ABSTRACT

GARCIA, LLOYD EDWARD. Seasonal occurrence and epidemiology of tomato spotted wilt virus and *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) with emphasis on 3 peanut genotypes in North Carolina.

The purpose of the research has been to further the understanding of the seasonal occurrence of Tomato Spotted Wilt Virus (TSWV) and the insect vector, *F. fusca*, in relation to North Carolina peanut production. Emphasis was placed on 3 Virginia-type peanut genotypes, NC-9, NC-V11, and NC-12C, which were included in field and greenhouse experiments to determine relative disease and thrips levels and their interactions. These are components of a larger strategic goal to develop management strategies that can minimize future impacts of TSWV and be compatible with peanut production in North Carolina. Research was conducted to determine the winter, spring, and summer occurrence of *F. fusca* in NC peanut fields. Thrips movement in spring was significantly influenced by prevailing wind direction. No thrips were collected on sticky traps during days when maximum temperature did not exceed 18.7°C. *F. fusca*, caged with TSWV infected peanut plants in August, 1996 and sampled in March, 1997, were analyzed for the presence of TSWV by ELISA. A single thrips tested positive for the virus. In another experiment, three Virginia-type peanut genotypes were monitored for the incidence of TSWV symptoms and the presence of *F. fusca* at 3 locations in NC's peanut producing area. Overall disease incidence at the 3 locations was 6%. Of the 3 genotypes, NC-9 ranked highest in disease incidence (7%), followed by the genotypes NC-12C (6%) and NC-V11 (5%). *F. fusca* counts were greatest on NC-V11, followed by NC-9 and NC-12C. A comparison of the survival and reproductive success of *F. fusca* on TSWV infected and uninfected plants of the 3 genotypes was conducted under greenhouse conditions in NC. Effects of genotype and virus by genotype interaction were not significant. However, TSWV infected plants had significantly fewer adult and larval *F. fusca* than did uninfected plants.

SEASONAL OCCURRENCE AND EPIDEMIOLOGY OF TOMATO SPOTTED WILT VIRUS AND *FRANKLINIELLA FUSCA* (HINDS) (THYSANOPTERA: THRIPIDAE) WITH EMPHASIS ON 3 PEANUT GENOTYPES IN NORTH CAROLINA

by

LLOYD EDWARD GARCIA

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Entomology

Raleigh
1999

APPROVED BY:

Co-chair of Advisory Committee	Co-chair of Advisory Committee

DEDICATION

This work is dedicated to my family. Their cooperation made this project possible and their support has made it all worthwhile.

BIOGRAPHY

Lloyd Edward Garcia was born on 24 December 1952 in Bellefonte, Pennsylvania. He received his elementary and secondary education in Raleigh, North Carolina, graduating from N.B. Broughton High School in 1970.

He received his Bachelor of Science degree in both Horticultural Science and Botany from North Carolina State University in 1977 and his Master of Science degree in Entomology from North Carolina State University in 1981. Since this time, he has been employed by the North Carolina Department of Agriculture, excluding a two-year leave-of-absence when he was employed by the Near East Foundation of New York as their representative with the University of Khartoum, Shambat and the Sudanese National Council of Research in Sudan. His pursuit of the doctoral program in entomology has been at the request and with the support of the North Carolina Department of Agriculture while acting as the Department's Staff Entomologist.

The author is married to the lovely Carmen R. Lanz-Garcia, and they have two children, Morgan, born in 1982 and Oliver, born in 1986.

ACKNOWLEDGMENTS

The North Carolina Department of Agriculture and Consumer Services provided financial support and the opportunity for this research. I am indebted in particular to the encouragement of Howard Singletary, Willard Dickerson, and John Scott. I am grateful for the opportunity they presented to me.

I thank Dr. Rick Brandenburg for his advice, humor, and patience in this endeavor. Drs. George Kennedy, Jack Bailey, and J. R. Bradley generously provided assistance and guidance, as well as critical reviews of the manuscripts. Their support is greatly appreciated.

In Dr. Brandenburg's lab, I would like to acknowledge Dr. Jim Barbour, Brian Royals, Brenda Watson, and Peter Hertl for their help both in the field and at the lab. Russ Groves, Carol Berger, Scott Costa, and Vann Covington in Dr. Kennedy's lab were a source inspiration and assistance with the greenhouse studies. I enjoyed their sense of humor. Dr. Katrin Hoffmann and Jan Speck, in Dr. James Moyer's lab, spent many patient hours helping me during the analysis of plant tissues making this aspect of the research possible.

Steve Barnes at the Peanut Belt Research Station in Lewiston was responsible for the selection and preparation of the field sites. Griffin Farms and the Umphlett Bothers Farm

in Bertie and Gates Counties kindly allowed me to work in their peanut fields. I am grateful to them for their generosity.

I want also to thank my family for their patience during this project. I am especially grateful for the stamina and perseverance of my wife, Carmen, and my parents during the years. My children, Morgan and Oliver, have been a terrific source of pride and an educational experience in themselves throughout this endeavor. I love you all.

TABLE OF CONTENTS

LIST OF TABLES. ix

LIST OF FIGURES. xii

I. WINTER OCCURRENCE AND SPRING MIGRATION OF *FRANKLINIELLA FUSCA* (HINDS) (THYSANOPTERA: THRIPIDAE) IN NORTH CAROLINA PEANUT (*ARACHIS HYPOGAEA* L.) FIELDS 1

Introduction 2

Materials and Methods. 2

Winter Trapping. 2

Winter Survival of TSWV Infected Tobacco Thrips 3

Sticky Traps. 4

Trap Plants. 5

Exclusion Boxes 5

Weather Monitoring. 5

Statistical Analysis. 6

Results. 6

Winter Trapping. 6

Winter Survival of TSWV Infected Tobacco Thrips 6

Sticky Traps and Trap Plants 7

Exclusion Boxes. 7

Weather Effects. 7

Discussion. 8

References Cited 10

II. INCIDENCE OF TOMATO SPOTTED WILT VIRUS (BUNYVIRIDAE: *TOSPOVIRUS*) AND *FRANKLINIELLA FUSCA* (HINDS) (THYSANOPTERA: THRIPIDAE) IN THREE VIRGINIA-TYPE PEANUT (*ARACHIS HYPOGAEA* L.) GENOTYPES IN NORTH CAROLINA. 24

Introduction. 25

Materials and Methods 27

1995 Experimental Field Design. 27

Bertie County Field Evaluation. 27

Gates County Field Evaluation. 28

1996 Experimental Field Design 28

Disease Rating. 29

Thrips Collection. 29

Yield Determination. 30

Laboratory Design. 30

Data Analysis 31

Results 31

1995 Bertie County 31

1995 Gates County 31

1996 Disease Incidence 32

Yield. 32

Thrips Counts. 33

Mechanical Inoculations 33

Discussion. 33

References Cited. 36

III. SURVIVAL AND REPRODUCTIVE SUCCESS OF TOBACCO THRIPS (THYSANOPTERA: THRIPIDAE) ON 3 TOMATO SPOTTED WILT VIRUS (BUNYVIRIDAE: *TOSPOVIRUS*) INFECTED AND NON-INFECTED PEANUT (*ARACHIS HYPOGAEA* L.) GENOTYPES IN NORTH CAROLINA. 56

Introduction. 57

Materials and Methods. 58

Experimental Design. 58

TSWV Inoculation. 59

Thrips Infestations 59

Data Collection and Analysis. 60

Results 60

TSWV Inoculations 60

Thrips Counts 61

Discussion. 62

References Cited 63

LIST OF REFERENCES. 70

List of Tables

Chapter I

1. Total number of tobacco thrips collected from cylindrical sticky traps set at 20.32 cm above ground level at a rate of 4 traps per field. 13
2. Total tobacco thrips counts and SEM at 3 elevations (Bertie Co., North Carolina 1992-92) 14
3. Mean tobacco thrips counts and LSD per sticky traps and trap plants at each sampling period with years combined (Bertie Co., North Carolina 1992-93). 15
4. 1993 Mean tobacco thrips counts and SEMs per trap location and sample period at the Peanut Belt Research Station, Lewiston, North Carolina (Bertie Co., North Carolina 1993). 16
5. Daily tobacco thrips catch, precipitation (mm), and temperature (°C) data collected at the Peanut Belt Research Station, Lewiston, Bertie County, North Carolina, during 13-26 May, 1992 and 12-25 May, 1993. 17

Chapter II

1. Mean weekly TSWV disease rating of peanut genotypes (NC-9, NCV-11, and NC-12C) at 3 treatment locations

(Bertie, Gates, and Lewiston), 1996. 41

2. Mean weekly TSWV disease rating of the 3 peanut genotypes (NC-9, NC-V11, and NC-12C) across locations (Bertie, Gates, and Lewiston), 1996 42

3. Average per plant yield at each location and for each genotype 43

4. Mean and SEM of total pod weight per plant, pod count per plant and average weight per pod, at each of the three treatment locations and from each of the three evaluated genotypes (Bertie and Gates Cos., North Carolina, 1996) 44

5. Average weekly counts and SEM of adult and larval *F. fusca* by location and peanut genotype (Bertie and Gates Cos., North Carolina, 1996). 45

6. Weekly mean counts and SD of adult *F. fusca* by locations and by the three genotypes (Bertie and Gates Cos., North Carolina, 1996). 46

7. Weekly mean counts and SD of larval *F. fusca* by locations and by the three genotypes (Bertie and Gates Cos., North Carolina, 1996). 47

Chapter III

1. Percentage of caged plants with tobacco thrips at the

end of the sampling period (30 days) by TSWV infected plants and uninfected plants, and by peanut genotype, 1998. 66

2. Mean *F. fusca* adult and larvae counts and SEM from caged plants by genotype and by plants with and without zero counts, 1998. 67

3. Mean *F. fusca* adult and larvae counts and SEM from TSWV infected and uninfected caged plants including and excluding caged plants with zero counts, 1998. 68

4. Mean *F. fusca* adult and larvae counts and SEM from caged plants by virus and genotype, 1998. 69

List of Figures

Chapter I

1. Daily mean minimum winter temperatures, January through March, for 1993 - 1996 at the Peanut Belt Research Station, Lewistion, North Carolina 18

2. Total tobacco thrips counts per sticky trap location during the 14 day trapping periods in May 1992 and 1993 at the Peanut Belt Research Station, Lewiston, North Carolina. 19

3. Total tobacco thrips counts per trap plant during the 14 day trapping periods in May 1992 and 1993 at the Peanut Belt Research Station, Lewiston, North Carolina 20

4. Total daily tobacco thrips counts from all sticky traps during the 14 day trapping periods in May 1992 and 1993 at the Peanut Belt Research Station, Lewiston, North Carolina 21

5. Total daily tobacco thrips counts from all trap plants during the 14 day trapping periods in May 1992 and 1993 at the Peanut Belt Research Station,

Lewiston, North Carolina. 22

6. Total of daily tobacco thrips catches on sticky traps plotted by daily maximum temperatures for the 14 day trapping periods during May 1992 and 1993 at the Peanut Belt Research Station, Lewiston, North Carolina. 23

Chapter II

1. The percentage of TSWV infected plants at each location at the end of the season (Bertie and Gates Cos., North Carolina, 1996). 48

2. Mean TSWV disease rating at each location beginning at week 5 post planting (Bertie and Gates Cos., North Carolina, 1996). 49

3. Mean TSWV disease rating for each genotype beginning at the fifth week post planting (Bertie and Gates Cos., North Carolina, 1996). 50

4. Log of the adult tobacco thrips counts taken from 20 unopened quadrifoliate leaves per plot at each location beginning at week one post planting (Bertie and Gates Cos., North Carolina, 1996) 51

5. Log of adult tobacco thrips counts taken from 20 unopened quadrifoliate leaves per plot for each

genotype beginning at week one post planting (Bertie and Gates Cos., North Carolina, 1996). 52

6. Log of the larval tobacco thrips counts taken from 20 unopened quadrifoliate leaves per plot at each location beginning at week one post planting (Bertie and Gates Cos., North Carolina, 1996) 53

7. Log of the larval tobacco thrips counts taken from 20 unopened quadrifoliate leaves per plot for each genotype beginning at week one post planting (Bertie and Gates Cos., North Carolina, 1996) 54

8. Mean optical density readings of ELISA plate wells at 405 nm of peanut genotypes beginning at 13 days post inoculation and continuing for 4 weeks at 7 day intervals in 1996 55

Chapter I

Winter Occurrence and Spring Migration of *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) in North Carolina Peanut (*Arachis hypogaea* L.) Fields[1]

Garcia, L.E., Brandenburg, R.L., Kennedy, G.G., Bailey, J.E., and Bradley, J.R.

Abstract: To evaluate overwintering of *Frankliniella fusca* (Hinds), tobacco thrips, in North Carolina and their subsequent spring movement into peanut fields, 2 winter sampling techniques and 3 spring sampling techniques were utilized at the Peanut Belt Research Station, Lewiston, North Carolina. In the spring of 1992 and 1993, for 14 days following peanut planting, the aerial movement of tobacco thrips was monitored using cylindrical sticky traps, trap plants, and cages covering planted peanut seeds. *F. fusca* were trapped significantly more often at low trap elevations and during the afternoons. Thrips movement was significantly influenced by prevailing wind direction. Movement was not observed with sticky traps on days when maximum temperatures did not exceed 18.7°C. *F. fusca* began to colonize emerging peanut plants as they cracked the soil surface on days when environmental conditions were favorable for movement (temperatures above 18.7°C and no precipitation). During 3 consecutive winters, 1993-96, aerial *F. fusca* movement was monitored with sticky traps. Individual *F. fusca* were collected on sticky traps throughout the winter, however, counts were lower in months and years with lower temperatures. Tobacco thrips, caged with Tomato Spotted Wilt Virus (TSWV) infected peanut plants in August, 1996 and sampled in March, 1997, were analyzed for virus acquisition and infectivity by ELISA using a monoclonal antibody developed by M. Bandla and J. Sherwood, University of Oklahoma. A total of 8 tobacco thrips were collected, of which one tested positive.

[1]This chapter will be modified and submitted for publication to J. Econ. Entomol. as: Garcia, L.E., Brandenburg, R.L., Kennedy, G.G., Bailey, J.E., and Bradley, J.R. Winter occurrence and spring migration of *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) in North Carolina peanut (*Arachis hypogaea* L.) fields.

Key Words *Frankliniella fusca*, tomato spotted wilt virus, overwintering, spring migration

Tomato Spotted Wilt Virus (TSWV) is a worldwide disease in numerous field, vegetable and ornamental crops (Peters 1996). Periodic economic losses have occurred in Texas and Georgia peanuts, *Arachis hypogaea* L., as a result of this virus (Mitchell 1991). Seven thrips vectors have been identified (Mound 1996) and the principal TSWV vector in NC peanut fields is considered to be *F. fusca* (Barbour 1994). Additional information is necessary regarding the habits of *F. fusca* and the complex relationship between tobacco thrips, TSWV, and peanuts to augment management practices designed to help prevent economic losses that result from this disease.

The objective of this study was to better understand the source of migrating tobacco thrips at the time of peanut planting in NC (early May). All experiments were conducted at the Peanut Belt Research Station, Lewiston, NC (PBRS) from 1992-96. Trapping was conducted and tobacco thrips populations were sampled during the winter months to determine the movement of *F. fusca* and the survival of viruliferous thrips in NC . At peanut planting, an array of cylindrical sticky traps, trap plants and emergence cages were set in peanut fields to investigate dispersal habits of *F. fusca*.

Materials and Methods

Winter Trapping. The aerial movement of tobacco thrips was monitored in harvested peanut fields during 3 consecutive winters, 1994 to 1996, and in corn fields during 2 consecutive winters, 1995 and 1996. Sampling was conducted at the PBRS. Traps consisted of a 10.2 cm x 2.9 cm piece of clear acetate film coated on one side with Tanglefoot® (Great Lakes IPM, MI). The film was wrapped around an 11.43 cm section of 1.91 cm diameter polyvinyl chloride (PVC) pipe painted blue (Sinclair Paint, Inc.) (Matteson 1992). Traps were slid onto a 61cm section of 1.27 cm diameter conduit pipe

and held at 0.2 m above ground level. Four traps were randomly placed in 1-2 hectare peanut field and corn field each year. Traps were replaced monthly for December, January, and February, and every 2 weeks during March and April. Tobacco thrips were identified with the aid of a dissecting microscope.

Winter Survival of TSWV Infected Tobacco Thrips. Overwintering of TSWV infected tobacco thrips on peanuts has been reported in GA (Chamberlin 1993). The ability of tobacco thrips to overwinter on TSWV infected peanut plants in NC was investigated during the winter of 1995-96. Forty-five field grown peanut plants (NC-7) showing visible symptoms of TSWV, including ring-spots and twisted petioles were dug on 23 June. The plants were randomly transplanted in groups of 3 plants. Plant groups were 1m apart within a row at the PBRS. Dead plants were replaced on 20 and 27 July with diseased plants. Each group of 3 plants was enclosed in a circular cage with a perimeter of 1.8 m and a height of 60.96 cm. The cages consisted of a chicken wire frame and a tubular sleeve made of thrips-proof nylon screen (Bugbed 123™, Greenthumb Group, Downers Grove, IL 60515). The chicken wire frame and nylon screen extended 15.24 cm into the soil. The screening was gathered and twisted above the plants then secured with nylon string. Three additional cages without peanut plants were erected on methyl bromide fumigated soil.

On 10 August 100-200 laboratory reared individual *F. fusca* were added to each group of caged peanut plants. No thrips were added to the 3 cages without peanut plants. All cages were then secured with duct tape in addition to the nylon string closure. Water was applied to the soil at the perimeter of the cages as required by the plants.

The peanut plants in the cages died during the low temperatures of November and December. The weeds within cages were controlled by an application of Gramoxone ® (Zeneca Inc.) on February 1, 1996 to eliminate alternative thrips host plants. Beginning on 1 March, and at 7 day intervals, a 1-week old greenhouse grown peanut seedling was

added to each cage. The seedlings were held in watered floral tubes stuck in the ground with the cotyledons at ground level. Plants were collected every week for 8 weeks into a sealable plastic bag and examined in the laboratory for the presence of tobacco thrips.

All tobacco thrips recovered from the peanut seedlings were assayed for TSWV by ELISA using a monoclonal antibody and protocol developed by Dr. M. Bandla and Dr. J. Sherwood, University of Oklahoma, Department of Plant Pathology (Bandla 1994). This monoclonal antibody bonds to a non-structural protein encoded for by the small RNA of TSWV. The protein is only present during replication of the virus. Replication of the virus in thrips is necessary for virus transmission (Ullman 1993).

Sticky Traps. The migration of tobacco thrips into a peanut field was monitored for 14 days post planting in 1992 (May 13 - 26) and 1993 (May 12 - 25) at the PBRS. Three sampling methods were used to evaluate tobacco thrips movement. In each field thrips counts were taken from 13 locations arranged on two perpendicular transects with 6 locations each, plus a common midpoint. Locations along each transect were 13.72 m apart. At each location, 3 sticky traps, of the type used during the winter surveys above, were stacked onto a 2.4 m x 1.27 cm section of conduit pipe driven into the ground. Traps were spaced on the conduit pipe at 0.2 m, 0.9 m, and 1.8 m above the soil surface. The ends of each PVC trap were notched with two grooves 180° apart which allowed the tube to rest in a stable position on a 0.64 cm diameter wooden dowel inserted through the conduit pipe. The dowels were aligned along a north/south axis and the compass orientation of each captured thrips was noted. Traps were changed 3 times per day at 0600, 1200, and 1800 hours. After each sampling period, the sticky sheets were removed from the PVC tube and placed on polyethylene film until the thrips could be removed by soaking for 15 minutes in Histoclear™ (Great Lakes IPM, MI) and mounted on a microscope slide with CMC-10 Mounting Media (Master's Chemical Company, Inc., IL). Tobacco thrips counts were recorded by day, location, elevation, sample period and compass direction (N,S,E, or W).

Trap Plants. For the second sampling method, 2 to 3 week old potted (10.16 cm diameter pots) peanut plants were placed 3 m north of each of the sticky trap locations. Each plant was trimmed to a uniform size of 3 unopened tetrafoliate leaves. At all of the sampling times (0600, 1200, and 1800 hours) the above-ground portion of the plants was removed with scissors and placed in a vial with 70% ethyl alcohol. Thrips were mounted as described above and the day, location, and sample period recorded for each tobacco thrips.

Exclusion Boxes. Fifty-six clear plastic sweater storage boxes (50.8 cm x 30.48 cm x 20.32 cm) were placed over the peanut rows immediately following planting. The boxes were set on a 7 by 8 grid in the peanut field with boxes 13.5 m apart within rows and 9 m apart across rows. Boxes were randomly assigned a position in the grid. Each day three randomly selected boxes were removed and set aside for a 24 h period to expose the row sections beneath the boxes to migrating thrips. After 24 hours the boxes were replaced. A unique group of boxes were set aside each 24 h period. A fourth box was also randomly selected each day and the peanut seeds/plants removed to estimate plant development. At the end of the 14 day period, all above ground foliage from each box was removed with scissors and placed in 70% ethyl alcohol. Adult tobacco thrips counts per box were recorded.

