) and others likely exist as well. These weed species and others are known to occur in western New York, but their relative abundance in the vegetable producing landscape in this region is not known.

A comprehensive survey of common weed species, including those known as hosts for IYSV, PLRV and PVY, would be valuable for understanding the epidemiology and management of these viruses in the agroecosystem where onion and potato are grown. Thus, the objective of this study was to estimate densities of the most common weed species in the Elba Muck region of Western New York State, keeping in mind that some of these species are known hosts for IYSV, PLRV, and PVY.

MATERIALS AND METHODS

A. Sampling location and period

Weed population densities were recorded from five sites located in the Elba Muck region of New York in 2008 and 2009. Sites were separated from each other by > 1.5 km. Each site was a 10 m by 90 m area of fallow land that was adjacent to a muck field that was currently in vegetable production. The same site was sampled in both years of this study. In 2008, data were collected every two weeks from 9 May to 30 August and again on 26 September (10 sampling dates). In 2009, data were collected every two weeks from May 18 through October 5 (11 sampling dates). This schedule was chosen to ensure that summer-annuals, winter-annuals, biennials, and perennials would be encountered in the sampling.

B. Weed survey and density estimates

On each sample date, weed densities at each of the five sites were estimated by recording the number of individuals per weed species in a 0.25 m^2 quadrat every 10 m over a 90 m linear transect. Quadrats were not permanent but were located at permanent transects. Transects were located >50 m from vegetable crop fields and were parallel to their respective fields. For this study, a single quadrat was constructed from PVC pipe. The internal dimensions of the quadrat measured 1 m^2. String was tied to opposing legs of the quadrat to divide the greater quadrat into sixteen cells each 0.0625 m^2. Weeds were categorized as either singular broadleaf weeds that could be quantified to a per-plant basis or as plants that required quantification to a percent cover basis. In the interest of simplicity, this latter category of species will be referred to as clonal species. This category included poaceous weeds and broadleaf weeds exhibiting cespitose, prostrate or creeping habits.

On each sampling date, singular broadleaf weed populations were estimated by counting the number of plants per species in the four innermost cells (0.25 m^2) of each of the ten quadrats at each site. For clonal species, percentage cover in the 0.25 m^2 quadrats was visually estimated. Data were recorded by the same observer each year. Populations in these 10 quadrats were totalled at each site and again across all sites on each sampling date. Thus, total abundance of singular broadleaf species was divided by the total area sampled per date (12.5 m^2) to estimate the number of plants per m^2. These estimates were then extrapolated to a plants per hectare basis on each sampling date. Values for all sampling dates were averaged to find the estimated mean plants per hectare for each weed species over the course of the season. Population densities of percent-cover species were estimated by

calculating the mean % cover over all transects on each sampling date, then calculating the mean % cover per sampling date. Transects at each of the five sites occurred in the same locations throughout the duration of this study.

RESULTS AND DISCUSSION

Ninety-eight weed species were identified in this study, including 55 singular broadleaf species and 43 clonal broadleaf weeds and grasses (Tables 1 and 2). Fifty percent of all species identified in this study were members of families Asteraceae, Brassicaceae, and Poaceae, accounting for 22, 9, and 18 weed species, respectively. Species from these families were also among the most prevalent with 7 of the 11 most abundant species in the Asteraceae, including dandelion, Canada goldenrod, *Solidago canadensis* L., and Canada thistle, *Cirsium arvense* (L.) Scop. Five of the 10 most abundant clonal species were grasses (Poaceae), including fall panicum, *Panicum dichotomiflorum* Michx, Canada bluegrass, *Poa compressa* L., and timothy, *Phleum pratense* L.

Of the 98 weed species observed, 17 are known hosts of viruses infecting onion and potato, two of the most valuable crops in the Elba Muck region of Western New York State (Table 3). Ten species identified in our study are known hosts of IYSV, four species are known hosts for PLRV and at least 13 species are known to be susceptible to PVY. Lambsquarter is a host for all three viruses. Lambsquarter, redroot pigweed, shepherd's purse, horseweed, and dandelion were among the most abundant weeds observed in this study (Table 1).

Many of the species identified in this study are known to be susceptible

Table 3.1 Density (plants/hectare) of singular broadleaf weed species recorded in fallow areas adjacent to crop fields in the Elba Muck vegetable production region, Genesee and Orleans Counties, NY, USA in 2008 and 2009[1].

Family	Species	Common Name	Biology[2]	Plants/ha 2008	2009	Mean
Asteraceae	*Taraxicum officinale* G.H. Weber ex Wiggers	Dandelion	P	54600	66255	60427
Asteraceae	*Solidago canadensis* L.	Canada Goldenrod	P	55120	26109	40615
Asteraceae	*Cirsium arvense* (L.) Scop.	Canada Thistle	P	39160	36073	37616
Chenopodiaceae	*Chenopodium album* L.	Common Lambsquarters	SA	42960	2182	22571
Asteraceae	*Conyza canadensis* (L.) Cronq.	Horseweed	P	42440	1673	22056
Amaranthaceae	*Amaranthus retroflexus* L.	Redroot Pigweed	SA	25920	10618	18269
Brassicaceae	*Sinapis arvensis* L.	Wild Mustard	WA/B/P	25520	7127	16324
Urticaceae	*Urtica dioica* L.	Stinging Nettle	P	20880	10255	15567
Asteraceae	*Erigeron* spp. L.	Fleabane spp.	SA	10560	18400	14480
Asteraceae	*Matricaria discoidea* D.C.	Pineapple weed	SA	23720	218	11969
Asteraceae	*Artemisia vulgaris* L.	Mugwort	P	12080	9527	10804
Plantaginaceae	*Plantago lanceolata* L.	Buckhorn Plantain	P	7640	13891	10765
Brassicaceae	*Thlaspi arvense* L.	Field Pennycress	WA	9800	8655	9227
Asteraceae	*Cichorium intybus* L.	Chicory	P	8880	8364	8622
Brassicaceae	*Lepidium virginicum* L.	Virginia Pepperweed	WA	8920	7709	8315
Brassicaceae	*Capsella bursa-pastoris* (L.) Medik.	Shepherd's Purse	WA	12560	3491	8025
Asteraceae	*Solidago* sp. L.	Solidago	P	9360	3418	6389
Asteraceae	*Ambrosia artemisiifolia* L.	Common Ragweed	SA	8640	2036	5338
Apiaceae	*Daucus carota* L.	Wild Carrot	B	5160	4509	4835
Apocynaceae	*Asclepias syriaca* L.	Common Milkweed	P	6320	2473	4396
Asteraceae	*Hieracium caespitosum* Dumort	Yellow Hawkweed	P	2680	3345	3013
Solanaceae	*Solanum ptycanthum* Dunal	East. Black Nightshade	SA	4120	1600	2860
Ranunculaceae	*Ranunculus bulbosus* L.	Bulbous Buttercup	P	3920	945	2433
Apiaceae	*Conium maculatum* L.	Poison Hemlock	B	2840	1818	2329
Brassicaceae	*Barbarea vulgaris* Ait. f.	Yellow Rocket	WA/B/P	2720	1745	2233
Asteraceae	*Arctium minus* Bernh.	Common Burdock	B	2440	1745	2093
Lamiaceae	*Nepeta cataria* L.	Catnip	P	2080	2036	2058
Asteraceae	*Sonchus arvensis* L.	Perennial Sowthistle	P	3360	291	1825
Onagraceae	*Oenothera biennis* L.	Evening Primrose	B/P	1280	1455	1367

