ABSTRACT

MECK, ELIJAH DANIEL. The Phenology of the Twospotted Spider Mite *Tetranychus urticae* (Acari: Tetranychidae) in North Carolina Tomato Systems. (Under the direction of James F. Walgenbach and George G. Kennedy.)

The twospotted spider mite, *Tetranychus urticae* Koch, is a cosmopolitan and highly polyphagous pest of many fruits, vegetables, ornamentals, and field crops. While twospotted spider mite is a well-documented pest of corn and peanuts in eastern North Carolina, only recently has it been recognized as a consistent and serious pest of vegetables in the piedmont and mountains of North Carolina. Mites infest a number of vegetables in North Carolina including tomato, pepper, eggplant, and sweet corn, but tomato is by far the most seriously affected crop. The objectives of this study were to 1) determine the effect of vegetation on the dispersal of twospotted spider mites from tomatoes to overwintering hosts, and 2) to investigate the potential importance of various factors, including location, planting date, field history, surrounding area, pesticide use, and mite populations in surrounding vegetation, that may affect mite infestations in tomato fields in different regions of North Carolina. Two vegetation management techniques (herbicide and cultivation) plus an untreated control plot were established around senescing tomato plants. Twospotted spider mite dispersal was monitored by planting chickweed trap plants at 2, 6, and 12 m from the tomatoes. Sampling took place in the fall of 2004 & 2005 and the spring of 2005 & 2006. Only a small number of mites were collected in the 2004-2005 sampling period, making it difficult to draw conclusions. The 2005-2006 sampling period showed that herbicide-treated soil facilitated mite dispersal in the fall, while there were no differences in mite populations among treatments in the spring, suggesting a high rate of overwintering mortality. Tomato fields in

the mountains and piedmont region were sampled in a grid pattern on a bimonthly basis to determine the importance of year, location, planting date, previous crop, adjacent crop, insecticide use, acaricide use, and mite populations in surrounding vegetation on mite intensities in those fields. Based on samples from 80 tomato fields, previous crop, acaricide use, insecticide use, and mite intensity in the weeds were important factors that were associated with seasonal mite intensity in tomato fields. Acaricide use and mite intensity in the weeds were important factors associated with the maximum mite intensity in tomatoes. Year, location, planting date, and acaricide use were all important factors associated with the time it took for tomato fields to reach their maximum density. Upon further analysis, it was found that none of the dependent variables (year, location, previous crop, adjacent crop, planting date, acaricide use, insecticide use) were associated with seasonal mite intensity in weeds or mite intensity in weeds on the last two sample dates. However, previous crop and insecticide use were significant factors associated with mite intensity in weeds on the first two sample dates. Furthermore, seasonal mite intensity in weeds was significantly correlated with seasonal and maximum mite intensity in tomato fields. While previous crop, current season insecticide use, and mite intensity in weeds were factors associated with mite intensities in the field, a high overwintering mortality appeared to negate the effects of these factors; consequently it was not possible to predict in advance fields that were most susceptible to high mite infestations. Acaricides will likely remain a key management strategy in the near future, and the development of sampling plans and economic thresholds will be necessary to use these materials in a judicious manner.

THE PHENOLOGY OF THE TWOSPOTTED SPIDER MITE *TETRANYCHUS URTICAE* (ACARI: TETRANYCHIDAE) IN NORTH CAROLINA TOMATO SYSTEMS

by

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BIOGRAPHY

Elijah Daniel Meck was born on December 17, 1981, and is the son of Mr. and Mrs. Steven Daniel Meck. He was raised in the small village of Klinesville, Pennsylvania along with his two younger brothers Jeremiah and Josiah. Growing up Elijah developed an appreciation for the outdoors, and has many fond memories of the hunting and fishing adventures that have led him through the mountains and valleys of Pennsylvania.

On farm work experience both in crop production and small plot experiments, and agricultural classes in school pointed the way toward a career in agriculture. After graduating from Kutztown Area High School in 2000, Elijah continued his studies in agriculture at the Pennsylvania State University. In 2004 he received a Bachelor of Science degree in Agroecology.

In pursuit of his ambitions to obtain a degree in Entomology, Elijah applied and was accepted into the Department of Entomology at North Carolina State University in 2004. Under the direction of Dr. James Walgenbach and Dr. George Kennedy he began work towards a Master of Science degree. His research revolved around the population dynamics of twospotted spider mites in North Carolina tomato systems.

While attending the North Carolina State University, Elijah met his future wife, Michelle Giudici who was also pursuing a degree in Entomology. With both of their research areas located in the mountain regions of the state, Elijah and Michelle spent countless hours together driving back and forth between Raleigh and Fletcher. They had many adventures hiking in the mountains and fishing off the beaches. Elijah and Michelle were married in October of 2006 and look forward to the adventures in the many happy years ahead.

ACKNOWLEDGEMENTS

I would like to thank all of the individuals that helped make this work possible. I would especially like to thank my committee; Dr. James Walgenbach, Dr. George Kennedy, and Dr. David Monks for all of their suggestions and guidance throughout the past few years. I greatly appreciate the efforts of the 2005 and 2006 summer crews at the Mountain Horticultural Crops Research and Extension Center in Fletcher, NC. They spent many hours on the road and in the field. I would also like to thank all the grower cooperators for letting us sample their fields, and Dr. Cavell Brownie in the NCSU Department of Statistics for all of the statistical consultation she offered. Lastly I would like to thank my wife, Michelle, for all of her help and support over the past few years.

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The twospotted spider mite, *Tetranychus urticae* Koch, is a cosmopolitan and highly polyphagous pest of many fruits, vegetables, ornamentals, and field crops. Bolland et al. (1998) list over 930 different host plants for *T. urticae*. Given optimal conditions of high temperatures and low humidity, populations of *T. urticae* can reach high densities that cause adverse effects to host plants.

Spider mites feed on host plants by inserting their stylets into the leaf tissue and removing cell contents (Tomczyk and Kropczyńska 1985). Feeding injury results in the loss of leaf chlorophyll and a reduction in the net photosynthetic rate (Sances et al. 1981; DeAngelis et al. 1982; Campbell et al. 1990; Park and Lee 2002), and can lead to yellow to white discoloration of the leaf often referred to as bronzing. Damage to the host plant may cause a decline in overall plant health or death (Tomczyk and Kropczyńska, 1985).

The life cycle of the twospotted mite consists of an egg, larva, protonymph, deutonymph, and adult. All three active immature stages feed on the host plant, and are followed by a period of quiescence called the protochrysalis, deutochrysalis, and teliochrysalis, respectively. The larval form has only 3 pairs of legs while the proto- and deutonymphs each have 4. The time that a mite remains in each stage depends on the temperature and humidity levels during that particular lifestage. Boudreaux (1958) showed that mites held in higher humidity laid fewer eggs and experienced higher mortality as neonates than those held in a lower humidity environment. Herbert (1981) determined that the developmental threshold for *T. urticae* was 10º C, and females lived 26.12 ± 2.78 days, 35.5 ± 2.15 days, and 30.58 ± 1.53 days at 15º, 18º, and 21º C respectively. Cagle (1949) recorded 9 generations of insectary reared twospotted spider mites in 1946 and 10 in 1947.

Development from hatching to adult took as little as 5 days for both sexes and as long as 20 days for males and 59 days for females. Males develop faster than females, and wait in close proximity to the female teliochrysalis for the adult female to emerge. Mating occurs almost immediately after adult female emergence. Parthenogenesis may occur in *T. urticae* resulting in the production of haploid males.

Spider mites produce webs from silk glands located at each palp. Spider mite females of the genus *Tetranychus* lay their eggs within or under webbing. Larvae and nymphs also spin webs and colonies on a plant are defined by the web (Gerson 1985). Webbing may be used to protect against climatic factors such as wind and rain, but also protects the mites from natural enemies and exposure to chemicals (Davis 1952). Spray droplets may become caught up in webbing and fail to contact the mites.

While mites coexist with natural enemies, modern agriculture creates conditions favorable for twospotted spider mite populations to grow to extremely high densities. Monocultures of host plants are grown using pesticides that can directly and indirectly contribute to high mite densities through the elimination of natural enemies (Roush and Hoy 1978), behavior-modifying effects (Iftner and Hall 1983, 1984; Ayyappath et al. 1995), and hormoligosis. The polyphagous nature of twospotted spider mite allows it to exploit a diversity of habitats during the year. When the quality of host plants declines due to high mite populations, plant senescence, or when a crop is harvested, mites must disperse to new hosts. Dispersal may occur over short distances by crawling or over longer distances by wind-assisted aerial dispersal (Kennedy and Smitley 1985). Crawling is important in the movement of mites from field borders into crop fields, as demonstrated in a corn/peanut agroecosystem by Brandenburg and Kennedy (1982) and Margolies and Kennedy (1985).

Crawling is also important for dispersal within and throughout a plant as well as the field. Aerial dispersal of *T. urticae* is observed mostly in adult females, and occurs when populations are concentrated in the upper canopy of the plant. In response to wind and light *T. urticae* will orient itself in a negative phototactic manner and raise its forelegs (Smitley and Kennedy 1985). The mite is caught in wind updrafts resulting in aerial dispersal.

Twospotted spider mites can overwinter as reproducing populations on host plants or in a state of diapause (Veerman 1985). In regions with mild winter climates, such as the southeastern US, reproducing populations can remain active throughout the winter on weeds such as red clover, henbit, chickweed, Carolina geranium, and brambles (Brandenburg and Kennedy 1981; Meagher and Meyer 1990). *Tetranychus urticae* adult females will enter a state of diapause in response to decreased photoperiod and temperature, and the condition of the host plant. Once mites enter a diapause state they move from the host to hibernation sites (Veerman 1985), such as soil clods (Collingwood 1955; Masse 1942; Weldon 1910), cracks in poles, and dried leaves (Masse 1942). Diapause is terminated when temperatures and photoperiod increase. In response to increased temperatures winter weeds may senesce, and mites may disperse into nearby fields or other non-cultivated host plants. Margolies and Kennedy (1985) found that mites crawled into corn in the spring, and, after increasing to high densities on corn, aerially dispersed from corn to nearby crops during the summer months.

While twospotted spider mites are well-documented pests of corn and peanuts in eastern North Carolina, only recently have they been recognized as consistent and serious pests of vegetables in the piedmont and mountains of North Carolina. Mites infest a number of vegetables in North Carolina including tomato, pepper, eggplant, and sweet corn, but tomato is by far the most seriously affected crop.

In conventional tomato production, twospotted spider mite populations are managed mainly through the use of acaricides. Current regulations allow for the use of abamectin, bifenazate, dicofol, oxamyl, fenpropathrin, and spiromesifen to control twospotted spider mites in North Carolina tomatoes (Walgenbach et al. 2006). While environmental factors such as temperature and humidity influence mite reproductive rates and longevity, they may also regulate epizootics that affect mites. Fungi in the order Entomophthorales have been shown to decimate twospotted spider mite populations (Carner and Canerday 1970) and are capable of overwintering in North Carolina (Brandenburg and Kennedy 1981).