Weather Monitoring. Daily minimum and maximum temperatures and precipitation measurements were collected at a weather station located on the PBRS. Wind direction information was collected hourly at two airport weather stations. The stations were located at the Rocky Mount/Wilson Airport (55 k southwest) and the Elizabeth City Airport (85 k northeast). Readings from these two stations were compared and the prevailing wind direction determined. Weather data collected at the nearby airports were provided by the State Climate Office of North Carolina. Thrips compass orientation was characterized as either being in the direction of the prevailing wind, or not being in the direction of the prevailing wind.

Statistical Analysis. Tobacco thrips counts from spring sticky traps and trap plants were analyzed by factorial analysis of variance using the General Linear Models Procedure and Least Squares Means of SAS (Ver. 6.12, SAS Institute, Cary, NC). Winter sticky thrips counts were too low for analysis. T-test was used to calculate the least significant differences in the reported means of counts at height and sample period. Segmented regression with Proc NLIN of SAS was utilized to estimate the maximum temperature where daily thrips counts on sticky traps starts to be non-zero.

Results

Winter Trapping. Tobacco thrips were caught on sticky traps during the winter months in each of the sampling seasons (Table 1). More thrips were trapped in the winter of 1994-95. An equal number of thrips were trapped in peanut fields during the winters of 1993-94 and 1995-96. The winter of 1994-95 experienced the warmest temperatures of the three winters sampled with only 3 recorded days when temperatures fell to -10°C (Figure 1). The winter of 1993-94 experienced 4 days with temperatures < -10°C, and 1 day with a temperature of -15°C, all occurring in January. The recorded cold temperatures during the winter of 1995-96 occurred in February when temperatures reached -10°C and -16. 7°C. A low of -7.8°C was recorded on 10 March 1996.

Winter Survival of TSWV Infected Tobacco Thrips. A total of 8 adult tobacco thrips were collected from the overwintering cages on 6 March 1996, the first sampling date. One thrips was collected on the second sampling date, 14 March. No further thrips were collected. All thrips were analyzed by ELISA. A single thrips, collected on 6 March, tested positive for TSWV by ELISA. The optical density reading for this thrips was greater than 3 times the healthy control's standard deviation plus the healthy control's mean.

Sticky Traps and Trap Plants. Location of sticky traps ($F=1.56$ and $p=0.09$) and trap

plants (F=2.10 and p=0.02) was not a significant factor in the number of tobacco thrips trapped in either year (Figure 2 and 3). However, the number of thrips trapped per day varied significantly in each year for both sticky traps (F=15.99 and p=0.0001) and trap plants (F=6.99 and p=0.0001) (Figure 4 and 5). Significantly more thrips were trapped at the lower trap heights in both years on the sticky traps (F=8.19 and p=0.0003) (Table 2) and sampling time was significant in both years for sticky traps (F=225.4 and p=0.0001) and trap plants (F=35.4 and p=0.0001). More tobacco thrips were caught in the afternoons than in the mornings or at the evening sampling times with both sticky traps and trap plants (Table 3).

Exclusion Boxes. In 1992, tobacco thrips were collected from the plants within the sweater boxes beginning on Day 9 post planting. Peanut plants were cracking the soil surface on Day 5 post planting, however, precipitation (0.5 cm) was recorded on Days 6, 7, and 8 and Days 7 and 8 were cool (maximum temperature 19.6°C). In 1993, tobacco thrips were collected from the sweater boxes beginning on Day 4 post planting. Peanut plants were cracking the soil surface on Day 4 post planting.

Weather Effects. In both years, the compass orientation of the sticky traps where the greatest number of thrips were caught was significant (F=26.48 and p=0.0001). The number of tobacco thrips caught on the sticky traps was significantly greater at p=0.05 on the portion of the trap facing the prevailing wind direction in 1993 (Table 4). Wind direction data were not available for 1992.

Thrips were not trapped on days when mean maximum temperature 18.7°C (Fig.6). Precipitation also negatively influenced the number of tobacco thrips trapped on the sticky traps. Low temperature and/or precipitation resulted in a low quantity of tobacco thrips trapped (Table 5).

Discussion

The winter trapping data suggest that overwinter survival of tobacco thrips in NC may be related to temperature. Low temperatures may also affect the movement and population growth of tobacco thrips. At Lewiston, NC the number of tobacco thrips trapped on sticky cards through the winter was lowest during winters with lower temperatures. The winter mean low temperatures did not appear as important to thrips survival as the actual low temperatures achieved and the number of days with relatively low temperatures. The timing of the low temperatures did not appear to affect spring (April) catches. The low captures of 1993-94 and 1995-96 may reflect a direct impact of cold temperatures on thrips survival. In these winters, temperatures fell quickly to 15°C reducing the thrips ability to acclimate (McDonald 1997). Or, low survival may be an indirect result of cold damage to thrips host plants resulting in fewer sites for thrips to develop and for thrips to use as a refuge from the cold temperatures. However, more information is required before a strong correlation can be made between winter temperatures and tobacco thrips overwintering survival.

Previous experiments have established that tobacco thrips can overwinter in NC (Cho 1995). In the current experiment it was shown that TSWV viruliferous tobacco thrips can also overwinter in an infective state in NC. At the time the single viruliferous thrips was collected (March 6), numerous weed species were present at the PBRS which are suitable hosts for both TSWV and tobacco thrips. Overwintering viruliferous thrips may move into peanut fields at planting. However, it seems more likely they transmit TSWV to alternate host plants where it can be acquired by subsequent tobacco thrips generations in the spring who then vector the virus to other plants, including peanuts.

At the time of peanut planting in NC, tobacco thrips populations are already present and migrating. This has also been documented in VA (Birdswhistell 1992). Most of the migrating thrips move close to the ground over peanut fields and movement appears to be

involve short distances, as in GA (Camann et al. 1995) and in Australia (Latham 1997). Additionally, tobacco thrips movement in spring can be restricted by temperatures below 18.7°C and by precipitation.

The evidence collected in this experiment regarding the strong association between prevailing wind direction and direction of tobacco thrips movement suggests that it may be possible to identify the local origin of the majority of migrating thrips. Since it has been shown that most tobacco thrips are migrating to peanut fields from relatively short distances, migrating populations should be issuing from weed species (Cho 1986) located upwind from peanut fields. By surveying the upwind weed populations and resident thrips for TSWV, it may be possible to determine the relative threat an individual peanut field is subject to each spring. The ability to predict the relative abundance of tobacco thrips adjacent to peanut fields, their level of TSWV infection, and the probability of these populations moving into adjacent peanut fields would be important for management. In addition to factors proposed in Georgia's TSWV Risk Assessment Index (Yancey 1997) which affect individual field incidence of TSWV in peanuts, such as historical field occurrence of TSWV, peanut genotype, planting date, plant spacing, and the use of chemical controls, environmental factors, especially the impact low winter temperatures have on tobacco thrips survival and the prevailing spring wind patterns, are important in the early incidence of thrips and TSWV in peanut fields.

Acknowledgments

The technical assistance of Brenda Watson and Brian Royals is appreciated. Field preparation and selection was coordinated by Steve Barnes at the PBRS. We are grateful to Cavell Browning for assistance with statistical analysis. Katrin Hoffmann's advice regarding ELISA techniques is greatly appreciated. The North Carolina Department of

Agriculture & Consumer Services generously supplied resources and provided the opportunity to conduct the experiments. Partial funding for this project was provided by the North Carolina Peanut Grower's Association, Inc. and USAID Peanut CRSP (Grant No. DPN-4048-G-00-0041-00).

References Cited

Bandla, M.D., Westcot, C.M., Chenault, K.D., Ullman, D.E., German, T.L., and Sherwood, J.L. 1994. Use of monoclonal antibody to the nonstructural protein encoded by the small RNA of tomato spotted wilt tospovirus to identify viruliferous thrips. Phytopathology 84, 1427-1431.

Barbour, J.D., and Brandenburg, R.L. 1994. Vernal infusion of thrips into North Carolina peanut fields. J. Econ. Entomol. 87, 446-451.

Birdswhistell, A.J. 1992. Movement patterns and phenology of the tobacco thrips, *Frankliniella fusca* (Hinds), in Virginia peanuts. MS. thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Camann, M.A., Culbreath, A.K., Pickering, J., Todd, J.W., and Demski, J.W. 1995. Spatial and temporal patterns of spotted wilt epidemics in peanut. Phytopathology 85, 879-885.

Chamberlin, J.R., Culbreath, A.K., Todd, J.W., and Demski, J.W. 1993. Detection of tomato spotted wilt virus in tobacco thrips (Thysanoptera: Thripidae) overwintering in harvested peanut fields. J. Econ. Ent. 86, 40-45.

Cho, K., Eckel, C.S., Walgenbach, J.F., and Kennedy, G.G. 1995. Overwintering of thrips (Thysanoptera: Thripidae) in North Carolina. Environ. Entomol. 24, 58-67.

Cho, J.J., Mau, R.F.L., Consalves, D., and Mitchell, W.C. 1986. Reservoir weed hosts of tomato spotted wilt virus. Plant Disease. 70, 1014-1017.

Latham, L.J., and Jones, R.A.C. 1997. Occurrence of tomato spotted wilt tospovirus in native flora, weeds, and horticultural crops. Aust. J. Agric. Res. 48, 359-369.

Matteson, N.A., Terry, L.I. 1992. Response to color by male and female *Frankliniella occidentalis* during swarming and non-swarming behavior. Entomol. Exp. Appl. 63, 187-201.

McDonald, J.R., Bale, J.S., and Walters, K.F.A. 1997. Rapid cold hardening in the western flower thrips *Frankliniella occidentalis*. J. Insect Physiol. 43, 759-766.

Mitchell, F.L., and Smith, J.W. 1991. Epidemiology of tomato spotted wilt virus relative to thrips populations. *In* Hsu and R.H. Lawson (eds.), Virus-thrips-plant interactions of tomato spotted wilt, proceedings of a USDA workshop. Beltsville, MD

Mound, L.A. 1996. The Thysanoptera vector species of tospoviruses. Acta Hort. 431, 298-309.

Peters, D., Wijkamp, F., Wetering, F. van de, and Goldbach, R. 1996. Vector relations in the transmission and epidemiology of tospoviruses. Acta Hort. 431, 29-43.

SAS Institute. 1985. SAS user's guide. SAS Institute, Cary, NC.

Ullman, D.E., German, T.L., Sherwood, J.L., Westcot, D.M., and Cantone, F.A. 1993. *Tospovirus* replication in insect vector cells: Immuno-cytochemical evidence that the nonstructural protein encoded by the S RNA of tomato spotted wilt tospovirus is present in thrips vector cells. Phytopathology 83, 456-463.

Yancy, C. 1997. Refining the risk index. Peanut Farmer, 33, 36-38.

Table 1. Total number of tobacco thrips collected from cylindrical sticky traps set 20.32 cm above ground level at a rate of 4 traps per field. One peanut field was trapped in 1993-94, and one peanut and one corn field were trapped in subsequent winters (Bertie Co., North Carolina, 1993-1996)

Trap Period	Season					
	Mean Temp. °C 93-94	Winter 93-94 peanut*	Mean Temp. °C 94-95	Winter 94-95 peanut/ corn	Mean Temp. °C 95-96	Winter 95-96 peanut/ corn
December	5.4	0	9.5	12/19	9.7	0/0
January	3.5	0	6.5	2/1	8.6	1/0
February	6.7	0	5.5	0/1	10.9	0/2
March 1-14	10.1	0	10.0	18/13	6.7	0/1
March 15-31	12.7	0	12.5	21/18	10.0	0/0
April 1-14	16.4	1	14.2	20/22	13.2	4/0
April 15-30	19.6	4	17.4	22/58	18.2	0/5

*A peanut field at PBRS was monitored during the winter of 1993-94, and a peanut field and a corn field were monitored in the 2 subsequent winters

Table 2. Total tobacco thrips counts and SEM at 3 elevations (Bertie Co., North Carolina 1992-93)

Year	n	Elevation		
		0.2 m	0.9 m	1.8 m
1992	546	206 ± 0.02a*	123 ± 0.01b	96 ±0.01b
1993	546	127 ± 0.01ab	133 ± 0.01a	96 ± 0.01b

* Means of tobacco thrips counts in each year with the same letter do not differ significantly at the 5% level (LSD multiple range test).

Table 3. Mean tobacco thrips counts per sticky traps and trap plants at each sampling period with years combined (Bertie Co., North Carolina, 1992-93)

SAMPLING PERIOD*	STICKY TRAPS	TRAP PLANTS
0600 - 1200	0.43 b**	0.12 b
1200 - 1800	1.51 a	0.34 a
1800 - 0600	0.19 c	0.07 b

*Sampling periods are presented in 24 hour format.

** Means of sticky traps and trap plants with same letter do not differ significantly at the 5% level (LSD multiple range test).

Table 4. 1993 Mean tobacco thrips counts and SEMs per trap location and sample period at the Peanut Belt Research Station, Lewiston, North Carolina (Bertie Co., North Carolina, 1993)

Trap Orientation	Wind Direction	
	South or West*	Not South or West
South or West	0.12 a** ± 0.03	0.02 b ± 0.01
Not South or West	0.03 b ± 0.02	0.04 b ± 0.02

*The prevailing wind direction at the PBRS during the May, 1993 sampling period was from the south to southwest.

** Means with the same letter do not differ significantly at the 5% level (LSD multiple range test).

Table 5. Daily tobacco thrips catch, precipitation (mm), and temperature (°C) data collected at the PBRS, Bertie County, NC, during 13-26 May, 1992 and 12-25 May, 1993

Year	Day Post Planting	Thrips Catch	Precip.	Temp. Max.	Temp. Min.	Temp. Mean
1992	1	39	0	25.2	9	17.4
	2	26	0	28.6	14	21.3
	3	50	0	29.7	16.8	23.5
	4	49	12.7	28.6	15.7	22.4
	5	27	0	29.1	16.2	23
	6	49	101.6*	32.5	15.1	24.1
	7	0	45.7	19	16.8	17.9
	8	2	53.3	19.6	9	14.6
	9	58	0	26.9	8.4	17.9
	10	34	0	29.7	6.2	17.9
	11	26	0	31.9	10.1	21.3
	12	65	0	33	12.3	23
	13	0	0	14.6	13.4	14
	14	0	12.7	15.7	12.3	14
1993	1	2	0	30.8	20.7	25.8
	2	12	0	28	16.8	22.4
	3	3	43.2**	21.3	13.4	17.4
	4	30	0	29.1	11.8	20.7
	5	34	0	31.9	17.9	25.2
	6	59	0	30.2	17.9	24.1
	7	64	127***	31.4	16.2	24.1
	8	9	114.3***	24.6	17.4	21.3
	9	1	0	21.3	15.7	18.5
	10	9	0	21.8	11.2	16.8
	11	11	0	22.4	10.6	16.8
	12	45	0	26.9	7.8	17.4
	13	38	0	28.6	14.6	21.8
	14	48	0	29.7	17.4	23.5

*Rain occurred after sampling period for the day had ended at 1800h.

**Rain occurred during morning sampling period from 0600 - 1200h.

****Rain occurred after 1600h.

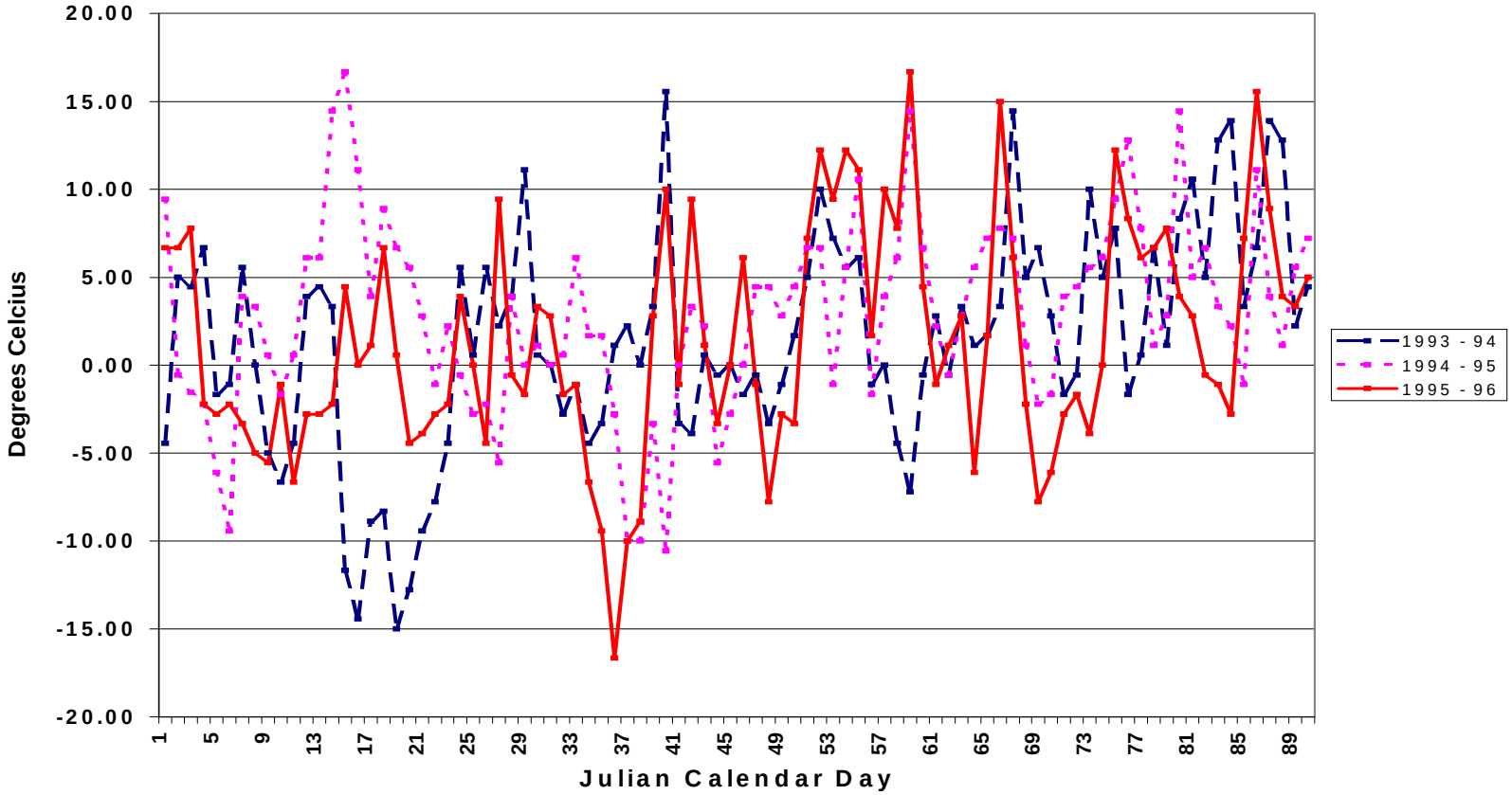


Figure 1. Daily mean minimum winter temperatures, January through March, for 1993 - 1996 at the Peanut Belt Research Station, Lewiston, North Carolina.