Table 3.1 (Continued)

Asteraceae	*Lactuca serriola* L.	Prickly Lettuce	P	2160	0	1080
Asteraceae	*Sonchus oleraceus* L.	Annual Sowthistle	SA	1920	0	960
Brassicaceae	*Alliaria petiolata* (M. Bieb) Cavara & Grande	Garlic Mustard	B	0	1745	873
Lamiaceae	*Mentha x piperita* L.	Peppermint	P	160	1455	807
Brassicaceae	Sp. Juss.	Unknown crucifer	--	1360	0	680
Asteraceae	*Symphyotricum novae-angliae* (L.) G.L. Nesum	New England Aster	P	560	655	607
Caryophyllaceae	*Saponaria officinalis* L.	Bouncing Bet	P	1200	0	600
Asteraceae	*Senecio vulgaris* L.	Com. Groundsel	WA/SA	1040	0	520
Plantaginaceae	*Plantago major* L.	Broadleaf Plantain	P	840	145	493
Brassicaceae	*Descurainia Sophia* (L.) Webb ex Prantl	Flixweed	WA/SA	937	0	469
Rosaceae	*Rubus* spp. L.	Wild Raspberry	B/P	320	441	381
Asteraceae	*Cirsium Vulgare* (Savi) Ten.	Bull Thistle	B	240	145	193
Amaranthaceae	*Amaranthus powellii* S. Watson	Green Pigweed	SA	0	364	182
Polygonaceae	*Rumex crispus* L.	Curly Dock	P	160	73	116
Scrophulariaceae	*Verbascum thapsus* L.	Common Mullein	B	80	145	113
Brassicaceae	*Hesperis matronalis* L.	Dame's Rocket	B/P	0	218	109
Apiaceae	*Pastinaca sativa* L.	Wild Parsnip	B	160	0	80
Asteraceae	*Centaurea maculosa* Lam.	Spotted Knapweed	P	160	0	80
Brassicaceae	*Raphanus raphanistrum* L.	Wild Radish	WA/SA	0	145	73
Malvaceae	*Abutilon theophrasti* Medik.	Velvetleaf	SA	0	145	73
Rosaceae	*Frageria vesca* Coville	Wild Strawberry	P	0	145	73
Asteraceae	*Leucanthemum vulgare* Lam.	Oxeye Daisy	P	80	0	40
Rosaceae	*Potentilla norvegica* L.	Rough Cinquefoil	A/B/P	80	0	40
Rosaceae	*Potentilla recta* L.	Sulphur Cinquefoil	P	80	0	40
Scrophulariaceae	*Linaria vulgaris* Mill.	Common Toadflax	P	80	0	40
Asteraceae	*Sonchus asper* (L.) Hill	Spiny Sowthistle	SA	0	73	36
Total: 17	55			467298	263860	365579

[1]Plants were identified in 50 non-permanent quadrats measuring 0.25m^2 (12.5m^2 total) from 5 permanent transects (10 equally-spaced quadrats at each of the 5 90m linear transects) on 10 sampling dates in 2008 (bi-weekly from May 9 to August 30 and again on September 26), and on 11 sampling dates in 2009 (bi-weekly from May 18 to October 5).
[2]SA = summer-annual, WA = winter-annual, B = biennial, P = perennial. Combinations indicate that multiple life histories are known to occur.

Table 3.2 Percentage cover of grass weed species and clonal broadleaf weed species recorded in fallow areas adjacent to crop fields in the Elba Muck vegetable production region, Genesee and Orleans Counties, NY, USA in 2008 and 2009[1,2].

				%cover		
Family	Genus, Species	Common Name	Biology[3]	2008	2009	avg
Poaceae	*Panicum dichotomilflorum* Michx.	Fall Panicum	SA	--	5.57	5.57
Poaceae	*Poa compressa* L.	Canada Bluegrass	P	--	4.67	4.67
Poaceae	*Phleum pretense* L.	Timothy	P	--	3.94	3.94
Polygonaceae	*Persicaria maculosa* L.	Ladysthumb	SA	0.80	5.78	3.29
Fabaceae	*Medicago lupulina* L.	Black Medic	P	3.79	2.70	3.25
Poaceae	*Bromus tectorum* L.	Downy Brome	WA	--	2.99	2.99
Poaceae	*Echinochloa crus-galli* (L.) P. Beauv.	Barnyard Grass	SA	--	2.30	2.30
Vitaceae	*Parthenocissus qinquefolia* (L.) Planch.	Virginia Creeper	P	4.13	0.12	2.13
Malvaceae	*Malva neglecta* Wallr.	Common Mallow	WA/B/P	2.03	2.15	2.09
Polygonaceae	*Polygonum convolvulus* L.	Wild Buckwheat	SA	1.60	2.52	2.06
Rubiaceae	*Galium aparine* L.	Catchweed Bedstraw	SA	2.51	1.50	2.01
Polygonaceae	*Polygonum pensylvanicum* L.	Penn. Smartweed	SA	1.96	1.02	1.49
Lamiaceae	*Lamium purpureum* L.	Purple Deadnettle	WA	1.96	0.13	1.04
Caryophyllaceae	*Silene alba* (Mill.) E.H.L. Krause	White Campion	P	0.12	1.80	0.96
Poaceae	*Poa annua* L.	Annual Bluegrass	WA/SA	--	0.93	0.93
Fabaceae	*Trifolium pretense* L.	Red Clover	P	0.81	0.88	0.84
Poaceae	*Dactylis glomerata* L.	Orchardgrass	P	--	0.67	0.67
Poaceae	spp.	Unknown grasses	--	--	0.66	0.66
Fabaceae	*Lotus corniculatus* L.	Birdsfoot Trefoil	P	0.28	1.03	0.66
Poaceae	*Bromus inermis* Leyss.	Smooth Brome	P	--	0.60	0.60
Poaceae	*Panicum capillare* L.	Witchgrass	SA	0.50	0.66	0.58
Anacardiaceae	*Toxicodendron radicans* Kuntze	Poison Ivy	P	0.56	0.46	0.51
Convolvulaceae	*Calystegia sepium* (L.) R. Br.	Hedge Bindweed	P	0.23	0.75	0.49
Poaceae	*Phragmites Australis* (Cav.) Trin. Ex Steud.	Phragmites	P	--	0.48	0.48
Poaceae	*Setaria glauca* (L.) Beauv.	Yellow Foxtail	SA	--	0.37	0.37
Polygonaceae	*Polygonum scabrum* Moench.	Green Smartweed	SA	0.00	0.69	0.35
Caryophyllaceae	*Cerastium fontanum* Baumg.	Mouseear Chickweed	P	0.00	0.65	0.33
Poaceae	*Elytrigia repens* (L.) Gould	Quackgrass	P	--	0.30	0.30
Oxalidaceae	*Oxalis stricta* L.	Woodsorrel	SA	0.59	0.01	0.30
Poaceae	*Bromus secalinus* L.	Rye Brome (Cheat)	WA	--	0.27	0.27