Tomatoes are typically planted from April through early July in the piedmont and mountains of North Carolina. During the course of the growing season some fields may experience high population densities of twospotted spider mites. Insecticides used to control a diversity of tomato pests may contribute to high mite populations. Through a process called hormoligosis mite reproductive rates may be enhanced by certain chemicals (Dittrich et al. 1974; Margolies et al. 1985; James and Price 2002). High mite populations may also be due to acaricide resistance and/or the suspension of acaricide applications later in the season when economic conditions do not justify their use.

Many tomato fields have high mite densities in the autumn when the crop senesces or is abandoned. As the crop declines and the field is dismantled, mites can move onto overwintering weeds in the field borders. Overwintering mites in field borders serve as the source of mites infesting tomato fields the following growing season. Based on low captures of mites on aerial sticky traps surrounding tomato fields in the spring and fall (J.F. Walgenbach, unpublished data), movement of mites to and from overwintering sites is assumed to be a short range phenomena mediated by interplant movement, rather than long distance aerial dispersal.

The first objective of this study was to determine if a vegetation-free area around a tomato field could prevent twospotted spider mites from reaching overwintering hosts. If mites are unable to reach nearby overwintering hosts, it may be possible to delay or prevent an infestation the following season. The second objective of this study was to sample tomato fields and field borders for twospotted spider mites to better understand the source of mites, how mite populations develop throughout the season, and to determine if location, planting date, adjacent crop, previous crop, acaricide use, or insecticide use influenced mite populations during the growing season.

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Chapter 1: Effect of vegetation management on movement of the twospotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae), from tomatoes to overwintering sites in western North Carolina

I. Introduction

The twospotted spider mite, *Tetranychus urticae* Koch, is a widespread and highly polyphagous pest of many fruits, vegetables, ornamentals, and field crops. Bolland et al. (1998) list over 930 different host plants for *T. urticae*. Given optimal conditions, populations of *T. urticae* can reach high densities that severely damage its host plant.

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While mites coexist in the environment with natural enemies, modern agriculture creates conditions favorable for twospotted spider mite populations to grow to high densities. Monocultures of host plants are grown using pesticides that can directly and indirectly contribute to high mite densities through the elimination of natural enemies (Roush and Hoy 1978), behavior-modifying effects (Iftner and Hall 1983, 1984; Ayyappath et al. 1995) and hormoligosis and trophobiosis effects that enhance mite reproductive rates (Dittrich et al. 1974; Margolies et al. 1985; James and Price 2002). The polyphagous nature of twospotted spider mite allows it to exploit a diversity of habitats during the year. When the quality of host plants declines due to high mite populations, plant senescence, or harvesting of the crop, mites disperse to new hosts. Dispersal may occur over short distances by crawling or over longer distances by wind-assisted aerial dispersal (Kennedy and Smitley 1985). Depending on location, twospotted spider mite can overwinter as reproducing populations on host plants or in a state of diapause (Veerman 1985). In regions with mild winter climates, such as the southeastern U.S., reproducing populations can remain active throughout the winter on weeds such as red clover, henbit, chickweed, Carolina geranium, and brambles (Brandenburg and Kennedy 1981; Meagher and Meyer 1990). In the spring when overwintering hosts senesce, mites disperse into nearby fields or to other non-cultivated host plants. Margolies and Kennedy (1985) found that mites crawled into corn fields in the spring, and, after increasing to high densities on corn, aerially dispersed from corn to peanuts in the summer months.

While twospotted spider mites are well-documented pests of corn and peanuts in eastern North Carolina (Brandenburg and Kennedy 1982; Boykin and Campbell 1984), only recently have they been recognized as consistent and serious pests of vegetables in the piedmont and mountains of North Carolina. Mites infest a number of vegetables in North Carolina including tomato, pepper, eggplant, and sweet corn, but tomato is by far the most seriously affected crop.

Tomatoes are typically planted from April through early July in the piedmont and mountains of North Carolina. During the course of the growing season, some fields may experience high population densities of twospotted spider mites. Due to acaricide resistance and/or the suspension of acaricide applications later in the season when economic conditions do not justify their use, many tomato fields harbor high mite densities in the autumn. As the crop declines and the field is dismantled, mites may move onto overwintering weed hosts in the field borders. Overwintering mites in field borders could potentially serve as a source of mites infesting tomato fields the following growing season. Based on low captures of mites on aerial sticky traps surrounding tomato fields in the spring or fall (J.F. Walgenbach, unpublished data), movement of mites to and from overwintering sites in the spring and fall is assumed to be a short range phenomena mediated by interplant movement and crawling over the soil surface, rather than longer distance movement afforded by aerial dispersal.

The objective of this study was to determine if a vegetation free area around a tomato field could prevent twospotted spider mites from reaching overwintering hosts. If mites are unable to reach nearby overwintering hosts, it may be possible to delay or prevent an infestation the following season.

II. Materials and Methods

Plot Layout: In mid-June of 2005 and 2006, five-wk-old 'Mountain Fresh' tomato transplants were planted in two 54.8 m long rows planted on 1.5 m centers at the Mountain Horticultural Crops Research Station (MHCRS), Fletcher, NC. Plants were planted in black polyethylene mulch with drip irrigation, spaced 0.46 m apart within rows, and staked and strung as needed during the season. Twospotted spider mites were introduced into the study over the course of the growing season from a laboratory colony grown on bush beans. To encourage the buildup of mites, plants were sprayed weekly with carbaryl 1.1 kg[A.I.]/ha (Sevin 80S, Bayer, Research Triangle Park, NC).

Six plots, representing 2 replicates of 3 different vegetation management treatments, each 9.1 m long by 13.1 m wide, were established along the outside of each row (12 plots total). The vegetation management treatments were assigned using a randomized complete block design and consisted of cultivated soil, soil treated with a herbicide, and a non-treated control in which no weed control practices were applied.

Within each plot, 1 m^2 sub-plots were established at 2, 6, and 12 m from the tomato rows into which nine chickweed plants (*Stellaria media*) were planted as trap plants on 24 and 30 September in 2004 and 2005, respectively. Subplots were staggered within the main plots such that at 2 m they were in the center, at 6 m they were offset one half meter to the right of center, and at 12 m they were offset one half meter to the left of center. This was done to ensure that mites moving from the tomatoes would not have to cross one set of trap plants to reach the next set of trap plants.

On 20 July 2004, 0.56 kg[AI]/ha metribuzin, (Sencor 75DF, Bayer, Research Triangle Park, NC) was applied to all plots, with the exception of each of the subplots. This application was not made in 2005. Metribuzin was applied again in early September 2004 with glyphosate (Roundup ULTRA, Monsanto, St. Louis, MO) as a tank mixture to eliminate any remaining or newly emerging weeds within the herbicide treatment plots. In early August 2005 metribuzin plus 0.8 kg[AI]/ha paraquat dichloride, (Gramoxone Max, Syngenta, Greensboro, NC) was made to the herbicide treatment plots only, again the subplots were not treated. A second application of paraquat dichloride was made to the herbicide treatment plots in late August 2005 to eliminate any remaining or newly emerging weeds. The cultivation treatment consisted of tilling the soil with a rototiller (TroyBuilt, Troy, NY) to destroy weeds. The soil was tilled every two weeks from the beginning of September through October 2004 and 2005.

Mite Sampling: In fall 2004, four chickweed plants were cut at the soil surface with a knife, placed in 3.8-liter plastic bags, transported to the laboratory in a cooler with ice, and the bags were weighed. To determine the weight of plant material, 10 bags (no plants) were weighed, and the average weight of these bags was subtracted from the total weight to determine the fresh weight of the plant material. A sieve was constructed by cutting a 14 cm diameter hole in the bottom of a 4.7 liter bucket and fitting a piece of 6.35 x 6.35 mm hardware cloth in the bottom. A no. 10 U.S.A. Standard Sieve Series sieve was placed underneath to capture the intermediate sized debris, but allow mites through, and a no. 50 U.S.A. Standard Sieve Series was placed below that to capture mites but allow for fine particles to pass through. Plant material was removed from a bag, placed in the top sieve and washed thoroughly with water to dislodge mites. After the plant material was washed the top sieve was removed and all of the debris in the no. 10 sieve was washed. That sieve was then removed and the contents in the no. 50 sieve was washed and collected into a 125 mL, screw-cap glass container. All material collected was preserved in 70 % ethyl alcohol and labeled. Samples were processed by placing the preserved contents in a 150mm x 25mm plastic dish with 20mm grids (Flacon Integrid, BD Biosciences, San Jose, CA), examining it under a dissecting microscope, and counting the number of twospotted spider mites.

In spring and fall 2005 and spring 2006, four plants were collected from each subplot and weighed as described above. For these collections, the plants were placed in modified Berlese funnels with 40-watt incandescent light bulbs on top. Jars containing 50% ethyl alcohol were placed under each funnel to preserve mites that dropped through. The chickweed remained in funnels 24 to 72 hours, depending on the amount of chickweed collected, to allow mites and other insects to move out of the plant material and into the jar below. Samples were processed in the same manner as described above. These data were log transformed and analyzed as a 3 by 3 (soil treatment by distance) factorial design using GLM in the statistical program SAS 9.1 (SAS Institute 2002-2003).

In the fall of 2005, sticky-traps were placed adjacent to the subplots of the control and herbicide treatments to monitor aerial dispersal of mites. Traps were constructed by cutting 7.62 cm lengths of 2.54 cm diameter schedule 40 PVC pipe, and wrapping the outside with a 8 x 10 cm piece of stable fly sticky sleeve (Great Lakes IPM Inc., Vestaburg, MI). Traps were placed approximately 0.5 m above the soil by sliding them over a 9.5 mm diameter wooden dowel rod and resting them on a wooden clothespin clasped to dowel rod. Traps were replaced weekly from early October through early December. The traps were wrapped in plastic wrap, labeled with a permanent marker and placed in the freezer until they were processed. Each trap was examined under a dissecting scope and the number of mites was recorded. These data were square-root transformed and analyzed as repeated measures using GLM in the statistical program SAS 9.1.

III. Results

Mite Sampling: The average numbers of mites found during the 2004-2005 and 2005-2006 seasons for all treatments are illustrated in Figures 1 and 2, respectively. The number of mites found in the 2004-2005 (lsmean -0.1) season was significantly lower than that in 2005-2006 (lsmean 0.2; t = -5.12 P <0.0001). In 2004-2005, neither time (fall versus spring), vegetation management treatment, nor distance from tomatoes were significant factors (Table 1). However, in 2005-2006, time and vegetation management were significant, while distance from tomatoes was not significant.