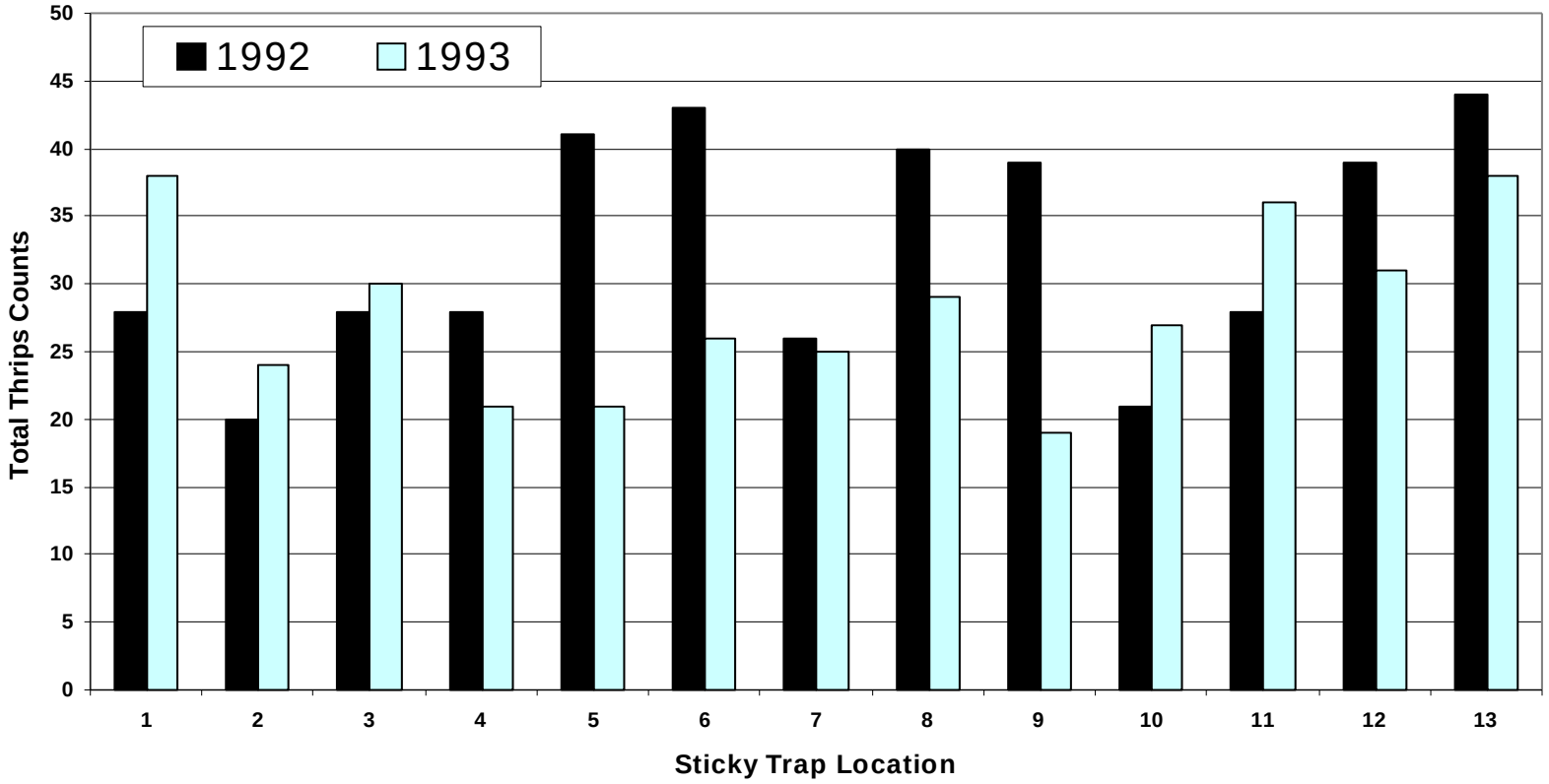


Figure 2. Total tobacco thrips counts per sticky trap location during the 14 day trapping periods in May 1992 and 1993 at the Peanut Belt Research Station, Lewiston, North Carolina.

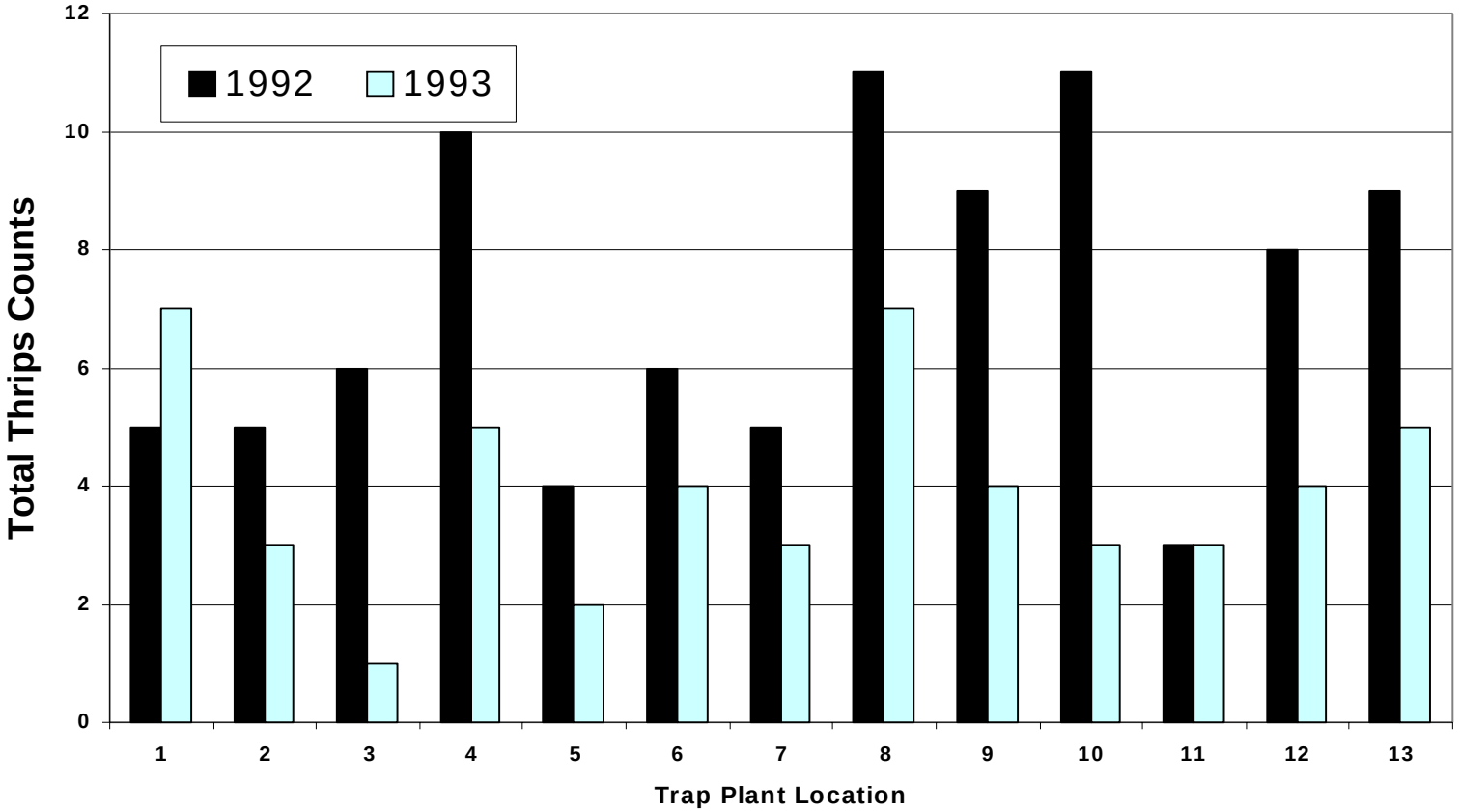


Figure 3. Total tobacco thrips counts per trap plant location during the 14 day trapping periods in May 1992 and 1993 at the Peanut Belt Research Station, Lewiston, North Carolina.

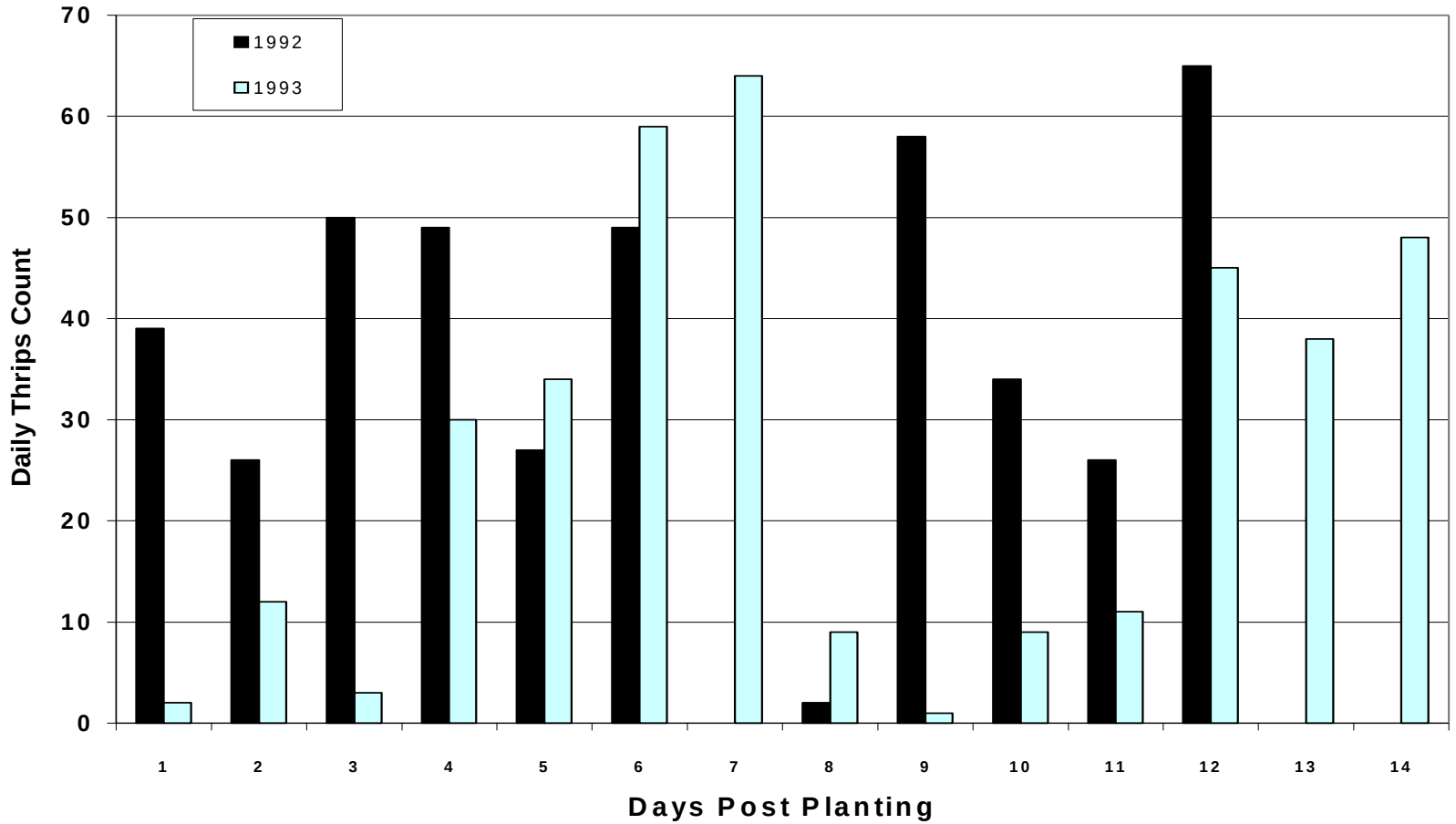


Figure 4. Total daily thrips counts from all sticky traps during the 14 day trapping periods in May 1992 and 1993 at the Peanut Belt Research Station, Lewiston, North Carolina.

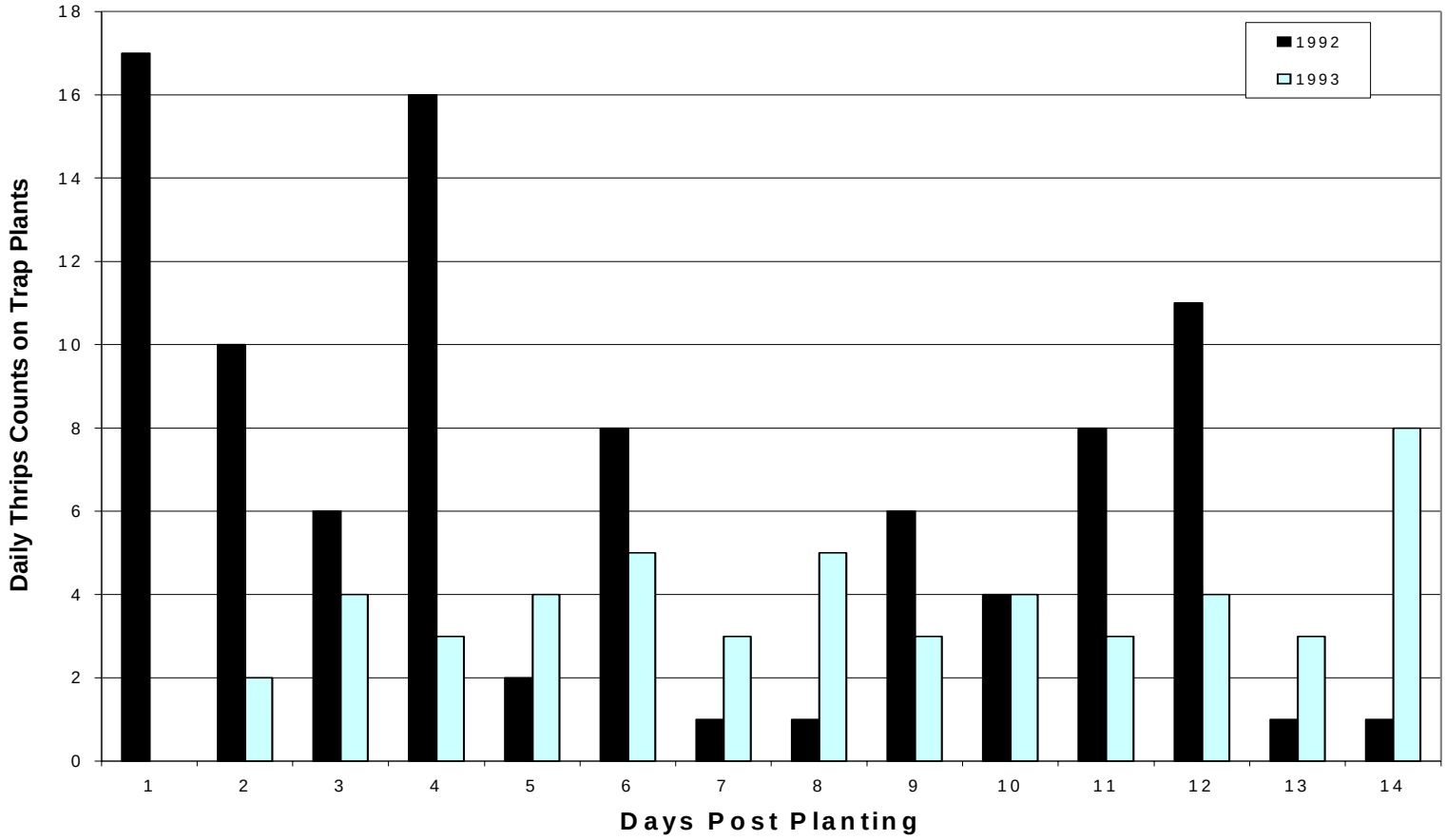
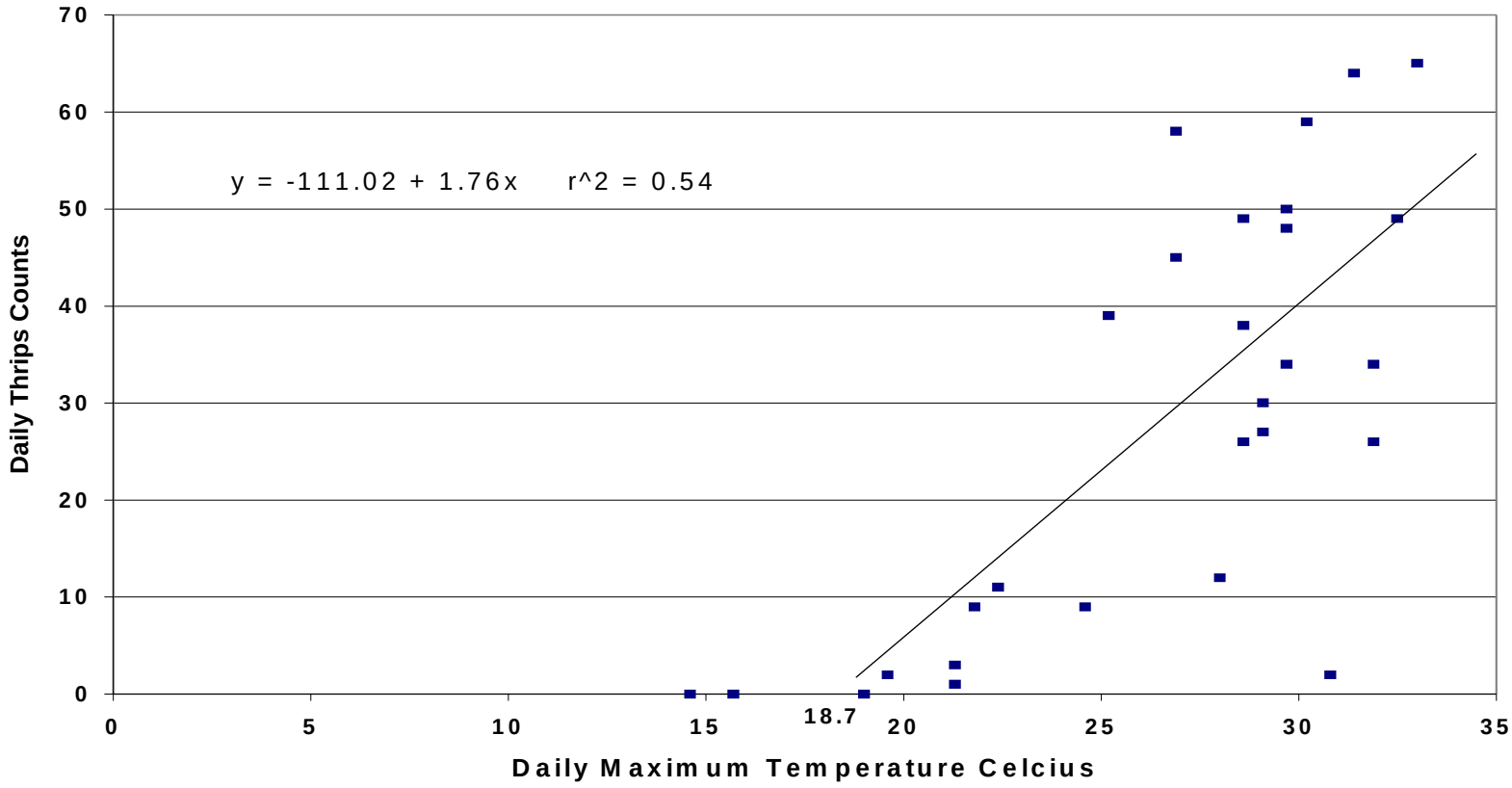


Figure 5. Total daily tobacco thrips counts from all trap plants during the 14 day trapping periods in May 1992 and 1993 at the Peanut Belt Research Station, Lewiston, North Carolina.



Figure

6. Total of daily tobacco thrips catches on sticky traps plotted by daily maximum temperatures for the 14 day trapping periods during May 1992 and 1993 at the Peanut Belt Research Station, Lewiston, North Carolina.

Chapter II

Incidence of Tomato Spotted Wilt Virus (Bunyviridae: *Tospovirus)* and *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) in three Virginia-type peanut (*Arachis hypogaea* L.) genotypes in North Carolina[2]

Garcia, L.E., Brandenburg, R.L., and Bailey, J.E.

Department of Entomology, North Carolina State University, Raleigh, North Carolina 27695

ABSTRACT Virginia-type peanut (*Arachis hypogaea* L.) genotypes were monitored for incidence of Tomato Spotted Wilt Virus (TSWV) and abundance of *Frankliniella fusca* (Hinds), the tobacco thrips, in North Carolina during 1995 and 1996. Selection from among 225 peanut genotypes for TSWV resistant or tolerant genotypes occurred in 1995. The incidence of TSWV in NC-9 was twice that of NC-V11. In 1996, field trials were conducted with 3 peanut genotypes. The three genotypes included NC-9 and NC-V11, which are among the top 5 genotypes in terms of acres in production in North Carolina. The third genotype, NC-12C, is a newly-released genotype. A randomized complete block design was utilized at 3 locations in the North Carolina peanut-producing area. Two sites (Bertie and Lewiston) were located in Bertie County, and one site in Gates County. Planting at the Gates location was delayed by 2 weeks relative to the Bertie

---

[2]This chapter will be modified and submitted to Plant Disease as: Garcia, L.E., Brandenburg, R.L., and Bailey, J.E. Incidence of tomato spotted wilt virus (Bunyviridae: *Tospovirus*) and *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) in three Virginia-type peanut (*Arachis hypogaea* L.) genotypes in North Carolina.

County sites due to rainfall. Disease incidence was evaluationed weekly from 2 weeks post planting until 2 weeks prior to harvest. Foliar TSWV symptoms were confirmed with enzyme-linked immunosorbent assay (ELISA). Mechanical inoculation of the 3 genotypes resulted in no difference in relative leaf virus titer as determined from optical density readings following ELISA for 4 successive weeks beginning at 13 days post inoculation. NC-9 ranked highest in incidence of disease (7%), followed by NC-12C (6%) and NC-V11 (5%). Thrips counts were greatest on NC-V11, followed by NC-9 and NC-12C. Disease incidence overall was 5.96%. Lewiston experienced the highest level of disease at 11.15%, followed by Bertie at 3.52%, and Gates at 3.08%. Yield was affected by the temporal occurrence of symptoms beginning at the fifth week post planting. Greatest yield losses occurred in those plants with the earliest visible foliar symptoms.