Table 3.2 (Continued)

	Lamiaceae	*Lamium amplexicaule* L.	Henbit	WA	0.53	0.01	0.27
	Caryophyllaceae	*Stellaria media* (L.) Vill.	Common Chickweed	SA	0.00	0.50	0.25
	Poaceae	*Digitaria sanguinalis* (L.) Scop.	Large Crabgrass	SA	--	0.23	0.23
	Poaceae	*Setaria viridis* (L.) P. Beauv.	Green Foxtail	SA	--	0.18	0.18
	Cyperaceae	*Cyperus esculentus* L.	Yellow Nutsedge	P	0.00	0.34	0.17
	Fabaceae	*Trifolium repens* L.	White Clover	P	0.05	0.29	0.17
	Vitaceae	*Vitis labrusca* L.	Wild (Fox) Grape	P	0.23	0.01	0.12
	Lamiaceae	*Glechoma hereracea* L.	Ground Ivy	P	0.16	0.00	0.08
	Asteraceae	*Bellis perennis* L.	English Daisy	P	0.00	0.05	0.03
	Poaceae	*Avena fatua* L.	Wild Oat	WA	--	0.01	0.01
	Poaceae	*Setaria faberi* Herrm.	Giant Foxtail	SA	--	0.01	0.01
	Portulacaceae	*Portulaca oleracea* L.	Common Purslane	SA	0.02	0.00	0.01
	Polygonaceae	*Polygonum aviculare* L.	Prostrate Knotweed	SA	0.00	0.00	0.00
Total:	13	43	--	--	22.86	48.23	47.63

[1]Grasses (Family: Poaceae) were present but not recorded in 2008. Average percentage-cover for Poaceae species reflects only 2009 data.
[2]Plants were identified in 50 non-permanent quadrats measuring 0.25m^2 (12.5m^2 total) from 5 permanent transects (10 equally-spaced quadrats at each of the 5 90m linear transects) on 10 sampling dates in 2008 (bi-weekly from May 9 to August 30 and again on September 26), and on 11 sampling dates in 2009 (bi-weekly from May 18 to October 5).
[3]SA = summer-annual, WA = winter-annual, B = biennial, P = perennial. Combinations indicate that multiple life histories are known to occur.

Table 3.3 Weed hosts of *Iris yellow spot virus* (IYSV), potato virus Y (PVY)[1], and potato leafroll virus (PLRV) found in the Elba Muck vegetable production region, Genesee and Orleans Counties, NY, USA in 2008 and 2009.

Species	Common Name	IYSV[2]	PLRV	PVY
Amaranthus retroflexus L.	Redroot Pigweed	Gent et al. 2006	Natti et al. 1953	--
Arctium minus Bernh.	Common Burdock	Hsu et al. 2010	--	--
Capsella bursa-pastoris L. Medik.	Shepherd's Purse	--	Ellis 1992	Fletcher 2001
Chenopodium album L.	Common Lambsquarters	Sampangi et al. 2007	Kazinczi et al. 2004	Lichkov 1987
Cichorium intybus L.	Chicory	Hsu et al. 2010	--	Kaliciak & Syller 2009
Conyza Canadensis (L.) Cronq.	Horseweed	--	--	Kaliciak & Syller 2009
Lactuca serriola L.	Prickly Lettuce	Sampangi et al. 2007	--	Kaliciak & Syller 2009
Lamium purpureum L.	Purple Deadnettle	--	--	Kaliciak & Syller 2009
Plantago lanceolata L.	Buckhorn Plantain	--	--	Zitter 2001
Portulaca oleracea L.	Common Purslane	Cosmi et al. 2003	--	Marchoux et al. 1976
Rumex crispus L.	Curly Dock	Hsu et al. 2010	--	--
Senecio vulgaris L.	Common Groundsel	--	--	Lichkov 1987
Setaria viridis (L.) P. Beauv.	Green Foxtail	Evans et al. 2009	--	--
Solanum ptycanthum Dunal	Eastern Black Nightshade	--	Natti et al. 1953	Jeffries 1998
Sonchus oleraceus L.	Annual Sowthistle	--	--	de Paz et al. 1997
Sonchus asper (L.) Hill	Spiny Sowthistle	Nischwitz et al. 2007	--	--
Stellaria media (L.) Vill.	Common Chickweed	--	--	Zitter 2001
Taraxicum officinale G.H. Weber ex Wiggers	Dandelion	Hsu et al. 2010	--	Lichkov 1987

[1] Of the four main strains of PVY, potato is susceptible to PVY^{O} (common strain), PVY^{C} (stipple streak strain), and PVY^{NTN} (potato tuber necrotic ringspot disease), but is largely asymptomatic when exposed to PVY^{N} (tobacco veinal necrosis) (Radcliffe & Ragsdale 2002). Hosts listed include the three injurious strains infecting potato.