Based on a t-test, more mites were found in fall 2005 (lsmean 0.3) than the spring of 2006 (lsmean -0.003; t = 3.65, P = 0.0006). In addition, mite densities in the herbicide treatment (lsmean 0.3) were higher than those in either the control (lsmean 0.07; t = -2.3357, P = 0.0231) or cultivation treatments (lsmean 0.08; t = -2.2569, P = 0.0279). The control and cultivation treatments were not different from each other (t = 0.0787, P = 0.9375).

Sticky Traps: The initial analysis of sticky trap data showed that there were no significant differences in mite captures between soil vegetation management practices, nor was the interaction between vegetation management and distance significant (Table 2). The number of mites captured was averaged across soil treatments and plotted over time (Fig 3). Based on a *t*-test, there were more mites caught on the traps at 2 m (lsmean 1.03) versus 6 m (lsmean 0.6; t = 2.7076, P = 0.0079) or 12 m (lsmean 0.7; t = 2.04, P = 0.0438). There were also more mites caught on week one than any other date (Fig 4).

IV. Discussion

The larger number of mites sampled in 2005-2006 compared to 2004-2005 may have been due to the large amount of rainfall in fall 2004. Average monthly precipitation at the MHCRS for August through December totaled 70.2 cm in 2004, but only 32.6 cm in 2005 (State Climate Office of North Carolina 2006). The large amount of rain could have washed mites from leaves and across the ground, drowned them in periods of heavy rain while dispersing, or created conditions (mud) that would have made crawling difficult. The method of collecting mites may have also contributed to the difference in number of mites collected. The washing technique used in the fall of 2004 may not have been as efficient as the modified Berlese funnels for recovering mites from plant material.

In 2005-2006, the higher number of mites found in the fall compared to spring samples suggests that considerable mite mortality occurred during the winter. While some mites may have remained active, others may have entered a state of diapause. Once mites enter diapause they move from the host to hibernation sites (Veerman 1985) such as soil clods (Collingwood 1955; Masse 1942; Weldon 1910), cracks in poles, dried leaves (Masse 1942) as well as other places. Optimal conditions for diapause include low temperatures and high humidity (Parr and Hussey 1966). Mites overwintering near the soil surface or other places could have been exposed to desiccating winds. Collingwood (1955) indicated that while *T. urticae* may seek refuge in soil clods, they are not often successful surviving the winter in these locations; many mites were found overwintering in the soil of hop and blackcurrant fields, but no infestation was observed in the field the following summer. Weldon (1910) also observed large numbers of mites moving from orchard trees into soil clods at the end of the season. However, upon inspection in the following spring, most mites were found to be dead with the exception of a moist clod that contained only 6 live mites.

The higher number of mites per sample on chickweed trap plants in the herbicide treatment compared with the control in fall 2005 suggests that the presence of bare soil between tomatoes and chickweed facilitated mite dispersal to chickweed subplots. The herbicide was applied to loose soil that was not disturbed thereafter. Rainfall contributed to the top layer of soil becoming compacted, which created a surface that may have allowed for easy movement of mites by crawling. Parker (1913) showed that the speed of mite movement depended on the type of soil surface; i.e. mites could move a greater distance over packed soil as compared to loose soil, and that loose soil was also responsible for many changes in direction.

In contrast to the herbicide treatment, the cultivation treatment plots were tilled every two weeks. The loose and uneven soil surface and soil clods were not conducive to mite crawling, which may have prevented many mites from reaching overwintering hosts.

Hollingsworth and Berry (1982) suggested that tillage could cause mortality due to abrasion, burial, and exposure to climatic influences. These factors may have contributed to lower number of mites found in the trap plants.

The control plots had a large number of weeds, including overwintering hosts such as chickweed and henbit. Mites dispersing aerially or by crawling could have easily found an overwintering host before they reached the trap plants. This could be an explanation of why there were fewer mites found on the trap plants in the control treatment than in the herbicide treatment.

Aerial trap captures suggest that mites were moving on the wind to the trap plant areas. Mites were caught at all distances and on all of the traps at some point during the trapping period, although the period of highest aerial movement occurred during the first week trapping which took place the first week of October (Fig 4). Mite catches decreased for a period of two weeks then showed a slight increase before decreasing again to zero (Fig 3). The increase in mite capture may be because immature mites not capable of dispersal earlier (i.e., wk 2) did not disperse until they matured. Hence, it is likely that aerial dispersal contributed to the mite populations on trap plants, but the higher number of mites recovered in trap plants in the herbicide compared to control treatment suggests that crawling may have been a more important means of dispersal to the nearby chickweed trap plants.

Boykin et al. (1984) examined the effects of barren borders on the movement of twospotted spider mite into peanut fields in the spring in eastern North Carolina. They observed that a weed free distance of 3.0 m was not sufficient to prevent mites from crawling into fields. Widths of 4.5 or 6.0 m were observed to delay, but not prevent infestation due to aerial dispersal. Our study focused on the fall dispersal of mites from tomatoes to overwintering hosts, but no significant differences were observed in the number of mites found at 2, 6 and 12 m. However, our results suggest that making an herbicide application on the border of fields between tomato plants and overwintering weeds may create a favorable condition for mites to crawl to overwintering hosts. Apparent high overwintering mortality, however, negated the impact of vegetation management effects by the following spring. Making an herbicide application around the field toward the end of the growing season will eliminate spider mite weed hosts forcing mites to move farther away from fields. While this may create a favorable condition for mites to crawl, the high rate of overwintering mortality and resulting increased distance between mite hosts may contribute to a delayed spider mite infestation the following spring. Regular tilling of the soil during periods of peak mite dispersal may limit the number of mites that reach overwintering hosts by crawling; however, aerial dispersal may allow other mites to reach these hosts. More thoroughly understanding the relative importance of overwintering mortality and crawling versus aerial dispersal of mites to overwintering hosts in the fall will be necessary to assess the potential of using soil management practices to suppress twospotted spider mite populations near tomato fields.

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Table 1. ANOVA results of twospotted spider mite dispersal study from tomatoes to chickweed trap crops under different vegetation management practices in two different years.

Year	Factor	*F*	df	*P*
2004-2005	Rep	0.71	3	0.5495
	Sampling time	0.06	1	0.812
	Vegetation management	0.88	2	0.419
	Trap crop distance	1.08	2	0.3457
	Error	-	63	-
2005-2006	Rep	0.93	3	0.4322
	Sampling time	**13.56**	**1**	**0.0006**
	Vegetation management	**3.59**	**2**	**0.0349**
	Trap crop distance	1.92	2	0.1563
	Time x vegetation	0.1	2	0.3003
	Vegetation x distance	1.25	4	0.907
	Vegetation x distance x time	1.18	6	0.3306
	Error	-	51	-

Table 2. ANOVA results of number of twospotted spider mites caught on sticky traps placed at 2, 6, and 12 m from senescing tomato plants during the fall of 2005.

Factor	*F*	df	*P*
Replicate	1.21	3	0.3023
Vegetation Management	0.02	1	0.8784
Sticky trap distance	**3.98**	**2**	**0.0202**
Week	**21.69**	**4**	**<0.0001**
Vegetation x distance	0.12	2	0.8875
Error	-	107	-

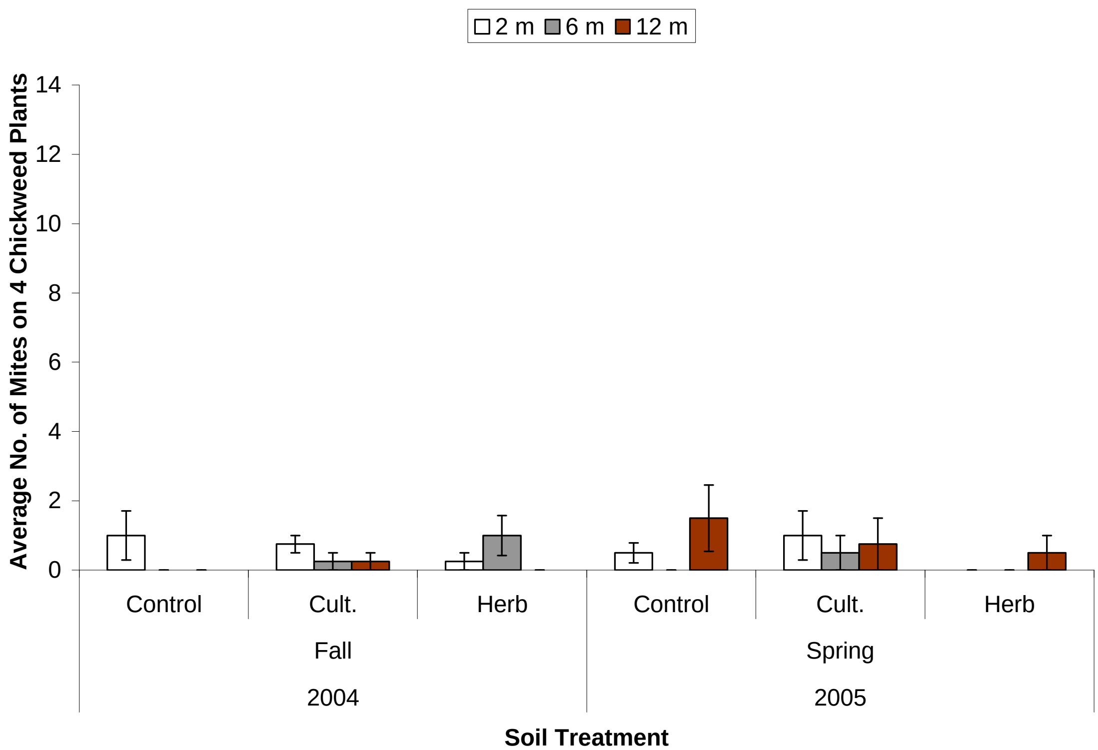

Fig. 1. Mean number of mites recovered from 4 chickweed plants at 2, 6, and 12 m from tomatoes in the fall and spring of 2004-2005.