KEY WORDS tobacco thrips, peanuts, tomato spotted wilt virus

Tomato Spotted Wilt Virus (TSWV) was first identified in Australia in 1916 (Brittlebank, 1919) and is now distributed worldwide (German, 1992; Peters, 1996; Ullman, 1996). It is a significant disease of many plants, including both food and ornamental crops, with over 600 recognized host plants (Goldbach, 1994). Some localized geographic control of the disease was achieved in the 1940's and 1950's through insecticidal control of the thrips vector in Europe (Peters, 1996). Subsequent spread of TSWV has been attributed to spread of western flower thrips, *Franklinella occidentalis* Pegrande. In North America, TSWV first began to appear in ornamental crops on the West Coast. Subsequently, the disease spread from the West to the East coast of the United States, infecting peanuts in Texas in 1974 and causing yield losses there by the mid 1980's (Stewart, 1989). A similar pattern was reported in Georgia, where TSWV was widespread by 1989 (Brown, 1992). Yield reductions were observed in Georgia by 1993 (Culbreath, 1994). TSWV was first recognized in North Carolina peanuts in 1990

(Bailey, pers. com.), and by 1995 was widely reported throughout the peanut producing area of the state. However, the impact of TSWV on North Carolina peanuts at this time has remained minimal and there have been no appreciable yield reductions attributable to TSWV epidemics.

TSWV is vectored in a persistent fashion (Sakimura, 1962, 1963) by thrips species. Thrips acquire the virus as first instar larvae (Linford, 1932) and are then capable of transmitting the disease after a latent period of 3-7 days (Peters, 1996). It was first thought only adults were able to transmit the virus; however, it has been shown that TSWV can be transmitted by second instar *F. occidentalis* larvae and adults (Wijkamp, 1993). Adult thrips are then capable of vectoring the disease in as little as 5 minutes (Shakimura, 1962) making control of spread with insecticides difficult. TSWV is not transmitted transovarially (Wijkamp, 1995), and is not seed-borne. Mound (1996) lists 7 confirmed vector species: *F. fusca* (Hinds); *F. intonsa* (Trybom); *F. occidentalis* (Pegrande); *F. schultzei* (Trybom); *Thrips palmi* Karny; *T. setosus* Moulton; and *T. tabaci* Lindeman. Three of these species, *F. occidentalis*, *F. fusca*, and *T. tabaci*, are found in association with agroecosystems in North Carolina (Eckel, 1995). Of this group, *F. occidentalis* and *T. tabaci* occur only incidentally in North Carolina peanuts (Barbour and Brandenburg, 1994).

Disease management based on thrips control in peanut is difficult because of thrips small size and their thigmotactic behavior. When insecticides are utilized, TSWV incidence is usually not reduced when compared with control plots (Todd, 1996). Cultural techniques have, however, been successful in limiting TSWV epidemics. Experiments conducted in Texas (Black, 1987) and Georgia (Culbreath, 1992, 1994) have documented up to a two-fold difference among peanut genotypes in the incidence of TSWV. Yield losses caused by TSWV may ultimately be avoided through the application of transgenic technology (Ullman, 1996); however, identification and utilization of peanut genotypes that are either resistant or tolerant to TSWV, in combination with other cultural techniques, has offered

protection in the short-term in Georgia (Brown, 1996). This experiment was conducted in an attempt to identify similar TSWV resistance or tolerance in genotypes of Virginia-type peanuts under field conditions in North Carolina.

MATERIALS AND METHODS

1995 Experimental Field Design. Evaluations of TSWV incidence in Virginia-type peanut genotypes were made at two locations in 1995. In Bertie County, at the Peanut Belt Research Station, Lewiston, North Carolina, thrips damage and TSWV incidence in two peanut genotypes, NC-9 and NC-V11, was assessed. Each plot in Bertie County consisted of two rows, 27 m long. Because of field constraints, plots of NC-9 were replicated 3 times and plots of NC-V11 were replicated 4 times. Both genotypes were located within a six acre planting of several different peanut genotypes.

The second evaluation was conducted in Gates County, North Carolina. The peanut genotypes evaluated for TSWV incidence were selected from an on-farm test of 225 genotypes established by Dr. T. Isleib, Crop Science Department, NCSU, to evaluate *Sclerotinia minor* Jagger resistance. The *S. minor* test plots were randomly arranged in plots of 14 plants each with 4 replications per genotype. Six genotypes were selected for evaluation of TSWV incidence in October based on a visual rating of TSWV symptoms conducted on July 24, 1995.

Bertie County Field Evaluation. Thrips damage was assessed by determining the presence of thrips feeding damage on 50 randomly selected unopened leaflets per plot. Damage was evaluated on 3 occasions: 22, 38, and 43 days post-planting. TSWV incidence was determined by recording the number of plants per plot with visual TSWV symptoms. Symptoms observed included combinations of leaflet bronzing, petiole twisting, concentric ring spotting, and plant stunting or wilting. Plots were evaluated on 2 dates: 91 and 113 days post-planting.

Gates County Field Evaluation. Two young leaflets and two root samples were taken from all surviving plants in each plot of 6 selected genotypes in October, 1995. The leaflet and root samples from each plant were pooled separately and tested by ELISA using a kit (Agdia 1000 Reagent Set, DAS ELISA, Peroxidase) obtained from Agdia, Elkhart, IN. Each pooled sample was tested utilizing 3 microtiter plate wells. On each microtiter plate, 5 wells each were devoted to healthy controls, positive TSWV controls, and grinding buffer blanks. Plates were read at 405 nm. A well was classified as positive if its optical density value was greater than the individual plate's healthy control mean value plus 3 times the standard deviation of the healthy control wells.

1996 Experimental Field Design. Three Virginia-type peanut genotypes were selected for field evaluation in 1996 based on the previous season's results. The three genotypes were: (1) NC-9; (2) NC-V11; and (3) NC-12C. NC-9 and NC-V11 are among the top 5 peanut varieties with the highest production acreage in North Carolina. NC-12C is a newly-released peanut variety that has shown a low susceptibility to TSWV in preliminary field evaluations. The peanuts were planted in a randomized block design at three locations in the peanut production area of northeastern North Carolina. Each treatment was a portion of a larger peanut field and consisted of a site 45 m by 19.8 m. At each location, there were 12 plots, or 4 replications per variety. Replicated plots were assigned randomly and consisted of 6 rows, each 7.2 m in length. The inner two rows of the plots were evaluated for TSWV incidence, thrips populations, and per plant yield. Plants within the inner two rows were thinned to a 0.25 m spacing in an attempt to increase disease incidence (Black, 1994; Gorbet, 1994). There were a maximum of 56 plants per replicated plot. All plots were separated by two rows, or 1.8 m, of Tamrun 88, a variety that is highly susceptible to TSWV (Black, pers. com.).

Two study sites were located in Bertie County, the Griffin Farm (Bertie) and the Peanut Belt Research Station (Lewiston). The third treatment location was in Gates County, at the Griffin Farm (Gates). The Bertie soil type is classified as Norfolk sandy loam, the

Lewiston soil type is Goldsboro sandy loam, and the Gates soil type is Craven-Shabuta. Standard production practices were followed according to NC Cooperative Extension Service recommendations (Sullivan, 1995), with the exception that no insecticides were used. Fungicides and herbicides were used at each location as part of a typical pest management program.

Seeds were planted with a conventional six-row planter on May 9, 1996 at the Bertie and Lewiston sites. Rain delayed planting at the Gates site until two weeks later, May 23. Because of this delay in planting, all collections at Gates were initiated two weeks later than those at Bertie and Lewiston. For purposes of data analysis, however, sampling dates were calculated as time from planting.

Disease Rating. The genotypes were rated for visual symptoms of TSWV every week from two weeks post planting until two weeks prior to harvest, for a total of 15 weeks per treatment. The inner two rows of each plot were used to rate TSWV incidence. Plants were considered as symptomatic if they had one or more leaves with TSWV's characteristic concentric rings. Ratings were as follows: 1 = no symptoms; 2 = 1 to 33% of the leaves with symptoms; 3 = 34 to 66% of the leaves with symptoms; 4 = 67 to 100% of the leaves with symptoms; and 5 = plant death. Two leaflets from each symptomatic plant were collected in plastic bags and stored in an ice cooler with frozen gel packs. Leaf tissue from symptomatic plants was then analyzed by enzyme-linked immunosorbant assay (ELISA) according to Agdia (Elkhart, IN). An individual plant was considered positive if it had both visual foliar symptoms and a positive optical density reading with the ELISA plant reader. Positive plants were flagged in the field.

Thrips Collection. Beginning at 14 days post planting, May 22 at Bertie and Lewiston, and June 6 at Gates, samples were collected to monitor the thrips populations. Twenty individual unopened quadrifoliate leaf samples were collected from the inner two rows of each plot at every sampling period. Samples were collected every seven days for 13

weeks. Plot samples were collected and stored in 20ml scintillation vials partially filled with 70% ETOH. Samples were examined in the laboratory under a dissecting microscope and the number of tobacco thrips adults, thrips larvae, or other thrips species were recorded.

Yield Determination. Plants were harvested individually on October 2 and 3 at Bertie and Lewiston respectively, and on October 18 at Gates. The plants were bundled by treatment and plot and stored in a heated greenhouse until the pods were dry. Pods were removed by hand and placed in an unsealed paper bag for an additional drying period of two weeks. The total pod weight and pod count per plant was recorded.

Laboratory Design. Twelve plants from each of the three genotypes were mechanically inoculated on June 17, 1996 with TSWV to determine their susceptibility to a high titer of a known strain of TSWV. The strain of TSWV used for mechanical inoculation was TSWV-10, an isolate from peanut plants grown in North Carolina and maintained in Dr. J. Moyer's laboratory, Department of Plant Pathology, NCSU. Inoculation was conducted with extract from infected leaves ground in inoculation buffer (0.01 M Tris, 0.01 M Na_2SO_3 , and 0.1% Cysteine HCL, pH 7.8). The TSWV-10 strain was maintained in *Emilia sonchifolia* (L.), flora's paintbrush, and mechanically transferred to *Nicotiana benthamiana* Domin. seedlings where it was allowed to increase for one week prior to peanut inoculation. Individual peanut seeds were sown in sterile soil in 10 cm diameter plastic pots. Beginning at 13 days post inoculation, two leaflets were removed from the youngest fully expanded leaves on each plant. Leaflets were removed every 7 days for 4 weeks. The virus titer in the leaflets was determined by the use of double antibody sandwich ELISA (Agdia). Each leaflet was ground in a 1:10 ratio of plant to extraction buffer and transferred to 3 wells (Nunc microtiter plate). The optical density (OD) of each well was read one hour after the addition of substrate buffer. The contents of a well were considered positive if its value was greater than 3 times the standard deviation of the OD value of 5 predesignated healthy control wells plus the mean of 5 healthy control

wells located on the same microtiter plate.

Data Analysis. Weekly disease ratings and thrips counts from all three locations were analyzed by analysis of variance (SAS 1985) treating varieties and locations as fixed effects. The protected LSD procedure was used to compare means for locations and means for varieties averaged over locations. Similar analysis was carried out on log transformed larval and adult counts for each week.

RESULTS

1995 Bertie County. The average thrips damage was greater in NC-V11 than in NC-9. At 22 days post-planting NC-9 damage was 12% and NC-V11 was 16%. At 38 days post-planting NC-9 samples were 37% damaged and NC-V11 were 55% damaged. Damage at 43 days post-planting was 36% for NC-9 and 51% for NC-V11.

The average number of plants expressing TSWV symptoms was higher in NC-9 than in NC-V11. NC-9 had an average infection level of 8.67% at 91 days post-planting and 3.33% at 113 days post-planting. NC-V11 infection level was 2.25% at 91 days post-planting and 1.5% at 113 days post-planting.

1995 Gates County. Incidence of TSWV was greater in NC-9 than in NC-V11. Of 42 NC-9 plants sampled, 47.6% tested positive for TSWV; 20 root samples were positive and 3 leaflet samples were positive. Of 41 NC-V11 plants sampled, 23.8% tested positive for TSWV; 9 root samples were positive and 3 leaflet samples were positive. Root samples were often positive when foliage samples were negative. A plant was considered positive if either the root sample or the foliage sample tested positive with ELISA. In the remaining 4 genotypes the incidence of TSWV was: 23% of NC-7/NC-9; 17.5% of NC-V11/NCAc18016; 55.5% of NC-V11/NC-10C; and 32% of NC-V11/NCAc18229.

1996 Disease Incidence. Overall, incidence of disease was 5.99% of all plants across genotypes and locations. Disease incidence across genotypes was greatest at Lewiston with 11.06% of plants infected followed by Bertie with a 3.63% infection level and Gates with an infection rate of 3.08% (Fig 1). Disease symptoms began to appear in the genotypes in week 5, approximately 50 days after planting (Fig. 2). Total mean disease rating per plant was significantly higher at Lewiston than Bertie and Gates beginning on week 9 and continuing throughout the season. The differences between the weekly disease ratings at Bertie and Gates were not significantly different (Table 1). NC-9 consistently had higher disease ratings than NC-V11 and NC-12C. The ratings were significant in weeks 8, 9, 10, and 11 (Table 2). Ratings among NC-V11 plants were somewhat higher in weeks 5 through 12 than NC-12C plants (Table 2)**,** however, this condition reversed in weeks 13 through 15 (Fig. 3).

Disease symptoms during the period of week 5 through week 8, tended to occur first in NC-9. As the season progressed, from week 9 through week 12, the incidence of TSWV symptomatic plants increased among all genotypes. Overall, more plants became infected during weeks 9-12, and the number of newly symptomatic plants decreased after week 13 across all genotypes. At Lewiston the cumulative incidence of peanut plants with TSWV symptoms was higher in NC-9 (25 plants) than in NC-V11(15 plants) (Table 3).

Yield Yield per plant, pod number per plant, and mean weight per pod were significantly greater at Bertie, followed by Lewiston and Gates (Table 4). Among the genotypes and across locations, NC-12C had significantly greater yield per plant than NC-9, but not significantly greater than NC-V11. Mean weight per pod was highest with NC-12C. NC-V11 had significantly greater mean pod count per plant (Table 4). Plants which became symptomatic early in the season had lower yields compared to plants which became symptomatic later in the season, and plants which remained asymptomatic until harvest (Table 3).

Thrips Counts Season-long counts of adult and larval *F. fusca* were significantly higher at Lewiston than Gates or Bertie (Table 5), however, weekly counts of adults and larvae fluctuated (Tables 6 and 7). Overall counts of adult and larval tobacco thrips were highest in NC-V11 than in the other 2 genotypes, but only significantly greater than NC-12C (Table 5). Adult *F. fusca* counts peaked in weeks 2 and 3, or 14 and 21 days post planting, at all locations and across all genotypes (Figs. 4 and 5). Larval *F. fusca* counts for Lewiston and Bertie peaked in week 4, or 28 days post planting, and at week 6, 42 days post planting, for Gates (Fig. 6). Larval counts by genotype peaked consistently at week 4 (Fig. 7). Data from Gates for week 3 and from all but one set of replicates at Lewiston in week 5 were misplaced and are not represented in the data for those periods.

Mechanical Inoculations Mechanically inoculated peanut plants all had consistently high optical density readings (Fig. 8). No differences were apparent in the 3 genotypes following ELISA. All 3 genotypes had their highest virus titer on either the first sampling date (NC-9 and NC-12C) or the second sampling date (NC-V11) with decreasing optical density values thereafter.

DISCUSSION

Field evaluations were more useful in this study than mechanical inoculations of peanut genotypes. When mechanically inoculated with a high titer of virus, all tested peanut genotypes became equally infected with TSWV. The high level of disease pressure represented in mechanical inoculations probably masked any subtle variations in disease tolerance or resistance mechanisms which may have been exhibited at lower levels of disease inoculum such as were witnessed in the field.

The greatest total incidence of TSWV occurred at Lewiston (11%). Lewiston also experienced the highest populations of *F. fusca* throughout the study period. A general relationship in 1996 occurred between high thrips populations and high incidence of

disease at Lewiston, but it was not present among peanut genotypes, nor across locations. The lack of a relationship between high thrips populations and high incidence of TSWV was corroborated by preliminary observations in North Carolina of thrips damage and disease occurrence with NC-9 and NC-V11 in 1995. In the present study, NC-V11 had higher thrips counts than the other 2 genotypes investigated but less disease than NC-9. Disease symptoms were particularly lower in NC-V11 than in NC-9 at Lewiston where disease incidence appeared to be the greatest. Disease ratings at Gates and Bertie were not significantly different, however, thrips counts at Gates were significantly lower than at Bertie. Lower thrips populations often result when peanuts are planted late (Satayavirut, 1988), as at Gates. Variation between symptomatic genotypes may also be related to differences in thrips survival rates on TSWV infected peanuts of different genotypes. The variation in disease symptoms among genotypes, especially evident between NC-9 and NC-V11 at Lewiston, suggests the presence of a range of TSWV symptom expressing genotypes among Virginia-type peanuts which can be selected and utilized in peanut production practices for North Carolina.

It is important to consider the significance of the comparatively high incidence of TSWV at Lewiston (11%) compared to the more moderate disease incidence at Bertie (3.52%) and Gates (3.08) as this disease becomes more abundant in peanut producing areas of the state. Lewiston is the site of the Peanut Belt Research Station, and is subject to annual production of peanuts in closely arrayed fields. The other two sites, Bertie and Gates, are part of private peanut production enterprises where peanuts or other TSWV hosts are not produced in immediately adjacent fields year after year. If thrips populations and virus levels are not considered to be static across peanut production areas of NC, then it is plausible that the virus inoculum may be increasing, or decreasing, at incrementally different rates at different locations in North Carolina. These fluctuations may be due to variations, at the local level, in the densities of viral hosts, including favorable plant hosts and thrips populations. Alternatively, viruliferous thrips may migrate preferentially at different locations based on plant host attractiveness or on localized environmental

factors which affect the number of thrips vectors migrating into production fields.

Sources of TSWV in the spring, at peanut planting, are viruliferous thrips and infected plant hosts. The importance of weeds as alternate hosts has long been recognized in the epidemiology of TSWV (Samuel, 1930; Cho et al. 1987). Tobacco thrips have been shown to overwinter in Florida (Toapanta, 1996), Georgia (Chamberlin, 1992, 1993; Buntin, 1995), Louisiana (Newsom, 1953), and South Carolina (Eddy, 1931). In North Carolina, overwintering tobacco thrips, the principal TSWV vector found on peanuts in North Carolina (Barbour, 1994), have been collected (Cho, 1995). It is therefore possible the virus overwinters in thrips and that these thrips are responsible for the primary infection of peanuts. The length of time a viruliferous adult tobacco thrips may survive during winters in North Carolina is unknown. However, experiments conducted with overwintering of tobacco thrips have recovered viruliferous thrips in NC in March (Garcia 1999). Overwintering viruliferous thrips are probably more important as a short-term bridge between alternate weed host plants and subsequent virus spread to offspring during the winter and spring than they are as a primary source of infection in spring planted peanuts.

From a management perspective, the selection of peanut genotypes with low incidence of disease is obviously preferred because it requires no additional inputs of capital, no environmental protection, and little or no educational programming to implement. This study has shown that there are differences in the level of TSWV infection among the preferred peanut genotypes currently being utilized in North Carolina. The differences between infection levels of NC-9 compared with NC-V11 and NC-12C may warrant the consideration of a shift in production away from specific peanut genotypes. Additional genotypes need to be evaluated under greater disease incidence before a peanut genotype with significant TSWV tolerance or resistance can be identified which has agronomic characteristics acceptable to North Carolina producers. Though not always practical, the careful selection of production fields for those with low levels of disease incidence or

inoculum, as recommended in Georgia's TSWV Risk Assessment Index (Yancey, 1997), together with the destruction of known TSWV host plants located at the field margins, may also be useful in North Carolina in helping to reduce the build up of the level of inoculum in the environment and the overall disease incidence in North Carolina peanut fields until less susceptible genotypes are identified.

Acknowledgment

We gratefully acknowledge the technical assistance of Scott Kennedy, Brian Royals, Brenda Watson, and Ian Winborne. Steve Barnes coordinated the field selection and preparation at Lewiston Peanut Belt Research Station. Dr. Tom Isleib's assistance was instrumental in the selection of the peanut genotypes used in this study. Cavell Browning provided advice with statistical analysis. Data analysis was conducted with SAS 6.12 for PCs. Katrin Hoffmann provided generous support and advice with ELISA procedures and techniques. The North Carolina Department of Agriculture and Consumer Services created the opportunity and lent valuable resources in the preparation of this work. Partial funding for this project was provided by the North Carolina Peanut Grower's Association, Inc. and USAID Peanut CRSP (Grant No. DPN-4048-G-00-0041-00).

References Cited

Barbour, J.D., and Brandenburg, R.L. 1994. Vernal infusion of thrips into North Carolina peanut fields. J. Econ. Entomol. 87, 446-451.

Black, M.C., and Smith, D.H. 1987. Spotted wilt and rust reactions in south Texas among selected peanut genotypes. Proc. Am. Peanut Res. Educ. Soc. 19:31.