[2] Dandelion, common burdock, lambsquarter, chicory, curly dock, and dandelion have been documented as hosts of *T. tabaci* larvae, indicating potential as a source of IYSV (see Chapter 2).

[3] Eastern black nightshade is not known to have tested positive for PLRV; however, susceptibility to this virus is thought to be universal among *Solanum* spp. (Natti et al. 1953).

to IYSV, PLRV and PVY, but the relative epidemiological importance of these weed species may vary. Factors that influence their importance include prevalence of the weed host, abundance and phenology of the vector, dispersal capability of the vector, modes of transmission of the virus and acquisition and transmission efficiencies of the virus by the vector.

While weeds have not been documented as sources of IYSV in onion crops, studies of other *Tospovirus* spp. suggest that suggest that weeds are likely to be important sources of inoculum (Groves et al. 2002). Weeds that are important sources for IYSV and other *Tospovirus* spp. must also serve as reproductive hosts for their respective vectors (Culbreath et al. 2003). *T. tabaci* is the only reported vector of IYSV (Gent et al. 2004; Gent et al. 2006) and is a major pest of onion crops worldwide (Lewis 1997). As with all *Tospovirus* spp., IYSV is persistent and propagative in its vector, meaning that individuals remain viruliferous for life and that the virus replicates itself within the vector (Moritz et al. 2004). Due to internal morphological transformations that occur during short periods of their development, Thysanoptera spp. can only acquire *Tospovirus* spp. as first instars, and can only transmit as second instars and adults (Ullman et al. 1993; Moritz et al. 2004). As such, a source of IYSV must be a host of *T. tabaci* larvae. IYSV-susceptible weeds that cannot support populations of *T. tabaci* larvae are said to be epidemiological "dead-ends" as the vector cannot acquire the virus as an adult. At least six of the ten IYSV-susceptible species reported in our study have been confirmed as hosts of *T. tabaci* larvae, and all six species have been observed in NY (Dandelion, lambsquarter, redroot pigweed, chicory, common burdock and curly dock) (see chapter 2). These six species may be important in the epidemiology of IYSV in the Elba Muck as well as similar agricultural

ecosystems in the Great Lakes region of the US.

In contrast to the relative vector-specificity of IYSV, many species of aphids (Hemiptera: Aphididae) are known to transmit PLRV and PVY; however, the green peach aphid, *Myzus persicae* (Selzer), has been identified as the most important vector of both viruses (Harrison 1984; Sigvald 1984). While acquisition and transmission of PLRV and PVY are not strictly linked to the life stages of aphids, nymphs and apterous adult *M. persicae* are more efficient at transmitting PLRV than alatae (Robert 1971) and alatae appear to be more efficient at spreading PVY than apterae (Ragsdale et al. 1994).

PLRV is persistent but not propagative in its vectors (Eskandari et al. 1979), and acquisition of PLRV increases with longer periods of feeding on viruliferous hosts (Leonard & Holbrook 1978). Transmission of this virus is subject to a latency period of at least 8 hrs (Tanaka & Shiota 1970). PLRV-infected plants are known to induce sustained feeding (Castle et al. 1998; Alvarez et al. 2009) which is beneficial to its epidemiology. Important sources of PLRV would include susceptible plants that are abundant in the landscape such as lambsquarter and redroot pigweed (Holman 2009).

Weeds bordering potato fields can act as important reservoirs for PVY (Ali et al. 2008; Kaliciak & Syller 2009). PVY is a non-persistent, stylet-borne virus (Nault 1997). This means that the virus is carried on the mouthparts and is transmitted mechanically by stylet probing (Bradley & Rideout 1953) as transient aphids “test” plants for suitability as feeding hosts (Kennedy et al. 1962; Powell et al. 2006). As such, there is no latency period for acquisition and transmission of PVY (Bradley & Rideout 1953). In fact, the presence of this virus in host plants promotes behaviors that benefit PVY epidemiology by supporting shorter feeding periods and transience (Alvarez et al. 2009). As

with PLRV, the most abundant hosts in the landscape near potato fields are likely the most important sources for PVY. In this study area, dandelion, lambsquarter, and horseweed are the most likely candidates.

Numerous weed species for IYSV, PLRV, and PVY were identified in the Elba Muck agroecosystem. These species also may be common in other muck crop producing areas throughout the Great Lakes, USA region. Information generated from this survey can be used to study the role that selective weed species may have in the epidemiology of these viruses in onion and potato production systems in this region. Moreover, this information may be useful if virus management strategies are developed that include a weed management component.

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Chapter 4

ONION THRIPS LARVAL ABUNDANCE AND *IRIS YELLOW SPOT VIRUS* INCIDENCE IN TWO COMMON WEED HOSTS AT VARYING DISTANCES FROM ONION FIELDS IN WESTERN NEW YORK

Abstract

In October, 2009, common burdock, *Arctium minus* (Hill) Bernh., and dandelion, *Taraxacum officinale* F.H. Wigg, were sampled for *Iris yellow spot virus* (IYSV) (*Bunyaviridae: Tospovirus*) and onion thrips, *Thrips tabaci* Lindeman, at varying distances from onion fields. No weed samples tested positive for IYSV, however *T. tabaci* densities were significantly higher on weeds adjacent to onion fields than on weeds at greater distances, and no *T. tabaci* were observed at distances > 5 km from onion fields. Future studies should determine if controlling these weeds in areas adjacent to onion fields can reduce incidence of IYSV in these fields.

INTRODUCTION

Onion, *Allium cepa* L. (Amaryllidaceae: Allioideae), production in the Great Lakes region typically occurs on muck soils. Muck soil is black, highly organic humus created from drained wetlands; it is resistant to compaction but requires highly efficient drainage systems as it retains moisture to a much higher degree than mineral soils (Lyon et al. 1920). These qualities make this type of soil ideal for onion production. Due to glacier activity, these former wetlands are located in isolated areas scattered across the landscape. In New York, the largest contiguous muck soil region is located in the southeastern

corner of the state in Orange Co., and the second largest muck region, the Elba Muck (2,500 hectares), is in the western part of the state and straddles Orleans and Genesee Counties (43.1N, 78.1W). Dry bulb onions predominate in the Elba Muck and are grown as annual crops. Onion crops in New York are established by planting seeds or transplanting onion plants in April and early May, and the crop is harvested from July through September. For a number of economical and historical reasons, onions are typically grown in the same fields year after year.

Onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), is a major pest of onion and other *Allium* spp. worldwide (Lewis 1997). *T. tabaci* damage onion plants by feeding on leaf tissue, often leading to significant reductions in bulb yield (Fournier et al. 1995; Childers 1997). *T. tabaci* is the only thrips species considered as a pest of onion in New York. Populations of *T. tabaci* overwinter in weedy vegetation as well as wheat and alfalfa (North & Shelton 1986), and in the soil within and near onion fields (Larentzaki et al. 2007). *T. tabaci* emerge early in the spring and can be found on volunteer onion plants in late March (Larentzaki et al. 2007), well before the onion crop is planted. Weeks later in June, thrips colonize the onion crop and populations are found on the crop until harvest. After harvest in the fall, *T. tabaci* can be found on several weed species such as common lambsquarters, *Chenopodium album* L., evening primrose, *Oenothera biennis* L., yellow nutsedge, *Cyperus esculentus* L., and smooth pigweed, *Amaranthus hybridus* L. (Larentzaki et al. 2007). In 2008 and 2009, *T. tabaci* larvae also were found on lambsquarter, evening primrose and 28 other weed species at various times during the year (see Chapter 2). The highest populations of *T. tabaci* larvae on these weed species were recorded in spring, before they were found

in onion crops, and in the fall during and after the period onions were harvested.

T. tabaci is a vector of *Iris yellow spot virus* (IYSV) (*Bunyaviridae: Tospovirus*), a serious pathogen of onion worldwide (Gent et al. 2006). In bulb crops, IYSV causes lesions on the leaves that can reduce photosynthesis, resulting in a reduction in bulb size (Gent et al. 2004). IYSV was first detected in New York onion fields in 2006 (Hoepting et al. 2007) and since has been found in all major onion growing regions throughout the state (Nault et al. 2008). IYSV is transmitted by *T. tabaci* in a persistent, circulative, propagative manner (Whitfield et al. 2005), meaning that once a vector has acquired the virus, that individual is viruliferous for life, and the virus circulates and proliferates within the vector. *T. tabaci* is the only naturally reported vector of IYSV (Kritzman et al. 2001), although *Frankliniella fusca* has shown the ability to transmit IYSV in laboratory experiments (Srinivasan et al. 2009). However, *T. tabaci* is the dominant thrips species in onion crops in NY (Gangloff 1999).

Vectors of *Tospoviruses* are only known to acquire these viruses as first instars and are only known to transmit as second instars or adults (Ullman et al. 1992; Wijkamp et al. 1993). IYSV is not known to be seed-transmitted (Kritzman et al. 2001; Gent et al. 2004; Bulajić et al. 2009), nor is it easily transmitted in a mechanical manner (Bulajić et al. 2009; Marc Fuchs, personal communication). Based on this information, a plant must support reproduction of the vector for at least one generation, allow the virus to be acquired by the vector, and its life cycle must be complimentary to that of the virus and the vector for it to be a significant source in the epidemiology of a *Tospovirus* sp. (Culbreath et al. 2003).

IYSV may be introduced annually into New York on imported onion

transplants, but it also may be permanently established by surviving in hosts that survive winters such as volunteer onions and biennial and perennial weeds (Hsu et al. 2010). The most abundant weed hosts for both IYSV and *T. tabaci* are common burdock, *Arctium minus* Bernh., and dandelion, *Taraxacum officinale* G. H. Weber ex Wiggers (Chapter 2). Among all of the potential sources of IYSV in New York's onion producing landscape, these two weed species may be significant in the epidemiology of IYSV in onion fields.

Controlling weeds that may be significant sources of tospoviruses in proximity to susceptible crops has been explored as a tactic for managing *Tomato spotted wilt virus* (TSWV) (Cho et al. 1989; Bautista et al. 1995; Martinez et al. 1999). Weed control also could be a useful tactic for reducing levels of IYSV in nearby onion fields. Because common burdock and dandelion may be significant early-season sources of IYSV in New York, management of these weeds near onion fields could reduce levels of IYSV in the onion crop. While onions are grown in isolated areas of muck soil, common burdock and dandelion are ubiquitous throughout the Great Lakes region. If IYSV levels and *T. tabaci* densities on common burdock and dandelion adjacent to onion fields are similar to those at greater distances from onion fields, controlling these weeds to manage IYSV may not be worthwhile because viruliferous thrips may disperse long distances to colonize onion fields. Alternatively, if IYSV levels and *T. tabaci* densities in these weed species are greater adjacent to onion fields than distances further away, local weed management may have a practical impact on IYSV management. The objectives of this study were to: (1) compare densities of *T. tabaci* larvae on common burdock and dandelion at varying distances from onion fields, and (2) compare levels of IYSV-infected common burdock and dandelion plants at

varying distances from onion fields.

MATERIALS AND METHODS

A. Study sites

This study was conducted during the first half of October 2009 in an area that encompassed the entire Elba Muck onion production region and surrounding area in western New York (Fig. 1). Common burdock and dandelion plants were sampled one time at three distance ranges from the nearest onion field in the Elba Muck region: 0-0.05 km, 3-5 km, and 9-14 km (Fig. 1). These distance ranges were considered treatments and referred to as the inner, middle and outer ranges, respectively. Within each distance range, weeds were sampled from five locations. Locations for each weed species in the inner, middle, and outer ranges were at least 1.5, 5, and 11 km apart, respectively (n= 15 locations per weed species). Common burdock and dandelion plants were generally sampled from different locations as it was difficult to find enough plants of both species to collect at a single location.

B. IYSV survey

For each weed species, 30 plants at each location were individually marked with flags and then sampled for IYSV on 12-13 October 2009 (total of 450 samples per weed species: 30 plants x 15 locations). A 0.5 g leaf tissue sample was removed from each plant in the field and then placed into an individual sealable sandwich bag for transport to the laboratory. Each tissue sample was considered the sampling unit. Tissue samples were tested using a double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA). Assays were generally conducted according to manufacturer