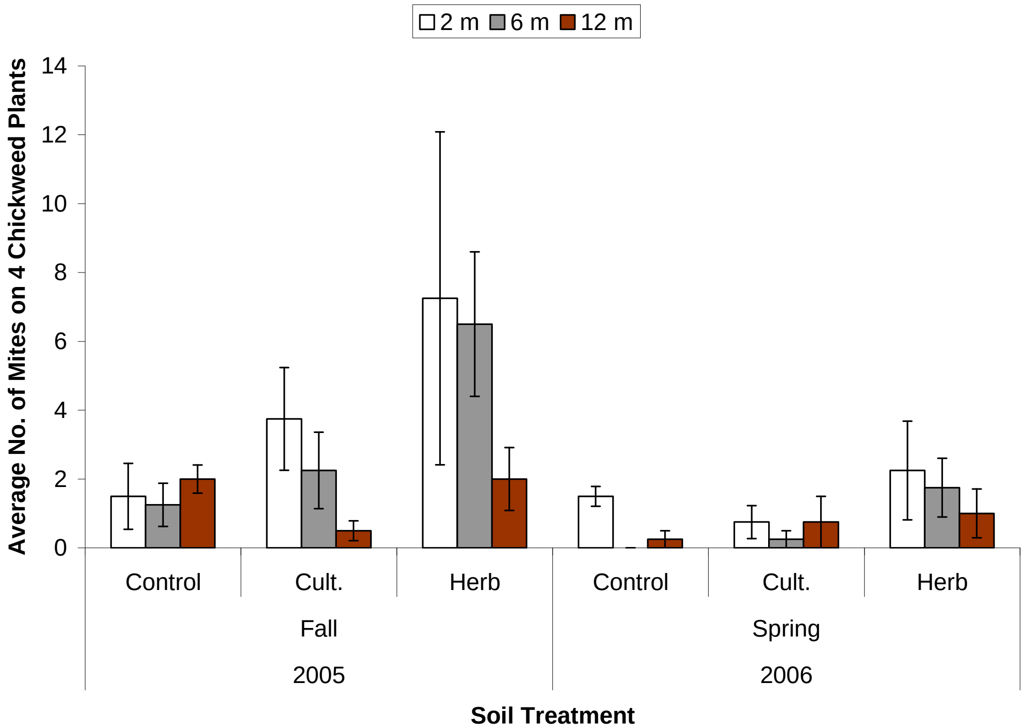

Fig. 2. Mean number of mites recovered from 4 chickweed plants at 2, 6, and 12 m from tomatoes in the fall and spring of 2005-2006.

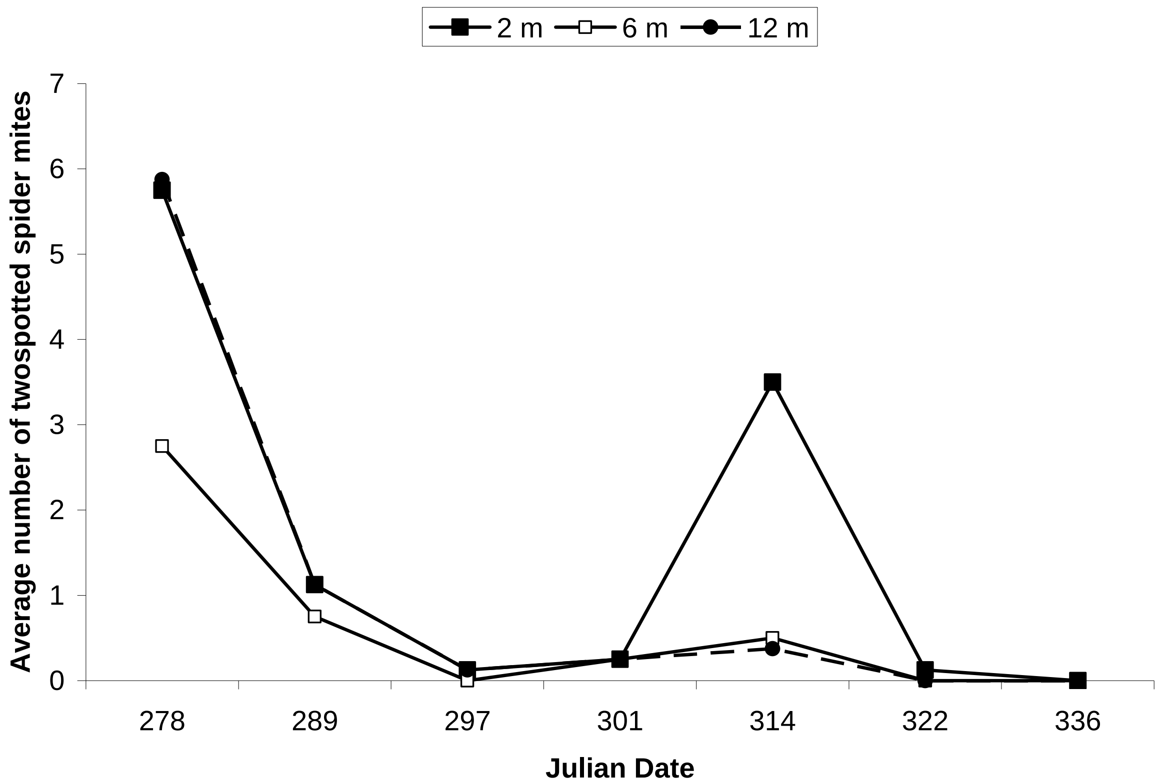

Fig. 3. Mean number of mites recovered on sticky cards placed at 2, 6 and 12 m from senescing tomato plants over time Fletcher, NC 2006.

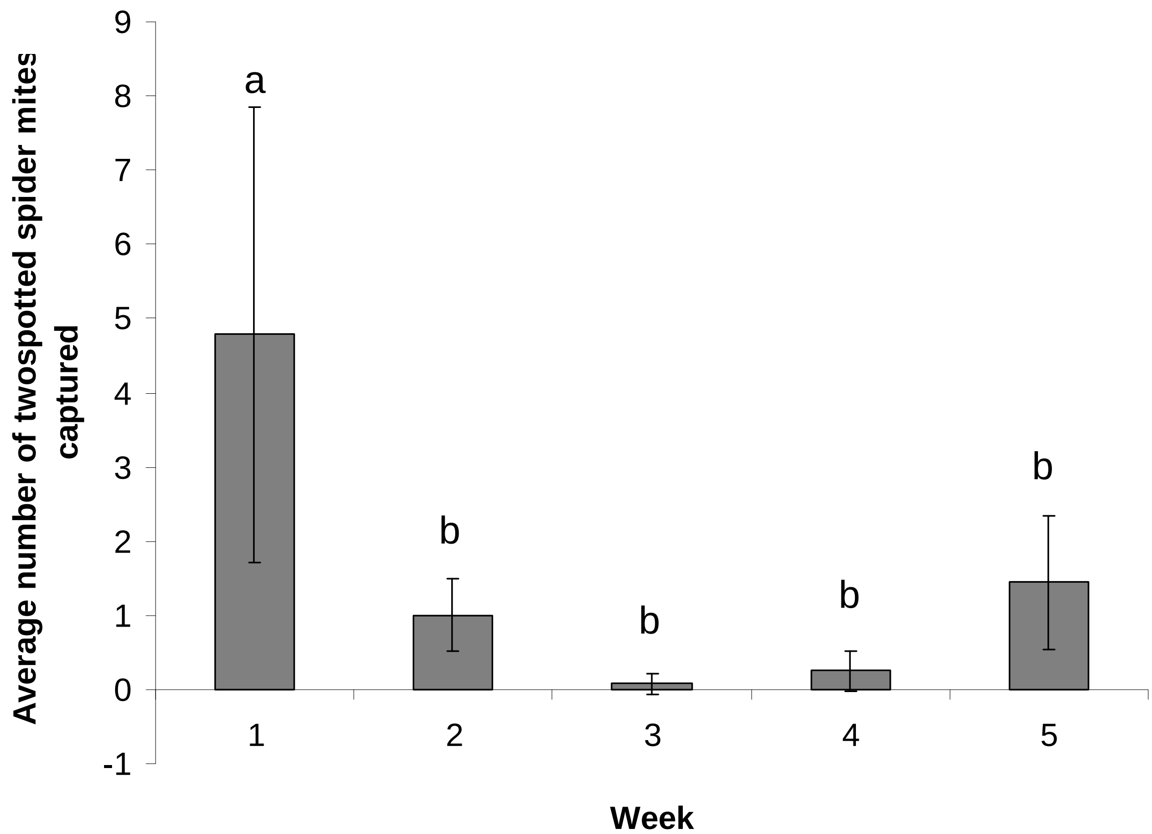

Fig. 4. Mean number of mites recovered on sticky traps during 5 weeks of aerial capture Fletcher, NC 2006.

Chapter 2: Phenology of the twospotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae), in central and western North Carolina tomato systems

I. Introduction

The twospotted spider mite, *Tetranychus urticae* Koch, is a widespread and highly polyphagous pest of many fruits, vegetables, ornamentals, and field crops. In recent years this mite has developed into a key pest of vegetable crops, particularly tomatoes, in central and western North Carolina. Mites feed on plants by inserting their stylets into plant tissue and removing cell contents (Tomczyk and Kropczyńska 1985). Feeding results in the loss of chlorophyll content and a reduction in net photosynthesis rate (Sances et al. 1981; DeAngelis et al. 1982; Campbell et al. 1990; Park and Lee 2002). This injury often leads to a yellowish to whitish discoloration of leaves, referred to as bronzing. Damage to the plant may cause a decline in overall plant health or death (Tomczyk and Kropczyńska, 1985).

While a diversity of natural enemies helps regulate mite populations in non-managed habitats, modern agriculture practices can create conditions favorable for twospotted spider mite populations to grow to extremely high densities. Monocultures of host plants are grown using pesticides that can directly and indirectly contribute to high mite densities through the elimination of natural enemies (Roush and Hoy 1978), behavior-modifying effects (Iftner and Hall 1983, 1984; Ayyappath et al. 1995) and hormoligosis and trophobiosis effects that enhance mite reproductive rates (Dittrich et al. 1974; Margolies et al. 1985; James and Price 2002). The polyphagous nature of twospotted spider mite allows it to exploit a diversity of habitats during the year. Spider mites are stimulated to disperse due to lack of food and/or the threat of desiccation (Smitley and Kennedy 1985; Margolies and Kennedy 1988). Dispersal may occur over short distances by crawling or over longer distances by wind-assisted aerial dispersal (Kennedy and Smitley 1985).

The seasonal phenology and colonization of host plants by twospotted spider mite is well documented in eastern North Carolina, but similar information is lacking for central and western NC (Smitley and Kennedy 1988). In the corn-peanut agroecosystem of eastern NC, mites dispersed from senescing overwintering weeds into corn fields in late spring. Mites increased to large densities on corn, due to the effects of soil applied terbufos for the control of rootworm and southern billbug (Margolies et al. 1985). In response to increasing levels of feeding injury to the corn plant, the mites dispersed to nearby peanut fields. In the fall, mites dispersed to overwintering weed sites. The elimination of terbufos use in NC corn (Van Duyn et al. 1999) has reduced the importance of corn as a nursery crop for mite dispersal to peanuts and other crops.