Black, M.C., Tewolde, H., Fernandez, C.J., and Schubert, A.M. 1994. Effect of seeding rate, irrigation, and cultivar on spotted wilt, rust, and southern blight diseases of peanut.

Proc. Amer. Peanut Res. Educ. Soc. 26, 50 (Abstr.).

Brittlebank, C.C. 1919. Tomato diseases. Journal of Agriculture, Victoria 27,231.

Brown, S.L., and Thompson, S.S. 1992. Tomato spotted wilt survey, 1991. Georgia Peanut Res. Ext. Rpts. Coop. Res. Ext., Publ. No. 2, 3-6.

Brown, S.L., Todd, J.W., and Culbreath, A.K., 1996. Effect of selected cultural practices on incidence of tomato spotted wilt virus and populations of thrips vectors in peanuts. Acta Hort. 431, 491-498.

Buntin, G.D., and Beshear, R.J. 1995. Seasonal Abundance of thrips (Thysanoptera) on winter small grains in Georgia. Environ. Entomol. 24,1216-1223.

Chamberlin, J.R., Todd, J.W., Beshear, R.J., Culbreath, A.K., and Demski, J.W. 1992. Overwintering hosts and wingform of thrips, *Frankliniella* spp., in Georgia (Thysanoptera: Thripidae): Implications for management of spotted wilt disease. Environ. Ent. 21, 121-128.

Chamberlin, J.R., Culbreath, A.K., Todd, J.W., and Demski, J.W. 1993. Detection of tomato spotted wilt virus in tobacco thrips (Thysanoptera: Thripidae) overwintering in harvested peanut fields. J. Econ. Ent. 86, 40-45.

Cho, J.J., Mitchell, W.C., Mau, R.F.L., and Sakimura, K. 1987. Epidemiology of tomato spotted wilt virus disease on crisphead lettuce in Hawaii. Plant Disease, 71, 505-508.

Cho, K., Eckel, C.S., Walgenbach, J.F., and Kennedy, G.C. 1995. Overwintering of thrips (Thysanoptera: Thripidae) in North Carolina. Environ. Entomol. 24, 58-67.

Culbreath, A.K., Todd, J.W., Demski, J.W., and Chamberlin, J.R. 1992. Disease progress of spotted wilt in peanut cultivars Florunner and Southern Runner. Phytopathology, 82, 766-771.

Culbreath, A.K., Todd, J.W., Branch, W.D., Brown, S.L., Demski, J.W., and Beasley, J.P., Jr. 1994. Effect of new peanut cultivar Georgia Browne on epidemics of spotted wilt. Plant Dis. 78, 1185-1189.

Eckel, C.S., Cho, K., Walgenbach, J.F., and Kennedy, G.G. 1995. Thrips fauna in North Carolina agroecosystems. *In* B.L. Parker, M. Skinner, and T. Lewis, eds., Thysanoptera: toward understanding thrips management. Plenum, New York.

Eddy, C.O. and E.M. Livingstone. 1931. *Frankliniella fusca* Hinds (thrips) on seedling cotton. South Carolina Agr. Exp. Sta. Bull. 271.

Garcia, L.E., Brandenburg, R.L., Kennedy, G.G. 1999a. Winter occurrence and spring migration of *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) in North Carolina peanut (*Arachis hypogaea* L.) fields. J. Econ. Entomol. submitted.

German, T.L., Ullman, D.E., and Moyer, J.W. 1992. Tospoviruses: diagnosis, molecular biology, phylogeny, and vector relationships. Ann. Rev. Phytopath. 30, 315-348.

Goldbach, R., and Peters, D. 1994. Possible causes of the emergence of tospovirus diseases. Sem. Virol. 5, 113-120.

Gorbet, D.W. and Shokes, F.M. 1994. Plant spacing and tomato spotted wilt virus. Proc. Amer. Peanut Res. Educ. Soc. 26, 50 (Abstr.).

Linford, M.B. 1932. Transmission of the pineapple yellow-spot virus by *Thrips tabaci*.

Phytopathology, 22, 301-324.

Mound, L.A. 1996. The Thysanoptera vector species of tospoviruses. Acta Hort. 431, 298-309.

Newsom, L.D., Roussel, J.S., and Smith, C.E. 1953. The tobacco thrips, its seasonal history and status as a cotton pest. LA Agric. Exp. Sta. Tech. Bull. 474.

Peters, D., Wijkamp, F., Wetering, F. van de, and Goldbach, R. 1996. Vector relations in the transmission and epidemiology of tospoviruses. Acta Hort. 431, 29-43.

SAS Institute. 1985. SAS user's guide: statistics. SAS Institute, Cary, NC.

Satayavirut, Turnjt. 1988. Thrips (*Frankliniella fusca* Hinds) population, damage, and yield relationship for peanut types and selected peanut cultivars in North Carolina. PhD Dissertation, North Carolina State University, Raleigh, North Carolina.

Sakimura, S. 1962. *Frankliniella occidentalis* (Thysanoptera: Thripidae), a vector of tomato spotted wilt virus, with special reference to the color forms. Ann. Ent. Soc. Amer. 55,387-389.

Sakimura, S. 1963. *Frankliniella fusca*, an additional vector for the tomato spotted wilt virus, with notes on *Thrips tabaci*, another vector. Phytopathology, 53, 421-415.

Samuel, G., Bald, J.G., and Pittman, H.A. 1930. Investigations on spotted wilt of tomatoes. Aust. Coun. Sci. Ind. Res. Bull. 44.

Stewart, J.W.,Cole, C., and Lummus, P. 1989. Winter survey of thrips (Thysanoptera: Thripidae) from certain suspected and confirmed hosts of tomato spotted wilt virus in

south Texas. J. Entomol. Sci. 24, 392-401.

Sullivan, G. (ed.). 1995. Peanuts 1995. NC Agricultural Extension Service Publication.

Toapanta, M., Funderburk, J., Webb, S., Chellemi, D., and Tsai, J. 1996. Abundance of *Frankliniella* spp. (Thysanoptera: Thripidae) on winter and spring host plants. Environ. Entomol. 25, 793-800.

Todd, J.W., Culbreath, A.K., and Brown, S.L. 1996. Dynamics of vector populations and progress of spotted wilt disease relative to insecticide use in peanuts. Acta Hort. 431, 483-490.

Ullman, D.E. 1996. Thrips and tospoviruses: advances and future directions. Acta Hort. 431, 310-324.

Wijkamp, I., and Peters, D. 1993 Determination of the median latent period of two tospoviruses in *Frankliniella occidentalis*, using a novel leaf disc assay. Phytopathology, 83, 456-463.

Wijkamp, I. 1995. Virus-vector relationships in the transmission of tospoviruses. PhD Dissertation, Wageningen Agricultural University, The Netherlands.

Yancy, C. 1997. Refining the risk index. Peanut Farmer, 33, 36-38.

Table 1. Mean weekly TSWV disease rating[a b] of peanut genotypes (NC-9, NCV-11, and NC-12C) at 3 treatment locations (Bertie, Gates, and Lewiston), 1996

Location	n	Week[c] 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Bertie	12	1.0031a	1.0082a	1.0100ab	1.0195a	1.0247ab	1.0266b	1.0301b	1.0393b	1.0449b	1.0648b	1.0754b
Gates	12	1.0000a	1.0000a	1.0000b	1.0063a	1.0077b	1.0222b	1.0394b	1.0485b	1.0611b	1.0718b	1.0718b
Lewiston	12	1.0015a	1.0112a	1.0309a	1.0323a	1.0503a	1.1104a	1.1189a	1.1549a	1.1825a	1.2173a	1.2292a

[a]Weekly disease ratings were taken throughout the season and averaged over each of 12 plots per location.

[b]Means within columns with the same letter do not differ significantly at the 5% level (LSD procedure).

[c]Disease symptoms began to appear from the fifth week post planting. Data were analyzed from planting date. Week 5 corresponds to June 20 at the Lewiston and Bertie locations, and to July 4 at the Gates location.

Table 2. Mean weekly TSWV disease rating[a b] of the 3 peanut genotypes (NC-9, NV-V11, and NC-12C) across locations (Bertie, Gates, and Lewiston), 1996

Genotype	n	Week[c] 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
NC-9	12	1.0031a	1.0149a	1.0303a	1.0443a	1.0613ab	1.0918a	1.1052a	1.11461a	1.1382a	1.1601a	1.1702a
NV-V11	12	1.0015a	1.0030a	1.0063a	1.0080b	1.0113b	1.0357ab	1.0454ab	1.0665a	1.0747a	1.0859a	1.0943a
NC-12C	12	1.0000a	1.0015a	1.0044a	1.0058b	1.0102b	1.0317b	1.0378b	1.0617a	1.0756a	1.1079a	1.1118a

[a]Weekly disease ratings for genotypes were taken throughout the season and averaged over 4 plots and 3 treatment location.

[b]Means within columns with the same letter do not differ significantly at the 5% level (LSD procedure).

[c]Disease symptoms began to appear from the fifth week post planting. Data was analyzed from planting date. Week 5 corresponds to June 20 at the Lewiston and Bertie locations, and to July 4 at the Gates location.

Table 3. Average per plant yield at each location and for each genotype. Per plant averages were based on the time from planting when TSWV symptoms were first observed. Sample weeks are the number of weeks post planting and are grouped into 3 periods. Asymptomatic plants never expressed any symptoms (Bertie and Gates Cos., North Carolina, 1996)

Location	Genotype	Sample Period[a]						Asymptomatic plants	
		Weeks 5-8		Weeks 9-12		Weeks 13-15		At Harvest	
		grams	plants[b]	grams	plants	grams	plants	grams	plants
Bertie	NC-9	0	3		0		0	116.4	193
	NC-V11	9.4	1	74.9	3	61.3	4	115.3	178
	NC-12C		0		0	86.9	9	126.7	177
Gates	NC-9	8.5	2	18.5	6		0	70.0	208
	NC-V11	0	1	20.9	4	72.0	3	73.7	206
	NC-12C	0	1	52.7	1	29.0	2	73.8	215
Lewiston	NC-9	0.7	5	16.1	12	43.7	8	86.2	159
	NC-V11	7.00	1	23.8	10	41.2	4	91.6	194
	NC-12C	7.9	1	31.0	17	82.6	8	97.8	205

[a]Disease ratings were made weekly beginning 2 weeks after planting and continued for 15 weeks at each location. Each sample period is the number of weeks post planting plus 2 weeks when samples were not taken.

[b]The total number of plants which expressed symptoms during the sampling period.

Table 4. Mean[a] and SEM[b] of total pod weight per plant, pod count per plant and average weight per pod, at each of the three treatment locations and from each of the three evaluated genotypes (Bertie and Gates Cos., North Carolina, 1996)

	Avg. Grams/Plant	Pod Count / Plant	Avg. Grams/ Pod
Bertie	117.85 ± 4.38a	56.59 ± 1.83a	2.04 ± 0.05a
Gates	70.97 ± 8.07c	41.64 ± 1.66b	1.70 ± 0.03b
Lewiston	85.24 ± 2.88b	45.24 ± 1.34b	1.80 ± 0.04b
NC-9	86.26 ± 6.34b	45.42 ± 2.31b	1.81 ± 0.05b
NC-V11	90.97 ± 6.32ab	50.93 ± 2.59a	1.73 ± 0.04c
NC-12C	96.83 ± 7.25a	47.12 ± 2.34b	1.99 ± 0.06a

[a]Number of replicate plots per mean was 12.

[b]Means of pod weights/plant, pod counts/plant, and average weight/pod with same letter not differ significantly at the 5% level (LSD procedure).

Table 5. Average weekly counts and SEM of adult and larval *F. fusca* by location and peanut genotype (Bertie and Gates Cos., North Carolina, 1996)

Location		**Adults**	**Larvae**
	n[a]	mean ± SEM[b]	mean ± SEM
Bertie	156	3.5 ± 0.05b	8.6 ± 0.06b
Gates	144	2.5 ± 0.05c	4.4 ± 0.06c
Lewiston	147	4.6 ± 0.05a	15.4 ± 0.07a
Genotype			
NC-9	149	3.6 ± 0.05ab	8.6 ± 0.07ab
NC-V11	149	3.7 ± 0.05a	10.1 ± 0.06a
NC-12C	149	3.1 ± 0.05b	7.6 ± 0.06b

[a]Number of replicated plots sampled 13 times during the season. Each plot sample consisted of 20 unopened tetrafoliate leaves.

[b]Means of thrips counts with same letter from locations and genotypes do not differ significantly at 5% level (LSD procedure following analysis of log transformed counts).

Table 6. Weekly mean counts[a] and SD of adult *F. fusca* by locations and by the three evaluated genotypes (Bertie and Gates Cos., North Carolina, 1996)

Sample	Treatment Location			Peanut Genotype		
Period	Bertie[b]	Gates	Lewiston[c]	NC-9	NC-V11	NC-12C
Week[d] 1	1.17 ±1.27c	8.33 ±4.42a	3.17 ±1.95b	3.25 ± 3.02b	6.00 ± 5.38a	3.42 ± 3.40b
Week 2	41.42 ± 8.25a	23.25 ± 3.31b	38.17 ± 8.52a	32.25 ±10.00b	39.33 ± 11.15a	31.25 ± 9.47b
Week 3	35.58 ± 11.50a	–	26.33 ± 4.74b	30.00 ± 7.73a	29.25 ± 13.01a	33.63 ± 8.65a
Week 4	6.75 ± 3.84b	7.75 ± 3.08b	12.75 ± 5.07a	8.33 ± 4.10a	10.00 ± 4.86a	8.92 ± 5.52a
Week 5	11.67 ± 6.47a	17.42 ± 7.80a	24.67 ± 10.97a	16.22 ± 10.56a	14.22 ± 7.50a	16.56 ± 7.68a
Week 6	5.42 ± 1.38b	4.08 ± 2.54c	11.75 ± 7.02a	7.67 ± 3.73a	8.08 ± 8.27a	5.50 ± 2.78a
Week 7	5.67 ± 2.93a	1.00 ± 1.04b	4.08 ± 1.98a	3.75 ± 3.22a	4.08 ± 2.78a	2.92 ± 2.64a
Week 8	4.00 ± 2.34a	4.00 ± 2.70a	4.25 ± 3.41b	3.08 ± 1.51a	2.25 ± 1.54a	1.75 ± 1.71a
Week 9	0.83 ± 0.83a	1.67 ± 1.53a	2.33 ± 2.19a	1.75 ± 1.71a	1.25 ± 1.86a	1.33 ± 1.61a
Week 10	3.17 ± 1.75a	0.17 ± 0.58b	2.92 ± 2.75a	2.33 ± 2.06a	2.17 ± 2.37a	1.75 ± 2.63a
Week 11	0.08 ± 0.29b	0.25 ± 0.45b	3.33 ± 2.50a	1.33 ± 2.57a	1.50 ± 2.32a	0.83 ± 1.27a
Week 12	0.67 ± 0.78a	0.08 ± 0.29a	0.17 ± 0.39a	0.33 ± 0.49a	0.42 ± 0.79a	0.17 ± 0.39a
Week 13	0.0 ± 0.0a	0.08 ± 0.29a	0.33 ± 0.65a	0.08 ± 0.29ab	0.33 ± 0.65a	0.0 ± 0.0b

[a]Number of replicate plots per mean count was 12, except as noted below.

[b]Means within rows for location and genotype with the same letter do not differ significantly at the 5% level (LSD procedure following analysis of log transformed counts).

[c]Data collected at Lewiston on June 13, Week 5, represents only 1 plot.

[d]Data were analyzed by planting date. Lewiston and Bertie locations were planted on May 9, 1996, and the Gates location was planted on May 23, 1996. Sample collection dates began two weeks post planting; therefore, Week 1 corresponds to May 22 at the Lewiston and Bertie locations, and June 6 at the Gates location. Sampling was conducted weekly throughout the season.

Table 7. Weekly mean counts[a] and SD of larval *F. fusca* by locations and by the three evaluated genotypes (Bertie and Gates Cos., North Carolina, 1996)

Sample	Treatment Location			Peanut Genotype		
Period	Bertie[b]	Gates	Lewiston[c]	NC-9	NC-V11	NC-12C
Week[d] 1	0.42 ± 0.67a	0.0 ± 0.0b	0.0 ± 0.0b	0.08 ± 0.29a	0.25 ± 0.62a	0.08 ± 0.29a
Week 2	2.25 ± 2.01a	3.17 ± 2.44a	3.25 ± 3.72a	2.33 ± 2.27a	4.50 ± 3.40a	1.83 ± 1.85a
Week 3	43.58 ± 24.78b	–	103.17 ± 66.00a	91.25 ± 74.68a	92.38 ± 52.56a	36.50 ± 13.49b
Week 4	270.17 ± 72.89a	33.50 ± 12.66b	337.42 ± 104.96a	270.0 ± 177.29a	197.0 ± 132.01b	174.08 ± 133.24b
Week 5	63.67 ± 26.70a	36.67 ± 18.95b	54.33 ± 26.10ab	54.44 ± 32.30a	52.22 ± 24.78a	45.22 ± 22.07a
Week 6	5.33 ± 4.16b	62.92 ± 21.50a	69.00 ± 22.72a	45.58 ± 30.31a	50.42 ± 37.42a	41.25 ± 36.38a
Week 7	54.83 ± 14.13a	21.67 ± 10.36b	64.00 ± 20.71a	48.67 ± 27.20a	44.50 ± 20.36a	46.83 ± 26.10a
Week 8	25.58 ± 6.20a	11.08 ± 6.10b	12.25 ± 5.51b	15.67 ± 11.20a	18.75 ± 8.30a	14.50 ± 6.53a
Week 9	8.50 ± 4.96a	6.92 ± 5.16a	5.75 ± 2.26a	8.17 ± 4.61a	7.67 ± 5.03a	5.33 ± 2.99a
Week 10	12.83 ± 7.44a	1.75 ± 1.60b	18.58 ± 7.97a	11.17 ± 10.69a	13.50 ± 9.52a	8.50 ± 7.91a
Week 11	1.00 ± 0.95b	1.08 ± 0.90b	32.58 ± 11.80a	10.58 ± 15.16a	12.92 ± 18.28a	11.17 ± 17.24a
Week 12	4.25 ± 2.60b	0.0010 ± 0.0c	9.92 ± 4.21a	5.33 ± 5.33a	5.50 ± 6.19a	3.33 ± 2.93a
Week 13	0.42 ± 0.90b	0.0 ± 0.0b	1.25 ± 1.42a	0.42 ± 0.67ab	0.83 ± 1.53a	0.42 ± 0.90a

[a]Number of replicate plots per mean was 12, except as noted below.

[b]Means within rows for location and genotype with same letter do not differ significantly at 5% level (LSD procedure following analysis of log transformed counts).

[c]Data collected at Lewiston on June 13, Week 5, represents only 1 plot.

[d]Data was analyzed by planting date. The Lewiston and Bertie locations were planted on May 9,1996, and the Gates location was planted on May 23, 1996. Sample collection dates began two weeks post planting; therefore, Week 1 corresponds to May 22 for the Lewiston and Bertie locations and June 6 for the Gates location. Sampling was conducted weekly throughout the season.