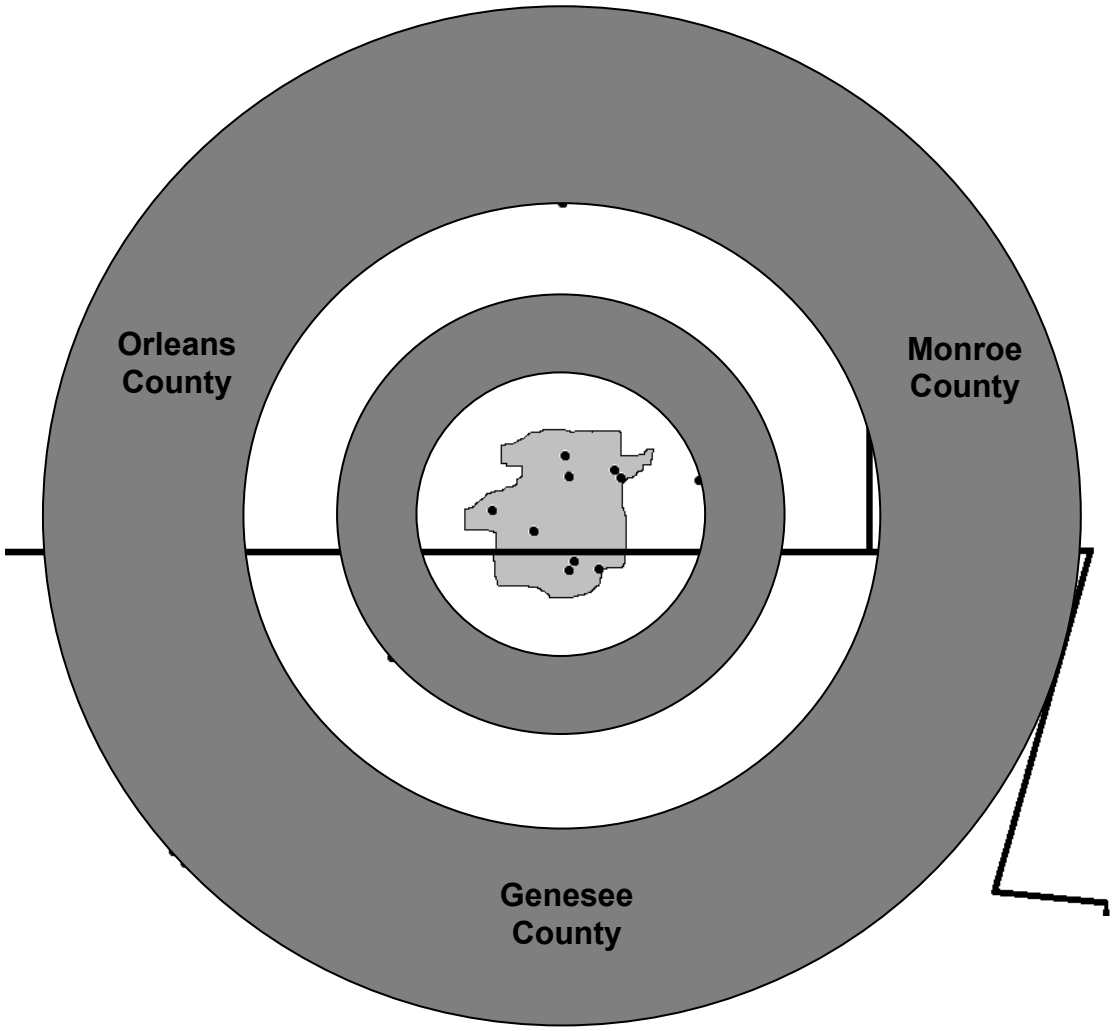

Figure 4.1 Sampling locations in western New York for estimating densities larval *T. tabaci* and IYSV incidence on common burdock, *Arctium minus*, and *Taraxacum officinale* at varying distances from onion fields[1].

[1]The Elba muck region in western New York is depicted in the center of this diagram. This region encompasses approximately 2,500 ha. Shaded areas indicate distance ranges from the nearest onion field within the Elba Muck to the location where either common burdock or dandelion was sampled. The innermost region (0-0.05 km), the middle region = 3-5 km, and the outer region = 9-14 km. Dots represent sampling locations for common burdock, dandelion, or both (both species were collected from a single location in the inner region and two locations in the outer region).

protocols (Agdia Inc., Elkhart, IN). However, based on preliminary studies, general extraction buffer 3 (GEB3) yielded fewer false-positive optical density (OD) readings with common burdock and dandelion than general extraction buffer 1 (GEB1) while maintaining sensitivity to IYSV-positive samples and positive controls (C. Hsu, personal communication). All experimental samples and controls were tested in duplicate wells. The mean OD reading of the two wells was used for analysis.

C. Population densities of *T. tabaci* larvae

Seven days after tissue samples were removed from flagged plants, a portion of these plants was sampled for *T. tabaci* larvae (19-20 October 2009). For each weed species at each location, five common burdock plants and 10 dandelion plants were sampled (n= 75 common burdock plants [5 plants x 15 locations] and n= 150 dandelion plants [10 plants x 15 locations]). All plants were clipped at ground level using pruning shears and placed into 5.68 L polypropylene containers (Sterilite Corporation, Townsend, MA) and then taken to the lab for thrips collection and identification. Lids were fitted with thrips-proof screen for ventilation (150 µm x 150 µm). For each species, plants within a location were combined into a single container to produce one composite sample per location (n= 15 plants per location per plant species). This composite sample was considered the sampling unit.

Identification keys do not exist for thrips larvae, so larvae were collected from the sampled plants and reared to the adult stage. Using a fine paintbrush, all larvae were transferred from the weed samples to cabbage, *Brassica oleracea Linne* (Capitata group), leaf disks to complete their development. Cabbage disks were contained within Petri dishes measuring 5

cm x 0.9 cm. Petri dishes were ventilated by a 1cm diameter hole covered with thrips-proof screen. Inside the Petri dishes, cabbage disks were placed on filter paper moistened with 8-10 ml of de-ionized water to inhibit desiccation. To ensure experimental integrity, cabbage disks were soaked in a 10% bleach solution (nine-parts de-ionized water: one-part sodium hypochlorite bleach) at least seven days prior to adding thrips larvae to kill pathogens as well as to ensure that no thrips were present. Once the larvae completed their development, adults were identified using the key by Moritz et al. (2001) and counted according to species. Some larvae did not complete their development to adulthood on the cabbage leaf disks. However, the number of these individuals that were likely *T. tabaci* was estimated by calculating the proportions of reared thrips that were *T. tabaci* and non-*T. tabaci*. For each weed species, the overall percentage of *T. tabaci* and the number of non-*T. tabaci* was identified from collected larvae that completed their development . The percentage of those that became *T. tabaci* was then multiplied by the number of dead thrips larvae. *T. tabaci* were counted and populations were adjusted to the number of larvae per plant for each location. Voucher specimens are maintained at the NYSAES in Geneva, NY.