Among the diversity of crops grown in central and western NC, twospotted spider mite populations have been most intense and problematic on tomatoes. In this region, tomatoes are grown in relatively small fields in agroecosystems that include a diversity of crops and non-managed habitats. Other common crops include small grains, corn, soybeans, vegetables, and both small fruits and tree fruits. Preliminary surveys have shown that strawberry and sweet corn are two potential crops that may serve as reservoirs for mite infestations in tomatoes. However, immigration of mites into tomato fields from adjacent overwintering weeds appears to be an important source of mites infesting tomato crops. Tomatoes are typically planted from April through early July, and during the growing season some, but not all fields experience high mite population densities. Due to acaricide resistance problems and/or the suspension of acaricide applications later in the season when economic conditions do not justify their use, many tomato fields have high mite densities in the autumn when the plants senesce or are abandoned. As the plants decline and fields are dismantled, mites may move onto other host crops in the immediate area or onto weed hosts within the field borders (J.F. Walgenbach, unpublished data).

The goal of this study was to investigate specific factors including location, planting date, field history, surrounding area, pesticide use, and mite populations in surrounding vegetation to determine their importance in contributing to mite densities in the tomato fields grown in different regions of North Carolina.

II. Materials and Methods

General Procedures: In order to determine the factors that influence the timing and density of a spider mite infestation, seasonal mite populations were monitored in 80 tomato fields and surrounding crops on a bimonthly basis in the central piedmont and western mountainous regions of NC in 2005 and 2006. Fields were selected based on planting date, surrounding habitat, and regional location. Previous crop history and chemical application records were obtained from each grower at the end of the season to use in statistical analysis along with data on planting date, location, and adjacent crop.

Sampling procedures: Sampling was conducted at 23 sites in the NC counties of Henderson, Haywood, Polk, and Rowan in 2005, and at 57 sites in the NC counties of Buncombe, Henderson, Haywood, Polk, and Rowan, and in Greenville County, SC, in 2006. Tomato fields were sampled in a grid pattern that included 4 transects across the width of the field, each consisting of 5 samples, for a total of 20 sample sites per field. Transects were spaced evenly down the length of the field and were separated by 15 to 40 m depending on field size. Sample sites within each transect included 2 sites from the periphery of fields, taken from the outside rows, and 3 sites from the interior of fields which were evenly spaced across the width of fields. This sampling pattern was adjusted in a small number of fields that were very long (>200 m), where a total of 5 transects were established consisting of 5 samples across the width for a total of 25 sample sites, or in very small fields (<0.5 hectares), where mites were sample on 50 random plants.

At each sample site within a field, a presence/absence sampling method was used in which the number of mite-infested trifoliate leaflets on 10 consecutive plants was recorded. The terminal trifoliate from a second or third most recently expanded leaf was observed with a 10X optivisor for the presence or absence of twospotted spider mites. In addition, the presence or absence of mites was recorded for 20 (2005) and 25 (2006) twospotted spider mite weed hosts surrounding each tomato field. Weed species sampled included Carolina geranium (*Geranium carolinianum*), common chickweed (*Stellaria media*), henbit (*Lamium amplexicaule*), red clover (*Trifolium pratense*), bramble (*Rubus* spp.), giant ragweed (*Ambrosia trifida*), morningglory (*Ipomoea* spp.), kudzu (*Pueraria montana*), black locust saplings (*Robinia pseudoacacia*), black nightshade (*Solanum nigrum*), horsenettle (*Solanum carolinense*), and vetch (*Vicia* spp.). Sampling was conducted every two weeks from the beginning of May through the end of September.

Other crop and vegetable fields in the immediate area of the tomato fields were also sampled for twospotted spider mites by examining 50 random plants. These other fields include pepper, eggplant, sweet corn, field corn, soybean, and strawberry.

Statistical analysis: For each tomato field sampled during 2005 and 2006, three mite infestation measurements were calculated: 1) seasonal mite intensity, which represented the intensity of mite populations averaged over time; 2) maximum mite intensity, which was the highest infestation rate (percentage of mite-infested leaves) of all sample dates; and 3) days to maximum mite intensity. The seasonal mite intensity was calculated by averaging the percentage of infested plants over sample dates. If a field had no mites for a period of longer than one sampling date, all zero infestation data points were eliminated except for the one immediately preceding an infestation greater than zero. The dependent variable days to maximum intensity was calculated by determining the number of days between the first sample date and the date of maximum mite intensity. Multiple regression analysis (GLM, SAS 9.1, SAS Institute 2002-2003) was used to determine the effect of various independent variables on the three aforementioned dependent variables. Seasonal mite intensity data were square-root transformed, maximum mite intensity data were log transformed, and the days to maximum intensity data was not transformed based on inspection of plots of predicted and observed residuals.

Eight different variables (year, adjacent crop, previous crop, location, planting date, acaricide use, insecticide use, and mite intensity in the weeds) deemed potentially important in affecting the twospotted spider mite infestations in tomato fields were included as independent variables in the regression analysis. The year factor was broken down into two categories: 2005 and 2006, and each field was placed into the respective category based on when it was sampled. Previous crop history and adjacent crop data were collected and classified into two categories: tomatoes or other crop. These two categories were classified as such because tomato was the only crop in this survey that supported high mite densities that could potentially contribute to significantly higher mite populations the following season. Although strawberry and sweet corn were potential previous crop hosts, only two tomato fields were preceded by these crops. Location was simply split into the two regions based on elevation. Elevation < 400 m was the piedmont region, which included Rowan and Polk County, NC, and Greenville Co., SC, while all other regions in the mountains (> 600 m) which included Buncombe, Henderson, and Haywood County, NC. Planting date was split into three categories: early planted fields, which were planted in April and early May in the piedmont and late May or early June in the mountains; mid-planted fields, which were planted in late May and early June in the piedmont; and late planted fields, which were planted in late June and July in the piedmont and in the mountains. The acaricide use factor was split into 2 categories: acaricide applied or not applied. The chemicals that constituted an acaricide application were abamectin (Agrimek, Syngenta, Greenboro, NC) or bifenazate (Acramite, Chemtura, Middlebury, CT). Insecticide use was split into two categories: insecticides that stimulate mite reproduction and those that have little effect on mite populations (neutral). Insecticides that were considered to stimulate mite reproduction in this particular study were permethrin (Baythroid, Bayer, Research Triangle Park, NC), and esfenvalerate (Asana, Dupont, Wilmington, DE). All other insecticides used by growers in this study were considered to have little or no effect on mite populations. The interaction between location and planting date was tested to evaluate potential differences in the dependent variables due to planting dates in the piedmont versus the mountains.

After an initial regression analysis on all of the dependent variables, independent variables were removed from each of the respective models one at a time, based on significance. The model was rerun after each deletion until the final reduced model was developed. The least square means were obtained from all significant factors and t-tests were conducted to determine the differences among significant factors.

Mite intensity in the weeds was then explored further by examining mite intensities in the weeds at specific intervals as dependent variables and relating them to the same independent variables as well as the mite intensity in the field on the last two sample dates. Mite intensities in the weeds were calculated for the first two sample dates, the last two sample dates, and the intensity of mites in the weeds during the mite infestation period in the field. After an initial regression analysis using the three weed specific intervals as dependent variables, independent variables were removed from each of the respective models one at a time, based on significance. The model was rerun after each deletion until the final reduced model was developed, and least square means were obtained from all significant factors. T-tests were conducted to determine the differences among significant factors.

III. Results

General population trends: In 2005, twospotted spider mite populations remained low for several weeks until they began to increase rapidly (Fig 1). This rapid growth resembled that of an exponential growth pattern. Also, late planted fields tended to reach higher population levels than early planted fields in the piedmont region, while tomato fields in the mountains showed a similar infestation level to that of late planted fields in the piedmont. In 2006 initial population trends showed a similar pattern to that in 2005, but after a period of rapid growth, populations peaked and then began to decline in all plantings in the piedmont with the exception of fields in South Carolina and Polk County, NC (Fig 2) and the early planted fields in the mountains (Fig 3). In contrast to 2005, the early planted fields in the piedmont experienced higher mite populations than the later planted fields of the same area, and the early planted fields of the mountains experienced much lower populations than that of the early and mid planted fields in South Carolina and Polk county, NC.

Regression models: Initial results of regression analysis for seasonal mite intensity showed that mite intensity in the weeds was a significant factor affecting seasonal mite intensity. Year, location, planting date, and adjacent crop were removed from the model, and the results of the reduced model show that previous crop, acaricide use, and mite intensity in the weeds were significant factors associated with the seasonal mite intensity (Table 1). Based on least square means, seasonal mite intensity was lower in fields that had a previous crop of tomatoes (lsmean = 3.2) versus a previous crop that was not tomatoes (lsmean = 3.9; t = -2.54, P = 0.0131), and seasonal mite intensity was lower in fields where acaricides were not applied (lsmean = 3.2) versus those where they were applied (lsmean = 3.9; t = -2.45, P = 0.0166).

The initial results for the full regression model for maximum mite intensity in the field show that mite intensity in the weeds was the only significant factor associated with maximum mite intensity in the field. When year, location, and planting date were removed from the model, the resulting reduced model showed that acaricide use and mite intensity in the weeds were significant factors associated with maximum mite intensity in the field (Table 2). Based on least square means, the maximum mite intensity was lower in fields where acaricides were not applied (lsmean = 3.4) versus those where they were applied (lsmean = 3.8; t = -2.11, P = 0.0381).

Initial regression analysis results for the number of days to maximum intensity indicated that year, location, and planting date were all factors associated with the time it took for fields to reach their maximum mite density. Based on these results, adjacent crop, insecticide use, and mite intensity in the weeds were removed from the model. The reduced model showed that year, location, planting date, and acaricide use were all significant factors that contributed to the number of days to maximum intensity (Table 3). Based on least square means it took more time (days) to reach maximum intensity in 2005 (lsmean = 81.7) than 2006 (lsmean = 71.4; $t = 2.62$, $P = 0.0106$). It also took mites longer to build to peak densities in the mountains (lsmean = 83.8) compared with piedmont fields (lsmean = 69.2; $t = 3.80$, $P = 0.0003$). In addition, maximum mite intensity occurred more quickly in late (lsmean = 69.4) versus early (lsmean = 78.6; $t = 2.2398$, $P = 0.0282$) and mid-planted fields (lsmean = 81.6; $t = 2.4491$, $P = 0.0167$), but there was no significant difference in time to maximum intensity between early and mid-planted ($t = 0.6813$ $P = 0.4979$). Finally, it took longer for mites to reach maximum densities in fields where no acaricide was applied (lsmean = 80.4) compared to those where acaricides were applied (lsmean = 72.7; $t = 2.03$, $P = 0.0458$).

Upon analysis, none of the factors (year, adjacent crop, previous crop, location, planting date, acaricide use, or insecticide use) were associated with the mite intensity in the weeds during the field infestation. Year, previous crop, and planting date were removed from the model and the resulting reduced model showed that the remaining factors were still not significantly associated with mite intensity in the weeds during the field infestation (Table 4).