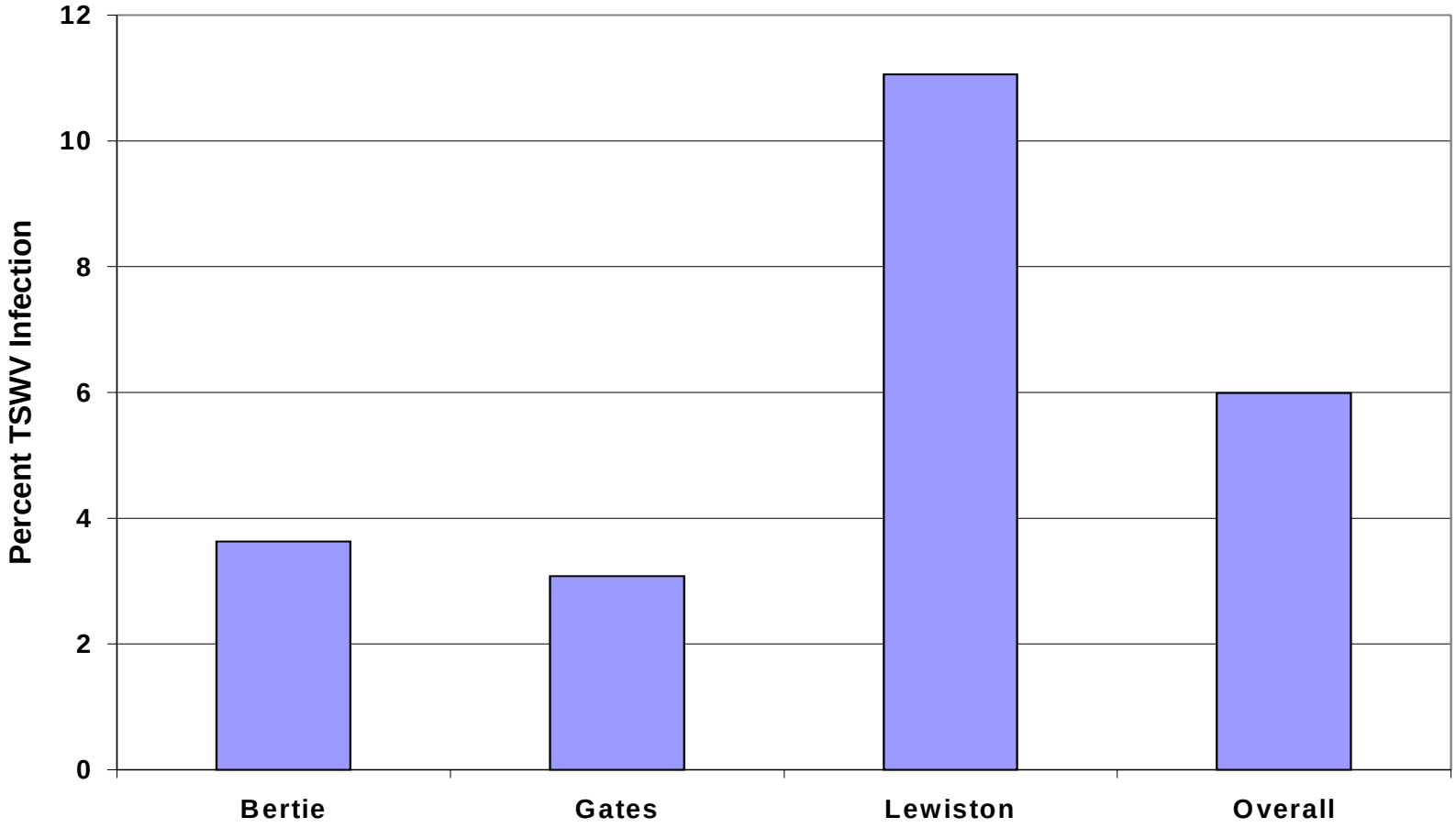
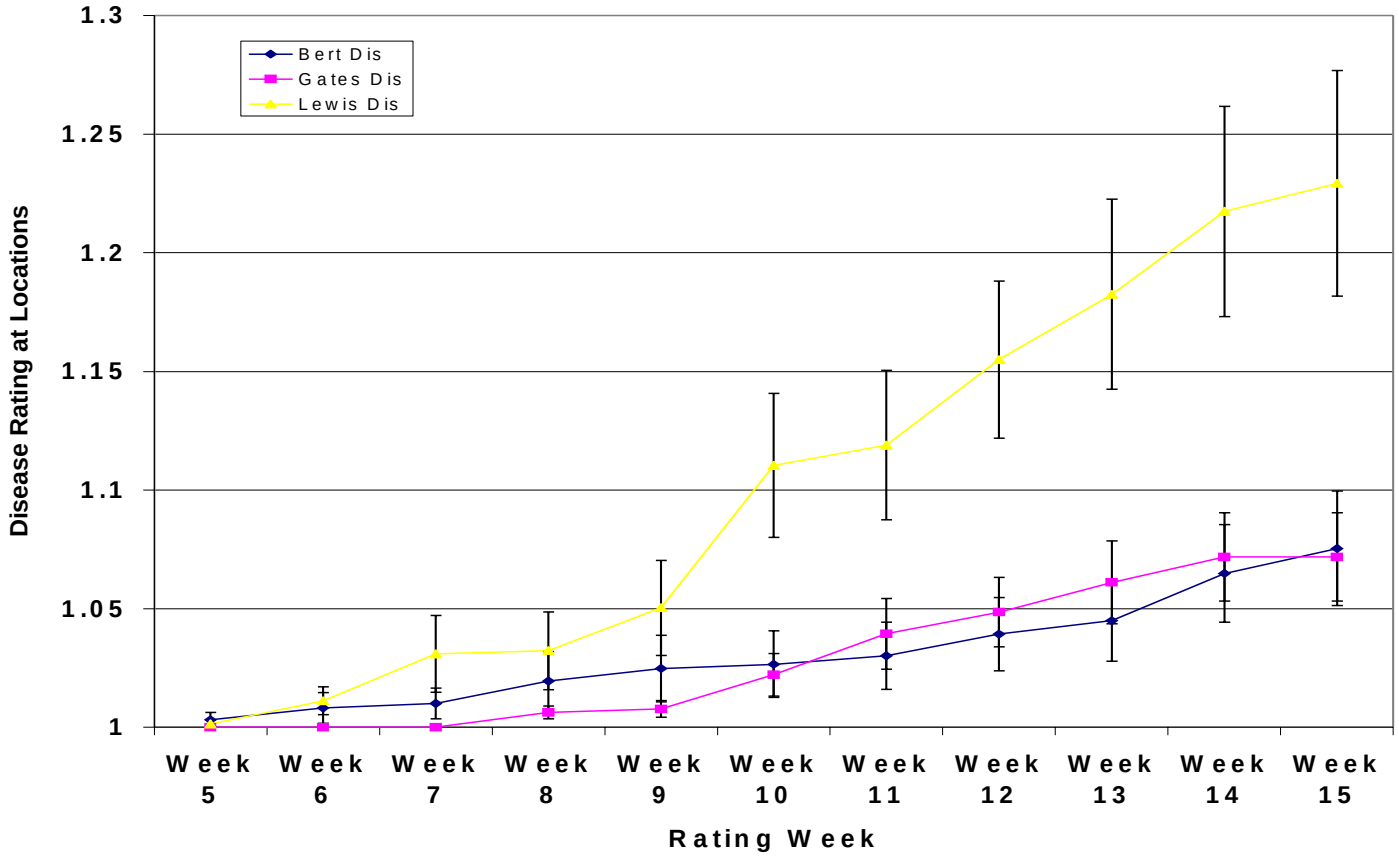
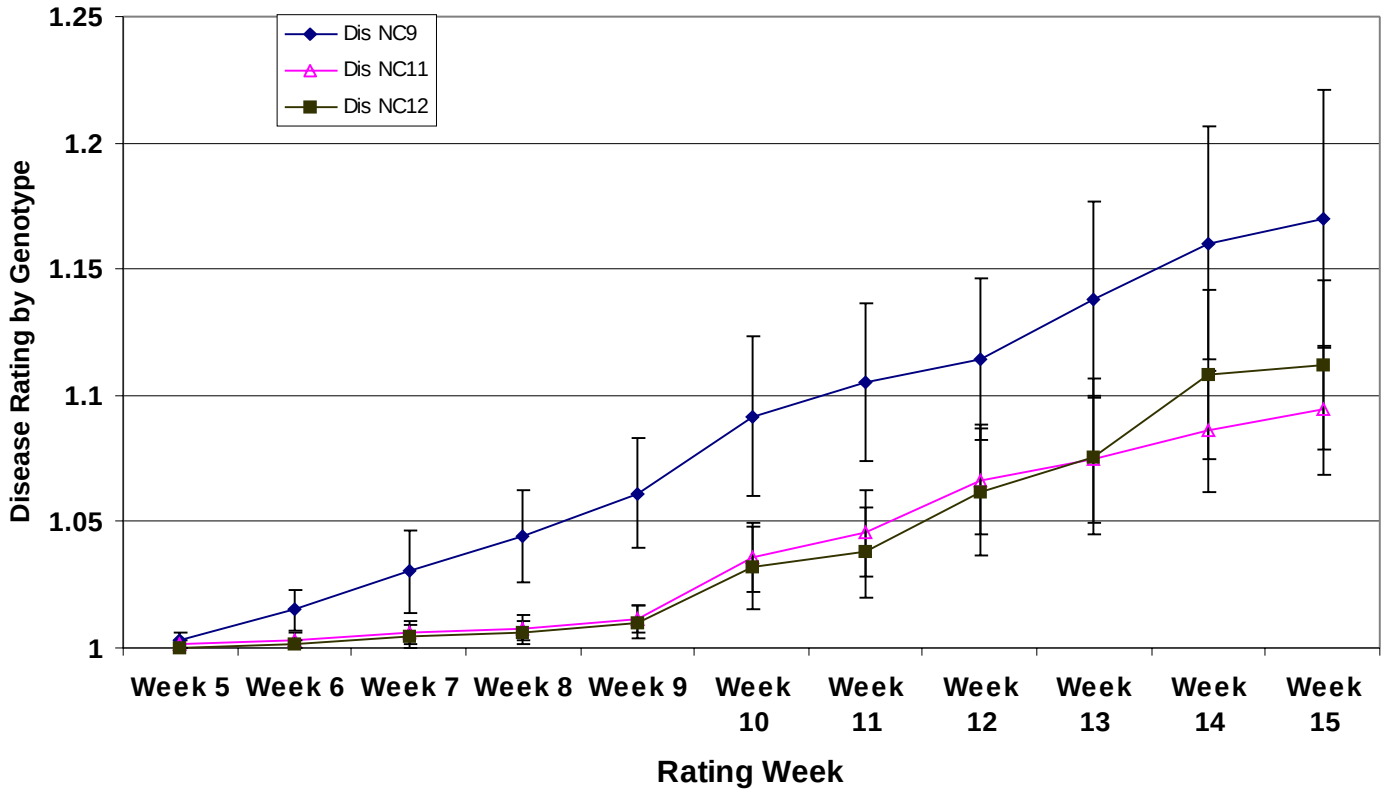


Figure 1. The percentage of TSWV infected plants at each location at the end of the season (Bertie and Gates Cos., North Carolina, 1996).



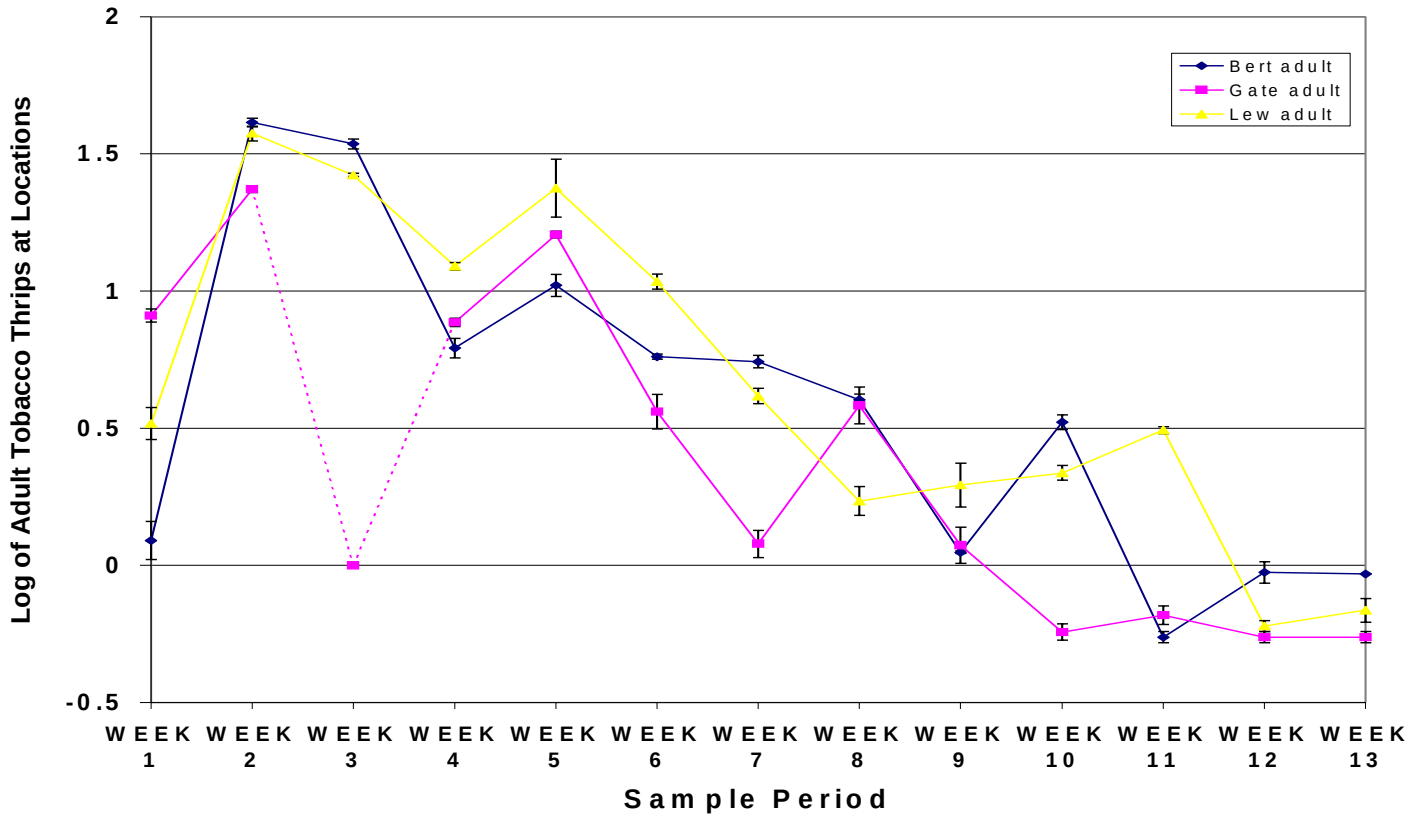
Figure

2. Mean TSWV disease rating at each location beginning at week 5 post planting. Because Gates was planted 2 weeks later than Bertie and Lewiston, week 5 at Bertie and Lewiston corresponds to June 13, and at Gates, week 5 corresponds to June 27 (Bertie and Gates Cos., North Carolina, 1996).



Figure

3. Mean TSWV disease rating for each genotype beginning at the fifth week post planting. Because Gates was planted 2 weeks later than Bertie and Lewiston, week 5 at Bertie and Lewiston corresponds to June 13, and at Gates, week 5 corresponds to June 27 (Bertie and Gates Cos., North Carolina, 1996).



Figure

4. Log of adult tobacco thrips counts taken from 20 unopened quadrifoliate leaves per plot at each location beginning at one week post planting. Count data from Gates at week 3 is missing. Because Gates was planted 2 weeks later than Bertie and Lewistion, week 1 at Bertie and Lewiston corresponds to May 16, and at Gates, week 1 corresponds to May 30 (Bertie and Gates Cos., North Carolina, 1996).

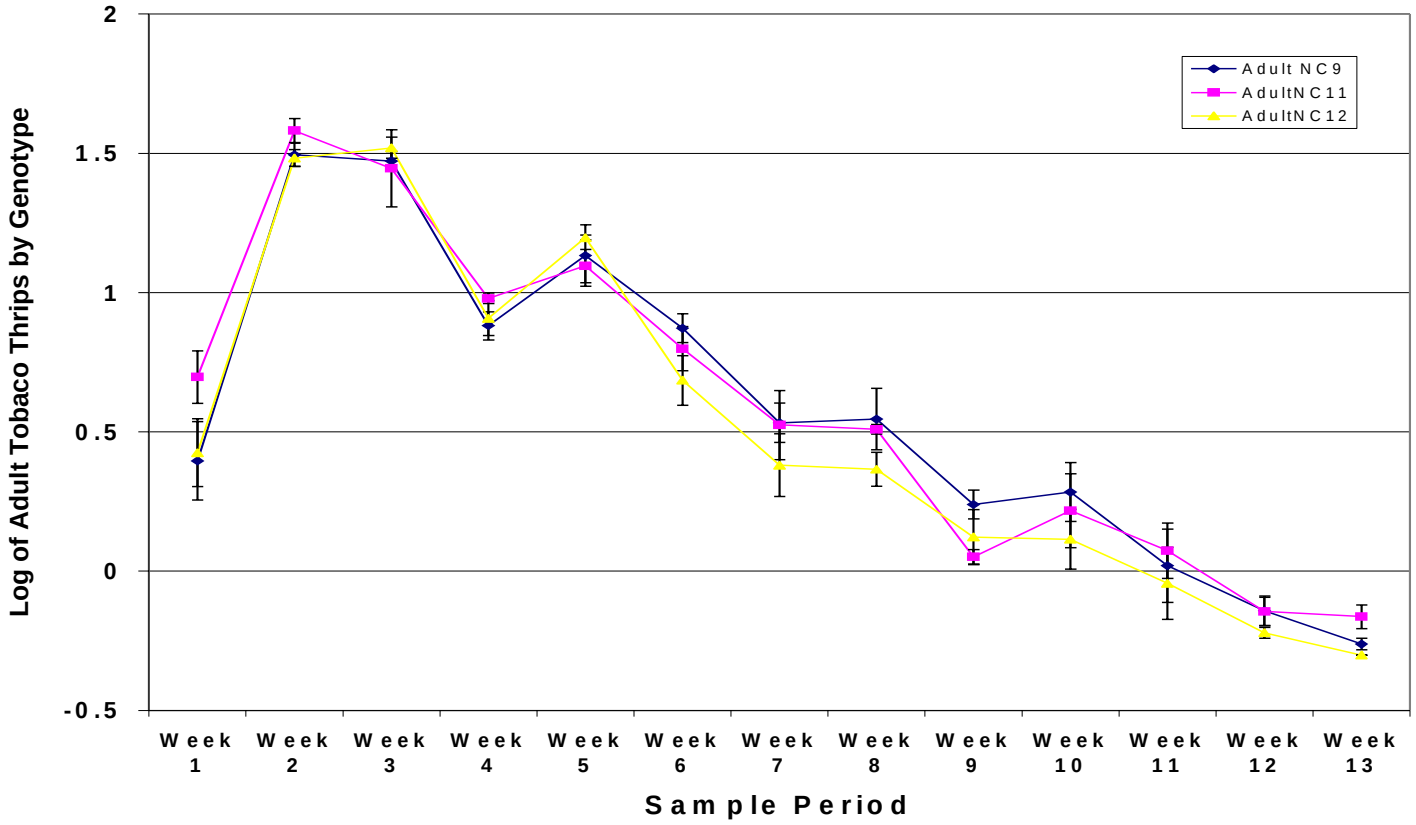


Figure 5. Log of adult tobacco thrips counts taken from 20 unopened quadrifoliate leaves per plot for each genotype beginning at one week post planting. Because Gates was planted 2 weeks later than Bertie and Lewiston, week 1 at Bertie and Lewiston corresponds to May 16, and at Gates, week 1 corresponds to May 30 (Bertie and Gates Cos., North Carolina, 1996).

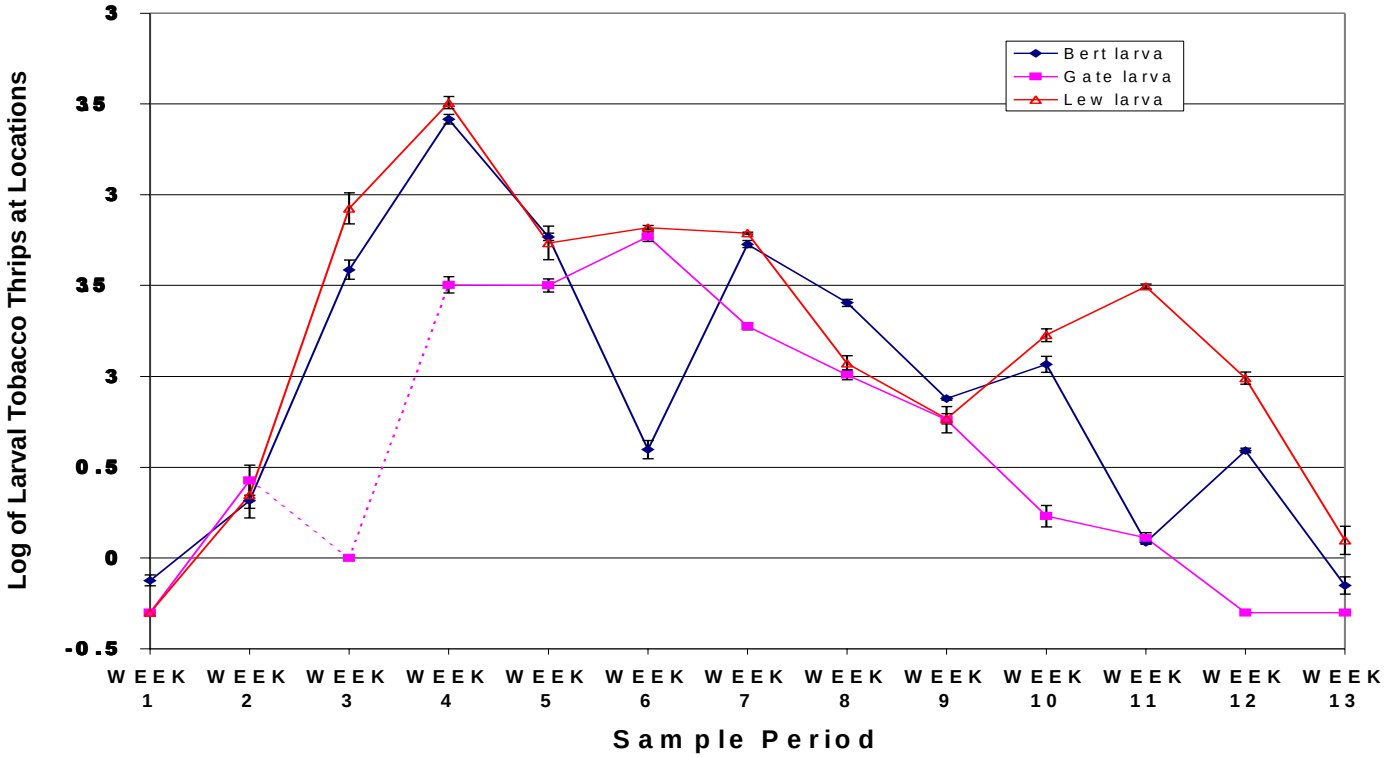


Figure 6. Log of larval tobacco thrips counts taken from 20 unopened quadrifoliate leaves per plot at each location beginning at one week post planting. Counts from Gates for week 3 are missing. Because Gates was planted 2 weeks later than Bertie and Lewiston, week 1 at Bertie and Lewiston corresponds to May 16, and at Gates, week 1 corresponds to May 30 (Bertie and Gates Cos., North Carolina, 1996).