D. Statistical analyses

T. tabaci larvae collected from each weed species was represented as the mean number of larvae per plant per location. Data were analyzed using regression analysis (PROC MIXED) in SAS 9.1 statistical software (SAS Institute Inc., Cary, NC). The model analyzed the effect of distance from onion fields on population densities of *T. tabaci* larvae on common burdock and dandelion plants. Data were transformed by the natural log (ln(x+1)) for

analyses, but untransformed data are presented.

RESULTS

A. IYSV survey

None of the 450 samples from either weed species tested positive for IYSV (0%). A sample was considered positive if OD readings were > 3x the negative control. Comparing OD readings of weed samples to positive and negative controls confirmed that the ELISAs were conducted properly.

B. Population densities of *T. tabaci* larvae

T. tabaci populations on both weed species were highest near onion fields. Population densities of *T. tabaci* larvae on common burdock decreased significantly as distance from onion fields increased ($F= 5.1$, $df= 2,8$, $P= 0.0374$; Fig. 2A). Results were similar for larval densities on dandelion ($F= 4.41$, $df= 2,8$, $P= 0.0511$; Fig. 2b). The mean number of *T. tabaci* larvae per common burdock plant was 3.5, 1.3, and 0 for locations in the inner, middle and outer distance ranges, respectively. The mean number of *T. tabaci* larvae per dandelion plant was 0.12, 0, and 0 for locations in the inner, middle and outer distance ranges, respectively.

For common burdock, differences in *T. tabaci* populations were not significantly different when comparing larval density per plant between the inner and middle ranges ($P=0.1678$), nor the middle and outer ranges ($P=0.1325$). However, larval density in the inner range was significantly higher than the density in the outer range ($P=0.0128$).

For dandelion, *T. tabaci* larval density in the inner range was significantly greater compared with densities in both the middle ($P=0.0330$)

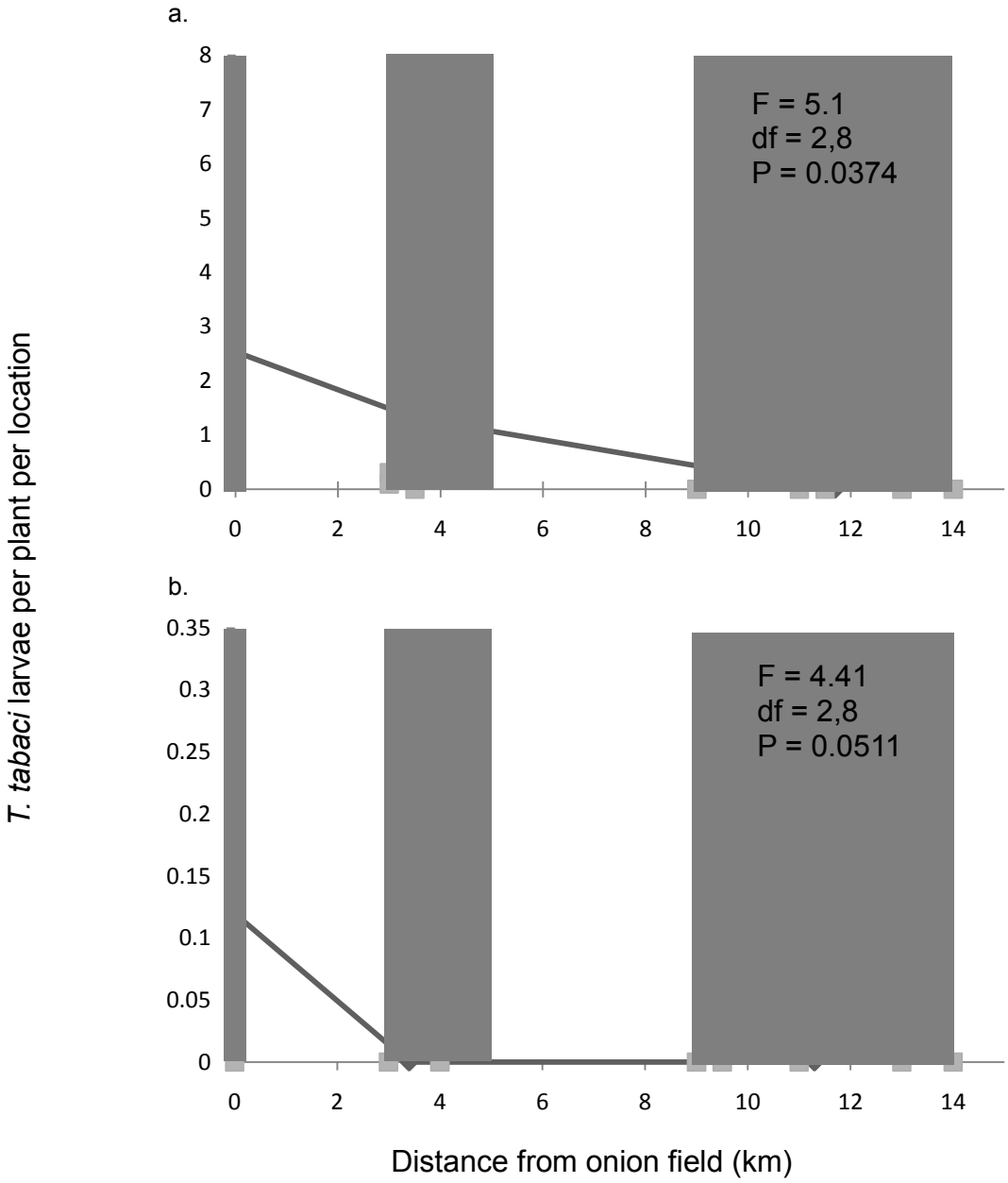

Figure 4.2 Densities of *T. tabaci* larvae on common burdock, *Arctium minus* (a) and dandelion, *Taraxacum officinale* (b) located at three distance ranges away from the nearest onion field in western New York[1, 2].

[1]Shaded portions indicate the three distance ranges in this study ("inner" = 0-0.05 km, "middle" = 3-5 km, "outer" = 9-14 km)
[2]n= 5 locations per distance range.

and outer ranges (P=0.0330), while densities in the middle and outer ranges were identical.

For common burdock, differences in *T. tabaci* populations were not significantly different when comparing larval density per plant between the inner and middle ranges (P=0.1678), nor the middle and outer ranges (P=0.1325). However, larval density in the inner range was significantly higher than the density in the outer range (P=0.0128).