Initial analysis showed that none of the factors (year, adjacent crop, previous crop, location, planting date, acaricide use, or insecticide use) were associated with mite intensity in the weeds surrounding tomato fields during the first two sample dates. Year, adjacent crop, and planting date were removed from the model and the resulting reduced model showed that previous crop and insecticide use were significant factors associated with mite intensity in the weeds during the first two sample dates (Table 5). Based on the least square means, mite intensities in the weeds were higher around those fields that had a previous crop of tomatoes (lsmean = 5.5) versus those that had a different previous crop (lsmean = 2.0; t = 2.14, P = 0.0359). Mite intensities were also higher in weeds surrounding tomato fields on the first two sample dates that had had insecticides applied that stimulate mite reproduction (lsmean = 5.9) versus those insecticides that were neutral (lsmean = 1.6; t = 2.22, P = 0.0292).

Analysis of the mite intensity in the weeds during the last two sample dates showed that none of the factors were associated with mite intensity in the weeds during the last two sample dates. Year, planting date, acaricide use, and insecticide use were removed from the model and the resulting reduced model showed that the remaining factors were still not significant (Table 6).

The mite intensity in weeds during the field infestation was significantly correlated with the seasonal mite intensity in the field (r = 0.4767, P < 0.0001) as well as the maximum mite intensity in the field (r = 0.4229, P = 0.0001). Mite intensity in the weeds on the last two sample dates was correlated with mite intensity in the field on the last two sample dates (r = 0.6580, P <0.0001). There was no significant correlation between the mite intensity in the weeds on the first two sample dates and the mite intensity in the field on the last two sample dates (r = -0.0357, P = 0.7566).

IV. Discussion

Mites were detected in all 80 tomato fields sampled in this study (Fig. 4). Among the 43 early planted fields sampled, 16 had a seasonal intensity of ≤10%, 21 fields had intensities ranging from 10-30%, and 6 fields had an intensity >30%. Among the 16 mid-season plantings, 3 had a seasonal intensity of ≤10% and 13 fields had an intensity ranging from 10-30%. Among the 21 late-planted fields, 12 seasonal intensities of ≤10% and 9 fields that had an intensity ranging from 10-30%.

Insecticide use was not a factor associated with mite intensities in the field, however it was found to be a factor associated with the mite intensity in the weeds on the first two sample dates. There were more mites found in weeds on the first two sample dates around fields where insecticides were applied that stimulate mite reproduction versus those fields treated with insecticides that have a neutral effect. This could be the result of chemical drift reaching the surrounding weeds, stimulating mite reproduction.

Acaricide use was a factor associated with seasonal and maximum mite intensity as well as the time to maximum mite intensity. Mite populations, both maximum and seasonal, were higher in acaricide-treated fields compared to those not treated with an acaricide. This was probably the result of acaricides being applied to those fields most heavily infested with mites or where mite populations developed most rapidly. Mite populations also reached their maximum intensity more quickly in fields treated with an acaricide versus no acaricide. The result of an acaricide application to those fields with high mite populations early in the season was a premature decline of the population. When fields were not treated with an acaricide, mite populations increased in density until host plant quality declined or temperatures decreased.

It was rather surprising that adjacent crop was not a factor that contributed to the susceptibility of tomato fields to mite infestations. Previous work conducted in eastern North Carolina showed that mites dispersed from infested corn fields to adjacent peanut fields (Brandenburg and Kennedy 1982; Margolies and Kennedy 1985). However, in our studies mite densities in adjacent crops were very low or followed similar trends to that of nearby tomato fields. This suggests that mites were infesting tomato fields and adjacent crops at the same time, and therefore mite movement among crops was not detected.

In view of the fact that twospotted spider mites are known to overwinter in weeds surrounding fields (Margolies and Kennedy 1985), and that seasonal mite populations in tomato fields and weeds were significantly correlated, it was hypothesized that high mite populations in tomato fields in one year would lead to high populations the following season. While previous crop was a significant factor affecting mite populations in tomato fields, it was not in the direction we expected – i.e., mite populations in non-rotated tomatoes (tomato followed by tomato) were significantly lower than in rotated fields (tomato preceded by an different crop). This occurrence is difficult to explain, but it suggests that mite populations in weeds had minimal impact on the intensity of mite populations in tomato fields.

Analysis of mite populations in weeds and tomato fields suggests that mites were reacting in a similar manner in both habitats. For example, correlation analysis showed that mite intensity in weeds and tomato crops were positively correlated; i.e., mite intensity in weeds and tomato fields increased in a similar manner. Mite intensity in weeds during the first two sample dates was also affected by current season insecticide use in tomatoes; i.e., early season mite populations in weeds were higher adjacent to tomato fields sprayed with pyrethroid insecticides. Finally, mite populations in weeds during the first two sample dates were higher when the previous crop was tomato versus another crop. It appears that the intensity of mite populations in weeds were a reflection of the mite intensity in the adjacent crop; i.e., tomatoes were the decisive factor in affecting mite populations, not weeds.

Although mite intensity in weeds during the first two sample dates was higher when the previous season's crop was tomato, early season mite populations were very low in weeds and tomatoes regardless of previous season crop. Of the 80 fields sampled in 2005 and 2006, mite infestations were detected in 31 fields on the first sample date, and in an additional 30 there were no mites detected in weeds preceding infestations in tomato fields. Figs. 5 & 6 show that mite population trends in fields that were not rotated (i.e., tomatoes followed by tomatoes) were very similar to those fields that were rotated (i.e., tomatoes planted in a different crop the previous year). In both field types, the initial mite infestation was very low, and over time exhibited an exponential type growth rate. The fact that initial mite intensities were very low regardless of previous crop, and by association previous mite population, suggests that overwintering mortality of mites was high and negated the impact of high mite populations the previous season. Results from chapter 1 suggested high overwintering mortality in the mountains, and high overwintering mortality was also observed by Collingwood (1955) in hops and blackcurrants, and Weldon (1910) in apples.

The difference in the number of days to reach the maximum intensity between 2005 and 2006 could be attributed to differences in the number of fields sampled. There were 22 tomato fields sampled in 2005, of which two were located in the mountain region. In 2006 there were 57 tomato fields sampled, of which 24 were located within the mountain region, and mites generally peaked earlier in piedmont versus mountain fields.

Difference in elevation, temperature, and humidity may have contributed to the differences found among locations. The elevation of fields in the piedmont in Rowan and Polk counties in NC, and Greenville County, SC, was 213.4, 365.8, and 319.43 m, respectively. The elevation in the two main mountain locations Henderson and Haywood, NC, was 630 and 811.4 m, respectively. These higher elevation sites had cooler temperatures than lower elevation sites (Table 7). Several studies have shown that both temperature and humidity, along with host plant quality, are important factors in spider mite development. Cagle (1949), Laing (1969), and van de Bund and Helle (1960) showed that spider mites took longer to develop at lower temperatures. Boudreaux (1958) showed that mites in high humidity environments produce fewer eggs and had a shorter life expectancy than those in dryer environments. Nickel (1960) showed that *T. urticae* developed faster and produced more eggs under low humidity (25-30%) than high humidity (85-90%). The average relative humidity during the growing season recorded at the Piedmont Research Station in Salisbury, NC, was 75% and 74% in 2005 and 2006 respectively, while those recorded at the Mountain Horticultural Crops Research Station in Fletcher, NC were 80% and 79% in 2005 and 2006 respectively (Table 8) (State Climate Office of North Carolina 2006a, b).

While later-planted fields did not experience a significantly higher intensity of mites, the time interval between planting and peak mite intensity was shorter than that in early and mid planted fields. This was probably because later fields were planted when temperatures were warmer, allowing mite populations to increase more rapidly than in those planted when temperatures were cooler.

While it is difficult to determine the major contributing factors to twospotted spider mite infestations in tomatoes, this crop is seriously affected and is an important summer host.

Failure to identify the major contributing factors to spider mite infestations in tomato fields complicates developing management strategies for this pest. Evaluating fields and field borders more often and more intensely, and evaluating the potential of mite movement of field workers may provide more insight to this problem. Regardless, acaricides will remain an important management tool, and resistance development is a key concern. Because virtually all fields are susceptible to mite infestations, growers must carefully monitor spider mite populations and use acaricides judiciously to both prevent injury to plants and preserve mite susceptibility to these products.

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Table 1. Multiple regression ANOVA results of factors associated with seasonal twospotted spider mite intensity in tomato fields.

Model Run	Factor	*F*	df	*P*
All factors	Year	0.02	1	0.8975
	Adjacent crop	0.49	1	0.4848
	Previous crop	3.90	1	0.0523
	Location	0.31	1	0.5768
	Planting date	1.05	2	0.3558
	Acaricide use	2.61	1	0.1107
	Insecticide use	0.65	1	0.4221
	Weeds	**14.94**	**1**	**0.0003**
	Location x Planting date	0.33	2	0.7219
	Error	—	68	—
Reduced	**Previous crop**	**6.45**	**1**	**0.0131**
	Acaricide use	**6.00**	**2**	**0.0166**
	Insecticide use	1.53	1	0.2203
	Weeds	**20.08**	**1**	**<0.0001**
	Error	—	75	—

Table 2. Multiple regression ANOVA results of factors associated with maximum twospotted spider mite intensity in tomato fields.

Model Run	Factor	*F*	df	*P*
All factors	Year	0.20	1	0.6561
	Adjacent crop	0.92	1	0.3414
	Previous crop	2.43	1	0.1237
	Location	0.16	1	0.6869
	Planting date	0.28	2	0.7541
	Acaricide use	3.67	1	0.0595
	Insecticide use	0.53	1	0.4676
	Weeds	**10.94**	**1**	**0.0015**
	Location x Planting date	0.29	2	0.7458
	Error	—	68	—
Reduced	Adjacent crop	1.45	1	0.2331
	Previous crop	3.39	1	0.0696
	Acaricide use	**4.46**	**1**	**0.0381**
	Insecticide use	1.02	1	0.3160
	Weeds	**12.53**	**1**	**0.0007**
	Error	—	74	—

Table 3. Multiple regression ANOVA results of factors associated with the time to reach maximum twospotted spider mite intensity in tomato fields.

Model Run	Factor	*F*	df	*P*
All factors	**Year**	**5.61**	**1**	**0.0207**
	Adjacent crop	0.13	1	0.7213
	Previous crop	1.77	1	0.1875
	Location	**8.77**	**1**	**0.0042**
	Planting date	**3.32**	**2**	**0.042**
	Acaricide use	2.18	1	0.1442
	Insecticide use	0.25	1	0.6219
	Weeds	0.75	1	0.3911
	Location x Planting date	0.53	2	0.5938
	Error	—	68	—
Reduced	**Year**	**6.89**	**1**	**0.0106**
	Previous crop	1.36	1	0.248
	Location	**14.43**	**1**	**0.0003**
	Planting date	**3.58**	**2**	**0.033**
	Acaricide use	**4.13**	**1**	**0.0458**
	Error	—	73	—

Table 4. Multiple regression ANOVA results of the seasonal intensity of twospotted spider mite in weeds surrounding tomato fields.