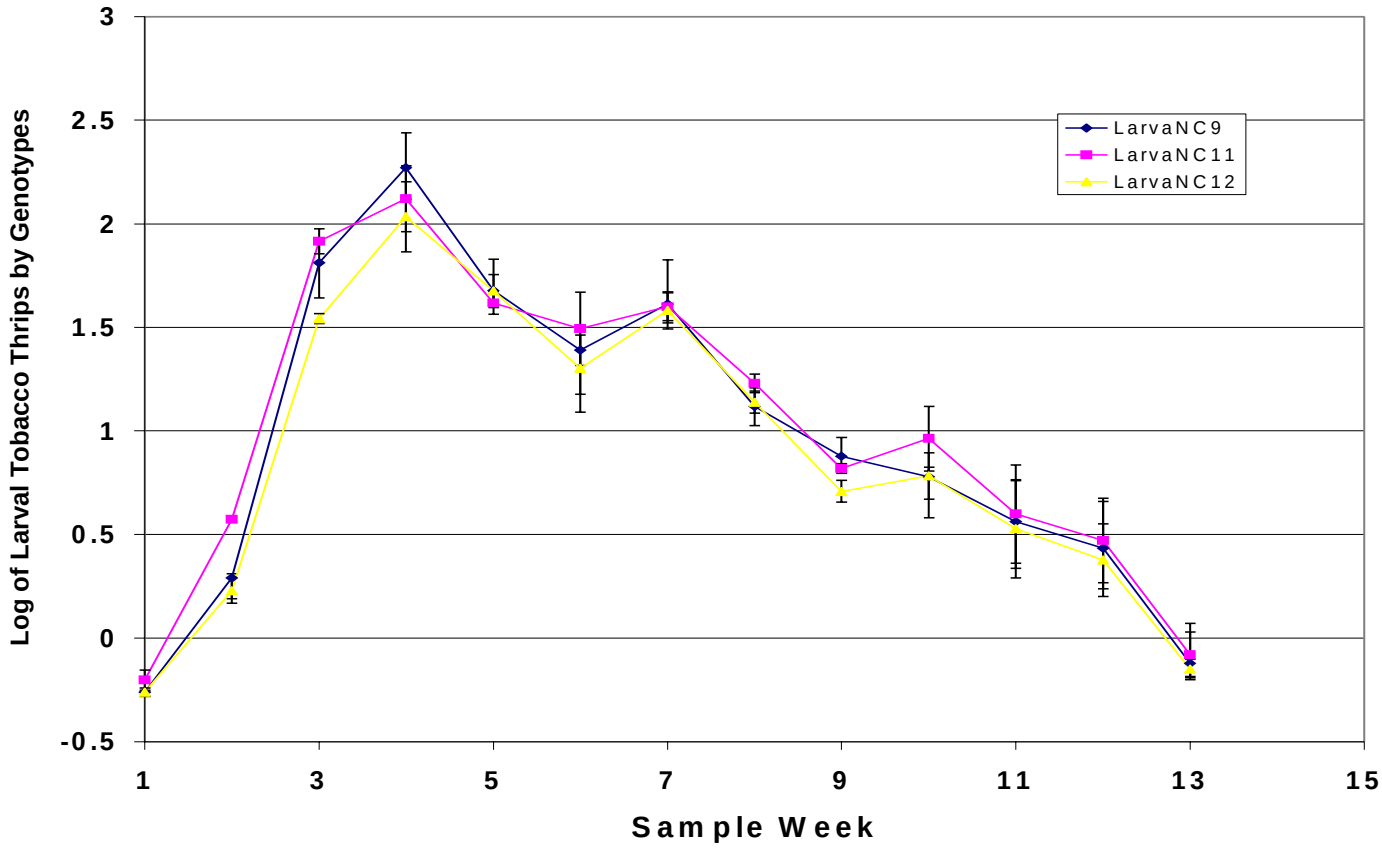


Figure 7. Log of the larval tobacco thrips counts taken from 20 unopened quadrifoliate leaves per plot for each genotype beginning at one week post planting. Because Gates was planted 2 weeks later than Bertie and Lewiston, week 1 at Bertie and Lewiston corresponds to May 16, and at Gates, week 1 corresponds to May 30 (Bertie and Gates Cos., North Carolina, 1996).

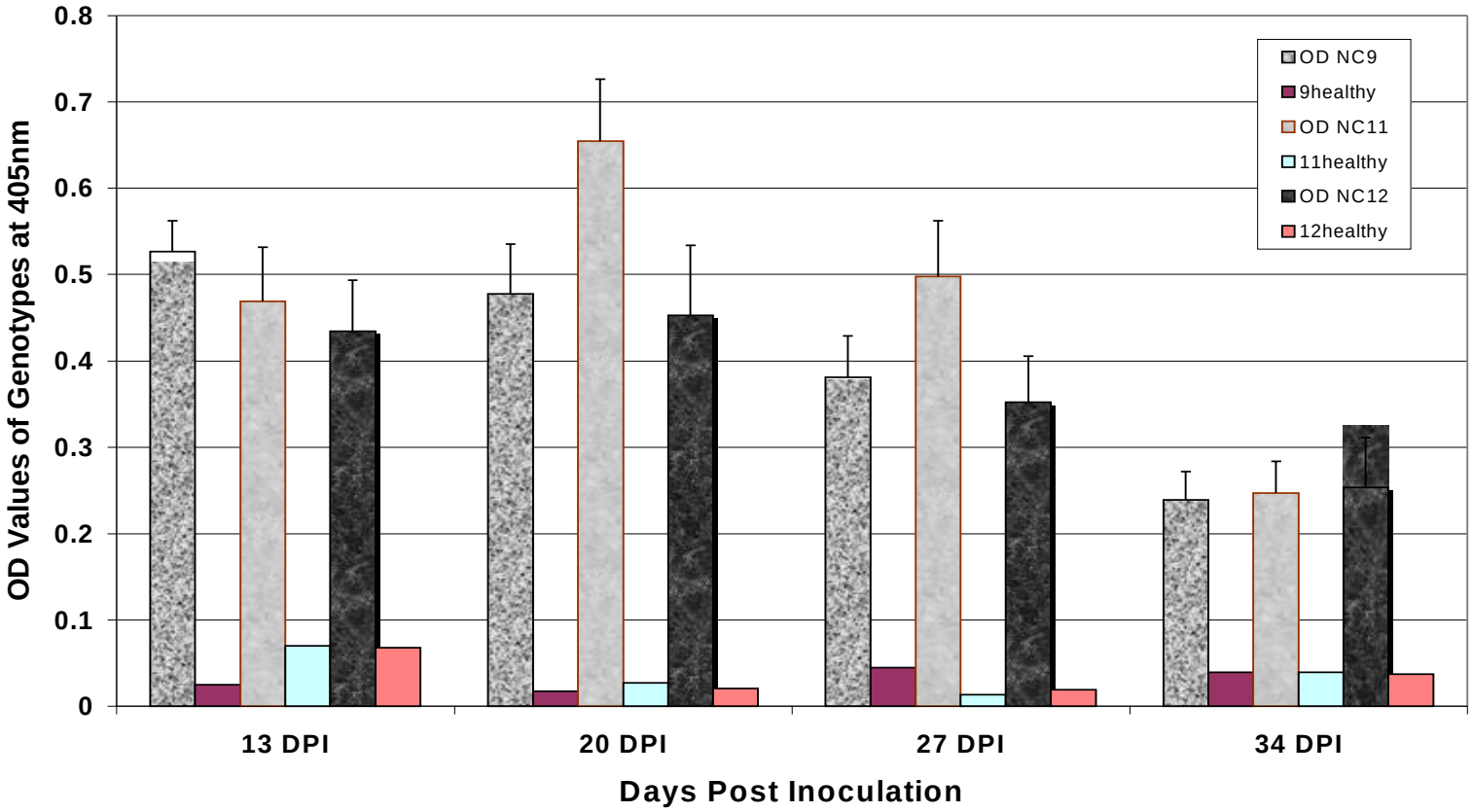


Figure 8. Mean optical density readings of ELISA plate wells at 405 nm of leaf samples taken from peanut genotypes beginning at 13 days post mechanical inoculation and continuing for 4 weeks at 7 day intervals. 1996.

Chapter III

Survival and reproductive success of tobacco thrips (Thysanoptera: Thripidae) on 3 tomato spotted wilt virus (Bunyviridae: *Tospovirus*) infected and non-infected peanut (*Arachis hypogaea* L.) genotypes in North Carolina[3].

Garcia, L.E., Kennedy, G.G, and Brandenburg, R.L.

Department of Entomology, North Carolina State University, Raleigh, North Carolina 27695

ABSTRACT A comparison of the survival and reproductive success of *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) on tomato spotted wilt virus (TSWV) infected and uninfected peanut plants was conducted under greenhouse conditions in North Carolina. Three genotypes, NC-9, NC-V11, and NC-12C, adapted to NC production practices were evaluated. A total of 180 individually caged plants, in 3 replicates, were infested with 20 female *F. fusca* each. Adult and larval thrips were collected after 30 days on the plants. Final counts were square root transformed and a mixed model analysis of variance conducted. Effects of genotype and the virus by genotype interaction were not significant. TSWV infected plants had significantly fewer adult and larval *F. fusca* than did uninfected plants at p=0.04 for adults and p=0.01 for larvae.

KEY WORDS *Frankliniella fusca*, tobacco thrips, TSWV, peanut

[3]This chapter will be modified and submitted for publication to Peanut Sci. as: Garcia, L.E., Kennedy, G.G., and Brandenburg, R.L. Survival and reproductive success of tobacco thrips (Thysanoptera: Thripidae) on 3 tomato spotted wilt virus (Bunyviridae: *Tospovirus*) infected and non-infected peanut (*Arachis hypogaea* L.) genotypes in North Carolina.

Tomato spotted wilt virus (TSWV), a *Tospovirus*, was first recognized as a significant plant pathogen in Australia in 1916 (Britlebank 1919). It has since become an important disease of many ornamental and food crops worldwide (Peters 1996). This virus is unusual among plant viruses in that it is a member of a family of viruses that predominantly infect animals, Bunyviridae. The virus may have adapted independently to thrips species after first originating as a vertebrate pathogen (Mound 1996). Currently, there are 7 confirmed thrips *Tospovirus* vectors (Mound 1996) and 9 serologically distinct *Tospoviruses* (Peters 1996).

In North Carolina, there are 3 thrips vectors of TSWV including *Frankliniella fusca* (Hinds), *F. occidentalis* (Pegrande), and *Thrips tabaci* Lindeman. Of these, *F. fusca*, the tobacco thrips, is the most common species associated with NC peanuts (Barbour and Brandenburg 1994). *F. occidentalis* and *T. tabaci* are only occasionally found in NC peanut fields.

The association of TSWV with its vector, *F. fusca*, and the epidemiology of the disease in NC peanuts is not completely understood. It has been recognized, however, that tobacco thrips overwinter in NC (Cho 1995) and that TSWV can be found overwintering in infected tobacco thrips (Garcia 1999a) and in infected winter annual and perennial weed species (R. Groves and G.G. Kennedy, unpublished). Tobacco thrips emerge in the spring from alternative weed hosts and/or overwintering sites (Barbour 1994, Garcia 1999a) and migrate to peanut plants as the plants crack the soil surface. Spring migrating thrips, principally from nearby locations (Garcia 1999a), vector the virus into peanut fields and are the source of primary infection.

Subsequent infection, or secondary infection, in peanut fields develops principally as a result of intra-field movement of viruliferous tobacco thrips from plant to plant (Camann 1995). For secondary infection to occur, TSWV infected peanut plants must be able to

support the development of immature thrips. Therefore, the extent to which secondary infection occurs is partially dependent upon the attractiveness and suitability of TSWV infected peanut plants as a host for thrips. Because TSWV is only acquired by immature thrips and vectored, following a 3-7 day latent period (Peters 1996), by adults in a persistent fashion (Sakimura 1962, 1963), it is especially important to the spread of this pathogen that the plant virus host also be a suitable thrips host.

The attractiveness and suitability of virus infected plants and uninfected plants as hosts for thrips varies (Terry 1997). There is some evidence indicating that *F. occidentalis* on lettuce and *T. palmi* on cucumber are more attracted to virus-infected plants (Yudin 1987, Culliney 1990, Terry 1997). Bautista (1995), also working with *F. occidentalis*, demonstrated feeding and oviposition preferences for various TSWV infected hosts versus noninfected hosts. However, there is disagreement in the literature concerning the suitability of virus infected host plants for survival and development of *F. occidentalis* (Robb 1989, Wijkamp 1995). The suitability of TSWV infected NC peanut genotypes as hosts for *F. fusca* larvae and adults as compared to noninfected plants was investigated in this greenhouse study.

MATERIALS AND METHODS

Experimental Design. The relative suitability of TSWV infected and noninfected peanut genotypes as hosts for adult *F. fusca* survival and larval development was compared on three commercially available peanut genotypes: NC-9, NC-V11, and NC-12C. The experiment was conducted under a regime of 14/10 h (light/dark) in a greenhouse on the campus of NC State University in Raleigh, NC during the summer of 1998. Temperatures in the greenhouse over the study period fluctuated from an average daily low of 22.8°C to an average daily high of 40.6°C.

Forty seeds from each genotype, at a rate of 2 seeds/pot, were sown on each of 3

treatment periods (21 April, 14 May, and 15 May, 1998). Sterile growing media was used (Scott's® Metro Mix® 220 Growing Medium, Scotts-Sierra, Marysville, MD). Plants in each pot were covered with a cylindrical thrips-proof cage constructed of clear plastic sheeting, "Vivak" (AIN Plastics of North Carolina, Greensboro, NC) which was extended into the potting media along the edge of the pot to a depth of 10.2 cm. The seams of the cylindrical cages were sealed with a silicone caulking compound. A thrips-proof screen (BugBed123™, Greenthumb Group, Downers Grove, IL 60515) covered the top opening of the cage and was also sealed with silicone caulk. Cages were approximately 25.40 cm in diameter and 41.6 cm tall.

TSWV Inoculation. At 9 days post-planting, the peanut seedlings were transferred to a dark environment at approximately 22.2°C. On day 10 (post-planting), half of each of the peanut plants from each genotype (20 plants, 2 per pot, 2 leaves per plant) were mechanically inoculated with TSWV. Inoculation was conducted with extract from infected leaves ground in inoculation buffer (0.01 M Tris, 0.01 M Na_2S_3, and 0.1% Cystine HCL, pH 7.8). The inoculum, designated as the GT strain of TSWV, originated in tomatoes from Georgia (GA) and was obtained from Dr. J. Moyer, NCSU, Dept. of Plant Pathology. It was thrips transmitted to *Emilia sonchifolia*, and mechanically transferred to *Nicotiana benthamiana* from which it was extracted to inoculate the peanut plants. The plants were returned to the greenhouse 24 hours after inoculation. Twelve days later, the plants were thinned to one plant per pot to minimize variation in plant size. Foliage samples were taken from the plants and tested by enzyme linked immunoabsorbent assay (ELISA) (Agdia, Elkhart, IN) to verify presence or absence of TSWV.

Thrips Infestations. Twenty adult female *F. fusca* were added to each caged plant 13 days after inoculation, or 23 days post-planting. Thrips of uniform age were selected from cultures where thrips were allowed to feed and oviposit on beans, *Phaseolus* sp. for 2 days before the beans were replaced. These beans were used to initiate colonies of

similar aged thrips. Thrips were aspirated into screened Pasteur pipettes and held for transfer to the potted peanut plants. As the thrips were transferred to the caged plants, all cages were checked for holes or openings that would permit the thrips to escape. The Pasteur pipettes were stuck into the potting media and the screen plug removed to allow the thrips to escape into the individual cages.

Data Collection and Analysis. Thirty days after the thrips were added to the caged peanut plants, the plants were cut off at soil level with scissors and quickly transferred to plastic buckets, 16 cm x 20 cm (ht x diam) with tight fitting lids and screened tops and bottoms. A single green bean pod (*Phaseolus* sp.)was added to each bucket as an alternative food source for the thrips. Cut plants were placed in an airconditioned room with fans for three days of drying time in the buckets before the thrips were aspirated out for counting. All adult thrips from each caged plant were counted and larvae from the last 2 treatments were counted. Thrips counts were recorded as adults or larvae and according to peanut genotype, presence or absence of virus, and treatment. Data were analyzed using SAS 6.12 General Linear Models Procedure and tests of hypotheses for Mixed Model Analysis of Variance with square-root transformed data. Because some of the plant samples contained no thrips, data were analyzed with and without the zero counts.

RESULTS

TSWV Inoculations. A plant was considered as systemically infected with TSWV if it exhibited positive foliar symptoms of TSWV at sites other than the points of inoculation and/or a positive optical density reading was obtained following ELISA (Agdia, Elkhart, IN). An ELISA optical density reading was counted as positive when the well reading was greater than 3 times the standard deviation of the optical density reading of 5 predesignated healthy control wells plus the mean of 5 healthy control wells located on the same microtiter plate. All mechanically inoculated plants exhibited symptoms of

systemic infection, such as concentric ring spots with purple discoloration and twisted petioles. Non-infected plants showed no symptoms. The mean optical density reading of the mechanically inoculated plants was 1.05 nanometers (nm) compared to a mean optical density reading of 0.023 nm for the non-inoculated plants.

Thrips Counts. Thrips in approximately 30% of the cages failed to establish, or survive the 30 day evaluation period. Failure to establish did not significantly differ among genotypes, nor inoculated/non-inoculated caged plants by variety (Table 1). Genotype did not have a significant effect on the number of thrips adults or larvae which developed during the study (Table 2). A significant effect was observed in both adult and larval thrips counts between virus-infected and uninfected plants (Table 3). Plants which were not mechanically inoculated with TSWV had significantly ($p = .10$) more adults and larval thrips at the end of the 30 day period than the TSWV inoculated plants. Reanalysis with a square-root transformation and zero counts removed resulted in more pronounced differences (adult $p = 0.04$ and larvae $p = 0.01$).

There was no significant interation between genotype and infected or non-infected plants. However, TSWV infected NC-9 had higher adult and larval counts (mean = 26.5 and 16.5, adult and larval counts, respectively) than infected NC-V11 (mean = 22.8 and 7.7, adult and larval counts, respectively) (Table 4). The situation was reversed in the non-infected plants. Non-infected NC-V11 had higher adult and larval counts (mean = 42.9 and 53.2, adult and larval counts, respectively) than non-infected NC-9 (mean = 36.6 and 29.8, adult and larval counts respectively). The adult counts of NC-12C were lower on both infected (mean = 21.9) and non-infected (mean = 29.6) plants than either NC-9 or NC-V11. Larval counts of NC-12C were lowest (mean = 24.5) on non-infected plants, but highest (mean = 23.8) on infected plants.

DISCUSSION

In this study, the results indicate that survival and reproductive success of *F. fusca* is lower for adults and larvae confined on TSWV infected peanut plants than for those confined on uninfected plants, at least on the 3 genotypes tested. The cause of the decrease in survival rate is unknown, but may be attributable to a reduction in the nutritional quality of the virus infected plants as suggested by DeAngelis (1993) with *F. occidentalis* and impatiens necrotic spot wilt virus infected *Lobelia erinus* L.. The results also indicate that the negative effect on thrips survival caused by TSWV infected plants may help to limit secondary spread in peanut fields by reducing the number of infective thrips.