For dandelion, *T. tabaci* larval density in the inner range was significantly greater compared with densities in both the middle (P=0.0330) and outer ranges (P=0.0330), while densities in the middle and outer ranges were identical.

DISCUSSION

Populations of *T. tabaci* larvae were highest on common burdock and dandelion plants found adjacent (≤0.05 km) to onion fields. No *T. tabaci* larvae were found beyond a distance of 5 km from onion fields. In southwestern Ontario, Boyce & Miller (1954) observed higher numbers of *T. tabaci* in red clover, *Trifolium pratense* L., and alfalfa, *Medicago sativa* L., within 50 yards (45.72 m) of an onion field compared with the number in these crops 0.25 mi (402.34 km) away. This supports the results of our study that indicate populations of *T. tabaci* are highest near onion fields.

Other studies have indicated that *T. tabaci* populations in and near onion fields are relatively localized and that populations may not mix readily over long distances. Examples illustrating this idea involve insecticide resistance patterns in *T. tabaci* populations in NY. Shelton et al. (2003; 2006) found that insecticide resistance in *T. tabaci* varied significantly between fieldslocated in

the same growing region. These studies suggest that *T. tabaci* populations are relatively localized and do not typically disperse far from their native hosts.

No plants tested positive for IYSV in this study, so we cannot infer any effect of distance from onion fields on IYSV incidence. However, Latham and Jones (1997) found that TSWV incidence sharply declined from an infection source; incidence dropped from >40% at a distance of 1.5m to <10% at a distance of 6m. This suggests that TSWV incidence is localized, mirroring the localization of TSWV's thrips vectors, in this case *Frankliniella occidentalis*. This study may also suggest that the distance ranges in our study may have been too great to detect IYSV as a number of our sites in the inner sampling range were located farther than 6 m away from onion fields. However, infection gradients may vary according to plant hosts and weather conditions.

In contrast to the relatively steep decline in TSWV incidence observed by Latham & Jones in marigold, *Calendula* spp., Groves et al. (2001) observed that TSWV spread at least 36.8 m from a known inoculum source to hairy buttercup, *Ranunculus sardous* Crantz, at varying distances, and that there was no gradient in infection rates by distance. However, a gradient may have been identified if observations were made at distances greater than 36.8 m. Decreases in rates of infection similar to those observed in *Calendula* were observed over distances of 61 m (Gitaitis et al. 1998), 100 m (Wilson 1998) and 300 m (Gitaitis et al. 1998) in tomato, lettuce and pepper, respectively. Also, Wilson observed that the highest incidences of TSWV in lettuce crops were at field edges that were immediately downwind of inoculum sources. This edge effect has also been observed in onion crops infected with IYSV that are downwind of adjacent sources of *T. tabaci* (Gent et al. 2004).

These studies and the observations of this chapter and chapter 2

suggest that (1) *T. tabaci* populations are relatively concentrated near onion fields, and (2) *T. tabaci* populations in weeds peak in spring, they decline as populations in onion crops increase during summer, and peak again at the time of onion harvest in the fall. If these population dynamics are the result of localized movements between weeds and onions, *T. tabaci* may be transmitting IYSV between these hosts.

Possible implications for management

Common burdock and dandelion are known hosts for IYSV (Hsu et al. 2010) and for *T. tabaci* (Ch. 2) and both weed species may be significant overwintering reservoirs for IYSV in NY. If *T. tabaci* populations are indeed localized near onion fields, controlling these weeds in areas adjacent to onion fields may reduce IYSV incidence in onion crops. This may be accomplished by using broadleaf-specific herbicides along field edges.

However, weed control will not reduce the threat of IYSV if source plants are located at greater distances from field margins, or if IYSV is found to successfully overwinter in *T. tabaci*, but not in weeds or volunteers. Further research is needed to identify the relative importance of these possible overwintering reservoirs and sources of IYSV.

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CONCLUSIONS

The research described in this thesis is an initial step in identifying the potential role of weeds as sources of IYSV in New York onion ecosystems. As reviewed in Chapter 1, IYSV has been identified in New York only recently, and has the potential to cause economic damage to the state's onion crop. Susceptible, winter annual, biennial and perennial weed hosts may be important sources for IYSV that allow the virus to persist in the ecosystem.

In Chapter 2, 25 winter-annual, biennial and perennial weed species that host *T. tabaci* larvae were identified. The presence of larvae indicates that the host weed species is potentially capable of being a source of viruliferous adult thrips. Of the 25 hosts of *T. tabaci* larvae, common burdock, chicory, curly dock, and dandelion are known to be susceptible to IYSV infection. By estimating the population densities of these weeds, and of the population densities of *T. tabaci* larvae on these weeds, it is estimated that common burdock and dandelion may be important weed hosts of IYSV.

In Chapter 3, the population densities of some of the most abundant weed species in the Elba Muck vegetable production region were estimated. Of the 98 species identified, 18 are known as hosts of IYSV, PLRV, and PVY.

In Chapter 4, the effect of distance from onion fields on population densities of *T. tabaci* on weed hosts was estimated. Conclusions from Chapter 2 were employed to hypothesize that *T. tabaci* larval densities on common burdock and dandelion would decrease as distance from onion fields increase, as would levels of IYSV infection in those weeds. This hypothesis was confirmed for densities of *T. tabaci* larvae as densities were significantly higher on plants collected from sites ≤ 0.05km from onion fields than on plants

collected from sites located at greater distances, and no *T. tabaci* were observed at distances > 5km. As none of the sampled plants tested positive for IYSV, it is possible that infection levels are typically very low. It is also possible that a sufficient number of weeds was not sampled from sites adjacent to onion fields. A more comprehensive study is needed to fully estimate levels of IYSV infection in susceptible weeds, and to estimate the effect of distance on infection levels. This may be accomplished by sampling weeds near onion fields that are known to have had high levels of IYSV infection.

Successful control of IYSV requires the identification of sources of inoculum, sources of viruliferous *T. tabaci*, and an accurate assessment of the relative importance of these identified sources. The next steps involving weeds as sources of IYSV should include studies of *T. tabaci* fecundity on weed species, as well as acquisition and transmission studies of *T. tabaci* on known weed hosts of IYSV. These studies should also include an assessment of transmission efficiency from weeds to onions. The frequency that *T. tabaci* disperse from IYSV-infected weeds into onion fields is also important. This information will be useful to the future study of weeds as sources of IYSV, and to the general study of IYSV epidemiology.