Model Run	Factor	*F*	df	*P*
All factors	Factor	*F*	df	*P*
	Year	0.05	1	0.8228
	Adjacent crop	0.83	1	0.3652
	Previous crop	0.23	1	0.7929
	Location	0.92	1	0.3412
	Plant date	0.24	2	0.629
	Acaricide use	0.47	1	0.4938
	Insecticide use	0.38	1	0.5379
	Error	—	69	—
Reduced	Adjacent crop	1.38	1	0.2441
	Location	1.13	1	0.2907
	Acaricide use	0.73	1	0.3945
	Insecticide use	0.46	1	0.4979
	Error	—	73	—

Table 5. Multiple regression ANOVA results of the intensity of twospotted spider mite in weeds surrounding tomato fields during the first two sample dates.

Model Run	Factor	*F*	df	*P*
All factors	Year	0	1	0.9587
	Adjacent crop	0.1	1	0.7479
	Previous crop	3.89	1	0.0526
	Location	0.15	1	0.6979
	Plant date	0.34	2	0.7144
	Acaricide use	0.94	1	0.3364
	Insecticide use	3.48	1	0.0664
	Error	—	69	—
Reduced	**Previous crop**	**0.23**	**1**	**0.0359**
	Location	4.57	1	0.6311
	Acaricide use	1.99	1	0.1624
	Insecticide use	**4.95**	**1**	**0.0292**
	Error	—	73	—

Table 6. Multiple regression ANOVA results of the intensity of twospotted spider mite in weeds surrounding tomato fields during the last two sample dates.

Model Run	Factor	*F*	df	*P*
All factors	Year	0.43	1	0.5119
	Adjacent crop	0.43	1	0.5152
	Previous crop	0.13	1	0.7214
	Location	1.21	1	0.2758
	Plant date	0.33	2	0.7219
	Acaricide use	0	1	0.9642
	Insecticide use	0	1	0.9773
	Error	—	69	—
Reduced	Year	0.5	1	0.483
	Adjacent crop	2.16	1	0.4207
	Previous crop	0.66	1	0.7081
	Location	0.14	1	0.1457
	Error	—	73	—

Table 7. Average monthly temperatures (ºC) through the growing seasons of 2005 and 2006 recorded at North Carolina Department of Agriculture research stations in Fletcher and Salisbury, NC.

Month/Year	Fletcher	Salisbury
April-05	12.2	14.4
May-05	15.2	17.6
June-05	19.9	22.8
July-05	22.4	25.5
August-05	22.2	25
September-05	19	21.9
April-06	14.4	16.4
May-06	15.7	17.8
June-06	19.9	22.7
July-06	22.2	25.2
August-06	22.4	24.9
September-06	17.1	19.5

Table 8. Average monthly humidity (percent) through the growing seasons of 2005 and 2006 recorded at North Carolina Department of Agriculture research stations in Fletcher and Salisbury, NC.

Month/Year	Fletcher	Salisbury
April-05	70	65
May-05	73	69
June-05	84	78
July-05	86	80
August-05	86	82
September-05	82	75
April-06	66	64
May-06	77	71
June-06	77	73
July-06	82	75
August-06	86	81
September-06	88	82

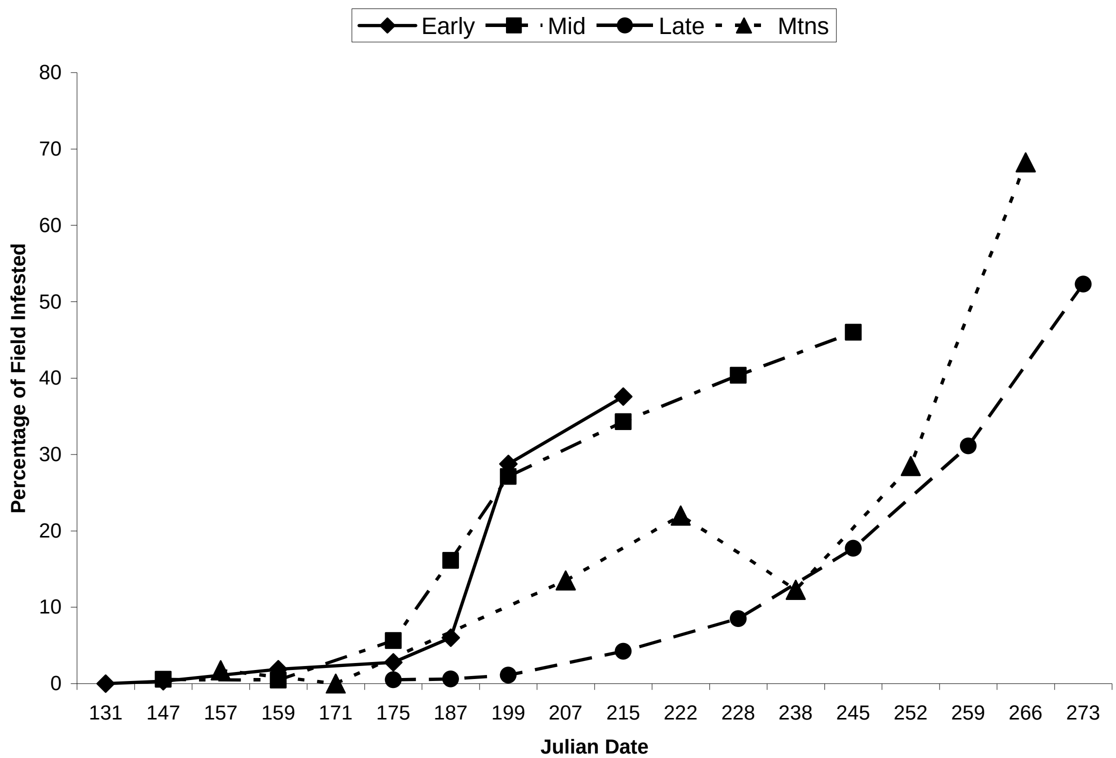

Fig. 1. 2005 Average twospotted spider mite infestations in three different planting times in the piedmont region and one planting time for the mountain region of North Carolina.

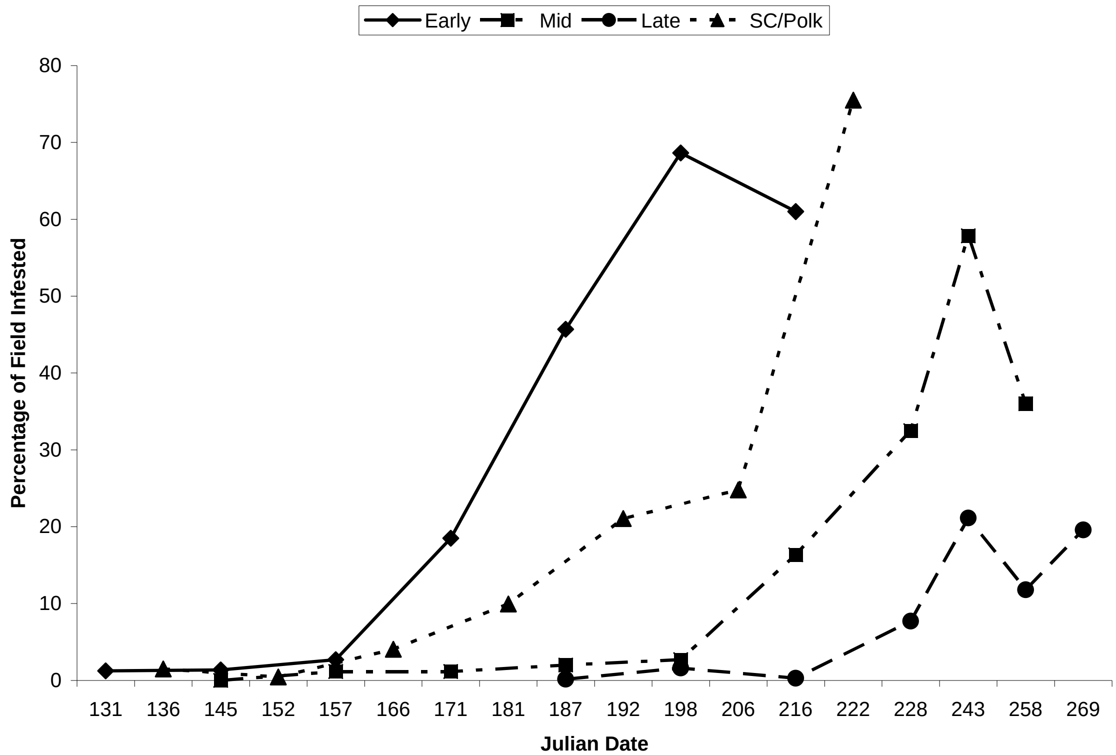

Fig. 2. 2006 Average twospotted spider mite infestations in three different planting times in the piedmont region of North Carolina and the average twospotted spider mite infestations in early plantings in Polk County, NC and Greenville County, SC.

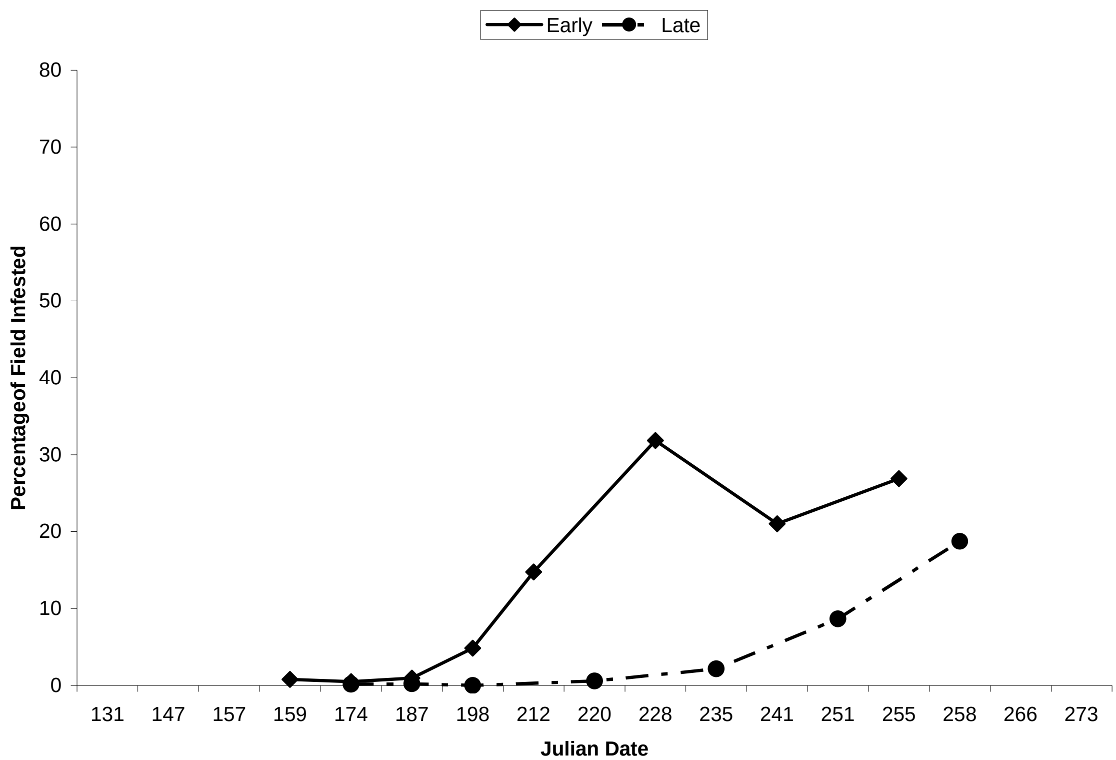

Fig. 3. 2006 Average twospotted spider mite infestations in early and late planted fields in the mountain region of North Carolina.