In a previous field study in which the level of TSWV infection on peanut plants ranged from 5-7%, Garcia (1999b) found that tobacco thrips were more abundant on NC-V11 plants than on NC-9 plants; however, NC-9 plants had a higher incidence of TSWV infection. In the present investigation, only uninfected NC-V11 plants had higher adult and larval thrips counts after 30 days than NC-9 uninfected plants. Infected NC-9 plants experienced greater thrips counts than NC-V11 plants. Though not statistically significant, this study would seem to suggest that uninfected NC-V11 is a better host than NC-9 and that infection with TSWV reduces the host suitability of both NC-9 and NC-V11, with the reduction in suitability being greater in NC-V11 than in NC-9. A greater survival rate of tobacco thrips on infected NC-9 plants may increase the likelihood of a higher incidence of secondary infection among NC-9 plants than among NC-V11 plants.

Adult and larval counts for uninfected NC-12C plants tended to be lower than for the other two genotypes. However, the highest larval counts among the infected plants were on TSWV infected NC-12C plants (Table 4). This suggests that when infected, NC-12C is a comparatively good host for tobacco thrips, and that uninfected NC-12C plants may not be as suitable as a host for *F. fusca* as uninfected NC-9 and NC-V11. This condition

could result in low rates of infection early in the season in NC-12C plants as compared to NC-9 and NC-V11 plants, followed by higher rates of spread among NC-12C plants later in the season as viruliferous thrips larvae develop into adults and migrate to nearby plants. A scenario similar to this was observed during a field study in NC. At 3 locations in NC in 1996, a general pattern among NC-12C plants of low infection levels early in the season was followed by an increasing rate of infection late in the season, as compared to NC-9 and NC-V11 (Garcia 1999b). From a management and production perspective, this trait would help lessen the damage caused by TSWV as the impact of the disease on peanut yields decreases as the season progresses (Garcia 1999b).

Acknowledgements

We thank R. Groves for technical assistance, the use of thrips cages and the supply of thrips adults; C. Berger, S. Costa, and V. Covington for advice and technical help; T. Isleib for the peanut seed; and J. Moyer for TSWV inoculum (North Carolina State University). C. Browning provided statistical analysis. This research was made possible and supported in part by the North Carolina Department of Agriculture and Consumer Services. Partial funding for this project was provided by the North Carolina Peanut Grower's Association, Inc. and USAID Peanut CRSP (Grant No. DPN-4048-G-00-0041-00).

References Cited

Barbour, J.D. and Brandenburg, R.L. 1994. Vernal infusion of thrips into North Carolina peanut fields. J. Econ. Entomol. 87, 446-451.

Bautista, R.C., Mau, R.F.L., Cho, J.J., and Custer, D.M. 1995. Potential of tomato spotted wilt tospovirus plant hosts in Hawaii as virus reservoirs for transmission by *Frankliniella occidentalis* (Thysanoptera: Thripidae). Phytopathology 85, 953-958.

Brittlebank, C.C. 1919. Tomato diseases. Journal of Agriculture, Victoria 27, 231.

Camann, M.A., Culbreath, A.K., Pickering, J., Todd, J.W., and Demski, J.W. 1995. Spatial and temporal patterns of spotted wilt epidemics in peanut. Phytopathology, 85, 879-885.

Cho, K., Eckel, C.S., Walgenbach, J.F., and Kennedy, G.G. 1995. Overwintering of thrips (Thysanoptera: Thripidae) in North Carolina. Environ. Entomol. 24, 58-67.

Culliney, T.W. 1990. Population performance of *Thrips palmi* (Thysanoptera: Thripidae) on cucumber infected with a mosaic virus. Proceedings of the Hawaiian Entomol. Soc. 30, 85-90.

DeAngelis, J.D., Sether, D.M., and Rossignol, P.A. 1993. Survival, development, and reproduction in western flower thrips (Thysanoptera: Thripidae) exposed to impatiens necrotic spot virus. Environ. Entomol. 22: 1308-1312.

Garcia, L.E., Brandenburg, R.L., Kennedy, G.G., and Bailey, J.E. 1999a.. Winter occurrence and spring migration of *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) in North Carolina peanut (*Arachis hypogaea* L.) fields. J. Econ. Entomol., submitted.

Garcia, L.E., Brandenburg, R.L., and Bailey, J.E. 1999b. Incidence of tomato spotted wilt virus (Bunyviridae: *Tospovirus*) and *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) in three Virginia-type peanut (*Arachis hypogaea* L.) genotypes in North Carolina. Plant Disease, submitted.

Mound, L.A. 1996. The Thysanoptera vector species of tospoviruses. Acta Hort. 431, 298-309.

Peters, D., Wijkamp, F., Wetering, F.van de, and Goldbach, R. 1996. Vector relations in the transmission and epidemiology of tospoviruses. Acta Hort. 431, 29-43.

Robb, K. 1989. Analysis of *Frankliniella occidentalis* (Pegrande) as a pest of floricultural crops in California greenhouses. Ph.D. Dissertation, University of California, Riverside.

Sakimura, S. 1962. *Frankliniella occidentalis* (Thysanoptera: Thirpidae), a vector of tomato spotted wilt virus, with special reference to color forms. Ann. Ent. Soc. Amer. 55, 387-389.

Sakimura, S. 1963. *Frankliniella fusca*, an additional vector for the tomato spotted wilt virus, with notes on *Thrips tabaci*, another vector. Phytopathology 53, 421-415.

SAS Institute. 1985. SAS user's guide: statistics. SAS Institute, Cary, NC.

Terry, L.I. 1997. Host selection, communication and reproductive behavior. *In*: Thrips as crop pests, T. Lewis, ed., CAB International, New York.

Wijkamp, I. 1995. Virus-vector interaction of tomato spotted wilt virus in *Frankliniella occidentalis* is neither accompanied by pathological effects nor by transovarial transmission. Ph.D. Dissertation, Wageningen Agricultural University, The Netherlands.

Yudin, L.S., Mitchell, W.C., and Cho, J.J. 1987. Color preference of thrips (Thysanoptera: Thripidae) with reference aphids (Homoptera: Aphididae) and leaf-miners in Hawaiian lettuce farms. J. Econ. Ent. 80, 51-55.

Table 1. Percentage of caged plants with tobacco thrips at the end of the sampling period (30 days) by TSWV infected plants and uninfected plants, and by peanut genotype, 1998

		Percentage[a] of Caged Plants with Thrips at 30 Days	
Virus Status	Genotype[b]	percentage[c]	SD
Positive	NC-9	67	0.06
Positive	NC-V11	73	0.21
Positive	NC-12C	70	0.10
Negative	NC-9	80	0.10
Negative	NC-V11	73	0.15
Negative	NC-12C	67	0.12

[a]Percentage of 3 replications with 10 plants per genotype mechanically inoculated with TSWV and 10 plants per genotype uninfected at each replication.

[b]Survival of tobacco thrips were investigated on 3 peanut genotypes including: NC-9, NC-V11, and NC-12C.

[c]Percentages of colonization success across genotypes and TSWV infected or uninfected plants were not significantly different at P=0.05.

Table 2. Mean[a] *F. fusca* adult and larvae counts and SEM from caged plants by genotype and by plants with and without zero counts, 1998

Genotype	Adult Count				Larval Count			
	All Plants[b]		Infested Plants		All Plants		Infested Plants	
	n	count ± SEM	n	count ± SEM	n	count ± SEM	n	count ± SEM
NC-9	60	31.6±5.3	44	43.1±6.5	40	17.3±3.5	29	23.9±4.2
NC-V11	60	32.9±5.7	44	44.8±7.0	40	22.7±5.2	29	31.3±6.5
NC-12C	60	25.7±4.0	41	37.7±4.8	40	16.4±3.2	27	24.2±3.9

[a]Means of 3 genotypes with 3 replicates, each with 20 plants.

[b]Means of tobacco thrips counts by genotypes were not significantly different at P=0.05.

Table 3. Mean[a] *F. fusca* adult and larvae counts and SEM from TSWV infected and uninfected caged plants including and excluding caged plants with zero counts, 1998

Virus	Adult Count				Larval Count			
	All Plants[b]		Infested Plants		All Plants		Infested Plants	
	n	count±SEM	n	count±SEM	n	count±SEM	n	count±SEM
Pos	90	23.7±3.5*	63	33.9±4.4**	60	10.6±2.4**	40	15.9±3.2**
Neg	90	36.4±4.6*	66	49.6±5.6**	60	27.0±3.7**	45	36.0±4.2**

[a]Means of 3 replications representing 10 TSWV infected and 10 uninfected plants in 3 peanut genotypes.

[b] Counts are significant at * P=0.10, and **P=0.05

Table 4. Mean[a] *F. fusca* adult and larvae counts and SEM from caged plants by virus and genotype, 1998

Virus	Genotype	Adult Count				Larval Count			
		All Plants[b]		Infested Plants		All Plants		Infested Plants	
		n	count±SEM	n	count±SEM	n	count±SEM	n	count±SEM
Pos	NC-9	30	26.5±7.1	20	39.8±9.3	20	10.8±4.4	13	16.5±6.2
Pos	NC-V11	30	22.8±5.4	22	31.1±6.6	20	5.5±2.0	14	7.8±2.7
Pos	NC-12C	30	21.9±5.5	21	31.3±7.0	20	15.6±5.1	13	23.9±6.8
Neg	NC-9	30	36.7±8.0	24	45.8±9.1	20	23.9±5.0	16	29.8±5.3
Neg	NC-V11	30	42.9±9.8	22	58.5±11.7	20	39.9±8.6	15	53.2±9.2
Neg	NV-12C	30	29.6±5.7	20	44.4±6.3	20	17.2±4.0	14	24.5±4.4

[a]Means of 3 replications of 3 genotypes, each with 10 TSWV infected plants and 10 uninfected plants.

[b]Means of adult and larval counts by TSWV infected or uninfected and genotype were not significantly different at P=0.05.

REFERENCES CITED

Bandla, M.D., Westcot, C.M., Chenault, K.D., Ullman, D.E., German, T.L., and Sherwood, J.L. 1994. Use of monoclonal antibody to the nonstructural protein encoded by the small RNA of tomato spotted wilt tospovirus to identify viruliferous thrips. Phytopathology 84, 1427-1431.

Barbour, J.D., and Brandenburg, R.L. 1994. Vernal infusion of thrips into North Carolina peanut fields. J. Econ. Entomol. 87, 446-451.

Bautista, R.C., Mau, R.F.L., Cho, J.J., and Custer, D.M. 1995. Potential of tomato spotted wilt tospovirus plant hosts in Hawaii as virus reservoirs for transmission by *Frankliniella occidentalis* (Thysanoptera: Thripidae). Phytopathology 85, 953-958.

Birdswhistell, A.J. 1992. Movement patterns and phenology of the tobacco thrips, *Frankliniella fusca* (Hinds), in Virginia peanuts. MS. thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Black, M.C., and Smith, D.H. 1987. Spotted wilt and rust reactions in south Texas among selected peanut genotypes. Proc. Am. Peanut Res. Educ. Soc. 19:31.

Black, M.C., Tewolde, H., Fernandez, C.J., and Schubert, A.M. 1994. Effect of seeding rate, irrigation, and cultivar on spotted wilt, rust, and southern blight diseases of peanut. Proc. Amer. Peanut Res. Educ. Soc. 26, 50 (Abstr.).

Brittlebank, C.C. 1919. Tomato diseases. Journal of Agriculture, Victoria 27,231.

Brown, S.L., and Thompson, S.S. 1992. Tomato spotted wilt survey, 1991. Georgia Peanut Res. Ext. Rpts. Coop. Res. Ext., Publ. No. 2, 3-6.

Brown, S.L., Todd, J.W., and Culbreath, A.K., 1996. Effect of selected cultural practices on incidence of tomato spotted wilt virus and populations of thrips vectors in peanuts. Acta Hort. 431, 491-498.

Buntin, G.D., and Beshear, R.J. 1995. Seasonal Abundance of thrips (Thysanoptera) on winter small grains in Georgia. Environ. Entomol. 24,1216-1223.

Camann, M.A., Culbreath, A.K., Pickering, J., Todd, J.W., and Demski, J.W. 1995. Spatial and temporal patterns of spotted wilt epidemics in peanut. Phytopathology 85, 879-885.

Chamberlin, J.R., Todd, J.W., Beshear, R.J., Culbreath, A.K., and Demski, J.W. 1992. Overwintering hosts and wingform of thrips, *Frankliniella* spp., in Georgia (Thysanoptera: Thripidae): Implications for management of spotted wilt disease. Environ. Ent. 21, 121-128.

Chamberlin, J.R., Culbreath, A.K., Todd, J.W., and Demski, J.W. 1993. Detection of tomato spotted wilt virus in tobacco thrips (Thysanoptera: Thripidae) overwintering in harvested peanut fields. J. Econ. Ent. 86, 40-45.

Cho, J.J., Mau, R.F.L., Consalves, D., and Mitchell, W.C. 1986. Reservoir weed hosts of tomato spotted wilt virus. Plant Disease. 70, 1014-1017.

Cho, J.J., Mitchell, W.C., Mau, R.F.L., and Sakimura, K. 1987. Epidemiology of tomato spotted wilt virus disease on crisphead lettuce in Hawaii. Plant Disease, 71, 505-508.

Cho, K., Eckel, C.S., Walgenbach, J.F., and Kennedy, G.G. 1995. Overwintering of thrips (Thysanoptera: Thripidae) in North Carolina. Environ. Entomol. 24, 58-67.

Culbreath, A.K., Todd, J.W., Demski, J.W., and Chamberlin, J.R. 1992. Disease progress of spotted wilt in peanut cultivars Florunner and Southern Runner. Phytopathology, 82, 766-771.

Culbreath, A.K., Todd, J.W., Branch, W.D., Brown, S.L., Demski, J.W., and Beasley, J.P., Jr. 1994. Effect of new peanut cultivar Georgia Browne on epidemics of spotted wilt. Plant Dis. 78, 1185-1189.

Culliney, T.W. 1990. Population performance of *Thrips palmi* (Thysanoptera: Thripidae) on cucumber infected with a mosaic virus. Proceedings of the Hawaiian Entomol. Soc. 30, 85-90.

DeAngelis, J.D., Sether, D.M., and Rossignol, P.A. 1993. Survival, development, and reproduction in western flower thrips (Thysanoptera: Thripidae) exposed to impatiens necrotic spot virus. Environ. Entomol. 22: 1308-1312.

Eckel, C.S., Cho, K., Walgenbach, J.F., and Kennedy, G.G. 1995. Thrips fauna in North Carolina agroecosystems. *In* B.L. Parker, M. Skinner, and T. Lewis, eds., Thysanoptera: toward understanding thrips management. Plenum, New York.

Eddy, C.O. and E.M. Livingstone. 1931. *Frankliniella fusca* Hinds (thrips) on seedling cotton. South Carolina Agr. Exp. Sta. Bull. 271.

Garcia, L.E., Brandenburg, R.L., Kennedy, G.G., Bailey, J.E., and Bradley, J.R. 1999a. Winter occurrence and spring migration of *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) in North Carolina peanut (*Arahcis hypogaea* L.) fields. J. Econ. Entomol. submitted.

Garcia, L.E., Brandenburg, R.L., and Bailey, J.E. 1999b. Incidence of tomato spotted

wilt virus (Bunyviridae: *Tospovirus*) and *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) in three Virginia-type peanut (*Arachis hypogaea* L.) genotypes in North Carolina. Plant Disease. submitted.

Garcia, L.E., Kennedy, G.G., and Brandenburg, R.L. 1999c. Survival and reproductive success of tobacco thrips (Thysanoptera: Thripidae) on 3 tomato spotted wilt virus (Bunyviridae: *Tospovirus*) infected and non-infected peanut (*Arachis hypogaea* L.) genotypes in North Carolina. Peanut Sci. submitted.

German, T.L., Ullman, D.E., and Moyer, J.W. 1992. Tospoviruses: diagnosis, molecular biology, phylogeny, and vector relationships. Ann. Rev. Phytopath. 30, 315-348.

Goldbach, R., and Peters, D. 1994. Possible causes of the emergence of tospovirus diseases. Sem. Virol. 5, 113-120.

Gorbet, D.W. and Shokes, F.M. 1994. Plant spacing and tomato spotted wilt virus. Proc. Amer. Peanut Res. Educ. Soc. 26, 50 (Abstr.).

Latham, L.J., and Jones, R.A.C. 1997. Occurrence of tomato spotted wilt tospovirus in native flora, weeds, and horticultural crops. Aust. J. Agric. Res. 48, 359-369.

Linford, M.B. 1932. Transmission of the pineapple yellow-spot virus by *Thrips tabaci*. Phytopathology, 22, 301-324.

Matteson, N.A., Terry, L.I. 1992. Response to color by male and female *Frankliniella occidentalis* during swarming and non-swarming behavior. Entomol. Exp. Appl. 63, 187-201.

McDonald, J.R., Bale, J.S., and Walters, K.F.A. 1997. Rapid cold hardening in the

western flower thrips *Frankliniella occidentalis*. J. Insect Physiol. 43, 759-766.

Mitchell, F.L., and Smith, J.W. 1991. Epidemiology of tomato spotted wilt virus relative to thrips populations. *In* Hsu and R.H. Lawson (eds.), Virus-thrips-plant interactions of tomato spotted wilt, proceedings of a USDA workshop. Beltsville, MD

Mound, L.A. 1996. The Thysanoptera vector species of tospoviruses. Acta Hort. 431, 298-309.

Newsom, L.D., Roussel, J.S., and Smith, C.E. 1953. The tobacco thrips, its seasonal history and status as a cotton pest. LA Agric. Exp. Sta. Tech. Bull. 474.

Peters, D., Wijkamp, F., Wetering, F. van de, and Goldbach, R. 1996. Vector relations in the transmission and epidemiology of tospoviruses. Acta Hort. 431, 29-43.

Robb, K. 1989. Analysis of *Frankliniella occidentalis* (Pegrande) as a pest of floricultural crops in California greenhouses. Ph.D. Dissertation, University of California, Riverside.

Sakimura, S. 1962. *Frankliniella occidentalis* (Thysanoptera: Thripidae), a vector of tomato spotted wilt virus, with special reference to the color forms. Ann. Ent. Soc. Amer. 55,387-389.

Sakimura, S. 1963. *Frankliniella fusca*, an additional vector for the tomato spotted wilt virus, with notes on *Thrips tabaci*, another vector. Phytopathology, 53, 421-415.

Samuel, G., Bald, J.G., and Pittman, H.A. 1930. Investigations on spotted wilt of tomatoes. Aust. Coun. Sci. Ind. Res. Bull. 44.

SAS Institute. 1985. SAS user's guide: statistics. SAS Institute, Cary, NC.

Satayavirut, Turnjt. 1988. Thrips (*Frankliniella fusca* Hinds) population, damage, and yield relationship for peanut types and selected peanut cultivars in North Carolina. PhD Dissertation, North Carolina State University, Raleigh, North Carolina.

Stewart, J.W.,Cole, C., and Lummus, P. 1989. Winter survey of thrips (Thysanoptera: Thripidae) from certain suspected and confirmed hosts of tomato spotted wilt virus in south Texas. J. Entomol. Sci. 24, 392-401.

Sullivan, G. (ed.). 1995. Peanuts 1995. NC Agricultural Extension Service Publication.
Terry, L.I. 1997. Host selection, communication and reproductive behavior. *In*: Thrips as crop pests, T. Lewis, ed., CAB International, New York.

Toapanta, M., Funderburk, J., Webb, S., Chellemi, D., and Tsai, J. 1996. Abundance of *Frankliniella* spp. (Thysanoptera: Thripidae) on winter and spring host plants. Environ. Entomol. 25, 793-800.

Todd, J.W., Culbreath, A.K., and Brown, S.L. 1996. Dynamics of vector populations and progress of spotted wilt disease relative to insecticide use in peanuts. Acta Hort. 431, 483-490.

Ullman, D.E., German, T.L., Sherwood, J.L., Westcot, D.M., and Cantone, F.A. 1993. *Tospovirus* replication in insect vector cells: Immuno-cytochemical evidence that the nonstructural protein encoded by the S RNA of tomato spotted wilt tospovirus is present in thrips vector cells. Phytopathology 83, 456-463.

Ullman, D.E. 1996. Thrips and tospoviruses: advances and future directions. Acta Hort. 431, 310-324.

Wijkamp, I., and Peters, D. 1993 Determination of the median latent period of two tospoviruses in *Frankliniella occidentalis*, using a novel leaf disc assay. Phytopathology, 83, 456-463.

Wijkamp, I. 1995. Virus-vector relationships in the transmission of tospoviruses. PhD Dissertation, Wageningen Agricultural University, The Netherlands.

Wijkamp, I. 1995. Virus-vector interaction of tomato spotted wilt virus in *Frankliniella occidentalis* is neither accompanied by pathological effects nor by transovarial transmission. Ph.D. Dissertation, Wageningen Agricultural University, The Netherlands.

Yancy, C. 1997. Refining the risk index. Peanut Farmer, 33, 36-38.

Yudin, L.S., Mitchell, W.C., and Cho, J.J. 1987. Color preference of thrips (Thysanoptera: Thripidae) with reference aphids (Homoptera: Aphididae) and leaf-miners in Hawaiian lettuce farms. J. Econ. Ent. 80, 51-55.