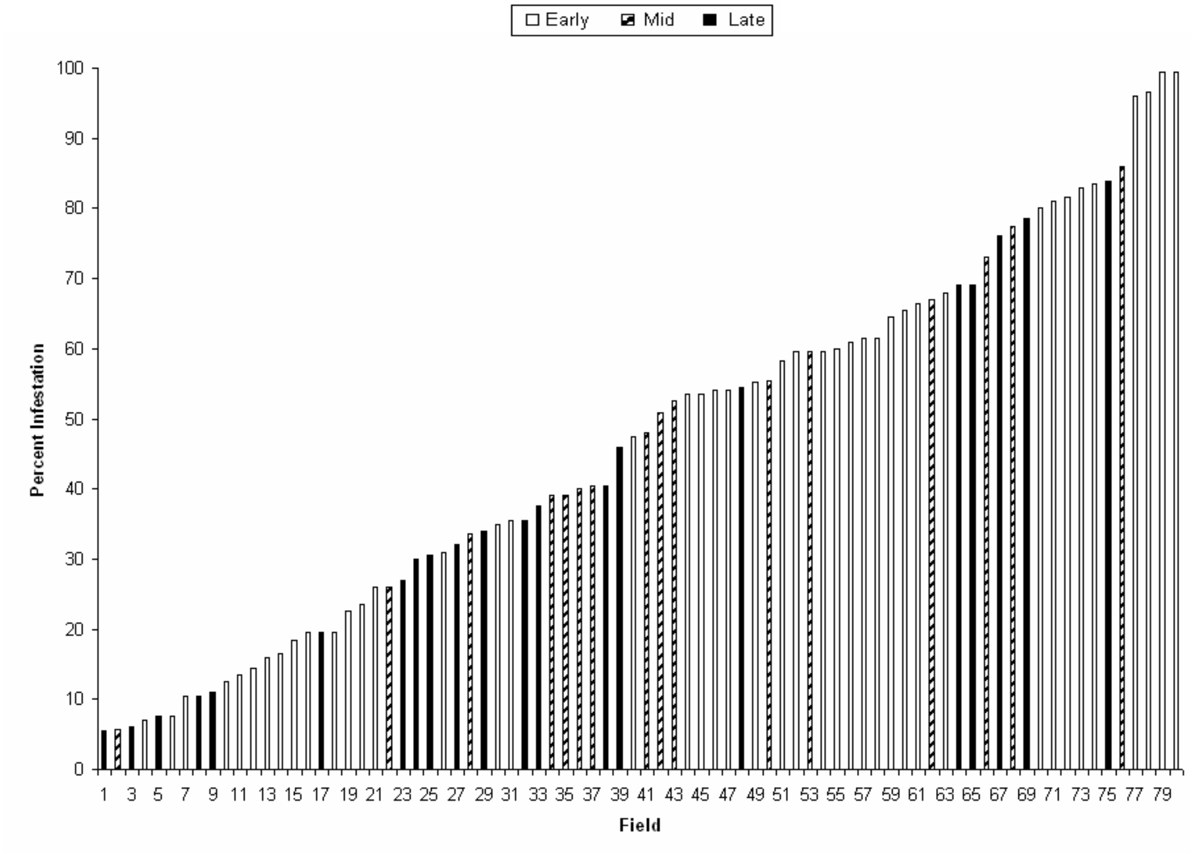

Fig. 4. The maximum twospotted spider mite intensity in each tomato field sampled in 2005 and 2006.

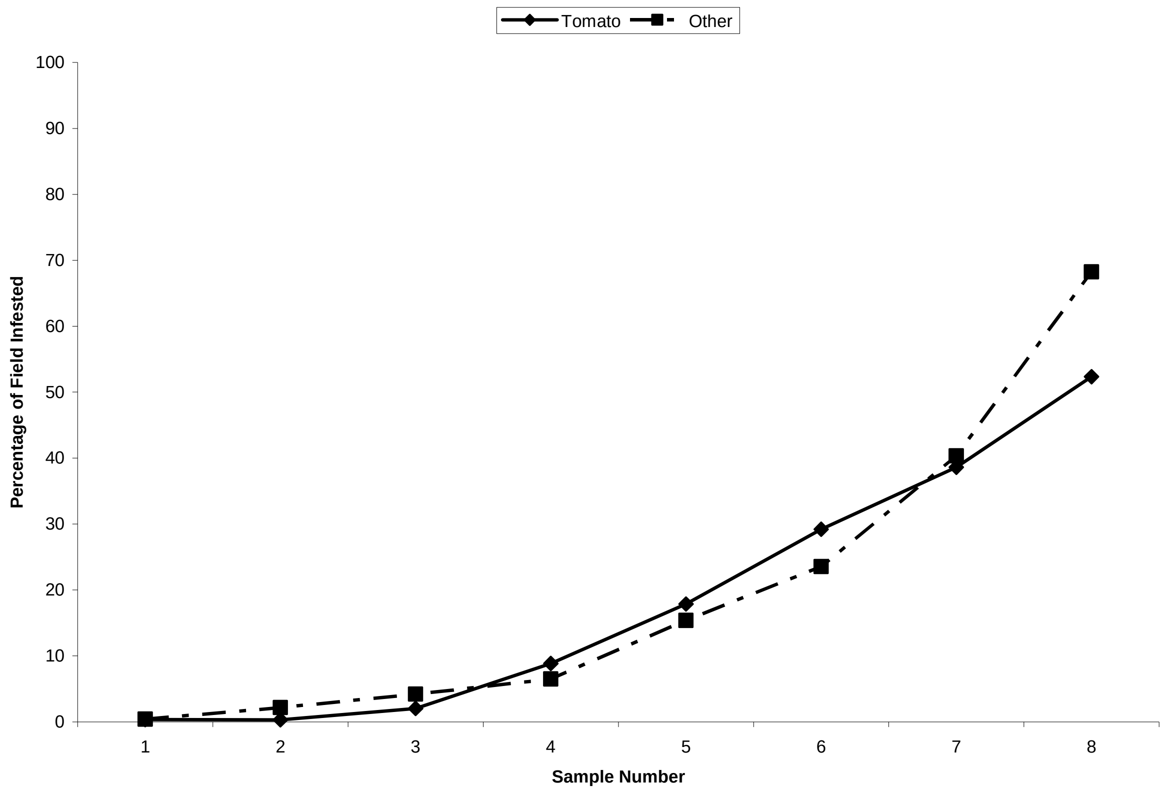

Fig. 5. 2005 Average mite intensity in tomato fields with a previous crop of tomatoes or other crop.

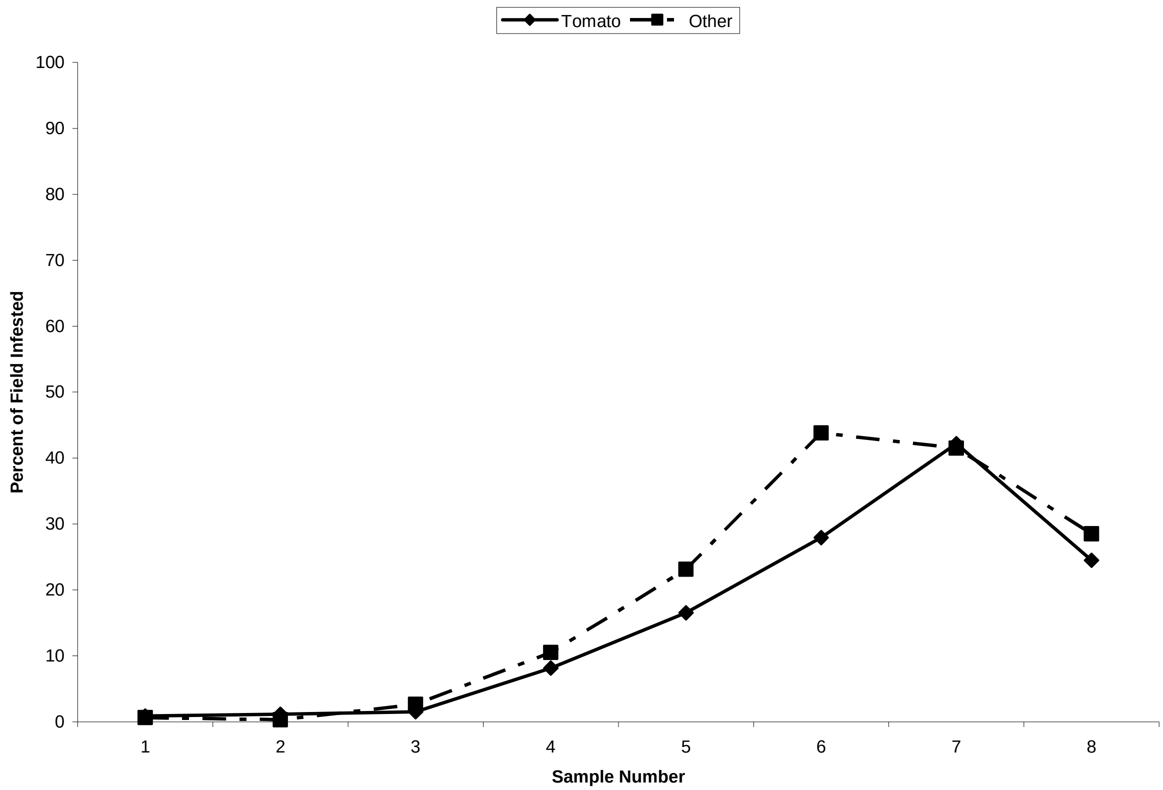

Fig. 6. 2006 Average mite intensity tomato fields with a previous crop of tomatoes or other crop.